MISCELLANEOUS PAPERS,

1896-1926.

Wilson, Charles B.

1. The Wrinkling of Frog's Eggs during Segmentation. American Naturalist, pp.761-773, pls. 13-14, Sept. 1896.
2. Experiments on the Early Development of the Amphibian Embryo under the Influence of Ringer and salt solutions. Archiv fur Entwicklungsmechanik der Organismen, Vol. 5, No. 4, pp. 615-648, Pls. 10-11, Leipzig, 1897.
3. Activities of Mesenchyme in certain Larvae. Zool. Bull. Vol. 2, No. 1, pp. 15-23, Text Figs. 1-4, Boston, 1898.
4. The Habits and Early Development of Cerebratulus lacteus (Verrill). A Contribution to Physiological Morphology. Quarterly Journal Micros. Sci., Vol. 43, New Ser., Pt. 1, pp. 97-198, pls. 9-11, 1900.
5. Our North-American Echiurids. A Contribution to the Habits and Geographical Range of the Group. Biol. Bull., Vol. 1, No. 4, pp. 163-178, One Plate, (Figs. 1-5 on plate). July, 1900.
6. Dragonflies of the Mississippi Valley collected during the Pearl Mussel Investigations on the Mississippi River, July and August, 1907. Proc. U. S. Nat. Mus. No. 1692, Vol. 36, pp. 653-671, Washington, June 19, 1909.
7. Notes on Dragonflies of Jamaica. Johns Hopkins Univ. Circular, pp. 1-5, Baltimore, Md., Feb. 1911.
8. Dragon Flies of the Cumberland Valley in Kentucky and Tennessee. Proc. U. S. Nat. Mus., No. 1928, Vol. 43, pp. 189-200, Washington, Sept. 7, 1912.

Wilson, Charles B.

9. Mussels of Central and Northern Minnesota. Department of Commerce and Labor, Bureau of Fisheries, Economic Cir. No. 3, pp. 1-5, 1912.
10. Mussel Beds of the Cumberland River in 1911. Dept. of Commerce and Labor, Bureau Fisheries, Economic Cir. No.1, pp. 1-4, Feb. 13, 1912.
11. The Mussel Fauna of the Maumee River. Dept. Commerce and Labor, Bureau of Fisheries, Document 757, pp. 1-72, pls. 1-2, Washington, 1912.
12. The Mussel Fauna of the Kankakee Basin. Dept. Commerce and Labor, Bur. Fisheries, Doc. 758, 52 pp. 1 plate, 1 map. Washington, 1912.
13. The Mussels of the Cumberland River and its Tributaries. Dept. of Commerce, Bureau of Fisheries, Doc. No. 781, pp. 1-63, 1 plate, Washington, D. C., 1914.
14. The Mussel Fauna of Central and Northern Minnesota. Dept. of Commerce, Bureau Fisheries, Doc. No. 803, pp. 1-26, one map, Washington, D. C., 1914.
15. Dragonflies and Damselflies in Relation to Pondfish Culture, with a list of those found near Fairport, Iowa. Bulletin Bureau of Fisheries, Vol. 36, Doc. No. 882, pp. 185-264, Figs. 1-63, 2 plates, Washington, D.C., 1920.
16. Water Beetles in Relation to Pond Culture. In: R. E. Coker -- Progress in Biological Inquiries, 1921, p. 20. Bureau Fisheries Doc. No. 911. Washington, D. C., 1922.
17. Life History of the Scavenger Water Beetle Hydrous (Hydrophilus) Triangularis, and its Economic Relation to Fish Breeding. Bull. U. S. Bureau of Fisheries, Vol. 39, 1923-24, Doc., No. 942, pp. 9-38, Text figs. 1-22, Washington, D. C., 1923.

Wilson, Charles B.

18. Water Beetles in Relation to Pondfish Culture, with Life Histories of those found in Fishponds at Fairport, Iowa. Bull. Bur. Fisheries, Vol. 39, 1923-24, Doc. No. 953, pp. 231-345, Text figs. 1-148, Washington, D.C., 1923.
19. Odonata, Aquatic hemiptera, and Aquatic Coleoptera. In: Fauna of Pekinese Island, 1923, (Edited by R. E. Coker). Biol. Bull., Vol. 50, No. 1, pp. 27, 29, 34, 35. January, 1926.

TOWN AND CO

UNTRY REVIEW *London, July 1936 thirty-seven*

Prof. CHAS. B. WILSON

Biologist

Until 1932 Head of the Science Department at State Teachers College, Westfield, Professor Wilson, who was immensely popular with the students and among his confreres of the faculty, is a Biologist whose favourite forte is the study of marine and fresh-water life. He was a member of the Johns Hopkins Biological Expedition to Jamaica in 1897, and in '98-'99 was a research worker in the Tufts College Biological Laboratory at South Harpswell, Maine. From 1900 to 1923 Dr. Wilson served during summer vacations as temporary assistant of the U.S. Bureau of Fisheries. In this latter work the summers of 1900 to 1906 were spent at Woods Hole, Mass., at Beaufort, N.C., and at Lake Maxinkuckee, Ind.

In 1910 he went with another Johns Hopkins Expedition to Jamaica, and four months were devoted to the study of the parasites of tropical fishes. During 1911 a survey of the ponds and lakes of Minnesota, and during 1912 of the Cumberland River, was made in the interests of the pearl button manufacturing industry. The summers from 1913 to 1923 were spent at the Bureau of Fisheries at Fairport, Iowa, investigating the relation of water insects to fishpond culture, and subsequent years to similarly interesting research, including the identification, at Woods Hole, Mass, of the copepod plankton obtained during the last cruise of the ship "Carnegie" which cruised under the auspices of the Carnegie Institute of Washington, D.C. Since his retirement Professor Wilson intends to devote most of the year instead of summer only, to these researches into marine life.

Dr. Charles Branch Wilson was born in Exeter, Maine, Oct. 20, 1861, and received his education at Colby College, graduating in 1881 with the B.A. degree. Remaining at Colby as postgraduate student and tutor in Botany from 1881 to 1884 he received the M.A. in the latter year. In 1908 he was accorded the honorary degree of Sc.D.

Dr. Wilson became Professor of Natural Sciences at the State Normal School, Gorham, Maine, but resigned to make further studies at Johns Hopkins University, where he remained as student assistant 1895-6, and from which he received the degree of Ph.D. in 1910. In September, 1896, he was appointed Professor of Biology at the State Teachers College, Westfield, and in 1897 was made head of the Science Department, which included Geography. From this position he retired after 36 years of continuous work with but a single leave of absence.

nas Sweet.

1

633210

761 Smithsonian

33

1896.]

Embryology.

CARD 1945

EMBRYOLOGY.¹

The Wrinkling of Frog's Eggs During Segmentation.—

The occurrence of wrinkles in frog's eggs during the process of segmentation was first observed and very briefly described by Prevost and Dumas, who have the honor of being the first observers of the segmentation itself (*Annales des Sciences Naturelles*, I ser., 1824, Tom II, p. 110).

A somewhat better description was given later by Bär (*Archiv. für Anatomie*, etc., 1837) and Reichert (the same, 1841), who gave to the phenomenon the name "Faltenkranz," and made some attempt to explain its nature and origin.

By far the best description, and, indeed, the only really good one which has ever been published, is that by M. Schultze, which appeared in 1863 (*Observationes nonnullæ de ovorum ranarum segmentatione*, Bonnæ).

He gives an excellent account of wrinkles observed in the eggs of *Rana temporaria* and *R. esculenta*, and concludes with an "explanation of their origin." But he really devotes only a very few lines to the explanation, and gives up the remainder of this portion of his paper to

¹ Edited by E. A. Andrews, Baltimore, Md., to whom abstracts reviews and preliminary notes may be sent.

a controversy with Reichert, over the existence of a vitelline membrane on the surface of the egg.

Similar wrinkles have since been observed in the eggs of the common toad by Goette (Die Entwicklungsgeschichte der Unke), and of *Amblystoma punctatum* by Eycleshymer (Journal of Morphology, Vol X). But neither of these authors offer any explanation of their origin. So far as known this "Faltenkranz" has never been described for any American species of frog, nor has any attempt been made to study it by means of serial sections.

The following paper is offered as a contribution of some new and interesting details in the occurrence of the phenomenon, together with the results of a microscopic study of sections, in the hope of arriving at a rational conclusion as to its origin.

The author desires to acknowledge his great indebtedness to Dr. E. A. Andrews, for the suggestion which led to the study, and for much subsequent assistance. Thanks are also due to Prof. T. H. Morgan, for the kindly loan of a copy of Schultze's paper.

FORMATION OF THE WRINKLES.

The eggs of a small wood-frog, in all probability *Chorophilus triseriatus*, were obtained for class work on March 27, 1896.

They were unsegmented when found, and were immediately placed in ice water to check any further development.

After remaining thus for five hours they were used in the laboratory, being removed to watch-glasses containing tepid water. Some were allowed to remain in the ice water for eight hours before being examined, and it was noticed that these segmented much more rapidly than the ones which had been kept only five hours. Actual segmentation had been prevented during the stay in the ice water, but there seemed to have been a storing-up of energy, a sort of preparation for segmentation, so that when removed to a favorable environment the process began very quickly (5-10 mins.) and was carried on much faster than it would have been normally.

These eggs were obtained from pools covered with ice quarter of an inch thick, and most of the bunches were quite near the surface.

This must occur frequently where the eggs are laid so early in the spring; and according to Morgan (AMERICAN NATURALIST, August, 1891), *Chorophilus* always lays its eggs very early.

The storage of energy noticed above may suggest a natural method of compensation whereby the warm sunshine of mid-day may offset the freezing cold of the nights, and in this way the eggs will really lose very little time in their development.

O. Hertwig and Schultze have recently experimented on the influence of a very low temperature upon the development of the eggs of *Rana fusca* with very different results.

Hertwig (Sitzungsberichte der König, Preuss. Akad. d. Wiss, 5 April, 1894, p. 313) found that freshly fertilized eggs were injured by an exposure to a temperature of 0° C. for 24 hours. On being raised to the ordinary temperature a portion were developed very much more slowly than normal eggs, while in the remainder a part of the yolk was found incapable of division.

Schultze (Anatomischer Anzeiger, X Band, No. 9) subjected eggs of the same species to a temperature of 0° C. for 14 days, and then obtained perfectly normal embryos from them. These eggs had reached later stages of development before being cooled, and he does not state whether their subsequent development was more or less rapid than ordinary.

Subjection to a temperature of 0° C. for so long a period would probably have a very different effect from that of only a few hours duration.

Loeb and Norman (Archiv. f. Entwickl, III Band, No. 1), experimenting on the eggs of the sea-urchin, *Arbacia*, found that when put in sea water to which had been added 2-3 per cent. NaCl or MgCl₂, segmentation of the protoplasm was wholly prevented, but that the nucleus went on dividing. On being put into normal sea water after a few hours exposure to the concentrated solution the eggs divided at once into several cells, the protoplasm merely rearranging itself around the new nuclear centers.

Possibly the same may be true in these frog's eggs when subjected for a short time to a freezing temperature, and the subsequent hastening of segmentation may be due to the fact that the nucleus has already divided.

In watching the segmentation of these eggs the great (comparative) size and depth of the furrows was specially noticed, together with the distinctness of the wrinkles formed along either side of them.

Accordingly it was determined to study their segmentation more in detail, and a fresh lot was obtained the next morning. These remained in ice water only one hour, just long enough to get them home. They were then transferred to watch-glasses and examined in strong sunlight. This fact must be taken into account in connection with the time periods given.

The first furrow appears at the superior pole without any previous flattening as in *Amblystoma* (Eycleshymer, Jour. of Morph., X, p. 348). At first it is a shallow groove just at the pole itself, but it soon spreads

over the pigmented hemisphere. The ends may progress at a uniform rate, or one may exceed the other in rapidity as in *Petromyzon* (Eycleshymer, loc. cit.).

At the first appearance of the furrow it is very shallow and perfectly smooth, and extends about 0.2 mm. on either side of the pole. It begins to deepen in two or three minutes, and at the same time minute wrinkles appear on either side (Plate I, figs. 1, 5, 7). If the eggs be placed upon a black surface in the sunlight these wrinkles are seen very distinctly as fine lines radiating from the pole (Plate II, fig. 31). The number and arrangement of these lines is not constant or definite either at this, or any subsequent period. The suggestion at once presents itself, that these wrinkles may be the foreshadowing of subsequent segmentations, and one egg was obtained in which the wrinkles seemed especially significant in their arrangement (Plate II, fig. 32). The entire lack of regularity in the size and arrangement of the wrinkles would, however, preclude any such idea, since the subsequent segmentations are very regular.

As the furrow gradually deepens and extends toward the yolk two changes are noticed :

1. New wrinkles appear along its sides ; these do not all radiate from the pole, but are inclined toward it at greater or smaller angles (Figs. 6, 8, 11).

2. The radial wrinkles first formed at the pole change considerably. Very fine and delicate at first they coalesce gradually into a few larger and deeper ones, which are sharply defined.

These fused ones may or may not occupy the position of one of the antecedent ones (Figs. 2, 3, 33, 34, 35). As the furrow progresses the number and position of the wrinkles changes constantly, new ones being formed and old ones disappearing. This is especially true of the finer ones ; some of the larger fused ones near the pole remain quite constant (Figs. 10-15).

This continual changing is best seen by making sketches of the wrinkles with a camera lucida at short intervals, as in the movements of the pseudopodia of *Amœba* (Figs. 1-4 and 10-15).

The whole appearance thus far is exactly as if the egg were covered by a very thin, but firm membrane, which was gradually pulled in toward the center at the groove. The remainder of the sphere being perfectly even, and with no chance for "give" at any point, in consequence of the uniform tension, the edges of the groove would necessarily be wrinkled, the wrinkles becoming more and more prominent as the groove deepened. The whole process takes place so slowly that the

most careful scrutiny fails to detect the actual motion, or to see evidences of any movement of the protoplasm within the egg, which might cause the wrinkling.

The furrow at the pole has become quite deep by the time its ends have reached the equator, in five or six minutes. The ends seem to stop here for a time, just at the border of the yolk area, while further changes take place in the pigmented portion. First the two edges of the groove approach each other at the pole, and seem to fuse slowly, the wrinkles entirely disappearing during the process. This fusion then extends in either direction along the groove for some distance, often half way to the equator, obliterating the wrinkles as it goes. By this means the groove may entirely disappear at the center while remaining near the periphery (Fig. 38).

At this point the furrow begins to enter the yolk area on either side, and at the same time the groove reappears along the center of the pigmented hemisphere. It now becomes very broad and deep. Indeed, it seems to reach clear through to the yolk, and its walls are considerably rounded on either side. But they are now smooth, so that the wrinkles remain in all fifteen or twenty minutes on the first furrow.

This first furrow divides the egg into two nearly equal parts (Figs. 3, 12, 28, 35). When its ends first reach the yolk area, where they stop for a time, as already noted, the two blastomeres thus formed are very much rounded at their ends, and diverge strongly from the groove. This is readily seen in the series given in figs. 1 to 4, but it becomes much more prominent after the reappearance of the groove—(Figs. 28 to 30). Under a higher magnifying power a wide space can now be seen at either end between the two segments. The floor of this space is triangular in shape and doubly curved, being concave from side to side, and convex antero-posteriorly. It is formed of light colored yolk, into which the pigment shades gradually around the borders. The two segments are thus rounded in a manner very similar to that of the first two blastomeres of a meroblastic egg.

As the furrow proceeds toward the inferior pole the space between the two pigmented segments diminishes, the borders of the furrow approach each other, and the surface of the egg becomes smooth once more, with the groove indicated merely by a narrow, faint line.

It remains in this condition some eight or ten minutes before the second cleavage begins, and this may be called its resting stage. The rapid closing of the groove previous to the appearance of the second furrow occurs also in *Amblystoma* (*Eycleshymer*).

The Second Cleavage.—The second furrows begin about forty or forty-five minutes after the first. They start *from the equator* and move toward the dark pole, and not vice versa as in *Rana*, *Amblystoma*, *Petromyzon*, and most of the amphibians. This was without exception in all cases noted (some thirty-five or forty). They form a right angle with the first groove, but do not always meet it at the same point (Figs. 19, 20). They are attended with the same appearance, fusion, and gradual elimination of wrinkles as the first furrow, with the slight difference that the wrinkles start at the equator instead of the pole, and are never quite as large. This is shown in figs. 16 to 18, in which both the wrinkles and the furrows can be seen approaching the pole.

The second furrows seem to reach the first over the dark hemisphere before they start toward the inferior pole. They start at about, but not necessarily exactly, the same time.

Here, too, there is the same rounding of the pigmented segments, though to a much less degree. This may be due to the fact that in this instance the furrows start from the periphery, and consequently the segments are more sharply defined there.

The Third Cleavage.—Half an hour after the appearance of the second set of furrows, and sometimes before they have reached the inferior pole, there are indications of the first horizontal cleavage. As seen from figs. 21–24 this occurs very much nearer the superior pole than the inferior. The furrows, accompanied as before by wrinkles along their edges, as seen in the figures, may start in each segment either from the first or second vertical, usually, however, from the second (Fig. 22).

They move much more rapidly than the preceding cleavages, and the entire process is completed in fifteen to eighteen minutes.

In all the eggs observed the grooves started usually at the second vertical in the two quadrants on the same side of the latter, and moved around toward each other at the first vertical.

They seldom met at the same point, but as a result of their formation the superior region was divided into four quite equal and nicely rounded cells, much smaller than the four inferior ones.

The only wrinkles formed upon the yolk area that could be detected by the most careful examination are the few which occur on the yolk side of this first horizontal groove. Schultze failed to detect any wrinkles whatever along this horizontal furrow, although he describes the other details with great exactness. This is all the more striking, because he both observed and figured them upon subsequent furrows up to the

32-cell stage. Other authors, with possibly a single exception, make no mention of them, except along the first furrow.

This confining of the wrinkles almost exclusively to the pigmented area is manifestly connected with the different organization of the two halves of the egg. The pigmented half is richer in protoplasm, and is to a higher degree under the influence of the cell nucleus; while the yolk has its protoplasm scattered about amongst the yolk granules, and is also further removed from the nucleus which lies in the pigmented half in the undivided egg (Hertwig). This results in the more rapid segmentation of the pigmented cells, and the presence of the wrinkles seems intimately associated with this rapidity of segmentation.

The Fourth Cleavage.—This appears from fifteen to twenty minutes after the third.

In this cleavage also the furrows started in every instance *from the periphery* of the four superior quadrants and move toward the pole, accompanied by wrinkles. These latter are now much smaller than heretofore, and are not easily detected under a low power. They are also very transitory, and disappear almost immediately. There is somewhat of a tendency in these furrows to run nearly parallel to the first or second vertical, recalling the conditions in teleosts (Figs. 26, 27).

There is a subsequent fusion and elimination of the furrows after each cleavage, as has already been noted in the first segmentation.

This elimination of the grooves, due to the fourth cleavage, leaves the pigmented pole of the egg divided into four cells of a totally different shape and arrangement from that of the four blastomeres resulting from the third cleavage (Fig. 37). After remaining thus for several minutes the furrows reappear, and the cells resume the shape seen in fig. 36.

From this point segmentation proceeds very rapidly, and in a manner exactly similar to that of other frog's eggs. The wrinkles have now become so small as to be seen only with the greatest difficulty and under a high power, and they disappear so quickly as to easily escape detection. But they are present at least up to the 128-cell stage, and appear, fuse, and disappear, as in the first cleavage.

Gastrulation begins about twelve hours after the first cleavage, and the blastopore closes at about the fifteenth hour. The neural folds appear and gradually fuse to form the neural canal as in *Rana*. By the end of the first day the embryo has elongated considerably, and the head is well differentiated.

The tail then becomes defined, the gill folds appear, and the eyes are seen as two minute black spots. And by the end of the third day the embryo escapes from the egg envelopes and swims about freely.

The yolk sac seems unusually large, and the tail is comparatively long at this period, but otherwise these tadpoles are externally like those of *Rana* and *Hyla*.

NATURE AND ORIGIN OF THE WRINKLES.

If the eggs be preserved during the first segmentation while the wrinkles are still present, and then sectioned parallel to a plane tangential to the superior pole, considerable additional light is thrown upon this process of wrinkling.

As has been noted in the eggs of other frogs the pigment is gathered into a thin surface layer over the superior hemisphere.

Houssay states that the pigment does not characterize this pole, but only happens to be there on account of the coincidence of its density with that of the surrounding protoplasm (*Etudes d'Embryologie sur les Vertébrés*, *Archiv. de Zoöl. Exper.*, 1890). However this may be, during segmentation pigment appears along the sides of the furrows, so that eventually the resultant cells come to have a more or less definite pigment layer around their periphery, Houssay accounts for this by saying that there is an intimate relation between the activity of the cell and the presence of pigment. When the resting cell becomes active its granules become smaller, and pigment appears in them as the result of chemical action.

The presence of pigment, therefore, is the result of an increased activity in the cell.

But Bambeke tells us that "the cortical layer, when it enters the interior of the protoplasm, is not entirely employed in limiting the spheres of new formation. In fact, I find masses of pigment whose presence can only be explained by considering them as debris from the cortical layer, which has penetrated into the protoplasm" (*Fractionnement de l'Oeuf des Batraciens*, *Archiv. de Biologie*, Vol. I, p. 346, footnote).

An examination of sections of these *Chorophilus* eggs shows a similar occurrence.

In addition to the pigment layer which borders the first segmentation furrow, and which is somewhat thicker near the centre of the section, there is also a lunate mass extending downward vertically from the superior pole on either side of the furrow (Fig. 39) and in immediate contact with it. This mass can be traced in the sections from the surface layer, in which it has very little area, down somewhat beyond the bottom of the furrow, where it spreads out laterally and is lost in the surrounding protoplasm. In this particular egg the mass does not

extend quite to the level of the nuclei, the position of the latter in the figure having been taken from subsequent sections in the series. This mass, however, is not to be regarded as "debris," but its presence is due to a definite cause to be explained later. The remainder of the section is occupied by homogeneous protoplasm filled with rather small yolk granules, and surrounded by the thin, transparent vitelline membrane.

Under a high power (Fig. 40) the wrinkles appear as deep sinuses extending obliquely into the protoplasm, and bordered by a thick layer of pigment. These sinuses are angular and irregular in outline, and often contract at their inner ends into long, narrow slits, with rather distinct walls. We can now see what it was impossible to detect from a surface view, namely, that the wrinkles are compound.

The larger, principal ones have secondary, smaller ones extending outward from their sides, approximately at right angles. Schultze observed and figured these compound wrinkles in his surface views of *R. temporaria*, and adds another detail which I have been unable to find in the *Chorophilus* eggs, viz., the breaking-up of a single wrinkle at its peripheral end into several smaller ones arranged radially from a common point.

The pigment usually fills the projecting protoplasm between adjacent sinuses. It is also much thicker in the region of the wrinkles than elsewhere along the furrow, as can be seen in fig. 40.

In view of these different facts, therefore, it seems evident that there is an intimate relation between the wrinkles and the pigment—and that both may be results of the same cause. It remains to ascertain what this cause is, if possible.

According to Schultze the egg is a single cell, and just as cellular division is brought about by the contractility of protoplasm, so is the segmentation of the egg due to the same cause. These contractions originate at the point where the furrow begins, and are at first confined to a very small area. Since the cortical portion of the egg protoplasm possesses a glutinous consistency, it is not to be wondered at that folds or wrinkles appear at the same time with the furrow, in its immediate vicinity, and at right angles to it. These subsequently disappear in consequence of the difference in contractility between the outer and inner protoplasm, due to their different consistency.

It is exceedingly difficult to understand how compound wrinkles, of such a nature as we have just described, could be produced by the simple contraction of a viscous cortical layer of protoplasm, especially if that contraction *starts from a fixed* point in the layer. Indeed, how

could it produce any wrinkles at all in the layer itself? Would it not rather tend to flatten the superior pole and stretch the viscous layer tightly over the underlying protoplasm in a manner similar to the action of the muscles of the diaphragm during respiration?

As to the difference in contractility between the outer and inner protoplasm, it is evident that if this is to smooth out the wrinkles, the difference must be in favor of the outside layer, and also the contraction must be *at right angles to the length of the wrinkles*. That means in the present instance that it must be parallel to the first furrow. Neither of these conditions seem possible, and we thus find both explanations inadequate when confronted by the facts in the case. They both fail to account for the mass of pigment under the superior pole also.

Bambeke states that "the entrance of cortical pigmented masses into the interior of the egg . . . can only be explained by admitting the existence of contractions in the ovular protoplasm during segmentation."

According to the interpretation of the present day, cell division is brought about by means of some force or forces acting along the length of the segmentation spindle. In the present instance this spindle was formed between the two nuclei represented in fig. 39, which lie some distance below the surface of the egg.

If we interpret Bambeke's "contraction of the ovular protoplasm" to be identical with this working force of the segmentation spindle, it will explain the presence of the lunate mass of pigment directly over the spindle, and will help us to understand the presence of a pigmented layer on either side of the segmentation furrows. But it does not explain in any way the formation of the wrinkles.

Reichert's wonderfully inconsistent explanation of the origin of the wrinkles is quoted, and sufficiently commented upon by Schultze, in the paper already referred to.

In view of the fact, therefore, that we have no explanation which can stand the test of our present knowledge of cell division, we venture to offer the following:

We agree with Schultze that the external pigmented layer is necessarily somewhat denser than the internal protoplasm.

Modern research indicates that this layer is drawn inward in some way, by the forces working along the segmentation spindle, to form the furrow which lies over the equator of the spindle. The bottom of the furrow, thus formed by an infolding of the surface layer, describes an arc which becomes shorter and shorter as the furrow deepens.

This shortening of the arc must result in one of two things. The bottom of the furrow may remain of the same length as at first, and

make up for the shortening of the arc by protruding a little from the surface of the egg at either end of the furrow. Such a condition is admirably shown when one creases the top of a soft felt hat, and would necessarily be even more manifest if the hat were filled with a viscous fluid.

An examination of any of the surface views will show that this is not the case with these *Chorophilus* eggs, but that the first indication of the groove at either extremity is a slight hollowing in of the surface, and not a bulging outward. This view is confirmed by a study of the sections.

The other alternative is that the shortening of the arc must result in longitudinal condensation along the bottom of the furrow, starting at the center and increasing as the furrow progresses.

Such a shortening or contraction along the bottom of the furrow would very naturally throw its sides into folds or wrinkles at right angles to its length. The pigment layer in contact with these walls would also be thickened in the region of the wrinkles, and toward the center of the groove.

Since the condensation starts at the center and advances in both directions with the progress of the furrow, the wrinkles would be arranged somewhat radially about the superior pole. This progressive contraction also accounts for the successive appearance and disappearance of wrinkles, and for the confluence of smaller into larger ones.

As the sides of the furrow begin to fuse into the permanent segmentation plane or cell-wall the wrinkles disappear through the gradual readjustment of former relations.

Indeed, the whole phenomenon seems very largely dependent on the rapidity of segmentation and the consequent sudden disturbance of normal relations before the different portions can adjust themselves to their new conditions.

This fact will serve to explain why the wrinkles show so prominently in this particular species, which has a very rapid development, and also why the conditions under which they were examined—the transference from ice to tepid water and the placing of the eggs in strong sunlight—were especially favorable.

It may also suggest a reason why one observer has failed to detect wrinkles in the eggs of a given species, while another, working under more favorable conditions, has seen and described them. And it will in a measure account for the absence of wrinkles on the yolk hemisphere, since segmentation is very much slower there.

If our explanation is a correct one there ought to be no wrinkles at all along the bottom of the groove, while they should be present and have their greatest depth about half way between the bottom and the surface.

The sections show that this actually occurs. Fig. 39 is a section cut just at the level of the bottom of the groove, and shows no trace of any wrinkles, nor are there any in the two or three preceding sections.

They then appear and gradually increase in size up to the level of fig. 40, which is a magnified portion of the same groove about half way to the surface.

The problem of the compound nature of the wrinkles finds its solution in the fact that there must be a condensation along the bottom of the larger wrinkles, in all respects similar to that in the groove, and due to the same cause, though, of course, on a very much smaller scale.

But in this instance the condensation would proceed in only one direction, and hence we find the secondary wrinkles all inclined in the same direction to the principal ones, just as we have already observed, and as Schultze has so finely figured.

Summary.—1. Subjection to a temperature of 0° C. for a period of eight hours completely arrests all development for the time being, but results, on the subsequent restoration of ordinary conditions, in a cleavage more rapid than that of normal eggs.

2. Segmentation, at least up to the 128-cell stage, is accompanied by the formation, fusion and subsequent elimination of well defined wrinkles along the sides of the furrows in the pigmented area. There are no wrinkles on the yolk, except along the inferior border of the third cleavage furrow.

3. As seen in an examination of cross-sections these wrinkles are compound in nature, the larger, principal ones having smaller secondary ones along their sides.

4. The wrinkles on the first furrow are arranged somewhat radially about the superior pole. On subsequent furrows they are inclined at an angle toward the point where the furrow starts.

5. The pigment which borders the segmentation furrows forms a thicker layer in the region of the wrinkles than elsewhere along the groove, thus showing an intimate relation between the two.

6. The probable cause of the wrinkling is to be found in the condensation along the bottom of the groove, which results from the shortening of the arc, and is a necessary consequence of the infolding of the surface layer to form the groove.

PLATE XIII.

Segmentation of *Rana*.

PLATE XIV.

28.

29.

30.

33.

31.

32.

34.

35.

39

37.

36.

38.

40

7. The second and fourth grooves *start from the periphery* and move toward the pole.

8. The blastomeres are more rounded and the segmentation furrows are deeper than those in most frog's eggs.

9. The development is very rapid; gastrulation begins within twelve hours, and the tadpole escapes from the egg during the second or third day.—CHARLES B. WILSON.

EXPLANATION OF PLATE I.

All figures drawn with Zeiss Camera x 16 diam.

- Figs. 1-4. Successive stages in cleavage of living egg at intervals of 3 mins., 3 mins., 2 mins.
Figs. 5, 6. Stages in cleavage of second living egg.
Figs. 7-9. Stages in cleavage of third living egg—intervals, 2 mins., 4 mins.
Figs. 10-15. Stages in cleavage of fourth living egg—intervals, 2, 6, 3, 4, and 5 mins.
Figs. 16-18. Stages in second cleavage of third egg.
Figs. 19, 20. Variations in second cleavage.
Fig. 21. Eight-cell stage of first egg.
Figs. 22-24. Stages in third cleavage of second egg.
Figs. 25-27. Variations in sixteen-cell stage.

EXPLANATION OF PLATE II.

All figures drawn with Zeiss Camera.

- Figs. 28-30. First cleavage under higher magnification to show rounded blastomeres.
Figs. 31, 32. Beginning of first cleavage, showing radiating wrinkles at pigmented pole.
Figs. 33-35. Variations in wrinkles on the first furrow.
Fig. 36. View of an egg during the fourth cleavage.
Fig. 37. The same egg four minutes later.
Fig. 38. Fusion and partial disappearance of the first groove.
Fig. 39. Horizontal section of an egg during the first segmentation, taken at the level of the bottom of the furrow. Nuclei added from the fourth section below this.
Fig. 40. A portion of the same furrow about half way between its bottom and the surface of the egg, more highly magnified.

Reprinted from The American Naturalist, September 1st, 1896.

CASPER 1945

2

Experiments

on the

Early Development of the Amphibian Embryo under the influence
of Ringer and salt solutions.

By

Chas. B. Wilson.

(With plate X and XI.)

Separat-Abdruck

aus dem

Archiv für Entwicklungsmechanik der Organismen.

V. Band, 4. Heft.

Leipzig

Wilhelm Engelmann

1897.

Experiments on the Early Development of the Amphibian Embryo

under the influence of Ringer¹⁾ and salt solutions.

By

Chas. B. Wilson.

With plate X and XI.

Eingegangen am 1. Juli 1897.

Many experiments have recently been made upon the physiology of the development of various eggs in order to arrive at a better understanding of the nature of the process, and to determine, as far as possible, what forces are concerned in it.

For this purpose eggs have been subjected to the action of various drugs; they have been exposed to temperatures abnormally high or low, and have been reared under other unfavorable conditions. By a comparison of these investigations with those pursued under normal conditions several interesting and important results have been obtained, which throw considerable light on the phenomena of early development and cleavage.

But in almost every instance the experiments were performed upon the eggs of a single species, which were fertilized artificially and placed in the solution or subjected to the abnormal conditions before they had begun to segment. The results, therefore, have been somewhat limited, and it has been difficult to compare them, owing to differences in the conditions under which they were obtained. In actual life the young embryos are more apt to meet changes in their environment during later periods of growth than to find themselves at the beginning under abnormal conditions which afterward remain unchanged.

¹⁾ For composition of RINGER solution see foot-note on pag. 627.

Accordingly the following experiments have been performed upon different species simultaneously, and upon the same species at different periods in its growth, with a view to determine, if possible, some relation between changes in environment and rapidity of growth, and more especially between such changes and the period of development at which they occur.

The eggs of the common spotted salamander (*Amblystoma punctatum*), the large wood frog (*Rana temporaria*), and one of the smaller wood frogs (*Chorophilus triseriatus*), were chosen because they seemed particularly adapted for such experiments in two essential particulars:

They are quite common in the vicinity of Baltimore, and often the three kinds can be found side by side in the same pool. The second and more important essential is that they vary greatly in the rapidity with which they develop.

The *Amblystoma* eggs, as determined first by CLARKE (8), and later by EYCLESHYMER (14) and others, develop very slowly.

According to EYCLESHYMER the rate of development is as follows:

Several hours intervene after fertilization before cleavage begins. For this reason these eggs are more often found in an unsegmented condition in the pools than those of the other two species. The first cleavage occupies an hour and fifty minutes or more, the second about an hour and forty minutes. From this point segmentation progresses more rapidly, but unevenly, over the two hemispheres. Gastrulation begins sixty hours after the first cleavage and the blastopore closes about eighteen hours later. The embryo escapes from the egg membranes in from eighteen to twenty-one days, and reaches the adult condition in about one hundred days.

The eggs of the large wood frog (*Rana*) develop more rapidly.

Only a short time intervenes between fertilization and cleavage—an hour or two. For this reason the eggs must usually be obtained very early in the morning if they are to be found unsegmented. The first cleavage occupies about an hour and the second somewhat less, while the third and all subsequent cleavages occur at much shorter intervals. Gastrulation begins toward the close of the second day, and is completed eight or ten hours later. The embryo escapes from the egg membranes during the latter half of the second week and reaches the adult condition in about ten weeks (70 days).

Being unable to find any account of the development of *Choro-*

philus triseriatus, I was compelled to determine it for myself since this point was essential to the experiments. The development was found to be peculiar in several interesting particulars and was published in the American Naturalist for Sept. 1st 1896 (50). Briefly the results are as follows: At ordinary temperatures segmentation begins within an hour after fertilization and progresses so rapidly that gastrulation takes place during the first twelve hours, and the tadpole escapes from the egg membranes by the second or third day. There is thus a difference of 25% to 30% between the first species, while between the large and small wood frogs it is even more than this, 40 to 50%.

In tabular form these three species present the following relative rapidity of development, the times given being the average from a large number of observations in each case:

Species	Fertilization to 1st Cleav.	Cleavage Periods			Gastrulation		External Gills	Adult Form
		1st	2nd	3rd	Begins	Ends		
Amblystoma	10 hrs.	110 mins.	100 mins.	100 mins.	60 hrs.	78 hrs.	19 days	100 days
Rana. . . .	3—5 -	75 -	60 -	50 -	42 -	50 -	14 -	70 -
Chorophilus.	1—2 -	30 -	40 -	30 -	11 -	13 -	3 $\frac{1}{2}$ -	30 -

Methods of Manipulation.

Since the experiments were to be performed upon eggs in different stages of development no effort was made to fertilize them artificially. They were taken directly from the pools and placed in the solutions in shallow dishes under a receiver. Moistened blotting-paper was put beside them to prevent evaporation with its consequent increases in the percentage of the solution. The latter was also replaced from time to time by a fresh supply in order to secure the best results.

The eggs were kept in a well lighted room where they received the sunlight about one hour during the day. The temperature was very uniform and stood at about 70 F.

Before the eggs were placed in the solutions the stage of development was carefully determined, and as a further safeguard samples were preserved and afterward sectioned. For hardening PERENYI'S weaker fluid was used followed by graded alcohols.

The author desires to acknowledge his indebtedness to Dr. E. A. ANDREWS of Johns Hopkins University for the suggestions

which originally led to the undertaking of the experiments, and for much subsequent advice and assistance.

To Prof. JOHN M. TYLER and Librarian WM. I. FLETCHER of Amherst College sincere thanks are due for the free use of the Reference Library, an invaluable aid in any investigation, and to Prof. HARRIS H. WILDER for a similar privilege at Smith College.

Experiments with 0.6% salt solution.

Two bunches of *Amblystoma* Eggs were obtained on March 7th. In one of these the eggs were unsegmented, in the other they were in the blastula stage.

Both bunches were used to verify experiments undertaken upon the same species at the suggestion of Dr. ANDREWS in the spring of 1895. An effort was then made to ascertain whether the results obtained by O. HERTWIG (23) upon *R. esculenta*, and *R. fusca* would also hold true for *Amblystoma* and *R. temporaria*.

In HERTWIG's experiments »thoroughly healthy« eggs were first fertilized and allowed to lie for an hour and a half. They were then put into six different solutions of common salt, of strengths varying from 0.5% to 1%. HERTWIG found that the 0.6% solution yielded the most interesting results and accordingly that strength was used in the present instance. But he was unable to carry any embryos beyond the sixth day through lack of material.

In attempting to verify his experiments it was determined to rear some of the embryos at least to the formation of the internal gills, or the true tadpole stage. The attempt proved successful and fully developed tadpoles were obtained, while HERTWIG's results were verified in nearly every essential particular. There were several important differences in detail, however, and since the present investigations were carried so much further than his they furnish much that is new and interesting.

General Results.

All the eggs were removed from the gelatine, and half of each bunch were freed entirely from the surrounding membranes. Those in the blastula stage were put into a 0.4% solution, while the unsegmented eggs were placed in a 0.6% solution. The eggs from which the membranes were removed developed to the closing of the neural folds and then all died. Of the remainder, those in the 0.6%

solution developed without any loss, being used up gradually in the preservation of material at regular intervals. Those in the 0.4% solution for some reason died before escaping from the egg membranes. From a careful study of the eggs developed in the 0.6% solution by means of surface views taken while the eggs were still alive, and by sections of the preserved material we can trace the following

Development of the Embryo. Segmentation.

Segmentation is considerably delayed and resembles very closely that of eggs subjected to a low temperature, as noted by HERTWIG (23). Sections of eggs taken during segmentation reveal the fact that the nucleus divides some little time before the protoplasm, and cells may often be found in which the nucleus has divided while the protoplasm still remains undivided. The same is true of cells at or near the centers of activity in all subsequent development. As a result karyokinetic figures are of frequent occurrence. Indeed I would venture to suggest this method of development in a 0.6% salt solution as a useful means in karyokinetic investigation. We see clearly, therefore, that the egg is affected in its different parts unequally by the salt solution, the vegetative half being hindered more than the animal half as HERTWIG notes. There is also a corresponding inequality in each cell, the protoplasm being affected more than the nucleus, as LOEB has well shown (33).

Segmentation Cavity.

At the end of the third day the yolk cells are still very large. In section they appear as spherical masses made up of coarse granules and lying loosely in the segmentation cavity, many of them entirely free (Fig. 11). Consequently the floor of the cavity is not clearly defined as in the normal egg, but it is very irregular, and the large cells forming the yolk plug fuse toward the surface into a coarsely granular homogeneous mass. This irregularity of the yolk cells is found in subsequent stages, and makes it difficult, sometimes, to determine the exact arrangement of different parts. There are no traces of any ectoderm covering this yolk plug, the outer cells being like the inner ones save for the presence of pigment (Figs. 12 and 13).

Gastrulation.

EYCLESYMER (14) states that »invagination always begins nearer the equator than the vegetative pole« in normal eggs, and that it

starts as an irregular broken line lying just below the equator and formed by the union of a number of cleavage furrows. In the present instance this line is even more irregular and angular, and it begins much nearer the vegetative pole (Figs. 1 and 2). It bears the same relation to the more deeply pigmented area of the superior hemisphere as in normal development and as noted by TSUDA (39), in *Rana temporaria*, i. e., it starts just beneath it. The pigmented cells, however, as can be seen from Fig. 1, which represents a camera lucida drawing of the surface of a living egg, stop at some little distance from the edge of the blastopore, and the latter is wholly surrounded by large yolk cells which are entirely free from pigment. Moreover these are the largest of the yolk cells, and should be, therefore, those formed at or near the vegetative pole. CLARKE (8) states that invagination normally begins at the vegetative pole in *Amblystoma*, while F. HOUSSAY finds the same true for the *Axolotl* (26), JORDAN for the *Newt* (29), and TSUDA for *Rana temporaria* (39). The present experiments would seem to yield good testimony in the same direction.

At first the gastrula groove is much branched and follows almost exactly the boundary lines between some of these large yolk cells. But it becomes more even later on and turns upward, eventually running around the egg about one third the distance from the vegetative pole. This may be seen in Fig. 2, another surface view of a living egg farther developed. Here the furrow is crescentic and comparatively regular, but at first the convex side of the crescent, instead of the concave side, is turned toward the yolk field. I fully agree with MORGAN that the yolk exposed is somewhat more than would be enclosed by the normal blastopore, and that any statement as to the extent of white closed over by normal embryos, based on these abnormal embryos, will give an erroneous conclusion* (39).

Formation of the Pigment.

The pigment is formed in situ in the yolk cells themselves, and can be seen as minute dark spots upon their surface. It certainly cannot be regarded as in any way of ectodermal origin for no ectoderm is formed over the yolk plug. But it does seem to be intimately associated with the centers of physiological activity as JORDAN suggests.

In normal development it does not usually appear among the

yolk cells, except to darken their borders, and to color the cells along both sides of the archenteric cleft. JORDAN has suggested that the relative lack of pigment in certain cells is due to a »more sluggish metabolism attendant upon less rapid cell division« (30).

We do know that where cell division is especially rapid, as in the vertebral somites and the ventricles of the brain, there is always an accumulation of pigment. The same thing exists in these *Amblystoma* embryos, but other conditions indicate quite conclusively that such an accumulation cannot be due merely to absolute activity, nor can the lack of it depend on sluggish division. The salt solution retards development and cell division is more sluggish than in normal embryos. This is especially true in the yolk cells. But in these embryos and more noticeably in those reared in RINGER solution, where the division is even more sluggish, nearly every yolk cell contains a large amount of pigment gathered around its nucleus. In the external cells it appears at the surface. We have here, then, an increase in pigment combined with a decrease in activity.

The cells within the blastopore crescent are first very large and entirely free from pigment. But they soon divide and each of the resultant cells acquires a small amount of pigment near its center (fig. 2). In subsequent division the pigment is also divided and appears at the center of the resultant cells. It gradually increases in amount until at the formation of the neural folds it appears at the center of all the cells (figs. 3 and 4). At the closing of the folds (fig. 5) the pigment spots cover a large portion of the cell, and still later in development (fig. 6) they have increased sufficiently to color the whole surface of the yolk nearly as dark as the surrounding ectoderm. The cells themselves, however, remain very large compared with the ectoderm cells. There seems to be, therefore, a well defined growth of pigment *in situ*, and in all subsequent development the surface of the yolk is approximately the same color as the ectoderm, but traces of the peculiar mottled appearance remain for some time (fig. 6). In the normal embryo such yolk cells are not very active and they are still less so here. But there is, in all probability, a greater difference in the relative activities of nucleus and protoplasm in these eggs, and hence, compared with its surroundings, the nucleus may be considered as quite active. It is probably this relative activity of the nucleus, rather than any absolute activity, which it certainly does not possess, that accounts for the accumulation of pigment around it.

The irregularity of the border between the pigmented and the light area is very noticeable during gastrulation. This is well shown in fig. 1. At some points the pigment extends far up toward the blastopore crescent in loose irregular streaks and blotches, while elsewhere it has been advanced but little beyond the equator. The cells in the dark blotches are of the same size as those in the light areas at the same level, and are much larger than the ectodermal cells. This irregularity cannot be explained, therefore, by a difference in the down growth of the pigmented cells of the upper hemisphere. It persists even after the formation of the blastopore ring and must be due to the inequality of the yolk cells themselves, and the consequent difference in the influence of the salt upon them.

A study of sections shows that no ectoderm is formed over the yolk plug, but that this darkening is due to the formation of pigment in situ (figs. 12 and 13).

TSUDA (39) found in *Rana temporaria* that »the growth of pigment does not correspond in any way to the growth of new ectoderm cells, but . . . varies in various lots of eggs of the same stage procured at different times«. That is, eggs from different females vary considerably in the amount of pigment they contain at any given stage in development.

But she further states that »all the eggs of the same stage from one cluster are alike in quantity of pigment«. In these eggs not even this was true, but different eggs from the same cluster varied considerably in the amount and distribution of pigment.

TSUDA concludes that the amount of pigment varies with the conditions previous to the beginning of segmentation. It would seem fair to add that conditions may also arise during segmentation which will modify the pigment considerably: or even cause it to appear abundantly in places where it is not usually found at all.

The Fate of the Blastopore.

Concerning this much discussed question the embryos developed in salt solution present many interesting details.

In the first place the real abnormality in such development lies in it's retardation. These *Amblystoma* eggs produced in twenty days embryos which in outward appearance were exactly like others reared normally in a little more than half the time (fig. 8). And a study of sections did not reveal any essential difference.

This retardation renders it possible to follow more easily the exact method of development, and we can determine the following facts:

1. There is no closing of the blastopore previous to the formation of the (temporary) anus as in normal development, but the yolk plug remains exposed until after the external gills and the heart have been formed. By this time the primitive gut is well developed and its different parts are performing their individual functions. Hence, in these embryos the formation of an anus capable of functioning as such is not at all dependent upon a previous closure of the blastopore.

2. The anus certainly occupies the anterior portion of the blastopore so long as the yolk plug remains exposed. This seems at first sight a direct contradiction of the results obtained by MORGAN, CLARKE and others, but it will be found upon further examination that it really supports their statements. Let it be remembered that the retardation is more effective upon the passive yolk cells than upon the active pigment cells. Hence we may expect to find any process in normal development intimately connected with these yolk cells very much delayed. It might even be possible for one stage in the process to occupy a considerable period of time, and that is just what occurs in the present instance.

In the normal development of *Amblystoma*, the archenteron forms a cavity which is large and deep anteriorly, but posteriorly narrows from before backward as it passes down to the anus, while it remains wide from side to side. This was first pointed out by MORGAN and has been amply confirmed during the present investigations. It is well shown in fig. 21, which represents a longitudinal median section of a normal embryo just after the closing of the blastopore. We see that in front the cavity extends down almost to the ventral surface of the embryo, while posteriorly it is pushed upward to the dorsal surface. The whole ventral portion in this posterior region is occupied by the mass of yolk cells which gradually withdraw into the blastopore as the latter closes. This closure of the blastopore, as recently determined by EYCLESHYMER and MORGAN for *Amblystoma*, and by JORDAN for the Newt takes place as follows: There is first a convergence of cells from all parts of the margin at a uniform rate. This process is gradually modified by the more rapid movement of cells on either side, which press in toward the mid-line until the blastopore becomes a longitudinal slit. Soon they

meet along the middle of the slit and fuse, leaving a small circular orifice at either end. The anterior of these openings is the neuropore, the posterior becomes the permanent anus. In embryos developed in salt solution there is at first a similar uniform convergence of cells from all parts of the blastopore margin, but this is quickly stopped. There is no rapid growth of the cells at the sides, and consequently no elongation of the blastopore. This cannot be explained by the influence of the salt solution, for if that had any effect at all, it would increase the difference between the activity of the cells at the sides and those at the ends of the blastopore i. e. it would retard the more active side cells less than the comparatively sluggish cells at the ends.

There is also positive evidence in later development that the side cells retain their activity. We are compelled, therefore, to look elsewhere for our explanation. If we examine a median longitudinal section of one of these salt embryos at this period we find that the archenteron is of about the same depth throughout its entire length (fig. 18). The cells of the yolk plug have not withdrawn from the blastopore, and hence do not fill up the posterior part of the archenteron.

The dorsal lip of the blastopore is larger, thicker, and rounded inward more than normally. This is due to a combination of circumstances.

In the first place the lip is hindered in its downward growth by the non-withdrawal of the yolk plug. As it elongates, therefore, it would tend to enlarge at the end, to round inward, and probably to lift up the dorsal surface of the embryo somewhat.

A second reason is found in the fact just mentioned, that the sides of the blastopore border cannot move inward to meet along the mid-line. That they tend to do so normally shows that they must possess considerable activity. In the present instance some other mode of exercise must be found for this activity. It is found in a migration of cells from the lateral borders toward the dorsal mid-line, and a consequent accumulation of material at that point. This contributes to the enlargement of the dorsal lip.

3. That there is such a migration of cells, and that the closing of the blastopore is here due not to a backward extension of all the material of the dorsal lip over the yolk, but only of its central portion, as MORGAN has suggested for the development of *Rana*, is clearly shown from the following considerations.

When first formed the medullary folds extend around the blastopore on either side nearly to its posterior end. As they gradually fuse beginning at the anterior end of the embryo, it is evident that when the fusion reaches the blastopore it must stop there unless some such migration takes place. The folds along the sides of the blastopore cannot come together over the yolk plug.

The fusion does not stop, however, for the folds along the sides of the blastopore disappear. Furthermore the dorsal lip of the blastopore, in the median line only, begins to grow backward over the yolk plug as seen in figs. 6 and 19. Such a growth could only take place by »new tissue coming up to the middle line from the sides, and placing itself with or behind the cells already present in the dorsal lip«.

HERTWIG says that in normal development the blastopore border, with the exception of the small portion which becomes the anus, thus serves for the origin of the dorsal organs, but that the greater portion of the border remained unused in his salt embryos (*Rana esculenta*), and simply surrounded the yolk fields.

It is interesting to note that in these *Amblystoma* embryos whose development was carried so much farther than that of his *Ranas*, we find a similar condition at first, but later on there is good evidence that the greater portion of the border does take part in the formation of the dorsal organs.

The fact that this backward growth is compelled by the presence of the yolk plug to take place horizontally instead of vertically, and the fact that the posterior lip of the blastopore remains free from yolk cells leaves the opening of the blastopore, the anus, where it was before, at the anterior end of the blastopore under the dorsal lip (fig. 12). Attention is called to the fact that during all this time the blastopore occupies the ventral portion of the posterior end of the embryo, and that the anus opens posteriorly, not ventrally.

The backward extension of the dorsal lip of the blastopore sometimes results in the production of abnormalities, owing to the fact that it remains free from the yolk.

One of the most common of these is seen in fig. 10. Here instead of growing downward over the yolk plug as is usually the case, the tail of the embryo has turned upward and grown directly away from it. This is much more common in *Rana* than in *Amblystoma* and is probably due to the fact that the cells on

the ventral surface of the tail increase more rapidly than the others.

4. The blastopore retains its position at the posterior end of the embryo for several days; the yolk cells then begin to withdraw very slowly. At the same time the dorsal lip of the blastopore grows down vertically over the yolk cells, while the archenteric cavity becomes narrowed by the withdrawal of the yolk cells into its posterior ventral portion (fig. 20). This process continues slowly for five or six days, the blastopore growing steadily smaller, until finally, between the 17th and 20th days the dorsal lip has reached the ventral lip (fig. 14). The anus now occupies what was originally the posterior portion of the blastopore and opens ventrally instead of posteriorly. The embryo has become normal in its outward appearance.

During this growth the anus has changed its position gradually, and has occupied successively every portion of the dorsoventral diameter of the blastopore.

This gradual closure of the blastopore can be well seen in figs. 17 to 20, which are a series of longitudinal median sections taken from embryos in different stages of development. Figs. 12 to 14 show the enlarged posterior ends of another similar series.

5. We are fully conscious that we are dealing here with abnormal conditions of development, and that the greatest care must always be exercised in reasoning from the abnormal to the normal. But from the fact that the abnormality in the present instance is chiefly a retardation, from which a normal embryo is ultimately developed, it would seem as if we might infer that in the normal closing of the blastopore the withdrawal of the yolk cells is a more important factor than has been hitherto supposed.

They are usually regarded as inert and insignificant factors in development, remaining passive while the active pigment cells grow down over them and push them in. From a study of these embryos, however, it would seem that they are really the active agents of their own withdrawal, and when in any way their vitality is impaired or hindered, the pigment cells have to wait for them to act before they can accomplish their own work. In fact the whole closure of the blastopore, in these embryos at least, seems hinged on the withdrawal of the yolk cells. It is possible that the difference in the modes of closure of the blastopore noted by different authors may depend quite as much upon variations in the activity and mode

of withdrawal of the yolk cells as upon individual peculiarities of the pigment cells.

6. It will be readily seen that a separate neuropore cannot be formed in these embryos. Ordinarily when the sides of the blastopore meet and fuse at the mid-line two openings are left, the anterior of which is the neuropore.

Here, however, as the blastopore gradually closes, the anus always occupies its extreme anterior end and there can be no opening in front of it. In the development of the Newt JORDAN shows »that the relative position of neuropore and anus cannot be constant«, but that the latter »may lie in almost any portion of the original mid-line through the blastopore« (29). Several figures are given showing different distances between anus and neuropore, the two being usually quite close together. All that separates them is a varying length of the fused sides of the blastopore. In these embryos the sides of the blastopore do not fuse and hence there is nothing to separate neuropore and anus and the two coincide in one common opening.

The neuropore is ordinarily quite transitory and even in the present slow development cannot be regarded as sharing this opening very long.

Is this fusion of neuropore and anus at the anterior border of the blastopore of any significance in determining »whether this anterior portion of the blastopore primitively opened freely, and has been only secondarily caught in as the neurenteric canal by the precocious closing of the medullary folds?« (29) It is certainly quite suggestive.

Experiments with Ringer solution¹⁾.

A second lot of eggs was obtained on March 20th from pools covered with ice a quarter of an inch thick. This lot included all three kinds, *Rana*, *Chorophilus*, and *Amblystoma*. Two large bunches of *Rana* eggs were still unsegmented while the remainder were in the gastrula stage. The *Chorophilus* and *Amblystoma* eggs were all in the blastula stage.

¹⁾ The Composition of RINGER Solution is:

Normal salt solution (0.75%)		100 cc.
Potassium Chloride solution (1%)		3 -
Calcium Phosphate added to saturation.		

Samples of each kind of eggs were placed in four different solutions, viz.

1. RINGER solution undiluted.
2. - - diluted one third with water.
3. - - - - half.
4. - - - two thirds.

The results obtained from the eggs in advanced stages of development can be considered more appropriately later, and we will concern ourselves here with the experiments upon unsegmented eggs (*Rana*) only.

Most of the eggs were left in the jelly as they were found except that the bunches were divided once or twice to reduce the bulk. Some of them, however, were removed from the egg membranes and placed in the solution entirely free. These developed as far as the closing of the neural folds and then all quickly died. By comparing this result with that obtained in salt solution, it seems reasonable to suppose that the closing of the neural folds represents a critical period in the development of these embryos.

Such a conclusion is strengthened by the following facts. In every bunch of eggs there is considerable difference in the rate of development. Some eggs reach the stage just mentioned sooner than others. These were usually the first to die, while those that developed more slowly lived until they reached the same stage. Thus the deaths were not simultaneous, but they did all take place at about the same development period.

Furthermore the very thing occurred which would be naturally expected-viz. a few eggs produced embryos more vigorous than the rest, and these developed for two or three days beyond the closing of the folds, and then gradually weakened and died. In every instance there was no more than the average loss previous to this stage. There must be something, therefore, nearly simultaneous with the closing of the neural folds, which renders this particular period fatal to embryos deprived of the protection afforded by the egg membranes. This something appears to be the:

Ciliation of the Larva.

This was first recognized by CLARKE in '80, but has been doubted or entirely overlooked by others. Very recently (Feb. '96) ASSHETON (2) has worked out the ciliation of *Rana temporaria*, and

of the Newt, *Triton cristatus*. He finds that the first indications of cilia in both species occur shortly before, or just at the time of the closing of the neural folds. The cilia are developed first upon the lateral expansions of the neural plates, and along its edges, and produce a current whose direction is from before backwards. Later a similar current is produced by cilia upon the ventral surface. The ciliation spreads rapidly until the whole embryo is covered, but the currents differ much in intensity, and are specially developed in certain regions.

ASSHETON concludes that there can be very little doubt that the purpose of this ciliation is respiratory. Such a conclusion is of special significance when taken in connection with the facts observed in the present experiments. In normal embryos the movement of the cilia produces not only a current in the surrounding medium, but also a horizontal rotary motion of the embryo itself within the inner egg membranes. This motion is increased by both salt and RINGER solutions and becomes so persistent that patient watching fails to catch the embryo at rest long enough to sketch it with a camera lucida. In order to obtain this it must first be killed. The cilia are so strong in some instances as to produce the same motion in embryos lying free upon the bottom of the dish, and these, so far as could be determined, were the ones which lived beyond the closing of the neural folds. Ordinarily, however, the greater amount of friction to be overcome against the bottom of the dish rendered such motion impossible. As can be seen from figs. 15 and 16 the chief areas of ciliation are the head, the neck, and a broad band extending obliquely across the sides of the body. When the embryo is freed from the membranes its weight causes it to rest upon one side on the bottom of the dish, and consequently the cilia upon that side are rendered practically useless. In its normal position within the egg membranes the fluid which surrounds it is denser than water, and hence more nearly of the same specific gravity as the embryo itself, and the latter has no difficulty in keeping free from the membrane. Furthermore the jelly in which the eggs are enveloped is comparatively thick and firm during earlier development, but gradually softens, and finally goes to pieces and allows the larvae to escape. There would seem to be established in this way a delicate adjustment of osmosis, whereby the larva is carried safely beyond the ciliated period and initiated gradually into the less dense medium. The rotary motion produced by the cilia, therefore, is probably of

considerable importance, and its failure under adverse circumstances results fatally.

The first sign of ciliation in these *Amblystoma* embryos consists of a backward movement along the neural folds on the posterior surface, just as in *Rana*. The two figures given in figs. 15 and 16 are camera lucida drawings of normal embryos showing the currents generated by the cilia after the neural folds have closed (fig. 15), and again twelve hours later (fig. 16). The cilia are confined chiefly to the head, neck, and side of the body. Their motion can be plainly seen under a good handlens, and the currents are easily made out with the aid of a little chalk dust or other light colored insoluble powder sprinkled in the water. In the earlier stage (fig. 15) the strongest current starts from the dorsal surface just behind the head and sweeps backward and downward around the side of the neck to the ventral surface just outside the heart.

It thus covers exactly the position occupied in later development by the gills. Another current starts from the anterior extremity of the head and moves backward along the ventral surface until it joins the first near the heart. The two then divide and pass backward in a broad band along either side of the body to the posterior extremity, broadening gradually as they go. A third current seems to be a portion of the second, which separates from it on either side just below the eye and circles around the latter.

In the later stage (fig. 16), the current which passes across the position of the future gills continues to be the strongest. But now it unites with its fellow from the opposite side, and the two, joined by the second current which maintains its former position, proceed backward along the ventral surface. The whole side of the body is covered by a very broad and comparatively feeble current which takes its origin at the dorsal surface just behind the neck and runs backward along the side of the body, bending toward the ventral surface just before it reaches the posterior extremity.

The ciliation of these *Amblystoma* embryos thus resembles very closely that given by ASSHETON for *Rana* and the Newt, *Triton cristatus*, especially in the strong current passing over the position of the future gills. This fact serves to emphasize still further his conclusion that its function is respiratory.

With reference to the currents about the stomodeum I was unable to determine anything definite save that such currents do exist.

Comparative Influence of Solutions upon Eggs and Embryos in Different Stages of Development.

It remains for us to determine, if possible, the relation of the influence of these solutions to the rapidity of development on the one hand, and on the other to the period of development at which the embryos are first subjected to that influence.

In order to ascertain these points the following experiments were instituted.

Care was taken to determine exactly the condition of the egg or embryo before it was placed in the solution. For this purpose in all doubtful cases samples were preserved, and the final decision was made only after sectioning.

The experiments include all three species of amphibians, and many different stages in the development of each. So far as these species are concerned, therefore, the conclusions are trustworthy.

Experiment 1. A single bunch of *Rana* eggs was obtained on March 23rd which, when examined, proved to have the third furrow just developed.

One hundred of these were cut out of the egg membranes and placed free in a 0.6% salt solution, with as many more left within the membranes. The remainder of the eggs were allowed to develop normally for 24 hours, when two hundred more were placed in the salt solution under the same conditions. The rest again developed normally for 24 hours and were then all put in the salt solution. All eggs placed in the solution free from the membranes developed to the closing of the neural folds with a loss of less than 10%, but then, or within 24 hours after, they all died. Those which had been left for 48 hours had nearly reached this stage before being placed in the solution, and so lived but a few hours longer. The first lot stopped segmenting altogether for a short time when placed in the solution, and then began again. The second lot seemed to stop for a longer period than the first, and the third lot longer than the second. The actual time was not taken, so that only a rough comparison could be made, but enough was observed to suggest that the effect of the solution was increased with the age of the embryo.

This suggestion was the only outcome of the experiments, for these embryos all died on or before March 30th.

Experiment 2. Some *Rana* eggs in the 4 cell stage were removed from the jelly, but left within the membranes, and placed in RINGER solution on March 27th.

They remained dormant for about two hours (this time is the average for all the eggs, of course there were many variations due to individual differences). They then gradually recovered and developed in all respects like those reared by HERTWIG and others in salt solution.

In later development these eggs showed the appearance and gradual growth of the cilia over the ectoderm very finely. It was possible to verify upon them the ciliated tracts and currents given by ASSHETON for the same species. For twelve days there was very little loss, but they then began to die quite rapidly and were all dead by the 15th day.

They were also considerably contorted as though the solution had affected the pigment cells in different portions of the body unequally. In ordinary development individual peculiarities are found in eggs from different bunches i. e. those laid by different females.

These solutions seem to magnify such peculiarities, and this factor must always be taken into consideration when comparing the effects produced by the solutions.

The development of different eggs in the same bunch is approximately uniform, and so the retarding influence produces nearly the same effect upon them all.

Experiment 3. Some *Rana* eggs in the 16 cell stage were placed in RINGER solution under the same conditions as those of Experiment 2. These remained dormant for a slightly longer period. This may have been due in part to individual differences in the two bunches of eggs, but subsequent experiments go to prove that it was partly also the result of their advance in development.

The solution seemed to have more influence over the yolk cells in these eggs and an enormous yolk plug protruded from the blastopore. The pigment was unable to cover this surface and so it remained light colored at the center, with numerous dark streaks running over it around the border. Ten individuals ($16\frac{2}{3}\%$) out of this lot were developed to the appearance of the external gills, which occurred on the 15th day. These were then preserved for further examination.

The proportion of eggs which died during development was much larger than in either of the previous experiments.

Experiment 4. A fourth lot of *Rana* eggs in advanced segmentation (64 cells onward) were placed in RINGER solution at the same time with those of Experiment 3, and were kept under the same conditions. The influence of the solution was more marked than in the previous cases, development was slower, and a much larger proportion died. The period of rest was nearly three hours (2 hrs. 50 mins.) and the eggs did not appear to recover as fully as in Experiment 3. There was also another significant difference. These eggs were farther advanced when placed in the solution, and yet their subsequent development was slower than that of the 16 cell eggs.

Although both were subjected to the solution at the same time, the 16 cell eggs reached gastrulation considerably in advance of the 64 cell ones.

Here again individual peculiarities may partially explain this difference in rapidity of development, but it does not seem probable that this alone could occasion so great a discrepancy. None of these embryos could be reared to the formation of the external gills although every effort was made to secure that result. They died off very rapidly during early development and none lived beyond the twelfth day.

Experiment 5. A bunch of *Rana* eggs in which the blastopore was fully developed was obtained March 25th. A portion of these were placed at once in a 0.6% salt solution. These lay dormant for nearly 10 hours without showing any signs of further development. They then advanced very slowly. Although the blastopore was fully developed and had begun to contract in size before the eggs were placed in the solution, this action ceased, and there was no further diminution for several days.

That this was not the result of a complete cessation of activity was proved by the fact that the embryos showed the usual amount of development elsewhere.

They elongated, the neural folds appeared and gradually fused, and the head was differentiated. Sections also showed that internal development was going forward slowly. The activity of the yolk cells alone seemed temporarily paralyzed. There was the same migration of material from the sides of the blastopore to the center of the dorsal lip, and the latter began to elongate and grow out into the tail. The failure of the borders of the blastopore to contract could not have been due, therefore, to any lack of activity in the

pigment cells, but must be attributed to the sluggishness of the yolk cells. This is another evidence in favor of the view that even at an advanced stage in the formation of the blastopore, the withdrawal of the yolk cells is the first requisite for the completion of that formation, and the yolk cells are themselves the active agents of their own withdrawal.

It would be suggested also that ordinarily these yolk cells contain just about enough active protoplasm scattered amongst their yolk granules to accomplish such a withdrawal. The influence of the salt solution weakens the activity of this protoplasm, and thus renders the withdrawal impossible for the time being. Subsequently this activity may recover from the influence of the solution, and increase until it is sufficient to move the yolk cells.

Such an adaptation of vital functions to altered conditions is by no means rare.

It may be said that something of the sort always occurs when the change in conditions is not sufficient to overcome the function altogether. If the change be comparatively small, as in the present instance, the organism may be able to recover completely, and resume its normal functions.

This is shown more clearly in Experiment 12. The remainder of these eggs were allowed to develop normally for four days before being placed in the solution.

In this time they had reached an advanced stage, the blastopore being closed, the body elongated, and the anterior and posterior ends well developed. The solution produced no visible external change in their further growth, but they all weakened and died within five days.

We have thus subjected *Rana* eggs in different stages of development to the influence of both salt and RINGER solutions.

We find that eggs which have already begun to segment always lie dormant for a time on being placed in the solution.

The first influence of either solution is like that of a low temperature and results in a complete checking or temporary paralysis of the vital activities. The eggs recover and go on developing after a period which varies with the amount of segmentation which they have undergone previous to being placed in the solution; the more advanced the segmentation the longer the period of rest.

Subjection to either solution at a late stage of segmentation is also more likely to prove fatal. After developing normally for a

time the organism is not as capable of with-standing adverse influences as when it is subjected to them before any development has taken place.

Experiment 6. Some *Amblystoma* eggs in the 4 cell stage were placed in the same dish with the *Rana* eggs of Experiment 3. (In RINGER solution.) This bunch was left with the jelly as it was found, and was not changed in any way.

The eggs developed very slowly for 17 days when the first traces of the external gills began to appear. They were thus delayed more than the eggs in 0.6% salt solution since the latter in the same time had produced embryos with the external gills fully formed. A few of them had a very small yolk plug still protruding, but the majority appeared perfectly normal.

We have already stated that these 4 cell *Amblystoma* eggs were put in the same dish with the 16 cell *Rana* eggs, so that the conditions of development must have been exactly the same. The results, however, were very different, for while only $16\frac{2}{3}\%$ of the *Rana* embryos lived to the 15th day, the *Amblystomas* were all alive on the 17th day.

About one half of them were then preserved and the rest allowed to develop. As soon as the stomodeum opened in both *Ranas* and *Amblystomas* a marked change took place in their development.

Hitherto the yolk cells had furnished the nourishment necessary for the growth of the embryo, and everything had advanced steadily, though slowly. Now the point was reached, where the digestive canal begins to function and external food becomes necessary. Ordinarily at this stage the embryo finds enough to eat in the aquarium. These had to be kept in a clean dish for obvious reasons. An attempt was made to feed them, but nothing proved acceptable, and hence they soon began to die. Two of the *Amblystoma* however lived until the 24th day.

In comparing *Amblystoma* with *Rana* we must keep in mind that the latter developed faster than the former, and so could not be expected to live as long. But this does not explain the fact that all the *Amblystomas* lived until after the opening of the stomodeum while most of the *Rana* died before reaching that stage.

Experiment 7. *Amblystoma* eggs in both the 16 and the 64 cell stages were placed in RINGER solution in the same dish. These were also left in the original jelly untouched, but they developed more slowly than those of Experiment 6. Here again we have eggs

at different stages of development, and in this instance eggs of the same species, placed simultaneously in the same solution under exactly similar conditions, and yet yielding very different results. They were necessarily taken from different bunches, but in the one case (Experiment 6) we find the *Amblystomas* all alive after 17 days development, and nearly all presenting a perfectly normal appearance (fig. 8). In the other case (Experiment 7) we find a much larger percent with their yolk plugs still protruding at the formation of the external gills (fig. 7), while nearly half (45%) of them died before reaching that stage. Considerable difference could also be detected in the early development of the two bunches in the present experiment.

Experiment 8. *Amblystoma* eggs with the blastopore just developed were placed in RINGER solution March 27th. In these very large yolk plugs were left protruding, even at the end of 16 days development, at which time also nearly all (90%) of them were dead.

By comparing these eggs with those in Experiment 6 several interesting facts appear.

These eggs had developed normally until the blastopore was fully formed and its borders had begun to contract. But on being placed in RINGER solution the action, begun and carried so far forward, was not completed, and the yolk plug remained very nearly of its original size. On the contrary the 4 cell eggs, in which even segmentation was scarcely commenced, formed a blastopore at the proper time, and most of them completely closed it.

Again the two lots of eggs were placed in the solution within an hour of each other, but at the end of ten days the 4 cell eggs were as far developed as the others. At the end of 16 days they were much farther developed, notwithstanding the fact that the eggs of the present experiment had so much the start of them. The difference between the 4 cell stage and gastrulation represents about three days development, and yet this comparatively large handicap was overcome within 10 days time. Evidently in this instance the influence of the surrounding medium was greatly modified by differences in the stage of development at which the egg was subjected to its action.

Experiment 9. *Chorophilus* eggs, unsegmented, were placed in RINGER solution. These eggs did not seem to lie dormant at all, but continued developing at once. The influence of the solution upon their development, however, was very marked in other ways.

Gastrulation was much delayed and the blastopore, when formed, occupied fully one half the surface of the egg. As the embryo began to elongate this yolk mass, which was out of all proportion to the size of the embryo, was left free, and occupied the whole of the ventral surface. In many cases the embryo was simply coiled around the yolk and presented an appearance very similar to that in the eggs of bony fishes. This free yolk became loose and mealy and portions of it sloughed off from time to time.

For this reason the embryos died rapidly, and none of them reached the closure of the neural folds. For the same reason it was found absolutely impossible to preserve any of the eggs so that they could be sectioned, though many different methods were attempted. Accordingly it was determined to try these eggs in a weaker solution, with the results given in Experiment 12.

Experiment 10. *Chorophilus* eggs in the 4 cell stage were placed in the same dish with the 16 cell *Rana* eggs of Experiment 3, and the 4 cell *Amblystoma* eggs of Experiment 6. These eggs had all been taken from the same pool in close proximity to one another, and by keeping them thus in the same dish it was possible to make intelligent comparisons of the relative influence of the solution upon them. The *Amblystoma* eggs were retarded most in their development, and the *Chorophilus* eggs the least. The former remained inactive for some time after being placed in the solution while the latter seemed scarcely to stop at all. The *Rana* eggs were inactive for a time, but not as long as the *Amblystomas*.

On the other hand the ultimate effect of the solution was exactly the reverse of this. The *Amblystoma* eggs recovered their activity slowly, but seemed to recover it fully, and continued developing until they became quite normal embryos with fully developed external gills.

In strong contrast with these the *Chorophilus* eggs, which at first were scarcely influenced by the solution, in later development were so affected by it that none of them could be reared even to the closing of the neural folds.

In this particular, also, the *Rana* eggs occupied the middle ground. They were more affected than the *Amblystoma* eggs, and not as much as the *Chorophilus*.

RINGER solution, therefore, retards most those eggs whose development is least rapid, while its ultimate influence is greatest upon those eggs which develop most rapidly.

Experiment 11. Some *Chorophilus* and *Amblystoma* eggs, each in the 64-cell stage, were placed together in a 0.6% salt solution on March 28th. Again the *Amblystoma* eggs remained dormant for some time (in this case 5 hours) while those of *Chorophilus* continued developing with scarcely a break, but very soon a marked difference between the two species became apparent.

Both kinds of eggs were at the same stage when placed in the solution, and according to the normal rate already given the *Chorophilus* eggs should have developed much more rapidly than those of *Amblystoma*. Such was not the case, however; they kept along very evenly for a day, and then the *Amblystoma* eggs gained slowly on the others and eventually reached gastrulation nearly 24 hours ahead of them.

The *Chorophilus* eggs which should have gastrulated within 12 hours did not reach that period until the 5th day, while the *Amblystoma* eggs that should have formed the blastopore on the second or third day were only delayed till the fourth day.

Moreover the *Chorophilus* eggs were very much shrunken and contorted, especially around the head and anterior end, this portion of the body being covered with ridges and small papillae.

The yolk plugs were very large and showed the same pigmentation as has already been noticed in the case of *Amblystoma* and *Rana*, though not quite so clearly.

These *Chorophilus* eggs lived for 15 days and in that time had not completed their gastrulation. The *Amblystoma* eggs on the contrary, developed with some loss up to the formation of the external gills when the few that were left were preserved.

In this experiment, therefore, the effect of the same solution under the same conditions was very different in the two kinds of eggs, and was the same as that obtained in the previous experiment.

Experiment 12. In connection with the fact that it was found so difficult to develop the *Chorophilus* eggs in any of the solutions beyond the gastrula period, the following experiment is of special significance.

It was suggested by the results obtained by DAVENPORT and NEAL in the »Acclimatization of organisms to poisonous chemical substances« (9).

Some unsegmented eggs of *Amblystoma*, *Rana* and *Chorophilus* were placed in a 0.05% salt solution on March 29th.

They were allowed to remain in this very weak solution for 24 hours. At which time the solution was poured off and replaced by one of double the strength (0.1 ‰). Subsequently every 24 hours the strength of the solution was increased 0.1 ‰ until it reached 1 ‰. All the eggs developed normally without any indication of the free yolk plug. Some of the *Chorophilus* eggs hatched out in four days, when the solution had a strength of 0.3 ‰. They lived until the reserve food material of the yolk was used up, when they all died, having refused any other food. The last one died on the 10th day when the solution had a strength of 0.9 ‰.

The *Rana* eggs hatched in 7 days (0.6 ‰ sol.) and some of them lived for 6 days afterward, when the few that remained were preserved for examination.

The *Amblystoma* eggs did not hatch until the 12th day, and then lived 4 or 5 days longer in a 1 ‰ solution.

We thus have embryos living and swimming about freely in a solution of sufficient strength to kill them if they had been placed in it immediately.

We know from our own experiments that the influence of the salt solution is negatively, rather than positively injurious i. e. it does not directly injure the protoplasm but simply hinders or prevents it from performing its normal function. This preventive influence has more effect upon the protoplasm than upon the nucleus and when it becomes sufficiently strong to overcome the functional activity of the latter the organism dies.

The present experiment teaches that the ability of both nucleus and protoplasm to withstand this influence in any particular case is capable of education and can be increased by being gradually exercised. This development can be carried so far as to enable the organism to easily overcome influences that would otherwise quickly prove fatal. There seems to be differences between the three species in their capacity for such development. In ordinary life many adverse influences, such as stagnation of the water or the presence of any salt or mineral in solution, come on gradually, and this capacity on the part of the embryo for increasing its ability to withstand such influences must prove of great service, and often times prevent a fatal issue.

In reviewing the teaching of these experiments the first general fact which they indicate is that »the extraordinary delicacy with which the frog's eggs respond to slight variations in the surrounding

medium« (HERTWIG) is closely connected with rapidity of development.

We can easily see that this must be so, for the rapidity varies with the relative amount of active protoplasm which the egg contains. Any given influence, therefore, will produce very different results according as it is exerted upon eggs having a large quantity of such protoplasm, or upon those possessing only a meagre amount.

A second fact is one already stated by HERTWIG. The »lowering of the energy in the different parts of the egg is not equal but regulates itself according to the proportion in which the active protoplasm substance and the more passive nourishment material are contained in the egg cavity«. This fact appears in every experiment with the three species now being considered as plainly as with the two species of *Rana* upon which HERTWIG experimented.

A third fact follows in logical sequence i. e. the effect produced by the surrounding medium does not depend upon the absolute amount of active protoplasm which the egg contains, nor upon the relative amount compared with its size, but upon the relative amount contained in the animal half compared with the vegetative half. The large *Amblystoma* eggs contain relatively a smaller amount of this active substance than the small *Chorophilus* eggs. Consequently their ordinary development is much slower, and they are retarded more by the restraining influence of the same medium. But there is less difference between their animal and vegetative cells in the amount of active protoplasm which each contains than is found in the more rapidly developing *Chorophilus* eggs. In consequence of this, the influence of the solution is more nearly equal upon the two kinds of cells. The both lie dormant for a time, and although the animal cells recover first they do not develop rapidly enough to prevent the vegetative cells from recovering in their turn and following them at a comparative rate approximately normal.

On the contrary, in the eggs of *Chorophilus* there is a great difference in the amount of active protoplasm contained in the animal and the vegetative cells. Consequently when brought under the influence of a restraining medium there is an increased difference in the effects produced upon the two kinds of cells. The animal cells have so much activity that they seem scarcely restrained at all, but continue to develop at nearly the normal rate. But the vegetative cells, possessing only a little active protoplasm are restrained so much that they can scarcely continue at all, or may

even be compelled to lie dormant for a while. In this way differences are produced which do not exist in normal development. These differences increase rapidly, and in a short time become so great as to result in the death of the embryo.

The *Amblystoma* egg, therefore, possesses a bulwark of safety in the more even distribution of its protoplasm, and is able thereby to overcome influences which result disastrously to its more rapidly growing relative. But at the same time the sluggish development, which is the result of this more even distribution, increases the period of exposure to danger, and a great many *Amblystoma* eggs usually die in the jelly.

Just subsequent to the experiments here given a dozen bunches of *Amblystoma* eggs were found in a boggy field at the edge of the woods. The water was nowhere more than 6 or 8 inches deep, and was so thoroughly impregnated with iron as to tinge the soil and herbage a deep rust color.

It did not seem as if any eggs could develop in such a medium, but subsequent examination proved that they actually did. Some of the bunches were taken to the laboratory and produced perfectly healthy embryos. A visit was made to the bog at about the right time and the eggs were found hatching, apparently with no more than the ordinary loss. No doubt they produced an average number of adults provided the water did not dry up prematurely. This furnishes a good example of the protection afforded against influences which must arise quite frequently in natural development.

Again we are able to infer that the amphibian embryo can accommodate itself to adverse circumstances at the very beginning of its development more readily than it can readjust its vital powers after a sudden change during later growth. The older it gets, and the farther it is developed normally the less becomes its ability to change into something abnormal.

This truth has been recognized for a long time as applying to the adult life of an animal, and it seems to be even more applicable to embryonic stages of development. According to the experiments here recorded, eggs at stages as near together as the unsegmented and the 64-cell stage show a difference in their ability to overcome the influence of the solutions. This becomes very marked in comparing eggs subjected to the solutions at the beginning and at the close of segmentation. We have here, perhaps, a stronger evidence than that given by HERTWIG, of the great delicacy with which

the amphibian embryo responds to variations in the surrounding medium.

These experiments also bear significant testimony in another direction. The early differentiation of cells as to function, and their consequent interdependence has been admirably worked out by eminent investigators in the recent morphological examination of different embryos (37 and 48), but it scarcely admits of physiological proof under normal conditions.

Under these abnormal conditions, however, a comparison of experiments indicates quite clearly that in the unsegmented egg there is very little differentiation. If there be any at all it is a very plastic one, and accommodates itself easily to changed conditions. But as soon as segmentation begins differentiation commences also, and the egg acquires thereby definite regional distinctions.

These increase with advancing development and at the 64-cell stage they become sufficient to hinder the egg perceptibly in accommodating itself to a new environment.

In the blastula stage they furnish a serious obstacle to any such accommodation, and by the time the blastopore is fully formed they have become so well established that they cannot be altered, and consequently the organism must die under the influence of any serious change in its environment.

HERTWIG has clearly shown that the cell material which is used in these embryos for the origin and development of the dorsal organs and the tail is differentiated in a very different manner from that which occurs in normal development.

The same truth has been shown in the present experiments when discussing the fate of the blastopore. It is this readjustment of differentiation which proves so difficult for the embryo, since material which has been gradually separated for a particular purpose, or at least for the accomplishment of that purpose in a particular way, must be used for a different purpose or for its accomplishment in an entirely different way. This subject of differentiation during development, and of the potency of the early blastomeres, has been eminently worked out by WILSON (49) and MORGAN (38) in very recent publications. They both frankly state that at present we do not know how such differentiation is brought about. MORGAN »thinks there are sufficient reasons to conclude that the power of differentiation lies within the egg itself, and does not depend directly on external stimuli« (38, pag. 134).

The present experiments would seem to strengthen this conclusion, and to show, in addition, that the power may be strong enough to overcome considerable adverse external influence. In spite of the restraining influence of the salt solution the differentiating power asserted itself and ultimately produced normal embryos, when the eggs were subjected to the solution before they had begun to segment.

Of course the more rapid the development the sooner will the differentiation be accomplished, and we may reasonably infer the more rigid will it be. Such eggs, therefore, as those of *Chorophilus* could not accommodate themselves as readily to a changed environment as those of *Amblystoma* in which the differentiation takes place more slowly, and thereby allows time for readjustment.

Westfield, Mass. U. S. A.

Zusammenfassung.

Diese Experimente ergaben, in Hinsicht auf die drei erwähnten Amphibien-species, die folgenden Thatsachen:

1) Sowohl einfache Salzlösung wie gemischte Salzlösung (RINGER-Lösung, s. pag. 627, Anm.) üben, je nach ihrer Konzentration, einen hemmenden Einfluss auf die Entwicklung aus. In einer 1%igen Salzlösung wird diese Einwirkung stark genug, um die Entwicklung völlig zu verhindern.

2) Entsprechend den Unterschieden der Aktivität der Dotterzellen und der pigmentirten Zellen (Bildungszellen) werden erstere stärker gehemmt als letztere. In Folge dessen ist alle Entwicklung, die irgendwie von den Dotterzellen abhängt, abnorm verzögert. In dieser Weise können Differenzen hervorgebracht werden, welche genügen, um Absterben hervorzurufen.

3) Aus demselben Grunde werden auch verschiedene Theile einer jeden Zelle verschieden betroffen. In Folge dessen sind die karyokinetischen Figuren nicht alterirt und daher gut zu sehen.

4) Je schneller eine Species sich entwickelt, desto geringer ist der un-mittelbare Effekt des hemmenden Einflusses auf entsprechenden Stadien;

5) desto schlimmer ist aber der Endeffekt.

6) In Eiern derselben Species auf verschiedenen Stadien der Entwicklung ist die Wirkung der Lösung um so größer, je vorgeschrittener die Entwicklung ist.

7) Die Fähigkeit von Amphibieneiern, derartigen Einwirkungen zu widerstehen, kann durch Gewöhnung bis zu einem Grade gesteigert werden, dass das Ei in einer Umgebung zu leben vermag, in welcher es sonst augenblicklich zu Grunde ginge.

8) In beiderlei genannten Lösungen wird Pigment *in situ* in den Dotterzellen entwickelt, bis die Oberfläche des Dotterpfropfes fast ebenso dunkel erscheint als das Ektoderm.

9) Bei *Amblystoma* bildet sich ein temporärer Anus am vorderen Ende des Blastoporus. Der Neuroporus nimmt eine Zeit lang an dieser Öffnung Theil. Mit fortschreitender Entwicklung durchwandert der Anus successive den ganzen anteroposterioren Durchmesser des Blastoporus, und der dauernde Anus des erwachsenen Thieres bildet sich am hinteren Ende des Blastoporus.

10) Auf der Rückenfläche der *Amblystomal*arve erscheinen an der Verschlussstelle der Neuralfalten Cilien, und breiten sich allmählich auf dem ganzen Ektoderm aus. Der stärkste Strom, den diese Cilien erzeugen, geht über die Stelle der späteren Kiemen.

11) Diese Cilien veranlassen (wie bekannt) eine rotirende Bewegung der Larve innerhalb der Eihüllen. Unter Bedingungen, welche diese Bewegung verhindern, starb die Larve.

Diese thatsächlichen Ergebnisse erlauben die folgenden allgemeinen Schlüsse:

1) Es besteht ein inniger Zusammenhang irgend welcher Art zwischen Pigmentbildung und physiologischer Aktivität. In beiden Lösungen wurde Pigment in der unmittelbaren Nähe von denjenigen Zellen oder Zelltheilen gebildet, welche physiologisch sehr thätig waren.

2) Die Entfernung der Dotterzellen ist ein primäres Erfordernis für den Verschluss des Blastoporus. Dieselbe erfolgt durch die funktionelle Thätigkeit der Dotterzellen selbst; wird sie irgendwie verhindert, so bleibt der Blastoporus offen.

3) Die Präcision, mit welcher Amphibieneier auf geringe Veränderungen des umgebenden Mediums reagiren, hängt eng zusammen mit der Entwicklungsgeschwindigkeit. Je größer diese ist, desto feiner ist die Reaktionsfähigkeit.

4) Die Wirkung von Salzlösungen hängt weder von dem absoluten Betrag an aktivem Protoplasma ab, welchen das Ei enthält, noch von dem relativen Betrag in Hinsicht auf die Größe des Eies. Eher hängt sie ab von der relativen Menge, die in den animalen Zellen im Vergleich mit den vegetativen enthalten ist, d. h. von der Relation zwischen aktivem Protoplasma und passivem Nährmaterial in den einzelnen Zellen.

5) Eine gleichmäßige Vertheilung aktiven Protoplasmas hat eine träge Entwicklung zur Folge und verlängert so die Zeit der Gefährdung des Eies. Dafür entschädigt dieselbe vielleicht durch den Schutz, den sie gegen schädigende Einflüsse im umgebenden Medium gewährt.

6) Die physiologischen Reaktionen dieser Amphibienembryonen gegen die Lösungen zeigen, dass eine funktionelle Zelldifferenzirung in wenig segmentirten Eiern nicht existirt, sondern eher ein Ergebnis allmählicher Entwicklung darstellt.

Literature.

1. ALCOCK, T., On the development of the common frog. *Memoirs Manchester Lit. and Philos. Soc.* Ser. 3. Vol. VIII. 1883.
2. ASSHETON, R., Ciliation of the Ectoderm of the Amphibian Embryo. *Quart. Journ. Mic. Sc.* XXXVIII. pag. 465. 1896.
3. BALFOUR, F. M., Comparison of early stages in the development of Vertebrates. *Quart. Journ. Mic. Sc.* XV. pag. 207. 1875.

4. BALFOUR, F. M., A treatise on Comparative Embryology. Mem. Edit. 1885.
5. BAMBEKE, CH. VAN, Nouvelles Recherches sur l'Embryologie des Batraciens. Archiv. de Biol. I. pag. 305. 1880.
6. BAMBEKE, CH. VAN, Le Sillon Médian ou Raphé gastrulaire du Triton alpestre. Archiv. de Biol. XIII. pag. 147. 1893.
7. BROOKS, W. K., Alternation of Periods of Rest with Periods of Activity in the Segmenting Eggs of Vertebrates. Stud. Biol. Lab. Johns Hopkins Univ. II. pag. 117. 1881.
8. CLARKE, S. F., The Development of *Amblystoma punctatum*. Stud. Biol. Lab. Johns Hopkins Univ. I. pag. 105. 1880.
9. DAVENPORT and NEAL, The Acclimatization of Organisms to poisonous chemical Substances. Archiv f. Entwicklungsmech. II. pag. 564. 1895.
10. DRIESCH, H., Entwicklungsmechanische Studien. Zeitschr. f. wiss. Zool. LV. 1893.
11. DURHAM, H. E., Note on the Presence of a Neurenteric Canal in *Rana*. Quart. Journ. Mic. Sc. XXVI. pag. 509. 1886.
12. ERLANGER, R. v., Über den Blastoporus der anuren Amphibien. Sein Schicksal und seine Beziehungen zum bleibenden After. Zool. Jahrb. IV. pag. 239. 1889.
13. ERLANGER, R. v., Zur Blastoporusfrage bei den anuren Amphibien. Anat. Anzeiger. VI. pag. 684. 1891.
14. EYCLESYMER, A. C., Early Development of *Amblystoma*. Journ. Morph. X. pag. 343. 1895.
15. EYCLESYMER, A. C., Paraphysis and Epiphysis in *Amblystoma*. Anat. Anzeiger. VII. pag. 215. 1892.
16. GAGE, S. H., Life History of the Vermillion Spotted Newt. Am. Nat. Dec. 1891. pag. 1084.
17. GATEHOUSE, J. W., Development and Life-history of the Tadpole. Journ. Mic. and Nat. Sc. I. pag. 11. 1888.
18. HALLEZ, P., Sur la Loi de l'Orientation de l'Embryon chez les Insectes. Compt. Rend. CIII. pag. 606. 1886.
19. HERBST, C., Experimentelle Untersuchungen über den Einfluss der veränderten chemischen Zusammensetzung des umgebenden Mediums auf die Entwicklung der Thiere. Mittheil. a. d. Zoolog. Stat. zu Neapel. XI.
20. HERTWIG, OSCAR, Beiträge zur Kenntniss der Bildung, Befruchtung und Theilung des thierischen Eies. Morph. Jahrb. III. pag. 32. 1877.
21. HERTWIG, OSCAR, Urmund und Spina bifida. Archiv f. mikr. Anat. XXXIX. pag. 353. 1892.
22. HERTWIG, OSCAR, Über den Werth der ersten Furchungszellen für die Organbildungen des Embryo. Archiv f. mikr. Anat. XLII. pag. 662. 1893.
23. HERTWIG, OSCAR, Beiträge zur experimentellen Morphologie und Entwicklungsgeschichte. I. Die Entwicklung des Froscheies unter dem Einfluss schwächerer und stärkerer Kochsalzlösungen. Archiv f. Mikr. u. Entw. XLIV. pag. 285. 1895.
24. HIGGINBOTHAM, J., Influence of Physical Agents on the Development of the Triton and Frog. Phil. Trans. Royal Soc. 1850.
25. HINKLEY, MARY H., Notes on the Development of *Rana sylvatica*. Proc. Bos. Soc. Nat. Hist. 1882.
26. HOUSSAY, F., Etudes d'Embryologie sur les Vertébrés. Arch. Zool. Expér. Sér. 2. T. VIII. p. 143. 1890.

27. JOHNSON, ALICE, Fate of the Blastopore and Presence of a Primitive Streak in the Newt. Quart. Journ. Mic. Sc. XXIV. pag. 659. 1884.
 28. JOHNSON, ALICE, and SHELDON, LILIAN, Notes on the Development of the Newt. Quart. Journ. Mic. Sc. XXVI. pag. 573. 1886.
 29. JORDAN, E. O., Habits and Development of the Newt. Journ. Morph. VIII. pag. 270. 1893.
 30. JORDAN and EYCLESHYMER, The Cleavage of Amphibian Ova. Journ. Morph. IX. pag. 407. 1894.
 31. KOSTANECKI, K., and SIEDLECKI, Über das Verhältnis der Centrosomen zum Protoplasma. Archiv f. Mikr. u. Entw. XLVIII. pag. 181. 1896.
 32. KASTCHENKO, N., Zur Entwicklungsgeschichte des Selachierembryos. Anat. Anzeiger. III. pag. 445. 1888.
 33. LOEB, J., Investigations in physiological Morphology. III. Experiments on Cleavage. Journ. Morph. VII. pag. 253. 1892.
 34. MARSHALL, A. M., Vertebrate Embryology. London and New York 1893.
 35. McCLURE, C. F. W., Early stages in segmentation in *Petromyzon marinus*. Zool. Anzeiger. XVI. pag. 367. 1893.
 36. MORGAN, T. H., On the Amphibian Blastopore. Stud. Biol. Lab. Johns Hopkins Univ. IV. pag. 355. 1889.
 37. MORGAN, T. H., Formation of the Embryo of the Frog. Anat. Anzeiger. IX. 1894.
 38. MORGAN, T. H., The Development of the Frog's Egg. Macmillan & Co. 1897.
 39. MORGAN, T. H., and TSUDA, UMÉ, The Orientation of the Frog's Egg. Quart. Journ. Mic. Sc. XXXV. pag. 373. 1894.
 40. NORMAN, W. W., Segmentation of the Nucleus without segmentation of the Protoplasm. Archiv f. Entwicklungsmech. III. pag. 106. 1895.
 41. ORR, H., Note on the Development of Amphibians. Quart. Journ. Mic. Sc. XXIX. pag. 295. 1888.
 42. ROBINSON, A., and ASSHETON, R., The Formation and Fate of the Primitive Streak with Observations on the Archenteron and Germinal Layers of *Rana temporaria*. Quart. Journ. Mic. Sc. XXXII. pag. 451. 1891.
 43. SCHWINK, F., Über die Gastrula bei Amphibieneiern. Biol. Centralbl. VIII. pag. 29. 1888.
 44. SCOTT, W. B., and OSBORN, H. F., On Some Points in the Early Development of the Common Newt. Quart. Journ. Mic. Sc. XIX. pag. 449. 1879.
 45. SCHANZ, Das Schicksal des Blastoporus bei den Amphibien. Jenaische Zeitschr. XIV. pag. 411. 1887.
 46. SIDEBOTHAM, H., Note on the Fate of the Blastopore in *Rana temporaria*. Quart. Journ. Mic. Sc. XXIX. pag. 49. 1888.
 47. WATASE, S., Studies on Cephalopods: I. Cleavage of the Ovum. Journ. Morph. IV. pag. 361. 1891.
 48. WILSON, E. B., The Cell Lineage of *Nereis*. Journ. Morph. VI. pag. 361. 1892.
 49. WILSON, E. B., The Cell in Development and Inheritance. Macmillan & Co. 1896.
 50. WILSON, C. B., The Wrinkling of Frog's Eggs during Segmentation. Am. Nat. XXX. pag. 761. 1896.
-

Explanation of Plate X and XI.

All the figures were drawn with a Camera lucida.

Figs. 1 to 9 are serial surface views of *Amblystoma* eggs and embryos developed in 0.6% salt solution: the eggs being unsegmented when placed in the solution.

- Fig. 1. Surface view of inferior hemisphere of a living egg showing first beginning of the blastopore invagination after being in the solution 72 hours. Magnified 36 diams.
- Fig. 2. Surface view of inferior hemisphere of a living egg which had remained 47 hrs. in a 0.4% solution. Magnified 36 diams.
- Fig. 3. Surface view, posterior, of living egg 103 hrs. in 0.6% salt solution. Magnified 36 diams.
- Fig. 4. Surface view of living embryo (dorsal) 123 hrs. in the solution. Showing formation of the neural folds and groove. Magnified 36 diams.
- Fig. 5. Surface view of freshly killed embryo just at the closing of the neural folds, 140 hrs. in the solution. Magnified 36 diams.
- Fig. 6. Surface view (lateral) of freshly killed embryo 11 days in the solution. Showing posterior elongation of dorsal lip of blastopore and large free yolk plug. Magnified 36 diams.
- Fig. 7. Surface view (lateral) of preserved embryo 17 days in the solution, showing external gills and balancer. The free yolk in this embryo was extraordinarily large. Magnified 24 diams.
- Fig. 8. Surface view (lateral) of preserved embryo 20 days in the solution, showing closure of the blastopore, and almost entire disappearance of all traces of the free yolk plug. This embryo is essentially normal in all its external features.
- Fig. 9. Surface view, enlarged, of posterior end of an embryo 103 hrs. in a 0.4% solution, showing temporary anus and comparative size of yolk and pigment cells. Magnified 52 diams.
- Fig. 10. Surface view (lateral) of an embryo showing abnormal separation of the posterior portion of the dorsal organ from the yolk plug.

Figs. 11—14 are sections of the same series showing formation and gradual closure of the blastopore. All from 0.6% solution.

- Fig. 11. Median section of blastula, showing segmentation cavity and the beginning of gastrulation.
- Fig. 12. Median vertical section of posterior end of embryo showing pigment layer over surface of the yolk, and thickened dorsal lip of the blastopore 120 hrs. Magnified 50 diams.
- Fig. 13. Similar section 40 hrs. later in development showing partial withdrawal of the yolk plug and downward growth of the dorsal lip of the blastopore.
- Fig. 14. Similar section 32 hrs. later in development showing complete withdrawal of yolk plug and formation of permanent anus.

Figs. 15 and 16 are outline sketches of normal *Amblystoma* embryos, showing currents generated by the cilia. Fig. 15 just after the closing of the neural folds and Fig. 16 12 hrs. later.

Figs. 17—20 are median longitudinal sections of *Amblystoma* embryos, showing method of closure of the blastopore, and the relation between the withdrawal of the yolk plug and the shape of the archenteron.

Fig. 17. Median section of an egg developed 91 hrs. in a 0.6% salt solution, showing very large, free yolk plug and temporary anus just beneath the dorsal lip of the blastopore.

Fig. 18. Similar section of an egg developed 108 hrs. in a 0.6% salt solution, showing elongation of embryo, uniform depth of the archenteron and enlargement of dorsal lip of blastopore.

Fig. 19. Similar section after 140 hrs. development, showing change in shape of Archenteron due to partial withdrawal of yolk plug.

Fig. 20. Similar section after 6 days development in 0.5% solution, showing further change in shape of Archenteron, almost complete withdrawal of yolk plug, and formation of vertebral somites and brain.

Fig. 21. Similar section from normal embryo at about the same period in its development showing comparative shape of Archenteron.

1.

2.

6.

5.

3.

4.

7.

8.

10.

9.

1.

2.

3.

4.

7.

8.

10.

6.

5.

9.

11.

12.

18.

14.

21.

13.

15.

19.

16.

17.

20.

11.

12.

13.

15.

14.

19.

16.

17.

18.

20.

21.

REPRINT

FROM

ZOÖLOGICAL BULLETIN

VOL. II. No. I

BOSTON
GINN & COMPANY
The Athenæum Press
1898

CARPENT 1945

ACTIVITIES OF MESENCHYME IN CERTAIN LARVAE.

CHARLES B. WILSON.

IN consideration of the attention which has recently been given to a study of the phenomena of the living cell, the following observations may be found of some interest. They were made during the summers of 1896 and 1897 upon mesenchyme cells in the larvae of certain species of molluscs and nemerteans.

Freshly laid eggs of the nudibranch mollusc *Tergipes despectus* (?) were obtained and reared to the veliger stage. Both egg and young embryo are nearly opaque, the gastrula invagination being distinguished only by a slight increase in the density. But after the mantle has been formed and the shell has been secreted, the veliger becomes perfectly transparent. The delicate shell is as clear as the finest glass, and the whole internal structure is now plainly visible.

Mesenchyme cells appear very early in development. They arise from large primitive endoderm cells at the posterior edge of the blastopore in the ordinary way for gastropod molluscs, and are set free in the segmentation cavity. At first they are approximately spherical in shape, and float about freely in the liquid which fills the cavity, but they soon begin to elongate, and become spindle-shaped. At this stage in their development activities were observed which are probably analogous to those described for the polar bodies of certain animals.¹

Unfortunately, I did not have with me at the time an objective of sufficient power to bring out the finer protoplasmic movements distinctly. Well-defined amoeboid changes of outline, however, could be plainly seen. The cell, as it moves about in the liquid which fills the segmentation cavity, puts out blunt pseudopodia-like processes. These change both their

¹ Andrews, E. A., "Some Activities of Polar Bodies," *Johns Hopkins University Circular*. November, 1897.

shape and position. There seems to be a special tendency to their formation whenever the cell comes close to the wall of the cavity, or when two cells approach each other. The processes remain short and blunt, and in no instance were they seen to reach either the wall or a neighboring cell. The putting out of these processes was seen to be accompanied in several instances by corresponding movements of the cell contents very similar to those in an amoeba.

Certain disturbances were also noticed in the liquid close to the surface of the cell. At the time these were considered analogous to slow ciliary motion, and they were probably caused by "filose" action.

It was impossible to determine with certainty whether the amoeboid changes ceased and were followed by a period of rest before the cell became permanently branched; but this would seem probable from analogy.

At all events, permanent processes soon appear, the cells become fastened in place, and after subsequent development function as muscles.

During the development, after the cells become branched, certain activities appear which are of an entirely different nature.

A single cell, or more often a pair of these mesenchyme cells, may be found in close proximity to the internal wall of the mantle on one (usually the right) side nearly in the center (Fig. 1).

FIG. 1. — Side view of veliger larva of *Ter-gipes*, showing position of the two contractile cells. Cam. luc. drawing, Leitz objective No. 3, Eye-piece No. 3.

These two cells are in close proximity to each other, and each consists of a body and radiating branches. The body is composed of finely granular protoplasm, and contains a distinct nucleus and several vacuoles. From it branches extend in many different directions. There are usually several fine branches reaching directly across from the body of one cell to

that of the other, which serve to bind the cells firmly together. The other branches are at first of about the same size, but one branch from each cell, extending outward (*i.e.*, away from the twin cell), becomes very quickly larger than the rest, sometimes approaching the diameter of the cell itself. These two larger branches are seldom in the same straight line, but usually make a more or less obtuse angle with each other. That they are really branches and not simply a prolongation of the cell body is apparent from the fact that they are finely fibrous in structure like all the other branches, and not granular like the body of the cell.

FIG. 2. — The two contractile cells enlarged to show their structure. Cells relaxed. Cam. luc. drawing, Leitz objective No. 7, Eye-piece No. 3.

These large branches

extend some distance from the cell and then divide dichotomously, ending in fine fibrils.

The smaller divisions of these branches, together with those of the cell itself, anastomose freely and form a loose reticular network. These details of structure appear to better advantage in the enlarged drawing of the two cells shown in Fig. 2.

At this stage of their development they are not attached to anything except to each other, but the network formed by their interlacing branches extends over a considerable area and holds them in position.

They appear like ordinary mesenchyme cells, but upon being watched they are seen to possess a peculiar contractile power, which is manifested at intervals. In a few individuals the contractions occurred at definite intervals as long as the cell was watched, but more frequently there was a period of rest after a few contractions. Both the time of contracting and the intervals of rest were subject to considerable variation, but the latter was never long enough to enable a camera lucida sketch

to be made. The drawings in Figs. 1 and 2 were taken from individuals which had been paralyzed with magnesium sulphate.

These cells are isolated from everything except the liquid in which they lie, and, consequently, if there be any stimulus previous to contraction, it must be given through the medium of the liquid or it must arise spontaneously in the cell itself.

By careful watching, the contraction can be seen to begin in the cell body and travel outward along the branches, though the contractile wave moves so quickly that it practically begins at all points simultaneously. As a result of its action the protoplasm draws together, the cell body becomes more spherical, all the branches, large and small alike, become shorter and thicker, and the whole meshwork of fibrils is drawn in until it occupies much less area than formerly.

When it first begins, the contraction is comparatively weak and results simply in a shortening of the branches and fibrils, but as it proceeds it becomes rapidly stronger and stronger. This increase in contraction cannot manifest itself in any further shortening of the branches, for they have already

FIG. 3. — The same two cells at the close of contraction. Leitz objective No. 7, Eye-piece No. 3.

shortened all they are capable of doing. The only way in which the two ends of any branch can now be brought nearer together is by a bending or folding of the fibers upon themselves, and this is what actually occurs. At the close of contraction (Fig. 3) the smaller branches and fibrils have been drawn in so much that they are twisted into a corkscrew shape for their entire

length. The large branches have also contracted so strongly that their surface becomes wavy or sinuous in outline. The bodies of the cells remain spherical, but become so opaque that neither nucleus nor vacuoles are visible.

This twisting or plication of the muscle fibers, whereby their retractive power is increased, is also shown in the retractor muscle of the velum (Fig. 1), and will be noticed later in certain muscles of the nemertean larva. The same thing has

been observed in "single fibrils in protoplasm, as well as contractile pellicles and substance membranes," and also in Metazoan cilia and the muscle bands in rotifers.¹ It seems to be carried farther here than in the muscles mentioned, for the simple reason that these filaments are unattached and, therefore, there is nothing to restrain it.

After remaining an instant in this extreme contraction, the cells relax, and the return to a normal condition is practically instantaneous. We have here, then, the same power manifested by the single mesenchyme cell, with its branches, that belongs to the more complicated retractor muscle, and that, too, when it is isolated from everything save the liquid in which it floats.

This must certainly be a very near approach to a primitive muscular contractility.

The contraction lasts one and a half or two seconds, the relaxation occupies but a very small fraction of a second, while the pause or rest varies from two or three to twelve or fifteen seconds. This suggests very forcibly a condition similar to that which obtains in the beating of the heart, with the exception that in these mesenchyme cells the relative duration of contraction and relaxation is reversed, the former being much longer.

This same contractile power is also possessed, to a less degree, by the other mesenchyme cells. They may often be seen to contract after they have become branched. The contractions are not as rhythmical as those just described, but they are as automatic. Some of these mesenchyme cells enter the velum during development and become attached to its walls until the whole interior is traversed from wall to wall by their branches, rendering it highly contractile.²

In this case, therefore, the same cell which contracts at first automatically may afterward become a part of the muscular network of the velum, where it is under the control of the central nervous system.

Similar phenomena were observed in the mesenchyme cells of the pilidium larvae of the Nemertean *Cerebratulus lacteus*

¹ Andrews, G. F., *The Living Substance as Such: and as Organism*, p. 103. 1897.

² Lang, *Comparative Anatomy*, Part II, p. 257.

Verrill. These larvae were reared from artificially fertilized eggs, and a full account of their development is in preparation for a subsequent paper. The eggs of this nemertean are opaque during cleavage and gastrulation, but become beautifully transparent on reaching the pilidium stage.

The mesenchyme first appears as isolated cells derived from the ectoderm, as observed by Metschnikoff (*Zeit. f. wiss. Zool.*, Bd. xxxix).

They move about freely in the gelatinous liquid which fills the space between ectoderm and entoderm. At first they are nearly spherical in outline, but they soon begin to develop processes and become branched, in which condition they are very readily distinguished from the other elements. So long as they remain free floating there is no indication of cell fibers, but simply a nucleus enclosed in cytoplasm. But as they begin to branch they grow larger, and granules appear in the cytoplasm, while the branches become gradually fibrous in structure. No amitotic division stages, however, were noticed in any of these cells, such as were found by Montgomery in the free-floating mesenchyme cells of the adult worm (*Zool. Jahrb.*, Bd. x). The branches hinder the freedom of motion of the cells, and the latter gradually become fixed in position.

The fibrils at the extremities of the branches are then fastened in place, and from being mere wandering mesenchyme the cell becomes one of the muscles of the pilidium. This transformation was watched several times in the formation of different muscles, and nearly all the intermediate stages were observed. The most important muscle of the pilidium is the one which extends from the apical plate downward to the anterior border of the lappets. The development of this muscle was watched in many different individuals. When the mesenchyme cells first develop branches, one of them can be seen to become stationary in about the position of the future apical muscle. One of its processes becomes fastened to the apical plate, while another fastens to the wall of the digestive tract, and sometimes a third connects with the aboral wall of the pilidium (Fig. 4). The number of processes is not constant, but the position assumed by the cell is approximately so.

Other cells become fastened to the walls of the digestive tract along its anterior border. The branches of these cells anastomose with each other and with the first cell, and from them are developed the strong muscle which enables the larva to retract the apical plate with its tuft of cilia. This muscle becomes attached at first to the wall of the digestive tract, as figured by Verrill (*Marine Nemerteans of New England*, p. 417). But as soon as the branches begin to anastomose it

FIG. 4. — Side view of pilidium larva, showing mesenchyme cells in position to form the apical muscle. Zeiss cam. luc. $\times 575$ diams.

develops along the line of mesenchyme cells seen in Fig. 4, and becomes fastened to the anterior border of the lappets. In a similar way a transverse muscle is formed just in front of the apical plate.

This consists of a single large mesenchyme cell which subsequently develops long processes reaching from one side of the pilidium to the other. In later development the whole internal surface of the umbrella is covered with a loose meshwork of anastomosed mesenchyme cells, which give the larva so much

contractile power that it frequently tears the umbrella cells apart by violent contractions when irritated.

While floating about freely these mesenchyme cells do not contract, so far as could be observed, but as soon as they begin to form processes they can be seen to contract. Occasionally two cells anastomose with each other before becoming attached to the wall of the pilidium.

In such a case they contract irregularly at first, the intervals between contractions being unequal, but later the contractions become rhythmical and very closely resemble those of the opisthobranch gastropods just described. Three or four contractions occur in rapid succession and are followed by a comparatively long rest. After the cell branches become fastened to the pilidium wall these rhythmical pulsations cease. The mesenchyme cells now become regular muscles of the larva and contract only when stimulated from the central nervous system.

We are witnessing here, then, the passage from an automatic condition, in which the cells contract quite independently from the rest of the larva, into a condition in which every contraction is definitely correlated with that of the other larval muscles.

In this nemertean larva the intense contractions resulting in a corkscrew shortening of the branches and fibers occurred subsequent to the fixation of the cells. It was not noticed in any of the free cells even when two of them anastomosed before becoming attached, and all the conditions appeared as favorable as in the veliger larvae. After attachment such a shortening is very noticeable, especially in the apical muscle and the fine radial muscles of the side lappets.

In an examination of these larvae, therefore, it is found that:

1. The mesenchyme cells are at first nearly spherical and are free-floating. In this condition they consist simply of a nucleus and cytoplasm; they may put out amoeboid processes, but they do not show any contractile movements.
2. They soon grow larger, become granular, and develop fibrous branches which hinder their free motion, and finally they become fixed in position and function as muscles.

3. In both larvae prior to such fixation cells may be found, singly or in pairs, which pulsate in more or less rhythmical contractions until their branches become fastened to the larval tissue, when the pulsations cease.

4. Both larvae, accordingly, show a well-marked transition from automatic pulsations to muscular contractions dependent upon the central nervous system.

STATE NORMAL SCHOOL, WESTFIELD, MASS.,

April 18, 1898.

7

REPRINTED FROM

THE QUARTERLY JOURNAL OF
MICROSCOPICAL SCIENCE.

The Habits and Early Development of Cerebratulus Lacteus (Verrill).

A Contribution to Physiological Morphology.

By
Chas. B. Wilson.

With Plates 9—11.

OUTLINE.

I. INTRODUCTION	99
II. THE ADULT WORM.	
A. Determination of Species	102
B. Habitat and Habits :	
(1) Geographical distribution	103
(2) Burrows and burrowing	104
(3) Food	107
(4) Breathing	109
(5) Locomotion	110
(6) Dismemberment	112
(7) Regeneration	119
III. LARVAL DEVELOPMENT.	
A. Sexual Organs :	
(1) The ovaries :	
(a) Germ tissue	121
(b) Oögenesis	123
(c) Formation of oviduct	125
(2) The testes :	
(a) Sperm tissue	126
(b) Spermatogenesis	126
(c) Formation of sperm-duct	127
B. Egg-laying	128
C. Fertilisation and Ripening :	
(1) Fertilisation	130
(2) Formation of polar bodies	131
(3) Activities of polar bodies :	
(a) Description of activities	133
(b) Connection with egg	135
(c) Polarisation	135

(<i>d</i>) Summary	138
(<i>e</i>) Conclusions	138
D. Segmentation:	
(1) Mode of cleavage	141
(2) Behaviour of polar bodies	141
(3) Filose activities	144
(4) Contractile movements	145
(5) Separation of blastomeres	149
(6) Blastula	149
(7) Summary	149
(8) Conclusions	151
E. Gastrulation:	
(1) Ciliation of the larva	153
(2) Formation of gastrula	154
(3) The apical plate	155
(4) Change from radial to bilateral symmetry	156
(5) Escape from egg-membrane	158
IV. THE PILIDIUM.	
A. Habits:	
(1) Locomotion	159
(2) Use of apical flagella	159
(3) Food	161
B. Morphology:	
(1) External morphology	162
(2) The primitive intestine	162
C. Mesoderm Formations:	
(1) Origin of mesenchyme cells	164
(2) Their contractility	165
(3) Development of the larval muscles:	
(<i>a</i>) Apical muscles	166
(<i>b</i>) Interparietal muscles	167
(<i>c</i>) Œsophageal muscles	168
(<i>d</i>) Circumoral muscles	169
(<i>e</i>) Parietal muscles	170
(<i>f</i>) Lappet muscles	171
(4) Summary	174
(5) Conclusions	175
D. Histology:	
(1) The epidermis	181
(2) The apical plate	182
(3) The cilia rows	185
(4) The intestinal canal	188
(5) Summary	189

INTRODUCTORY.

THE ontogeny of the Nemerteans, and more particularly that of the Schizo-nemerteans, is of special interest on account of the metamorphoses through which the young embryos pass.

Ever since its discovery and naming by Müller in 1847 (38) the pilidium form of larva has attracted the attention of leading scientists the world over. As a result of their investigations we are to-day in possession of the leading facts with reference to the histology of the pilidium and the metamorphoses from this free-swimming form into that of the adult worm.

Much work has also been done upon the origin and maturation of the sexual products in different species. But our knowledge of fertilisation, segmentation, and the early history of the pilidium has been derived almost wholly from two papers by Metschnikoff, one in 1870 (35) and another in 1882 (36).¹

The former paper I have been unable to examine, but from the excellent abstract given by Bürger (13) I judge that Metschnikoff obtained the eggs already fertilised, and followed their subsequent development as closely as possible.

At all events he confines his attention in both papers almost exclusively to the later development of the larva, and seems to have derived his facts from observation of histological material, and not from a study of the living embryo.

¹ Since the above was written it has been my pleasure to receive from the author, Dr. W. R. Coe, of the Sheffield Biological Laboratory of Yale University, a copy of his excellent paper upon "The Maturation and Fertilisation of the Egg of *Cerebratulus*" (16). This is the first step toward supplementing our knowledge of this long neglected group and is most praiseworthy.

In the present investigations for the first time, so far as can be determined, the eggs of a Nemertean were fertilised artificially.

The consequent abundance of embryos has rendered it possible to follow in detail every step in their development, and to use living material far more than has ever been done heretofore.

In much of the recent embryological work there has been a tendency to confine the attention almost exclusively to the study of sections and prepared material. And embryos have been reared for the sole purpose of furnishing such material. But it is clearly evident that the true purpose of histology is to supplement, and not to supplant, the study of the living animal. For this reason the morphological drawings in the present paper have been made, whenever it was possible, from living specimens, with the aid of the camera lucida.

Adults have also been captured and kept in aquaria where their habits could be closely watched, and many interesting facts have been thus discovered. Eggs have been laid and fertilised by individuals thus kept in confinement, so that it has been possible to verify all the details obtained from the artificially fertilised eggs, and, in addition, to discover the method of egg-laying and fertilisation.

The development and habits of the pilidium have been carefully watched for four successive summers, and as a result it is possible to present quite a full account of this particular species. A second result has been the growing conclusion that this species is particularly fitted for embryological work in our laboratories. Many different reasons have led to this conclusion, among which may be mentioned:

1. The vitality of the adults, by reason of which uninjured sexual products can be obtained from them even under very adverse circumstances. When reduced to such a dire necessity, a single piece of a disrupted worm, but a few inches in length, can be used at the rate of half an inch a day for a week or more, and it will yield all the while germinal pro-

ducts capable of producing normal embryos. A clean glass vessel (4 to 6 gals.) with plenty of the sand or mud from which the animals were taken, and a constant but slow renewal of the water, has proved to be the best aquarium. Only one pair of worms should be placed in a single vessel, and the supply of plant life should be very meagre. Under these conditions no difficulty has been experienced in keeping the worms for six or eight weeks, and they have laid profusely (cf. Coe, 15).

2. The ease and uniformity with which the egg may be fertilised artificially.

3. The persistence and remarkable activity of the polar bodies. They remain in close connection with the egg all through segmentation and gastrulation, the second body being actually connected with the blastomeres by protoplasmic processes, while both display to a marked degree those protoplasmic activities which have been designated as "spinning."

4. The transparency of the larva subsequent to gastrulation, which renders it very easy to follow its internal development. It is so clear that very high powers may be successfully used. An excellent opportunity is thus afforded for the study of muscular development, owing to the peculiar nature of the mesenchyme cells.

Every fact of importance has been included in the present paper; when not verified by personal observation, due acknowledgment has been made. The author desires to express his indebtedness to Librarian Wm. I. Fletcher, of Amherst College, for the free use of the science library of that institution, without the help of which the present work would have been impossible. It is likewise a pleasure to acknowledge the inspiration and the many valuable suggestions given by Dr. E. A. Andrews, of Johns Hopkins University, and by Mrs. G. F. Andrews. And to Dr. W. R. Coe, of the Sheffield Biological Laboratory, acknowledgment is due for the kindly loan of mounted material illustrative of spermatogenesis, and for much friendly criticism.

THE ADULT WORM.

Determination of Species.

The species under consideration is one of the largest of the Nemerteans, and possesses all the characteristics of the group. These consist negatively in the absence of all external appendages and of a definite body-cavity, and the entire lack of visible segmentation. Positively they include the possession of a smooth body, flattened dorso-ventrally, and of a very long tubular proboscis, which can be protruded by eversion from an aperture in the front of the head.

Much work has been done upon the classification of the Nemerteans with no decisive results. Different species and even genera frequently resemble one another so closely that they cannot be distinguished after preservation. Hence we can find in the attitude of different authors every variation from one (46) 75 per cent. of whose enumerated species are new creations, to another (27) who would include all the Schizo-nemerteans under a single genus. And our present species is classified by different authors under distinct names and even under different genera. The name we have chosen is the one selected by Verrill, but the same species was called by Girard *Meckelia fragilis*, by Leidy *Meckelia ingens*, though at first he designated it *M. lactea*. The name of the group, Nemerteans, was first applied by Cuvier, and is derived from *Nemertes*, one of the Mediterranean sea-nymphs, daughters of Nereus and Doris.

The generic name, *Cerebratulus*, was first given by Renier in 1804 to a single species, and continued until recently to be simply a specific name. It is derived from *cerebrum*, the brain, probably from a fancied resemblance of the tissues (41).

The specific name, *lacteus*, was given by Leidy to certain small white specimens, which afterwards proved to be the young of this species, and accordingly the name was

extended by Verrill, in 1892, to include the larger adults which are often not at all "milky" (46).

Habitat and Habits.

This large Nemertean is quite common along the entire Atlantic coast, from Florida to Massachusetts Bay, and is found locally at Casco Bay on the coast of Maine. From this latter locality were obtained all the specimens which furnished data for the present paper. Verrill states (46) that he found adults at Quohog Bay, one of the numerous inlets of Casco Bay. These were associated with a number of other southern forms, such as *Venus mercenaria*, *Crepidula convexa*, *Eupagurus longicarpus*, *Gammarus mucronatus*, *Nereis libata*, *Meckelia ingens*, *Asterias arenicola*, etc. These species properly belong to the region south of Cape Cod, and it might be inferred that *Cerebratulus* also was a southern species, and that it could be found in northern waters only under specially favourable conditions.

Such, however, is not the case; I obtained a number of specimens from Quohog Bay, but found them more abundant at Stover's Point on the east side of Harpswell Neck. All the specimens used were obtained here, but none of the southern species named above were found anywhere in the vicinity. Furthermore, the Point is only about a mile from the end of the Neck, and it gets the full sweep of the tide from the open ocean twice a day.

The largest colony of Nemerteans was on the outer or exposed side of the Point, and was associated exclusively with hardy northern species. The fishermen often find these worms when digging for clams during the winter, and some of the material used for the origin of the sexual products was obtained from them at that season. When we reflect on the severity of the winter upon the Maine coast, where the mud is exposed between tides to an atmosphere that frequently

registers many degrees below zero, we may conclude that *Cerebratulus* has at least become well acclimated.

This species burrows in sand and mud between tides, and in shallow water down to several fathoms in depth.

It occurs most plentifully at and just above low-water mark, but may be found under stones in sheltered positions (Quohog Bay), nearly up to the high-water mark of medium tides. It is gregarious in habits, and the finding of one is a good indication that there are others in the immediate vicinity. It also occurs in the same localities year after year, but after prolonged search in any one place the number of large specimens becomes very sensibly diminished. The largest specimens are not solitary, as McIntosh declares to be the case with the great *Lineus marinus* (34), but they are so limited in numbers as to warrant the conclusion that here, as in some of the higher forms of life, size is "inimical to profusion." One of its favourite haunts is along the edges of an old mussel-bed amidst the broken shells and stones, into which it is often almost impossible to drive a clam-hoe. But it is also dug up with clams in clean white sand and mud, and is known locally to the fishermen as a "clam-worm."

Scarcely a trace of the worms save the entrance to their burrows can be seen except at high tide. This is their period of activity, and they may then occasionally be observed gliding amongst the sea-weed on a muddy or sandy shore, or in the shade of the rocks in a large tide-pool. They are essentially nocturnal, and come out of their burrows much more frequently during the night tides than during those which occur in the day time. The burrow itself is little more than a hole or tubular opening through which the worm can move freely in either direction. The walls of this tube are coated thickly with the slimy mucus exuded from the worm's skin, which materially facilitates its progress.

The burrows are neither very long nor very deep, for even the largest worms are found within a few (six or eight) inches of the surface. There is no evidence to show that the same burrow is inhabited for any length of time. On the contrary,

all observations indicate that the worm roams about constantly in the mud after food, and that it is able to move quite rapidly, even when forming a new burrow. The enormous amount of slime secreted by the worm's ectoderm may be inferred from the fact that it keeps the walls of its burrow constantly coated.

This slime often oxidises the iron elements in the mud, with the result that the latter is tinged a dull rusty red in the immediate vicinity of the burrow.

Repeated attempts were made to ascertain just how the burrowing was done, by digging out specimens and throwing them on a fresh surface. It was noticed that the worm thrust its pointed head a little way into the mud and then seemed to brace itself for a further effort, the head at the same time being withdrawn slightly. The significance of this fact was in doubt for some time, but on placing a few worms in a glass aquarium with five or six inches of mud at the bottom, they immediately began to burrow near the glass. It was then seen that the bracing action was due to the fact that the worm was driving its proboscis into the mud ahead of itself. The proboscis was protruded for six or eight inches, and then enlarged slightly and crooked a little at the end. Aided by the hold thus obtained the worm was able to thrust its head rapidly into the mud, keeping it narrow and pointed the while.

The extreme tip of the head was then contracted into a broad rounded form, and the wave of contraction thus started passed slowly backward along the anterior portion of the body, thereby moving the latter forward about an inch. As soon as this wave was fairly started in its backward motion the head became pointed, the proboscis was thrust forward again, and the whole process was repeated. The tip of the head was then contracted, and a second wave was started backward before the first had reached the centre of the body. In this way one wave followed another so quickly that the resultant motion was nearly a steady advance instead of being jerky. This rapid burrowing by means of both proboscis and

body contractions must be of great service to the worm in escaping from its enemies and in obtaining its food. In locomotion the proboscis seems to be of use chiefly as an organ of feeling or touch, being thrust forward to determine the direction in which the burrow is to be made. Whenever it strikes an obstacle, such as a small stone, it feels around it, sometimes on several sides, and selects apparently the place that offers least resistance.

In doing this it often happens that the proboscis will be thrust up into the water. It is then quickly withdrawn only to be thrust up again, perhaps in a very few seconds.

The only idea of direction, therefore, seems to be to keep beneath the surface of the mud. It is also evident that when the proboscis is thrust forward forcibly into the mud or sand, it makes an opening for the subsequent passage of the head.

The worm may often be seen to withdraw its proboscis and push its head along in the opening thus left. It is also possible that the proboscis may have some tractile power in helping to pull the body forward. That it is actually used as an organ of prehension was witnessed several times.

The Nemertean was fed with common clam-worms (*Nereis*). When a *Nereis* in wriggling about came in contact with a Nemertean, or crossed the mouth of a burrow when a Nemertean was inside, the latter suddenly darted out its proboscis and coiled it spirally around the *Nereis*. The spiral coil covered an inch or more of the *Nereis*'s body, and the proboscis was then slowly withdrawn, bringing the *Nereis* up to the Nemertean's mouth, where it was finally swallowed. This corresponds exactly with the graphic description given by Kingsley (cf. 34) of a specimen of the species *Polia mandilla* (*Amphiporus lactifloreus*, McIntosh) in the act of devouring a fish. McIntosh, however, questioned Kingsley's accuracy (34), because the latter says that the proboscis assists in prehension, but *Cerebratulus* certainly uses it sometimes for that purpose.

When withdrawn the proboscis is coiled up in that portion

of the sheath which lies above the œsophagus, as can be seen in fig. 4.

Its large anterior end is continuous with the walls of the sheath just in front of the ganglionic commissure, while its small posterior end is fastened at a single point where the œsophagus joins the intestine. As the proboscis itself is several times the length between these two points of attachment it is coiled very closely. Furthermore, being attached at the posterior end, it follows that it must always be of double thickness, with a blunt anterior end when everted. This increases its strength for prehension and burrowing, and does not seem to detract from its delicacy as an organ of touch.

Food.—This species of *Cerebratulus* is almost wholly carnivorous, and feeds upon other worms which frequent the mud between tides, showing a decided preference for *Nereis*.

Several times both *Nereis* and Nemerteans were placed in the same dish when obtained; the former were found to have been swallowed by the latter on reaching the laboratory half an hour later. The *Nereis* is always swallowed tail first (fig. 1), which is exactly the opposite of the method usually followed by carnivorous animals, but is occasionally found in other carnivora, as when a snake swallows a frog or toad (23).

In such cases the animal swallowed is usually defenceless, while its captor is well armed, but in the present instance these conditions are exactly reversed. And it is very hard to understand how a Nemertean, which has neither teeth nor jaws, nor indeed offensive weapons of any kind, can yet overcome a well-armed Annelid nearly as large as itself. The head of the *Nereis*, with its powerful jaws, is left entirely free, but although I have seen the victim wriggle frantically in its efforts to escape, until it finally disappeared down its captor's throat, it never made any attempt to bite. This is the more remarkable in view of the well-known fact that when two *Nereis* come together they almost invariably fall upon each other tooth and claw, and often inflict very severe

wounds with their powerful jaws. Dr. E. A. Andrews has suggested to me that possibly the dense coating of slime which is constantly exuded from the Nemertean's ectoderm may afford it protection. If a minute drop of this slime be placed upon the tongue it will be found so intensely acrid as to parch the whole mouth, and the taste remains for a long time. This quality, then, might effectually prevent the Nereis from inflicting any injury with its jaws. These Annelids do not often leave their burrows altogether, but simply protrude the head and anterior portion of the body in search of prey. Taken in connection with the fact that the Nemertean swallows them tail first, this suggests that they are not ordinarily caught outside their burrows, but that the Nemertean probes around beneath the surface until it strikes the home of an Annelid, and then proceeds to swallow the unfortunate occupant. In such a case the Annelid's jaws would be practically useless, for it could not turn about in its burrow. The snout of the Nemertean, in front of the mouth, is usually turned backward during the process of swallowing, the proboscis being wholly withdrawn.

The digestive fluid acts very quickly. Several attempts were made to preserve a specimen with a Nereis nearly swallowed and protruding an inch or two from its mouth. But they failed at first because the Nereis was forcibly ejected as soon as the Nemertean touched the preserving fluid, no matter how far it had been swallowed. A subsequent attempt was crowned with success; a Nemertean with an inch of Nereis nearly as large as itself protruding from its mouth was plunged into boiling water for a moment and then preserved in formalin. This produced death so instantaneously that there was no time for ejection, and the perfectly preserved pair still remain to attest the fact (fig. 1).

But although the first efforts were failures in one direction they were a success in another. The swallowing of an ordinary Nereis occupies about ten minutes, but in every instance it was found more than half digested upon ejection.

The same thing happened when a dead squid was left in a pail with some Nemerteans. One of them swallowed a long arm of the squid, and when its further progress was stopped at the base of the arm it drew its body down in wrinkles until as much of the digestive tube as possible had come in contact with the arm. It remained in this position for five or six minutes and then withdrew, leaving the arm completely digested for more than half its length. Of course, there is very little substance to the body of a *Nereis*, and it can be assimilated without much change; but the arm of a squid is more substantial, and must require considerable digestion. It is evident that this takes place rapidly at the very beginning of the alimentary canal. This fact suggests one reason why the loss of the posterior portion of the body does not seriously affect the animal.

Several of the fishermen have told me that specimens of *Cerebratulus* are sometimes caught by them when fishing in shallow water with a bait of *Buccinum undatum* or *Natica heros*.

The same thing is noted by McIntosh (34) with reference to the deep-sea form, *Lineus marinus*, which was caught while fishing for cod. Like that species, *Cerebratulus* also must have "an indiscriminate appetite," feeding upon both living and dead forms, and ejecting the bristles and other indigestible material through the anus. Occasionally a bristled or spiny victim proves too much for its captor, with the result that the bristles or spines perforate the digestive tract and the body-wall.

Dr. W. R. Coe tells me that he found a *Cerebratulus* in this condition with a large *Nereis* half swallowed, the posterior portion of the *Nereis* protruding through a large rent in the ventral wall of the œsophagus. In confinement *Cerebratulus* eats readily almost any animal food, but prefers a *Nereis* to anything else.

Breathing.—This species and probably most other Nemerteans breathe by means of the walls of the œsophagus.

With the incoming tide the Nemertean opens the anterior

end of its burrow by turning it abruptly upward to the surface, and then lies with its head in the lower part of this vertical portion. The burrow around the head and in the immediate vicinity is enlarged somewhat, so that the water can circulate freely, and by alternately swallowing and ejecting mouthfuls of water the Nemertean generates a very perceptible current.

The swallowing is long and slow, while the ejection is short and abrupt, the two together occupying about ten seconds. This is evidently the Nemertean's mode of breathing, and the purification of the blood must take place in the walls of the œsophagus, as we should naturally infer from the arrangement of the circulatory system. These facts, of course, were chiefly gathered from specimens kept in an aquarium where the supply of water was constant, but it was curious to note that they alternated periods of rest with periods of breathing exactly as if they had been subject to the flow of the tide. And their periods of rest usually, though not always, corresponded closely with those of the ebb tide.

During the breathing the cephalic slits along the sides of the head were occasionally, though not regularly, opened and closed. At such times, of course, a current of water would enter the side-organs, and it is possible that they assist somewhat in the purification of the blood. But from the regularity of movement in the œsophagus and the entire lack of it in the cephalic slits, we must conclude that the former constitutes the true respiration.

Locomotion.—The mode of locomotion by means of which the Nemertean moves through its burrow has already been described.

They also come out of their burrows at times and swim about in the water. Verrill states (46) that "while swimming the body is turned up edgewise and thrown into many undulations, and the motion resembles that of an eel, but is less rapid." Coe adds (15) that "it is often met with at night swimming near the surface of the water." This is a

well-known habit of all species, the lateral margins of whose bodies are produced into a thin edge throughout the greater part of their length. But although I have been out at night repeatedly and towed over localities where the worms were abundant, I have never been fortunate enough to catch one swimming.

Frequently, however, some that were dug out of the sand were thrown into the water and watched swimming about, and others have often been seen swimming in the aquarium. Under such circumstances the Nemertean does not turn up edgewise, but undulates about in every possible position, the body being now dorsal side up, now ventral, now with the right side uppermost, now the left, the change from one position to another being continuous though slow. It would seem probable that they come out of their burrows and swim about most frequently during the breeding season, although eggs are laid inside the burrows, as we shall see later.

In addition to swimming and crawling through their burrows these Nemerteans are also capable of moving along on the bottom over the mud or stones quite rapidly, and yet as they have no setæ like the earthworm, nor any other means to prevent slipping, and as the surface of their body is slimy, there is always a considerable loss of motion. On a solid surface the mode of progression is by crawling in a manner similar to that of a Gastropod, with the exception that the waves of muscular contraction, passing backward from the head, are much more apparent.

But this is true only of the adults; young individuals can glide over the glass sides of an aquarium so smoothly that their bodies show scarcely a wrinkle (cf. 34).

The Nemertean also leaves a track of mucus, like the Gastropod. This mucus is exuded even when the animals are lying coiled up at rest, and it is so abundant that a pail containing several fresh vigorous worms is soon filled with a perfect meshwork of mucus, from which the worms must be pulled or cut out. And it acquires sufficient consistency to offer considerable resistance. If it be removed it is quickly

formed again, but several removals produce a marked diminution in the amount secreted. This abundance of mucus gives some of the smaller forms the ability to crawl back downward on the surface of the water, after the manner of nudibranchs, the mucus forming a sort of float, and being firm enough to give the animal a purchase for its muscles. McIntosh states (34) that "if a Nemertean is raised from the surface on which it crawls it always clings most pertinaciously by the anterior end; indeed it would appear that the lips exercise a kind of sucker-like action, or at least that the flattened under-surface of the snout does so."

I have never been able to verify this observation on *Cerebratulus*, for I could not see that one portion clung to the supporting surface any more than another. But the head and anterior oesophagus are usually kept in contact with the surface, while the other portions of the body are often removed temporarily.

Dismemberment.—Almost every scientist who has dealt with the Nemerteans has noted their disagreeable habit of dismembering themselves when irritated. But even the specialists have not gone beyond a mere statement of the fact except in one or two instances, while the best and most recent monograph on the Nemerteans, that published by Bürger as the 22nd volume of the 'Fauna and Flora of the Gulf of Naples,' does not even mention the habit at all.

We are informed that we must secure our specimens very quickly, and kill them in something that produces instantaneous death if we expect to obtain anything more than a handful of fragments for our pains; but we are left to answer for ourselves the many interesting questions that are sure to arise. Do the Nemerteans ever fragment without irritation? If so, under what conditions and what advantage is it to the worm?

After fission can both anterior and posterior fragments regenerate, the one a new body and the other a new head?

In answer to the first question, I had noticed for three

summers that it was very difficult to obtain perfect specimens toward the close of the breeding season, though they were fairly common at an earlier date. On the contrary, the number of specimens possessing regenerating papillæ increased as the season advanced. It was evident, therefore, that they must dismember for some reason during the breeding season, and it was suspected that the eggs might be discharged in this way. During the past summer the matter was put to test with the following results.

A perfect male and female *Cerebratulus* were secured during the latter part of June, and placed in an aquarium half filled with the same mud from which they were taken. They burrowed into this mud at once, and remained there under fairly normal conditions, and apparently perfectly healthy, until the 1st of September, when they were both preserved on leaving.

They were nearly sexually ripe when obtained, and after being kept a fortnight the female laid three batches of eggs at short intervals, each of which was fertilised by the male.

Soon after the last lot was laid they both dismembered, leaving but a comparatively short piece of the body attached to the œsophagus. This anterior portion at once began to regenerate, and by the 1st of September, an interval of three and a half weeks, it possessed a regenerating papilla nearly 50 mm. long in the female, and about 40 mm. in the male.

The posterior fragments lived for two weeks, and then died with no signs of regeneration. I have kept headless fragments alive, however, under much less favourable circumstances for nearly a month, and McIntosh in his monograph (34) states that most of the pieces of a fragmented *Lineus* were alive six months after dismemberment, and that the sexual products were developed and discharged from them in a perfectly normal manner.

But this happened to be a male, and he could obtain no eggs upon which to test the fertilising power of the sperms.

In another species the posterior fragment began to develop a new head, and he figures several stages in the process, which occupied nearly three months but was not completed.

Barrois also has described the regeneration of headless trunk-pieces in another species, and they have been known to regenerate new heads in the common *Lineus socialis*.

Fission certainly produces very little apparent effect upon vitality. I have repeatedly obtained headless fragments of both sexes containing unripe sexual products and kept them until they ripened, a period sometimes of two or three weeks, and then fertilised the eggs from one fragment with the sperm from another, and obtained perfectly healthy pilidiums as a result.

Of course the posterior fragments can eat nothing, but the anterior ones display as voracious an appetite as ever immediately after fission, or even during the process. This is attested by the preserved specimen whose photograph is shown in fig. 1. The prolonged retention of sexual functions by headless fragments under adverse circumstances gives some idea of the vitality possessed by these worms in their native haunts, but repeated search has failed to find a single one in which regeneration has even commenced.

These facts, taken in connection with those developed in the aquarium, lead to two conclusions. First, that *Cerebratulus* frequently dismembers at the close of the breeding season; and second, that while the anterior fragments regularly regenerate, the posterior ones seldom if ever do so.

Professor Benham, of Oxford, has noted a similar case of spontaneous dismemberment in the genus *Carinella* (10).

Here also there was a relation between fission and genital maturity, but of a different nature from that in *Cerebratulus*.

He found that the genital elements in *Carinella* were present only in the posterior regions of the body, and that this portion was constricted and cut off as fast as the elements ripened.

Fission in this genus, therefore, would be a method of discharging the ripened sexual products.

In *Cerebratulus*, on the contrary, the genital elements are distributed throughout the whole body, and if there be any priority in ripening, it is in favour of the anterior and not the posterior portion. Fission does not take place until after the eggs and sperm have been discharged, and hence it cannot be regarded as assisting that discharge in any way.

We are thus confronted again with the question, what advantage can result to the worm in thus parting company with a large portion of its body at this particular time?

The body is composed essentially of two series of pouches, arranged in alternating pairs on either side of the straight intestine. Ordinarily the digestive pouches occupy the larger part of the space, but as the breeding season approaches the reproductive organs begin to enlarge, and by the time the sexual products are ripe they occupy practically the whole of the space, and the intestinal cæca are flattened between them until their opposite sides meet. This is especially true in the posterior portion of the body, which at this time becomes little more than one large ovary or testis, divided into lobes by the flattened cæca. McIntosh (34) states that "the glandular elements in the walls of the digestive tract undergo a certain amount of atrophy during the period of reproductive perfection." For a long time, therefore, these intestinal pouches can function very little, if at all, and so they contribute nothing to the nourishment of the body.

After the eggs and sperm have been discharged there is evidently still less use for them until the next breeding season, and regeneration proceeds so fast that before that time a new body will have been formed. In fragmenting, therefore, at the close of the breeding season, it would seem that *Cerebratulus* is parting company with a portion of its body which has for some time been devoted to a single purpose, that of perfecting the sexual products, and of which, now that this purpose has been accomplished, it has no immediate need.

Fragmentation under irritation is evidently a defensive action. As Hubrecht (27) well says, "an animal that at the

approach of danger can separate in two or more parts, each of them capable of regeneration and so of producing an entire new animal, evades this danger very effectively by doing so."

But even if all the fragments are not capable of regeneration, the nemertean still has the chance that its enemy will be satisfied with half a loaf, and that the posterior half.

The actual fission of the body-walls is brought about by internal phenomena which will be discussed later (see p. 118).

The circular muscles at the severed ends contract violently, and draw the margins of the rupture together so tightly that the end is completely closed. It is also rounded like the true anal end of the body, and this resemblance is often increased by a slight emargination at the centre, due to the excessive contraction of the muscles, and by the formation of a regenerating papilla in this emargination (fig. 2).

Such a papilla is slender and almost pure white in colour. At first it is difficult to distinguish it from the true anal papilla with which the body normally terminates, but it may be recognised by the fact that it always possesses a very broad base which fades gradually into the body-wall, while the anal papilla is narrow and ends abruptly at the emargination.

After closing the broken end the circular muscles go into a kind of tetanus, and keep it closed until its edges are joined permanently by the formation of new tissue.

No such formation of new tissue has been observed thus far in the case of the posterior fragments, but their ends remain closed, and this no doubt aids them in retaining their vitality for so long a time. The regeneration papilla rapidly increases in length and width, but always tapers much more than the normal body and remains light-coloured. Specimens have been obtained in which this papilla was four or five inches in length.

Fission takes place through the intestinal cæca, since they offer the point of least resistance, and it usually involves a rupture of the adjacent sexual pouches.

The process is very rapid under irritation, and may be completed within a few seconds after the application of the irritant. It may also take place at two or three points at the same time.

If the irritation be extreme the process may be carried so far that the whole body is divided into very short fragments, the majority of which contain but a single pair of ovaries or testes. This is a frequent result when the worms die through a stagnation of the water in which they are kept.

In such instances the fission goes forward slowly and may occupy several hours, and the contents of the genital pouches are commonly discharged, whatever their state of maturity.

Fresh water acts as a powerful irritant upon *Cerebratulus*, and always induces dismemberment, but it does not kill very quickly.

Fission and regeneration in *Cerebratulus* is not confined to the body-walls; it often takes place in the proboscis.

Under the action of powerful irritants both the anterior and posterior connections of the proboscis are severed at once, so that the extruded organ is not turned inside out, but remains in its ordinary condition, or it may be half everted and then extruded bodily. In either case it often lives a long time, many days or even weeks. If it be irritated, and sometimes voluntarily, it moves in such a lifelike manner, and looks so much like a young worm, that it might easily be mistaken for one. Indeed, a similarly extruded proboscis of another species did mislead several excellent zoologists (6).

They described it as a young animal, and its possessor as viviparous, and presented both as such to the British Museum, where they now remain as striking examples of the folly of judging by external appearances. A proboscis thus extruded is reproduced by the formation of a small conical papilla on the surface of rupture just in front of the ganglionic commissure. This papilla grows backward rapidly, and a new organ is formed in a few weeks. A similar renewal takes place when the proboscis is forcibly removed by cutting (cf. 33).

This species, therefore, in common with others, possesses

the ability to restore lost parts so quickly, so easily, and with so little apparent inconvenience during the process, that anything short of being absolutely eaten whole could scarcely prove fatal.

We are left with the two most interesting questions to answer. First, how is fission actually accomplished? The only description of the process that can be found is the one given by Benham (10). From a study of sections in different stages of fission he concludes that a double row of nuclei appear in the connective tissue along the line of rupture, and that the longitudinal muscle-fibrils are severed between these rows of nuclei, either through the cell substance of the connective tissue becoming actively contractile and nipping off the fibrils, or in consequence of the fibrils being eaten through by some solvent action.

Neither of these conclusions would explain fission in *Cerebratulus*, for the whole process, under irritation, occupies only a fraction of a minute. Hence the connective tissue would have no time to become contractile, but must exist in that condition all the while, ready to act at an instant's notice, i. e. it must itself be muscle. On the other hand, any solvent powerful enough to act in so limited a time would not be likely to stop with the mere severing of the longitudinal muscle; it would dissolve everything within reach, and prevent any regeneration. How, then, is fission accomplished?

The rupture takes place through one of the intestinal cæca, where the body-walls can be most easily divided.

It may take place at any cæcum, and sometimes under extreme irritation the worm will divide itself into fragments so small that they contain but a single pair of pouches.

If there were any special apparatus for producing fission it ought to reveal itself opposite each of the cæca, at least in specimens killed after irritation. But careful examination fails to reveal anything of the sort.

What we do find is that *Cerebratulus* has a thick layer of circular muscles, which are almost entirely lacking in *Carinella*.

There are also well-developed dorso-ventral muscles in the walls separating the intestinal cæca from the reproductive pouches, and these muscles are enlarged into thick pillars at the inner ends of the walls (fig. 60). Finally, an examination of the regenerating longitudinal muscles shows that in early stages of growth they consist of both longitudinal and transverse fibres, about equally divided (fig. 60). Later the longitudinal fibres become more numerous, but there are always many transverse ones to be found among them.

We are left to conclude that in *Cerebratulus* dismemberment is at least greatly assisted, if it be not entirely produced, by a sudden and excessive contraction of these transverse muscles of the body. The dorso-ventral muscles being metamERICALLY arranged, and the others being evenly distributed, dismemberment would occur at a definite place in each segment.

The final question is one which demands the method of regeneration; we shall note only the most important points. Immediately after the rupture is completed the walls of the body are drawn together, and held in that position by the contracted circular muscles. This brings the severed edges of the ectoderm into contact with each other, and they quickly unite and heal the wound over with the exception of the posterior end of the intestine, which is left open to function as an anus. The cells in this newly formed ectoderm, and the mesoderm cells immediately beneath them, proliferate rapidly and form a regenerating papilla which grows backward, keeping the anus open at its extremity. This papilla is much paler in colour than the rest of the body, and at first consists of a thin ectoderm entirely filled except at the centre with mesoderm cells. At the same time the entoderm lining the intestine grows backward as a straight tube along the centre of the papilla. The muscular system is, of course, developed from the mesoderm, and two things are worthy of note in its differentiation. The circular muscles appear first, and are followed by the outer longitudinal layer. The latter is developed very slowly, and for a long time consists of a

meshwork of longitudinal and transverse fibres which cross each other nearly at right angles. The longitudinal fibres are then increased greatly in number and size, while the transverse ones remain about the same.

But the chief interest centres about the nervous system. There has been a great deal of controversy over the origin of this system in Nemerteans. Salensky in 1884 declared, as the result of his researches on *Monopora vivipara*, that the nervous system was derived from the epiblast (44).

Hubrecht, two years later, declared that in *Lineus obscurus* no portion of the central nervous system takes its origin in epiblast, but that it is all of mesoblastic origin, and he undertakes to disprove Salensky's statement in regard to *Monopora* (26).

Finally, Barrois and other investigators derive certain important portions of the nervous system from invaginations of the oesophagus, i. e. from hypoblast (7). All these investigators were working with embryonic material, in which it is usually very difficult to determine the exact relation of the different parts. It is interesting to note in this dismembered Nemertean the mode of regenerating the lateral nerve-cords, since the process is attended by phenomena which leave no possible doubt as to the origin of the new tissue.

At the same time that the muscle-fibres first appear we find upon the ventral surface two invaginations in the epiblast (fig. 21), forming two parallel grooves running longitudinally along either side of the central line and quite near to it.

The ectoderm external to these grooves contains gland cells, that in the grooves themselves and in the space between them contains no gland cells, but seems to be made up entirely of epiblast cells. A third groove then appears in the centre of the space between the other two, dividing it into two low ridges (fig. 23). Toward the inner surface of each ridge the epiblast cells are gradually changed into neuroblasts, and form one of the long nerve-cords. These cells are not fully differentiated, but seem more like the so-

called Ersatz cells, destined to give rise to epithelium, but still capable of being transformed into neuroblasts.

After being formed in this ventral position the nerve-cords migrate upward along either side of the body to their final normal situation, carrying with them a thick covering of the neuroblast cells (fig. 22). As soon as the nerve-cords leave the ridges, gland cells begin to appear in the epiblast covering the latter, and it becomes in all respects like that on the outside of the grooves. The grooves then disappear, and leave a smooth epithelial surface.

The new nerve, therefore, is in no respect an outgrowth from the old one, but results from a new growth of cells which are entirely independent of the old nervous system.

It hardly seems reasonable that this Nemertean in its embryology should derive its nervous system from mesoblast when in regenerating lost parts it shows such a distinctively epiblastic origin.

LARVAL DEVELOPMENT.

Sexual Organs.

The sexes are distinct as in most Nemerteans. There is no perceptible difference in external form or size, but in the breeding season there is a difference in colour, due to the sexual products which show through the body-wall.

The male then appears cream-coloured, while the female is greyish red, turning to a light chocolate-brown in many cases.

This difference is clearly seen in the male and female photographed in fig. 3, the latter being much the darker of the two.

In regard to the original formation of the genital pouches, nothing can be offered in the present paper, since the development is not followed that far. Hubrecht considers (26) that they arise as invaginations of the ectoderm in Lineus, but Bürger's comment seems far more probable.

He says (13, p. 480), "I have not been able to decide upon the origin of the sexual pouches in those forms in which they are preformed (e. g. *Drepanophorus*, *Cerebratulus*), but I am convinced that they are of mesodermal origin because they arise as clefts in the parenchyme or the dorso-ventral muscle layer, while there is no possible doubt that the sexual pouches in those forms in which they are not preformed (e. g. *Carinella*, *Malacobdella*), but are developed in conjunction with the sexual products, arise from the parenchyme, and hence are a tissue derived from the mesoderm."

The development of these pouches in a regenerating papilla bears suggestive testimony toward the same conclusion.

We have already stated that in regeneration a thin ectoderm grows backward from the surface of rupture to form the exterior of the papilla. At the same time the entoderm forms a straight tube through the centre, which is of the same size as the central lumen of the intestine since the anus remains at the extreme tip of the papilla, and which is at first without any side pouches (*en.*, fig. 60). The space between ectoderm and entoderm is filled with mesoderm, from which is developed the body musculature.

The circular muscles and the two longitudinal layers appear first, but are quickly followed by the dorso-ventral muscles.

A row of the latter muscles, each consisting of several fibres, appears on either side of the intestinal tube and close to it, at about the position they are to occupy when regeneration is completed. These form the thickened pillars at the inner ends of the germinal pouches (fig. 60, *dvm.*). Two lines of smaller vertical muscles extend from these pillars outward to the body-wall, diverging slightly. They are woven together by connective tissue so as to form walls which eventually separate germinal pouches from intestinal cæca. As the papilla increases in width the walls grow also, each pillar with its diverging walls enclosing a germinal pouch (*o.*).

As soon as the pillars and walls begin to form, the ento-

derm of the intestine grows out to the right and left between the pillars and along the side of the muscle walls, thus forming the intestinal cæca. A blood-vessel, connecting the dorsal with the lateral vessels, is formed in the connective tissue at the inner end of each cæcum (*bv.*). The genital pouches are thus bordered anteriorly and posteriorly by bands of dorso-ventral muscles, above by the proboscis sheath, and below by the lateral blood-vessel beneath the intestine.

An epithelium now appears, made up of small irregular nucleated cells which cover the pouch unevenly. It is impossible for this epithelium to be formed by an outgrowth from either the ectoderm or entoderm, since it nowhere comes in contact with either of them. It is evidently derived from the parenchymal tissue which binds together the vertical muscles to form the wall of the ovary or testis.

In winter the pouches are much smaller than the cæca, and are flattened between the latter until their sides meet.

Early in spring the sexual products begin to develop, appearing first at the outer end of the pouch nearest the muscles of the body-walls. In the figure given (fig. 63) it will be seen that the pouch extends, in the form of separate longitudinal pockets, both forward and backward along the ends of the adjacent cæca (cf. figs. 61 and 62).

Oögenesis.—The first appearance of egg development is an increase in one of the nuclei of the epithelium lining these pouches. This is carried so far that the nucleus with its large nucleolus comes to occupy a large portion of the cell.

It is then gradually surrounded by a layer of fine-grained protoplasm which protrudes into the lumen of the pouch (*ec.*', fig. 65).

Subsequent development consists in a continued growth of both cell body and nucleus, the latter developing into the large germinal vesicle and the former spreading somewhat over the adjacent epithelium cells which have remained apparently unchanged (*ec.*''). This gives the ovum a flask shape, the neck of the flask being inserted between the epi-

thelial cells into the underlying connective tissue. As the ovum matures the neck of the flask is gradually pinched off from its connection with the epithelium, and the egg is set free in the central cavity (*ec.*''').

It is not, however, naked as at first, but is now invested with a delicate follicle, and is soon surrounded by a thick layer of gelatine, both of which are apparently formed from adjacent epithelium cells. As fast as an ovum is pinched off into the central cavity the epithelium partly closes behind it and new ova are formed, this process continuing until the whole pouch is filled.

Interspersed among the ova and scattered through the jelly which fills the central cavity are small spherical highly pigmented bodies, granular in structure.

These are probably the same as those described by Hubrecht (27) for *Drepanophorus* and *Cerebratulus marginatus*, and like them they disappear gradually as the ova ripen. Hence they must contribute to the development of the egg, and undoubtedly furnish the yolk material. There are also other cells, slightly smaller and lighter in colour, but staining more deeply, which are scattered all through the central cavity. From these comes the gelatine which fills all the space not occupied by eggs (*gc.*, fig. 65).

In a ripe ovary the eggs are crowded together so closely that they become more or less angular in outline.

If a mass of these eggs be examined before they have touched any water they present the appearance seen in fig. 18. Each egg is separated from its fellows by the thick layer of transparent gelatine which surrounds it. This is bordered in turn by a stiffened external surface, where it comes in contact with the coats of adjacent eggs. This gives the whole mass somewhat the appearance of honeycomb, made up of angular gelatinous cells, with an egg in each cell very near its centre.

The gelatinous envelopes cling to the eggs almost as firmly as the similar jelly around amphibian eggs (*Amblystoma*, etc.), and they evidently serve the same purpose.

The ripe ovum is spherical, quite large (0·1 to 0·2 mm. in diameter), and appears white to the naked eye, but by transmitted light is seen to be dark brown and opaque, owing to the large number of yolk granules which it contains. It possesses a germinal vesicle fully one third its own diameter, much lighter in colour, translucent, and slightly elliptical in outline.

Inside the germinal vesicle is a large spherical nucleolus, which is nearly always eccentrically placed at one end of the vesicle, the end farthest from the original point of attachment (*ec.*''', fig. 65).

As the eggs are developed the ovaries increase greatly in size, until finally they occupy nearly all the space, and the cæca are flattened between them.

Formation of Oviduct.—The ovaries now push inward nearly to the wall of the intestine, and outward, downward, and upward to the body-wall. In both horizontal and vertical sections they appear larger at either extremity than in the middle.

When the eggs are nearly mature each sac pushes out into the longitudinal muscle layer, presumably at the point where it meets least resistance, i. e. on the dorsal surface about one quarter of the diameter of the body from its lateral edge.

It then penetrates the muscles as a fine canal, the first beginning of a genital duct, which as soon as the eggs or sperm are fully ripe pushes through the skin to the exterior. The epithelium lining this canal is made up of flattened cells, which are elongated until they look almost like muscle-fibres.

Just inside the mouth of the duct there is a cluster of gland cells, which secrete a large amount of mucus.

As maturity advances the ducts grow shorter, in consequence of the distension of the body and the resultant decrease in thickness of the body-walls. Hence when the genital products are ripe they are easily discharged through these ducts.

As soon as the egg enters the water it is seen to be sur-

rounded by a zona pellucida, which swells up in fifteen or twenty minutes to about twice the diameter of the egg itself (fig. 20).

This zona pellucida is entirely distinct from the gelatinous envelope already mentioned, from which it is separated by two concentric membranes, situated close to each other and at quite a distance from the surface of the egg. The membranes and the zona pellucida itself are perfectly colourless and transparent. Soon after the eggs are placed in water for artificial fertilisation, or soon after they enter the water when laid naturally, the outer gelatinous envelope dissolves and disappears, leaving the egg surrounded only by the zona pellucida and the membranes. If the eggs are placed in water before they are fully ripe the outer envelope does not disappear, but remains holding the eggs together in bunches.

After the ovum is pinched off into the central cavity of the ovary it retains its original flask shape for a long time, sometimes even after it is laid. Hence it occasionally happens that after the outer gelatinous envelope has disappeared the limiting membranes will be found to possess a teat-like protuberance on one side, which is manifestly the remains of the original connecting stalk (fig. 20). And sometimes a corresponding remnant may be found upon the egg itself, the neck of the old flask which has not been wholly withdrawn into its body. These protuberances are of special significance, because they enable us to orient the eggs perfectly, and to determine that the polar bodies always come off at a point diametrically opposite to them, and hence opposite to the original point of attachment. It should be added that since the egg is always elongated into its flask shape at approximately right angles to the surface of the epithelium, it follows that the egg axis bears no definite relation to the axis of the mother, but may stand at any angle with it.

Spermatogenesis.—The testes are formed and developed in the same way as the ovaries. The origin of the spermatozoa in Lineus has been admirably worked out by Lee (30). He

found that they were not developed in preformed sacs, but that they themselves gave rise to the latter, or rather furnished the occasion for their existence. A few large cells appeared in the body parenchyma, which were soon gathered into bunches, around which was developed a thin membrane, thus forming a testis. But in *Cerebratulus* the spermatozoa as well as the eggs are developed from the epithelium lining the genital sacs. The cells of this epithelium increase rapidly by division, and the original nuclei become larger, as in the development of the ova. Through the consequent crowding of the cells some of them are pushed out into the central cavity, where they become sperm mother-cells and form spermatozoa by segmentation (fig. 66). The transition from the sperm mother-cell, or spermatid, into the spermatozoon is apparently not direct, there being intermediate stages (fig. 68).

But the chromatic substance of the nucleus of the spermatid gradually separates itself as the head of the sperm, while the body draws itself out into a long flagellum (cf. figs. 67 and 68). The general type of development is thus very similar to that given by Lee (*loc. cit.*), the essential difference being that in *Cerebratulus* the testis is preformed and the sperms are developed from its epithelium.

When fully ripe the sperms are very large (0.05 mm. long) and of a peculiar shape (fig. 59; compare also fig. 42, in which a sperm and the polar bodies are drawn to the same scale).

The head is long and sickle-shaped, tapering to a very fine point at the anterior end, and usually somewhat curved into a crescent. The middle piece is nearly spherical, and caps the posterior end of the head like the top of a clothes-pin.

The tail or flagellum is very long, many times the length of the head and middle piece, and is undivided.

These sperms have a slow movement, but it is seemingly very strong, for they experience no difficulty in getting through the two egg membranes in order to reach the egg itself.

Egg-laying.

The breeding season extends over about two months or ten weeks. Some of the females begin laying by the 10th of June, while others delay till the 20th or 25th of August. In general those which live in sheltered coves or bays lay earlier than those found in exposed positions, while the nearer low water mark the worm is found the later will its eggs be deposited. By changing the locality, therefore, from which the eggs are obtained, fertile ones can be secured throughout the entire two months. Although Casco Bay is but little north of Long Island Sound, the above dates are radically different from those given by Coe (15), who states that in the vicinity of New Haven the breeding season extends over the month of April, and that by "the first of May nearly all the genital products have been discharged." This serves to emphasise still farther the marked differences which have been noted in the breeding seasons of other Invertebrates from these two localities.

Bürger (13) states that Nemertean eggs are usually joined together in strings or balls, but that they are rarely laid singly. Metschnikoff (35) gives *Lineus lacteus* as one of these rare instances, but he tells us nothing whatever as to the manner in which they are laid.

From the rapidity with which the outer gelatinous envelope disappears when the eggs are placed in water for artificial fertilisation, it would be naturally inferred that the eggs, if not laid singly, at least separated very quickly, since this envelope would be all that held them together. That this is what actually occurs was proven by observation. The first lot of eggs laid in the aquarium (cf. p. 113) were found early in the morning already fertilised. A day or two later the process was repeated while the aquarium was being watched, also early in the morning. A stream of eggs was noticed coming out of the opening of one burrow, while from another burrow at the opposite side of the aquarium sperms were issuing.

Fortunately the burrow occupied by the female was in contact with the side of the aquarium, and the whole process could be watched through the glass. It was seen that the contents of a very limited number of genital pouches near the anterior end of the body were being emptied. The eggs were assisted in their passage through the oviduct by a contraction of the circular muscles of the body-walls over the area occupied by the pouches. When first issuing from the body the eggs were gathered in loose bunches, held together by the gelatinous tissue already described. These bunches were pushed along gradually by successive waves of muscular contraction in much the same way that the ring of mucus formed by the earthworm in egg-laying is worked off the forward end of its body.

In this way the eggs came to lie at the bottom of the vertical portion of the burrow around the head of the Nemertean. Here the action of the water quickly dissolved the gelatinous material that held them together, and left them free. They were then caught in the current generated by the Nemertean's breathing, and carried upward out of the mouth of the burrow and some distance away from it. Eggs were laid in this manner several times, and upon them were verified all the phenomena of maturation and segmentation derived from artificially fertilised eggs. But in so restricted a space there was always a tendency to over-fertilisation, and many of the eggs were killed in this way. Whenever a considerable number were laid at once they collected together at the bottom of the aquarium, and were held together loosely by adhesion of the zonæ pellucidæ, but a slight disturbance in the water separated them and they floated away free.

Nothing could be seen of the burrow occupied by the male except its opening, but as sperms were issuing from this in the same way that eggs were from the other, and as a thick mass of sperms was afterward found at the bottom of the burrow in a position corresponding to that of the eggs, it would seem safe to conclude that the sperms are discharged in the same way as the eggs.

It follows that the eggs must be fertilised outside the body of the female, and that the sperms often have a considerable distance to travel before reaching the eggs. This will account in part for their very strong motion, and it also verifies the statement made by Coe (15) that all the genital products are not discharged at once, but only a limited portion of them. From the fact that the several lots of eggs were laid so near together, it seems probable that the period of egg-laying in any one individual does not occupy more than a week or ten days. When Nemerteans are kept in confinement without any chance to burrow, they usually pull themselves in pieces after a short time. If the sexual products are ripe when this occurs they are always discharged, and perfectly healthy fertilised eggs may often be obtained in this way.

Darwin, in his 'Descent of Man,' says that these animals, like many other Invertebrates, "apparently stand too low in the scale for the individuals of either sex to exert any choice in selecting a partner, or for the individuals of the same sex to struggle in rivalry." This is undoubtedly true, but we must remember with McIntosh that this does not exclude the possibility of a very delicate sexual instinct. The simple fact that the sperms are discharged simultaneously with the eggs, even though the burrows of the male and female may be some distance apart, proves the existence of such an instinct.

Fertilisation and Ripening.

There is nothing resembling copulation, eggs and sperm being discharged from separate burrows. When ripe the eggs fertilise almost immediately, but with a little care the entrance of the sperm into the egg may be seen, though its subsequent action must remain invisible owing to the opacity of the yolk granules. A great many sperms usually penetrate the limiting membranes, but only one of them enters the egg, though instances of polyspermy are not unknown. The sharp curved point of the sperm is placed against the surface of the egg, and a gentle vibratory movement is pro-

duced by the lashing of the long tail. Although this appears like a weak movement under the microscope, it must really be very strong, for the head of the sperm is pushed in steadily and quickly.

The curve in the head of the sperm renders any rotary motion impossible. As soon as it has entered the egg the latter becomes more opaque than before, and the large translucent germinal vesicle quickly breaks down and disappears. This is followed in turn by the giving off of the polar bodies.

If the supply of sperm be sufficient, so many of them penetrate the membranes that the latter are broken down and disappear entirely. Then the sperms, clinging to the egg with their heads and lashing with their tails, give the egg a rotary motion, exactly similar to that produced in later development by the cilia. This may be kept up for an hour or more.

Formation of Polar Bodies.—The first polar body appears about an hour and a quarter after fertilisation, and always at a point diametrically opposite the protuberance in the limiting membrane, when such a protuberance is present.

As already noted, this is the remnant of the original stalk whereby the ovum was joined to the wall of the ovary, and hence those eggs which do not exhibit it must have been separated so gradually and completely as to have left no trace of their former connection. But it is reasonable to infer that the polar bodies appear in them also opposite to the point where such connection formerly existed. If this be true, it follows that the connection of the ovum with the wall of the ovary during development results in its permanent polarisation, and the point at which the polar bodies are to appear is predetermined.

There is no perceptible separation of formative and nutritive material, but correlated phenomena indicate that the point of attachment is the vegetative pole. The food supply must come to the ovum through this attachment, and in early development the germinal vesicle often lies eccentrically near it (fig. 64). These facts, taken in connection with what has

already been given in reference to the early development of the ovum, furnish strong corroborative evidence to the truth of the view formulated by Mark in 1881 (32) and by Watasé ten years later (47). The ovum is at first isotropic, but afterward acquires polarity and other promorphological features through its topographical relation to the remaining cells of the maternal tissue. In this species the primary axis of the ovum seems to be formed at right angles to the surface of the epithelium from which it originates (cf. 50).

The appearance of the first polar body is accompanied by the usual flattening of the surface, and sometimes by a slight pitting in of the ectosarc to meet it (fig. 23a). The latter effect is often abnormally increased if the cover-glass is allowed to press upon the egg. The gradual emergence and rounding of the first polar body is shown in figs. 24—26.

A slight swelling first appears at the point of emergence, and rises as a symmetrical hemisphere. This increases in size, and within a minute becomes a short cylinder, or a more or less rounded conical protuberance (fig. 24).

Within half a minute more the base of the cylinder is constricted, and the constriction increases until the polar body has entirely separated from the egg (fig. 26). So far as observed a connecting protoplasmic band is always present, but it requires a good light and a high power to detect it.

The flattening of the pole draws the surface of the egg away from the membranes, so that the polar body after its extrusion is not very near them. It now becomes approximately spherical, the whole formation having occupied about three minutes.

It lies in contact with the surface of the egg or near it for ten or fifteen minutes, during which the egg resumes its original shape, and then withdraws a little, but still retains the connecting band of protoplasm. This withdrawal is simultaneous with the first appearance of visible spin-threads, and marks the beginning of a long series of remarkable activities which are of sufficient importance to demand a separate description (see p. 133).

About six or eight minutes later the first body returns to a position near the egg, and there awaits the second body.

A swelling appears at the point where the connecting band of protoplasm from the first body joins the egg (fig. 28). This rapidly becomes nipple-shaped, lifting the first body upon its slightly enlarged apex (fig. 29). There is the same gradual constriction as before, and the whole formation occupies about the same time, three minutes. There is also a second flattening of the egg, sometimes a slight emargination, whereby the surface is withdrawn from the membranes, so that the combined first and second bodies, even though the latter is elongated, do not get any nearer to them. The second body is smaller than the first, and does not become spherical, but is elongated parallel to the surface of the egg into a spindle or melon shape (fig. 35).

Sometimes the first body divides after separation, or, instead of a single second body, two occasionally appear side by side.

In both these abnormal cases one of the paired bodies withdraws by itself, while the other two remain and continue their filose activities.

Activities of the Polar Bodies.—During their formation and almost to the blastula stage the polar bodies afford a remarkable example of that form of protoplasmic activity which was first described in echinoderm eggs by G. F. Andrews, and designated "filose activities or spinning" (4).

These activities have already been carefully described in this Nemertean in an interesting paper by Dr. E. A. Andrews (2), in which some doubt was expressed as to the certainty that such activities were entirely normal. The eggs used by Dr. Andrews were fertilised artificially, but great care was used in observing them, and the results were verified by comparison with other eggs which developed into normal embryos. I am glad to add in confirmation the following description taken from eggs laid in an aquarium under fairly normal conditions and fertilised naturally.

The first polar body, immediately after separation, exhibits amœboid changes of outline, as can be seen by comparing different figures. These are most prominent during the first four or five minutes. At the end of this time the body has become spherical, and stands close to the surface of the egg, with which it is connected by a narrow band of protoplasm (fig. 26).

It now begins to exhibit spinning activities. Numerous fine transparent threads of protoplasm radiate outward from its surface, usually appearing first at one end (the body is considered as lying with its side toward the egg), but frequently elsewhere. The whole surface becomes covered with such radiating threads, which vary considerably in size and visible length. At the same time the body moves away from the egg slowly, but whether as a result of the spinning or the amœboid movement or both could not be determined.

No further change occurs until the appearance of the second polar body, except that sometimes the surface of the egg in the vicinity of the first body rises up into one or more small papillæ. These occur most frequently on eggs which afterward become abnormal, and they disappear quickly.

As soon as the second body appears there is a distinct change in the activities of the first body. The body itself is slightly elongated parallel with the surface of the egg, and becomes flattened on the inner side. The filose threads, which have been hitherto distributed over its surface, now aggregate toward one or both ends, and gather into long filaments visible under a low power. They extend outward and downward toward the surface of the egg (fig. 31), but could not be traced to actual contact with the surface. But this affords no proof that they do not reach it, for they are extremely delicate and transparent, and they diminish in size the farther they are followed, so that it becomes difficult to see them.

Certain phenomena at just the place on the egg toward which they point indicate that they really do reach the surface.

Furthermore, as Dr. Andrews has noted (2), the appearance of the first body during the extrusion of the second, and its subsequent changes in shape, are just what they would be if the first body were pushed upward by the second and at the same time held down to the surface of the egg by these filaments.

The band of protoplasm connecting the first body with the egg remains after the second body is formed, and connects the two bodies. The second body immediately begins to elongate parallel with the surface of the egg, and assumes a spindle or melon shape, which always characterises it. A small papilla now appears on the egg at either side of the second body and some little distance from it (fig. 33). These two papillæ are situated exactly where the long filaments from the first body would strike the egg if they reached that far, and it seems probable that the two are connected. The papillæ vary in size and number on different eggs, but they are usually two.

They are arranged symmetrically, one upon each of what will soon become the first two blastomeres (fig. 34). It is also significant that the spindle of the egg nucleus after the extrusion of the first polar body rotates through 90° , as in so many other eggs, and becomes parallel with the surface, its two ends being just beneath the points where the papillæ afterward appear (fig. 56).

The summits of the papillæ are covered with fine spin-threads, radiating outward, while the surface of the egg between them is flattened or even concave. They continue for about five minutes and then disappear (fig. 36). In eggs not quite ripe, or developed under abnormal conditions, especially pressure, the papillæ are increased in number, size, and duration (fig. 37).

I have repeatedly seen unripe eggs, on reaching this period in their development, put out ten or twelve large pseudopodia-like processes in place of the two papillæ, and gradually go to pieces.

When the papillæ disappear the egg returns to its

original form, thereby carrying the polar bodies nearer the membranes.

In one or two instances the recovery was carried so far that the polar bodies were pushed out into the membranes as in fig. 39.

This figure shows that there are two independent membranes, for only the inner one is bulged outward to any extent.

It also shows that the first polar body is surrounded by a zone within which spinning activities are sufficiently strong to prevent the membrane from entering. The relative distance of the two bodies from each other and from the egg does not seem affected at all by this contact with the membrane, so that the latter must be very delicate and yield readily to slight pressure. The second body in pinching off from the egg also leaves a narrow band of connecting protoplasm (fig. 35), which keeps both bodies in close relation to the egg.

When separated it begins to show activities somewhat different from those of the first body (fig. 36). While forming, fine threads are seen radiating outward from nearly all visible parts of its surface, but as soon as it assumes its characteristic spindle shape the two poles at the extremities of the spindle become the centres of filose activity.

At first they send out slender threads in various directions, but soon they begin to elongate as pseudopodia processes (fig. 35), carrying the centre of activity away from the body itself. The ends of the processes enlarge, and may even form secondary spindles, from which fine threads radiate in all directions (fig. 38). Short filaments still appear and disappear at different points on the body itself, but they are very transitory, and evidently of secondary importance.

In unripe eggs, and especially in those developed under abnormal conditions, the spinning activities may be greatly increased. These are the eggs usually covered with papillæ in the vicinity of the polar bodies, and the abnormal spin-

threads run back and forth between bodies and papillæ, lacing them together firmly (fig. 37). But even then the threads are remarkably independent of one another, and in no instance were two of them seen to fuse where they crossed, though sometimes one would divide and attach itself by two or more strands.

These abnormal activities also emphasise the fact that those spin-threads which connect polar bodies and egg emanate from the former. Of the spin-threads arising from the egg the longer ones do not extend toward the polar bodies, while the shorter ones, which do, evidently do not reach across.

The polar bodies take the initiative in spinning; and, although the egg responds, it never reaches the same degree of activity.

If a higher power is used the polar bodies are transparent enough to disclose something of their internal structure.

The first body is pear-shaped, with a short process extending from the smaller end like a stem (fig. 41). Numerous threads radiate in every direction from the enlarged tip of this process, while a similar bunch of threads radiate immediately from the body at its opposite end, and a few weak threads appear on the outer side. The interior is filled with fine-grained protoplasm, with chromosomes at or near the centre.

The normal number of these seems to be five, but they vary considerably, now appearing as five distinct curved rods (fig. 41), and again fusing to one large mass, with or without a smaller one beside it (fig. 40). The same chromosomes may be seen in the second body, sometimes separate (fig. 44), at others more or less fused (fig. 45). The fusion in both bodies occurs at the time when they frequently divide, but the karyokinesis does not show very plainly. During the emergence of the second body the first one shows quite a marked polarisation (fig. 34), but the resultant figure is never as perfect a spindle as in the second body, and the polarisation disappears early in segmentation (fig. 44). The second body, on the contrary, maintains its characteristic spindle shape through-

out segmentation, its ends are enlarged more than those of the first body, and they continue to be centres of filose activity nearly to the blastula stage (cf. figs. 44, 45).

Summary.—1. The first polar body acquires its spinning power soon after separation, manifests it chiefly in the form of diffused spinning with little polarisation, and loses it early in segmentation. The second body acquires this power during separation or immediately afterwards, possesses a marked polarisation, and retains its activity at least to the blastula stage.

2. In both bodies the poles are at either extremity of an axis parallel to the surface of the egg, and the spinning activities are more or less centred there. In consequence these two points assume a character notably similar to that of the two centrospheres at either end of the nucleus during segmentation.

3. Both bodies show in their interior chromosomes, whose normal number seems to be five, but which vary greatly in number as the result of partial fusion.

4. The surface of the egg in the vicinity of the polar bodies also exhibits spinning activities during and subsequent to the formation of the bodies. This spinning is quite diffuse, but just after the separation of the second body it becomes concentrated at two papillæ symmetrically arranged, one on either side of the first axis of segmentation. The long spin-threads from either end of the first body connect with these papillæ. The internal phenomena of fertilisation and segmentation are invisible through the yolk granules, but may be seen in sections.

Conclusions.—1. The polar bodies and the egg itself, in this species, are to a large extent physiological as well as morphological equivalents.

Evidently the half of the original egg nucleus which remains within the egg retains the same characteristics as the halves which are successively extruded in the polar bodies, or else the latter acquire distinct characteristics during extrusion—an hypothesis which is hardly tenable.

Hence the polar bodies on the exterior, where they are plainly visible, repeat for us the same activities, or very similar ones, that occur invisibly within the egg. We find both bodies elongated at right angles to the first plane of cleavage, while their ends, enlarged over each blastomere, become centres of spinning activity.

Externally the surface of each blastomere also manifests spinning activity by rising into a papilla which becomes connected with the enlarged end of the first body on its own side.

These visible filose activities of the egg are much more prominent while the egg nucleus remains near the superior pole, and diminish sensibly as it descends to meet the sperm nucleus.

Such a result would naturally follow the intervention of inert yolk material between the active nucleus and the surface of the egg. The increased activities of some eggs immediately after the extrusion of the second polar body (2, p. 232, and fig. 37), whereby the whole surface of the egg at the superior pole is raised into ridges and papillæ covered with filaments, admit of ready explanation if we assume that in such eggs for some reason the nucleus does not descend at once, but tarries awhile close to the surface.

Internally the female pronucleus, after the extrusion of the first polar body, rotates through 90° , as already stated, so that its ends are just beneath the points where the papillæ appear (fig. 56).

This has been noted in *Cerebratulus marginatus* also (16, figs. 20 and 22), where the amphiaser is plainly parallel to the elongated polar body. Furthermore there is good evidence for believing that the female pronucleus again rotates after the extrusion of the second body, and becomes parallel with the latter (fig. 57). But with the amount of material at my command for this particular phase of development I have been unable to decide beyond a doubt. After the egg nucleus has united with the sperm nucleus the resultant segmentation nucleus is also elongated at right

angles to the first plane of cleavage, and forms an amphiaster. Its ends are not enlarged in each blastomere, but there is instead a centrosome at either end, which becomes the centre of activities very similar to those manifested by the enlarged ends of the polar bodies (fig. 58).

Is it too much to conclude that this marked similarity between external and internal phenomena cannot be the result of chance, but that there must be a close relation between the two? These considerations lead naturally to our second and third conclusions.

2. In *Cerebratulus* we have an instance where oögenesis approaches more closely to spermatogenesis, and thereby shows more clearly the morphological equivalence of the two.

Adopting the view first put forward by Mark in 1881 (32), that the polar bodies are to be regarded as abortive eggs, we find in *Cerebratulus* an instance where they are less abortive than usual. In spermatogenesis the spermatocyte usually divides into four sperms, each of which is in every way the equal of all the others. But in the final division of the oöcyte the perfect egg ordinarily appropriates to itself all the activities of the three rudimentary ones, as well as the entire mass of the yolk. In *Cerebratulus*, however, it contents itself with taking all the yolk, and leaves quite a share of the activities for the polar bodies, especially the second one.

3. The egg-cytoplasm, and probably the female pronucleus also, exhibit a well-marked polarity at right angles to the first plane of cleavage before the two pronuclei have joined to form the segmentation nucleus.

This can be easily seen by reference to figs. 34 and 56. Even in those exceptional instances where the whole polar surface is covered with ridges and papillæ the same transverse polarisation is manifest in the increased size of certain of the papillæ (fig. 37; cf. also 2, fig. 12).

Segmentation.

Segmentation is total and equal. The first furrow lies along an axis joining the polar bodies and the point of original attachment. This fact furnishes further evidence that the axis of segmentation was determined early in development. About an hour and a quarter after fertilisation the egg begins to elongate at right angles to the axis just mentioned, thereby drawing the polar bodies away from the membranes. It continues to elongate until the long diameter becomes one and a half times the shorter one.

If viewed at this period under a low power with strong illumination, it can be seen that the nucleus has divided, and the halves have migrated to either end of the ellipse.

A shallow groove appears beneath the polar bodies and the egg elongates still more, the diameters bearing the relation to each other of five to eight. Two minutes later a corresponding groove appears on the opposite side, and they both deepen rapidly, the first more rapidly than the second. There is also a continued elongation, the diameters standing in the relation of five to nine. At the end of this period, which has lasted ten minutes, we find the egg divided into two almost perfectly spherical blastomeres, joined by a very narrow isthmus, whose distance from the polar bodies is twice that from the opposite pole (fig. 49).

Behaviour of the Polar Bodies.—Usually the flattening of the egg preliminary to segmentation moves the polar bodies, but sometimes the connecting band of protoplasm elongates and leaves them in their original position. When the furrow appears they are always pulled down into it. Under a low power it is seen that they follow the changes in position which the surface undergoes as if they were attached to it.

Under higher magnification one can detect that the bodies themselves are somewhat changed in contour by the process (fig. 42). Instead of its characteristic spindle shape, with the long diameter parallel to the surface of the egg, the

second body is pulled out at right angles to that surface, until sometimes the perpendicular axis becomes the longer one. Evidently its attachment must be firm enough to bring about such a change.

Its spinning activities are not disturbed in the least, and the former poles remain the centres of such activities. This often results in an irregular quadripolar appearance, the two connecting bands of protoplasm arising from the vertical poles, while from the horizontal ones radiate long filose spinthreads.

We have said that the cleavage groove nearest the polar bodies usually occupies two thirds or more of the entire diameter of the egg. Hence, if the polar bodies remained as near the bottom of the groove as they were when it started, they would be drawn in at least to the centre of the egg. But such is not the case. They do sometimes enter within the general contour of the whole mass, but they usually follow the groove only a little way, and remain partially or wholly outside the general contour. As a result, the band of protoplasm connecting the second body with the egg apparently changes its point of attachment to the latter. Instead of remaining near the bottom of the groove, it removes to a comparatively long distance from it on the side of one of the blastomeres (fig. 46).

Is this change of position real or apparent? Is it the body which has changed, or the bottom of the groove?

That portion of the egg where the connecting band originally appears is the centre of activity during the extrusion of the bodies, and naturally remains connected with them during their filose spinning. It then becomes the point at which the protoplasmic activities resulting in the first cleavage are manifested. Hence, if the point of attachment were to be changed, it would seem natural that it should be toward some other centre of activity. But no such centre can be found at or near the surface of either blastomere, so that *a priori* we should not expect any change. Again, the only way in which such a connecting band could change its position would

be either by the withdrawal of the filose threads of which it was composed and the protrusion of others from a new point, or by a gradual slipping along the surface. The latter hypothesis is untenable from the very nature of the spin-threads, and the most persistent watching failed to reveal any temporary withdrawal of the connecting protoplasm. We are left, therefore, to the conclusion that the change is only apparent, and that the actual point of attachment remains the same. This affords a means of identification whereby we can follow one particular portion of the surface during segmentation. In this way we find, first, that there is no investing membrane in contact with the surface of the egg, but that the protoplasm of the latter forms an ectosarc similar to that of the amœba. This is lighter in colour and more transparent than the remainder of the egg, partly because it contains no yolk granules.

Again, we find that the change of position is due to the fact that the point of attachment remains stationary, while the groove advances; in other words, the old ectosarc travels inward, during the formation of the groove, only the limited distance necessary to accommodate the more rounded outline of the blastomeres, and the ectosarc which covers the bulk of the groove is a new structure. This is easily formed, since it consists essentially of egg protoplasm minus its yolk granules.

Anticipating a little, we find that after the two blastomeres have come together again, and the furrow has been filled in by appression, the point of attachment does not return to the bottom of the furrow, but, approaching it closely, remains at a distance which varies within narrow limits for different eggs (fig. 50).

The two edges of the old ectosarc do not quite meet, but a portion of the new ectosarc remains exposed along either side of the furrow. This portion increases with subsequent segmentations until the point of attachment comes to lie near the centre of the cell in the 128-cell stage (fig. 45).

This is the natural result, since the egg increases slightly in size with each segmentation. The protruding surface of

each blastomere retains a portion of the old ectosarc near its centre, and this is surrounded by a border of newly formed ectosarc, whose relative width increases as segmentation advances.

Finally, the persistence of the point of attachment of the second polar body greatly facilitates the orientation of the egg. As soon as the first groove is formed the blastomeres become almost perfectly spherical. Most eggs having total cleavage show a rounding of the blastomeres, but in this Nemertean they are almost separated, so that the egg assumes a dumb-bell shape, with a short handle eccentrically placed.

As would be inferred, they are easily separated, with results to be noticed later.

Certain interesting phenomena precede the coming together and flattening of the blastomeres. In this egg, as in that of Echinoderms (5), filose activities similar to those of the polar bodies arise on the surface of the blastomere.

In fact, they are continuations of the same activity which has just been spinning the connecting bands of protoplasm and producing the first cleavage groove. Fastened at a point near the opening of the groove are the polar bodies (fig. 46).

Close watching in a good light now reveals spin-threads forming between the blastomeres. A small papilla appears nearly opposite the attachment of the polar bodies, and gradually increases until it becomes half as large as one of them.

At first filose threads radiate from this papilla in different directions, but they gradually fuse into one thick thread, extending obliquely across the groove to a point a little below where the polar bodies are attached (fig. 47). Half a minute later another spin-thread appeared below the first, but no papilla could be seen at its origin, probably because it was not in perspective. This thread divided when half-way across, and the two ends were attached separately (fig. 47).

At the same time spinning activities began on the opposite

side of the connecting isthmus. A large papilla was formed on the same blastomere to which the polar bodies were attached, and a moment later a similar one appeared on the other blastomere (fig. 47). Short spin-threads radiated from both papillæ; then the first papilla disappeared, but the spin-threads remained and formed quite a stout thread extending across the groove (fig. 48). In some eggs the threads first formed remain until those upon the opposite side of the isthmus have appeared. These eggs are of special interest, because they show that the spin-threads contain contractile protoplasm (fig. 51). The two blastomeres were drawn together on the side of the isthmus farthest from the polar bodies, and held for an instant and then released. During this contraction the spin-threads shortened and thickened visibly, showing that they were at least active agents in the process. The papillæ also were pulled out slightly in the direction of the spin-threads, as would be expected of yielding protoplasmic material. After an interval of five seconds the blastomeres were pulled together again, this time on the side nearest the polar bodies. These movements on opposite sides of the isthmus alternated at irregular intervals for two minutes, when the papillæ had entirely disappeared, and the blastomeres had been drawn together and flattened. These contractile movements were noted independently, and commented upon by a friend who was watching another lot of eggs, and were observed several times subsequently while studying other phenomena, so there can be no doubt of their reality. It must be remembered in judging these facts that the conditions are specially favourable in the present instance for the occurrence of just such phenomena. Intercellular connections by means of spin-threads have been clearly demonstrated in the eggs of many Metazoa (cf. 3), and have even been retained in preserved specimens.

We should expect to find them in *Cerebratulus* as a natural sequence to the marked spinning activities of the polar bodies. The perceptible motion of the blastomeres is rendered possible

by their almost complete separation ; the isthmus joining them is very slender, and can be bent by a slight force.

We thus have in these eggs a combination of strong spinning activities with just the physical conditions best adapted for rendering them manifest. These activities are more profuse at this early stage than in any later period of development. Whether the blastomeres are sensibly reduced by this spinning is difficult to determine, because they are continually changing their shape at just the time when the spinning is most profuse. In immature and abnormal eggs, however, they often produce a perceptible diminution of the blastomeres, and in such cases segmentation is usually unequal instead of equal, the third furrow producing four micromeres and four macromeres. Subsequent division proceeds on the same plan, but the eggs are so weakened that they seldom reach gastrulation. In this egg, as in the Echinoderm, there is thus a marked difference between normal and abnormal filose phenomena, as emphasised by G. F. Andrews (5). Such abnormalities are of little use in explaining normal cleavage, but may contain valuable suggestions. Finally, we may note that these abnormal activities are frequently carried so far that the egg spins out the entire substance of the blastomeres, and goes to pieces during the first segmentation.

This first cleavage, therefore, occupies about fifteen minutes, and is followed by an interval of rest lasting ten or twelve minutes.

This interval is occupied in the various phases of karyokinesis ; the nuclei of the two blastomeres divide, the halves separate and take a position at either end of the vertical diameter of each blastomere, where they can be seen under a low power.

The second cleavage groove then appears at right angles to the first, and divides the egg horizontally into four blastomeres. These are not spherical, although they appear so when viewed from the side (fig. 52). If the egg be rolled between cover-glass and slide, the blastomeres are seen to be

really egg-shaped or ellipsoidal masses lying side by side, with the polar bodies still attached to the first cleavage groove (fig. 53). When they flatten together an open space is often left in the centre as in the *Echinus* egg (fig. 52).

If the surface of the blastomeres bordering this opening be examined under a high power considerable filose activity is revealed. One spin-thread starts from a papilla on the side of a blastomere, and runs diagonally across to an adjacent blastomere. Several other fine threads can be seen radiating from the summit of the papilla, but they could not be followed across (fig. 52). Another thread crosses from one blastomere to the one opposite it, and makes a sharp bend or elbow halfway across, very similar to the bends figured for the star-fish blastula and the *Echinus* four-cell stage in the paper just referred to (5). The third thread visible at this level proceeded out a little way from the remaining blastomere, and then turned abruptly and ran down diagonally to an adjacent blastomere.

This central open space is subsequently obliterated by the flattening of the blastomeres. The polar bodies continue their filose activity, remaining attached to one side of the first furrow. In fig. 43 both bodies are seen to be bipolar, but the two poles of the first body are unlike.

One consists of a large but short and blunt process from whose tip and sides fine threads are given off, while the other is made up of a simple bunch of radiating threads, each of which starts from the body itself. Another blunt process projects toward the second polar body, and forms part of the connecting band between the two. Short fine threads also radiate from this process.

The second segmentation occupies not more than eight or ten minutes, and is followed by a rest of five minutes.

The third segmentation is vertical, and divides the egg into eight equal blastomeres. Subsequent segmentations take place more slowly than the first two, and the blastula stage is reached in about fifteen hours. During the second and third segmentations the egg elongates again, each time at right

angles to the plane of cleavage, and since the first three planes are in the three dimensions of space the successive elongations restore the sphericity of the egg. During the flattening together at the close of the third segmentation there is a twisting to one side, whereby the four upper blastomeres come to lie over the grooves between the lower four, i. e. the cleavage is spiral (fig. 54).

A change now takes place in the relative activity of the polar bodies; the first one has been more active hitherto, but it now loses its marked polarity and begins to resume its original spherical form. One of its poles has already been replaced by a bunch of radiating filose threads, and the other one now disappears gradually until the only remaining signs of activity are occasional spinnings from various points on the surface.

The second body, on the contrary, increases in activity; the processes at either end enlarge, and the filose spinning increases proportionally. The band of protoplasm connecting it with the egg changes continually in size and contour, and occasionally a lump or swelling appears near the centre of this band, looking like a third polar body. But it soon disappears. The two figures given (44, 45) show the relative activities in late stages of cleavage, and they also show that the chromatic substance is affected by these activities.

In the first figure the chromatin appears in the form of grains scattered through the body; in the second figure it has been gathered into a nuclear-like mass near the centre, whose size and shape change under the influence of the spinning.

This change of the chromatic substance under the influence of filose activity in the polar bodies corresponds well with the changes in position, size, and shape of the chromosomes in the nucleus during karyokinesis under the influence of the spindle activities, and is another evidence of the close relation between the two. We have no means of knowing how far they may agree in detail, but they are worthy of note as showing that the filose activities have a tendency in the same direction as those of the segmentation spindle.

A segmentation cavity appears very early, but not quite in the eight-cell stage as described by Barrois for *Lineus Gesserensis* (7).

As would be readily inferred, the first two blastomeres are easily shaken apart when joined only by the narrow isthmus, and the same is true of the four- and eight-cell stages.

The experiments of Morgan and others upon frogs' eggs at once suggested that blastomeres separated in this way might develop into larvæ. Accordingly experiments were made with the most satisfactory results. Even if the egg-membranes were broken in the shaking and the blastomeres set free, they segmented as though nothing had occurred, and developed into larvæ similar in all respects to those reared normally, except that they were only half as large, or even smaller in the case of isolated blastomeres of the four- and eight-cell stages.

Summary.—1. The axis of first segmentation is predetermined in the ovary at a very early stage of development. It extends from the point where the egg-cell is originally attached to the wall of the ovary, diametrically across the egg to a point where the polar bodies subsequently appear.

2. The ripe ovum is spherical. Segmentation is total and equal; the first three cleavage planes occupy the three dimensions of space, the second being horizontal. The first segmentation occupies fifteen minutes, and is followed by a period of rest lasting ten or twelve minutes. The second occupies not more than ten minutes, followed by a rest of five minutes.

Subsequent divisions proceed regularly but more slowly, and the blastula stage is reached at the end of the fifteenth hour.

3. The polar bodies remain attached to each other and to the egg through segmentation, and continue their filose activities.

All evidence indicates that the point at which the second body is attached to the egg remains constant. It appears at the bottom of the first cleavage groove, then changes, as the

groove deepens, to the side of that blastomere which first passes into the four-cell stage. After the blastomeres have been appressed it remains a short distance from the bottom of the groove. This distance increases with subsequent segmentations, until at the close of segmentation it appears near the centre of the external surface of one of the cells. These changes of position without change of identity enable us to determine—

a. That the egg possesses no surface membrane, but has an ectosarc similar to that of the amœba.

b. That the original ectosarc contributes but slightly to the covering of the cleavage grooves, the larger portion of that covering being a new structure.

c. That after appression a portion of this new ectosarc remains exposed along the lines of cleavage, and increases in relative width as segmentation progresses.

d. That gastrulation begins at the inferior pole, and the axis of first cleavage becomes the future dorso-ventral axis of the pilidium, and later of the adult (13).

4. The blastomeres show vigorous spinning activities during early segmentation. While the polar bodies are coming off, and immediately after the separation of the second one, numerous spin-threads appear on the surface of the egg just beneath the bodies. A papilla is formed on either side of the first cleavage plane, and from its summit spin-threads radiate outwards, some of them connecting with those from the poles of the first polar body, and re-establishing vital connection between the two. Both papillæ and spin-threads disappear before segmentation begins.

5. Papillæ are also formed on the sides of the cleavage grooves, from which spin-threads extend to adjacent blastomeres and aid in appression. These are easily seen in the first groove, less easily in the second, and can hardly be distinguished in the eight-cell stage. These threads are contractile, and during the first cleavage, when the blastomeres are almost separated, their contraction produces a perceptible movement.

6. The blastomeres may be entirely separated during early segmentation, with the result that each one produces a perfect undersized pilidium.

Conclusions.—Recent investigations (3 and 5) have disclosed in living eggs of Echinoderms, Annelids, and Molluscs activities similar to those just described, and filaments which were probably of the same nature were found in preserved eggs of Amphioxus and the Amphibia. The first observer of these activities (5) interpreted them as establishing the physiological continuity of the blastomeres during cleavage, and all subsequent investigations have only emphasised this inference.

Our first conclusion, therefore, reiterates the same truth :

1. The spin-threads connect the blastomeres and prevent any physiological separation during segmentation.

Few eggs undergo more complete separation of the blastomeres than those of *Cerebratulus*, but when most distinctly separated they retain their physiological unity by means of numerous cytoplasmic commissures. Evidently these spin-threads are portions of the internal protoplasm which have flowed out to the exterior, and are formed in the same way as the filose pseudopodia of Radiolarians and the larger pseudopodia of amœbæ.

We should expect to find them, therefore, as suggested (3), "high roads for the passage of living substance" between the blastomeres, and between them and the polar bodies. And under specially favourable circumstances the actual movement of granules along certain threads may be seen. The current runs now outward and again inward, as in a Radiolarian's pseudopod.

Hence in those filaments which reach from one blastomere to another, and remain for any length of time, there would be a greater or less transference of living material. Segmentation in such eggs cannot be regarded as a separation of the egg substance into independent "cells," but becomes rather a differentiation of different portions of the same unit mass for different purposes,

2. If spin-threads are outflows of internal protoplasm, their activities must be similar to those in the interior of the egg—a conclusion reached from other material by G. F. Andrews (4).

One of the activities of the spin-threads is a streaming movement of their more liquid contents. Unfortunately the blastomeres are so opaque that we cannot see whether there is a corresponding internal flowing of the protoplasm, but it hardly seems possible that the former could exist without the latter. Such streamings of the egg protoplasm have been witnessed by Erlanger (21) in the living eggs of several small Nematodes which are transparent enough to show it distinctly.

In each end of these eggs alternately the protoplasm moved from the poles to the equator, but as soon as the equatorial groove appeared the streaming turned inward at the groove and then backward toward the pole. After the first segmentation similar streamings appeared in the blastomeres. These movements were vigorous enough to distort the cleavage spindle, and Erlanger concluded that the whole of the egg, spindle and astral rays included, is always plastic and fluid, though the rays are more viscid than the remainder. Blunt pseudopodia were formed on these nematode eggs at various points, especially near the edge of the cleavage groove, but no spin-threads were noticed.

The observation of such phenomena in transparent eggs furnishes a strong presumption in favour of their occurrence in opaque eggs, particularly in connection with such vigorous external movements.

3. The spin-threads and other cytoplasmic connections assist materially in appression, and probably in other movements of the blastomeres.

The spin-threads possess a contractility of sufficient strength to move the blastomeres, and there can be no doubt that they assist in drawing them together after segmentation.

They produce visible motion after the first cleavage, but not in any succeeding stage, because the physical conditions

are not the same. But it is not unreasonable to suppose that the filaments formed in such stages really do assist in appression, even if we cannot see any motion. A similar function has been pointed out for the connecting filaments formed in Echinoderm eggs (5). It seems probable also that something of this sort produces the spiral movement during the third segmentation. We must admit that some portion of the internal protoplasm possesses contractility, or we are again driven to the improbability that the protoplasm which streams outward to form the spin-threads is radically different from that which remains inside the egg, and that the change takes place at the ectosarc. We thus see that all the facts and inferences to be derived from the visible filose activities give support on the one hand to the hypothesis of fibrillar contractility (van Beneden, 9), and on the other to the explanation by means of streaming or osmotic movements of the fluid portions of the protoplasm (Bütschli, 12). Neither of these views can well be excluded in face of the testimony here presented.

It seems equally impossible to escape the conclusion that both are correct, so far as the existence of the forces which they advocate is concerned. May it not be that we are to look for a full explanation not to either one of them alone, nor to any other single hypothesis already advanced, but rather to a compromise, including at least several of the principal ones?

GASTRULATION.

Ciliation of the Larva.—As soon as the blastula stage is reached cilia appear upon the external surface of the cells, and the embryo begins to rotate slowly about a vertical axis.

The displays of filose spinning already given by the polar bodies and the blastomeres incline me to the view recently expressed (4) that cilia owe their origin to similar activities.

During segmentation both polar bodies and blastomeres were sending out spin-threads, which often traversed spaces

of considerable width. What more natural than that this same activity should manifest itself at the close of segmentation in spinning out these cilia? Evidently they cannot be extrinsic in their origin, but must be intrinsic. Various names have been applied to them, but I would suggest that the term *filature* expresses better the actual facts in the case—i. e. a spinning out into threads of filose processes.

These cilia vary greatly in length, the majority of them being far longer than those ordinarily given in published drawings (see 4, p. 72). Furthermore they do not end abruptly at a definite distance from the cell surface, but terminate in fine processes similar to the terminations of the spin-threads from the polar bodies. I have ventured to represent these cilia in one drawing as they really appear (fig. 8), and I believe that such figures reveal their true nature.

Such a relation between spin-threads and cilia may be taken in evidence to explain the origin of motion in the latter.

The band of strong cilia around the edge of the oral surface are probably the ones first developed. At the close of segmentation there is a well-defined differentiation of cells into ectoderm and entoderm. The former are considerably the smaller, and are more or less cubical in shape, while the latter are elongated into well-defined cylinders (fig. 69).

During the blastula stage the egg maintains a position in which the entoderm cells occupy the inferior pole, while the ectoderm cells occupy the superior hemisphere and the upper part of the inferior one. The lower surface becomes somewhat flattened previous to gastrulation, and it is in the ectoderm cells bordering this flattened area that cilia are first seen (fig. 5).

The difficulty lies in proving that these cells maintain their original position through gastrulation.

Formation of the Gastrula.—Toward the close of the twentieth hour the large entoderm cells at the inferior pole turn inward and upward. The flattened area around this

invagination becomes the oral surface, while that which is for the present the superior portion of the embryo is the aboral surface. These correspond to the terms "sub-umbrella" and "umbrella," as used by Salensky (45). The opening in the centre of the oral surface—the blastopore—is the only opening into the invaginated entoderm. It is permanent, and functions as both mouth and anus during the life of the larva, and is probably transformed into the mouth of the adult as in other species, a new anus being formed. The entire inner surface of the entoderm is covered with cilia as soon as they appear on the ectoderm. The cilia around the edge of the oral surface are much larger and longer than elsewhere on the pilidium, and form what is known as the pre-oral ring, which corresponds with those on trochophore and turbellarian larvæ.

At this period the larva consists of a single outer layer of cubical ectoderm and an inner layer of invaginated columnar entoderm, also single. The space between these—the body-cavity—is filled with a colourless, transparent, gelatinous liquid.

Invagination is thus embolic, and the first stage in the formation of the pilidium is accomplished.

The Apical Plate.—As soon as invagination becomes distinct the embryo falls over on its side. At the same time a slight depression appears near the centre of the aboral surface (fig. 8), which is saucer-shaped at first, but becomes markedly cup-shaped in later development. It never lies exactly at the centre, but always a little anterior to it on the median line.

For this reason it marks the first appearance of bilateral symmetry in the embryo, which has hitherto preserved a distinctly radial form (cf. Korscheldt and Heider).

In the centre of the depression there is developed what at first sight appears to be, and what was long mistaken for, a single very strong flagellum. It is really a bunch or tuft of flagella, twenty to thirty in number, which are nearly always held firmly together. The depression, the apical plate, is

made up of ectoderm cells much smaller than the average, and elongated at right angles to the surface. In its formation the cubical epithelium becomes columnar and invaginates into the body-cavity as a thimble-shaped papilla. As invagination proceeds the columnar cells become wedge-shaped, with their bases toward the body-cavity, and, withdrawing a little, leave a depression at the centre of the papilla, which furnishes the requisite support for the flagella. The latter arise singly from the inner ends of the wedge-shaped cells, and are wholly unlike the rowing flagella possessed by so many larvæ, never being used for locomotion. They are rather enlarged cilia, soft and very flexible, and they originate, so far as can be determined, like the cilia, by a spinning out of the protoplasm from within the ectoderm cells. Consequently they are sensitive, and serve as tactile organs of considerable delicacy and power.

The Change from Radial to Bilateral Symmetry. —It has just been stated that the apical plate is eccentric in position.

This first appearance of bilateral symmetry is quickly emphasised by an elongation of the embryo parallel with the eccentricity, and the long diameter thus determined becomes the longitudinal axis of both larva and adult. In later development the entodermal invagination is elongated along this same axis, but in one direction only, i. e. away from the apical plate.

This completes the differentiation, and we are able to distinguish anterior and posterior, dorsal and ventral, right and left, and the second stage in the formation of a pilidium is complete.

Such a transition from radial to bilateral symmetry is of interest in its bearing on phylogeny. Embryologists generally agree that several of the largest groups of Metazoa show enough resemblance in their larval development to warrant the conclusion that they are all descended from a common ancestral form. These groups include Annelids, Molluscs, Rotifers, Gephyreans, Nemerteans, and possibly others.

There have been several attempts to arrive at an idea of their ancestral form, but the way is beset by so many difficulties that the attempts agree in few particulars. These few, however, are significant, for it is conceded that the archetype must have been very simple, that it possessed radial symmetry, and probably approached closely to a uniformly ciliated gastrula, with a rounded aboral surface and a flattened oral surface, in the centre of which was situated the mouth. Around the edge of the oral surface was a ciliated ring, possibly innervated.

Even in these meagre details we recognise almost an exact description of our *Cerebratulus* larva, which is, like that of many Nemerteans, developing through a pilidium.

The only noteworthy difference is the presence in the pilidium of the apical plate with its bunch of flagella, which forms a well-developed sense-organ. But in several important respects the pilidium larva is less highly developed than any of the others mentioned. This is especially seen in the form of the alimentary canal, in the absence of an anus, and in the lack of any true nervous system. In these particulars it approaches the ancestral type more closely than any existing larva, and in consequence the manner in which it changes from radial to bilateral symmetry becomes of interest.

The flattening of the inferior pole and the establishment of the gastrula invagination leads to the fixing of a structural axis passing vertically through the mouth, with the whole body arranged radially around it. But the next step is not an elongation of the aboral surface and the formation of an anus there, as assumed for the ancestral metamorphosis.

It is rather an unequal elongation of the oral surface, whereby the portion in front of the mouth forms the pre-oral lobe, while that behind the mouth develops into the trunk and forms an anus.

Thus the aboral surface retains its relative position and becomes the dorsal surface of the Nemertean.

The Escape from the Egg Membranes.—Cilia have now developed over the entire external surface of the larva, and as soon as it falls upon its side the rotary motion which they produce presses the aboral surface against the membranes.

This elongates the latter into an ellipsoidal form, and bends the tuft of flagella at a sharp angle near their base.

By continued rotation this sharp angle is driven against the membranes forcibly enough to bend them outward in a shallow dent (fig. 6). This keeps the sharp angle in position, and it soon bores its way through the membranes (fig. 7).

The bunch of flagella is then straightened out, tearing the edges of the rent still more, and some of the liquid which filled the membranes escapes. This causes them to collapse, and they fall against the rotating embryo, whose strong motion quickly tears them in pieces, leaving the larva free.

This is the second and probably the most critical period in the life of the embryo. Of those reared from artificially fertilised eggs fully one third fail to escape from the membranes, and normal embryos fare no better, since 35 per cent. of those under observation perished inside the membranes. When we reflect on the apparent ease with which the sperms penetrated these same membranes we are impressed with the delicacy of the apical flagella. Hatschek has noted in the Annelid *Eupomatus cruciatus* that the cilia pierce the membrane when they first appear, and it would seem as if the latter was not as tough as in *Cerebratulus* (Korscheldt and Heider, p. 173).

We find examples of both dextral and sinistral rotation, with a large majority in favour of the former.

The rapidity of rotation and the time at which the larva escapes also vary greatly. If unable to escape at the proper time the continued rotation reacts upon the larva and tears asunder the cells of which it is composed.

In consequence a ragged bunch of cells may often be seen rotating in the midst of a loose mass of individual cells which have been separated from it, the whole enclosed in the original membranes. Or sometimes the membranes give

way at the last moment, and the bunch of cells is set free rotating slowly.

THE PILIDIUM.

Habits.

Locomotion.—The larva always moves with the aboral surface ahead, as seen in fig. 8. Locomotion is accomplished wholly by the cilia, particularly the band of large cilia around the edge of the oral surface. Their combined action results in a uniform and quite rapid forward motion, and there is also a continuance of the old rotary motion, though the axis of rotation is now horizontal instead of vertical.

The life of the larva seems to depend on its constant motion, and if one is stopped for any length of time it goes to pieces, the cells being torn asunder by a vigorous contraction of the body muscles. This renders any extended examination of living specimens very difficult. Nevertheless it was determined to examine these larvæ alive for the reason that they become beautifully transparent immediately after gastrulation, so that internal development can be followed in detail.

After repeated trials it was found that the best method of keeping the larvæ quiet was to place them in a drop of salt water under a supported cover-glass, and then paralyse them with cocaine, or better with chloral hydrate. If just the right amount (which must be very small) be used the larva will remain stationary for a long time, with the cilia moving slowly and without any contraction of the muscles. In this condition camera lucida drawings are easily made, and the morphology which follows has been obtained entirely in this way from a study of living larvæ.

Use of Apical Flagella.—In swimming the long flagella are stretched far out ahead, and move round slowly in front of the advancing embryo. So completely are these flagella controlled by the apical muscle that they are capable

of movements in every possible direction and of great delicacy.

The larva is often seen advancing toward some object, or toward the outer surface of the drop of water in which it is swimming, and when still distant from it half its own diameter it turns suddenly, sometimes even completely around, and escapes coming in contact with it. Either, therefore, the flagella are sensitive enough to recognise an object when still some distance from it, or they are prolonged beyond their visible tips, the prolongations being invisible under the power used.

In view of what we have already seen we must conclude that the latter is far the more probable.

The flagella also serve as a steering apparatus, like the tuft of cilia at the apical pole of many Actinian larvæ, and the apical plate in its earlier origin is sometimes traced back to such a rudder-like tuft of cilia (cf. Korscheldt and Heider).

Here in the pilidium we find both apical plate and apical tuft, the latter retaining its original function of steering.

Farther than this the flagella take no part in locomotor movement, but are pre-eminently tactile, and constitute practically the only sense-organ possessed by the larva.

Their importance is shown by the comparatively complex structure of the apical plate from which they arise, and by the attachment to it of the largest and best developed muscle in the whole pilidium. And yet they are exclusively a larval organ, and take no part in the formation of the adult worm, being thrown off with the epithelial covering.

Sometimes there are two apical tufts instead of one as in the figure here given. In such a case the plate is broadened and thickened, but there is only a single apical muscle, developed in the usual way.

Pilidiums are sensitive to light, always congregating on the side of the aquarium nearest the source of light, but they show no response to ordinary sounds.

Food.—The pilidium swims at the surface of the water

until its transformation into the adult form. During this time its food supply is varied. It consists chiefly of very small particles of the refuse material always found in sea water; in no instance were living organisms found in the digestive organs. The cilia on the inner surface of the entoderm keep up a constant current inward through the single opening at the centre of the oral surface, and another intermittent current outward. The former runs along the anterior side of the invagination and carries with it the food particles.

In the stomach the current becomes more or less rotary, carrying the food round rapidly until all that is digestible has been absorbed. The refuse material is caught from time to time in the intermittent current and carried outward along the posterior side of the invagination, and discharged by the same opening at which it entered. This single opening, the blastopore, thus functions as both mouth and anus. Often the refuse is thrown to quite a distance by a vigorous flap of the lappets, the larva at the same time being driven forward with a jerk. After the primitive intestine becomes differentiated into stomach and œsophagus the opening between the two is strongly constricted by a sphincter muscle, which operates exactly like the pyloric sphincter in our own bodies.

Morphology of the Pilidium.—As the larva elongates in passing from radial to bilateral symmetry two enlargements appear, one on either side of the blastopore, growing downward from the border of the oral surface. These form ear-like lappets, diverging slightly from each other, and the larva has now assumed the helmet form of a typical pilidium. This species is slightly elongated antero-posteriorly, and the lappets are quite thick (figs. 9, 10).

The whole pilidium is built up of the three primitive tissues nearly unmodified. The ectoderm forms the skin, the entoderm the intestine walls, while the mesoderm fills the space between. The gradual development and transformation of these three tissues takes place very slowly, and affords a good opportunity for studying the tissues themselves and

their derivatives. The entire surface of the pilidium is covered with cilia, those along the edge of the helmet being thicker and stouter than elsewhere, since the pre-oral ring of the gastrula is continued around the edge of the lappets. By a contraction of the muscles with which the lappets are soon supplied a peculiar flapping movement is produced, very similar to that of a pecten's shell when swimming, and this seems to be of assistance in locomotion. The lappets are also quite sensitive, though they are always carried behind the larva when swimming, and hence cannot be of as much service as the flagella.

The larva has now become perfectly transparent, so that the details of internal development can be easily watched.

The Primitive Intestine.—At first no differentiation is possible in the invagination which forms the primitive intestine. It is composed throughout of a single layer of cells which are longer and narrower than those of the ectoderm, and which bear cilia upon their internal faces. These cilia are very delicate, and are manifestly the result of filose action. As soon as the embryo elongates, however, the invagination bends over toward one end, the future posterior end of the embryo (fig. 10). This flexed end approaches close to the wall of the pilidium, enlarges, and assumes a spherical shape.

A slight constriction appears at the point of flexure, and we can now distinguish an oesophageal portion which extends from the mouth to the point of constriction, and a stomach portion, the enlarged inner end. Histological examination reveals a clear distinction in structure also between the two (cf. p. 188).

As the stomach enlarges the aboral surface posterior to the lappets becomes larger than the corresponding anterior portion.

Consequently it rounds over somewhat where it joins the oral surface, and the latter sinks in as a shallow saucer-shaped depression, approaching closely to the wall of the stomach. But the two never meet as in the trochophore larva,

At first the oesophagus is cylindrical and of the same diameter throughout, but later it is enlarged laterally and constricted around the mouth as well as at its junction with the stomach. This dilation produces a lateral elongation of the mouth opening, which becomes more and more elliptical.

Both oesophagus and stomach walls are covered with muscle-cells. In the former muscles are formed, which, by inflation and constriction, assist in taking in and ejecting the food, and probably also in breathing. For in view of the fact that the adult breathes through these same oesophagus walls, and that a strong current of water is kept flowing over them by the action of their cilia, it seems rational that oxygenation should take place here in the larva. On the stomach the muscles do not seem strong enough to render much assistance in churning the food, but at the constrictions they develop into strong sphincter muscles. The one around the mouth in other species becomes the lip muscle of the adult worm.

The simplicity of this primitive intestine is the more remarkable when we reflect that it is the only portion of the pilidium which is preserved in the adult Nemertean.

Mesoderm Formations.—These include mesenchyme cells and the whole musculature of the larva. In no other larva with which I am acquainted can the development of the muscular system be followed so easily and in such detail.

This is due to a combination of peculiarly favourable circumstances. First the pilidium walls are as clear as glass, enabling the single mesenchyme cells to be seen through them from the very beginning. Then the mesenchyme cells themselves are large, and as soon as they become polar can be readily distinguished from all others. Finally the development into muscle is so gradual, and the ultimate tissue is so simple, that a single cell may be followed for some time after it has united with others, and has begun to function as muscle.

Consequently the development of the muscle system of the pilidium larva is one which discloses something of the real

nature of muscle tissue as to its origin and functions. And yet, so far as known, the present is the first attempt to work out this development in any pilidium. Even Bürger (13), in his excellent monograph, can only say, "The mesoderm gives rise to the gelatine, the star-shaped cells lying in it, and the muscle fibrillæ. The latter have doubtless developed out of the star-shaped cells."

Origin of the Mesenchyme Cells.—Metschnikoff has shown in the genus *Lineus* (35) that the mesenchyme originates from large entoderm cells around the border of the invagination, and the same is true in *Cerebratulus*. When gastrulation first begins, scattered mesenchyme cells separate from the entoderm in the angle between the invagination and the oral surface, and sometimes along the convex invagination itself (fig. 72).

Unlike *Lineus*, there are here two kinds of these cells, readily distinguished by their size (fig. 73).

The larger ones are given off first, and for a little while are the only ones to be seen; then both kinds come off together indiscriminately. We will call them macromesenchytes and micromesenchytes respectively.

At first the macromesenchytes are rounded in form, and float about freely. At this time they are difficult to discern against the background of ectoderm, but they soon become branched, and are then easily distinguished from all other tissue.

The branches hinder their freedom of motion enough to show that the liquid in which they float is gelatinous rather than watery, and they gradually become fixed in position and function as muscles. While free they exhibit amœboid movements, similar to those of blood leucocytes; then the cell puts out slender, blunt pseudopodia, which change their position, size, and shape, like those of an amœba. But they quickly become fixed in position, and are then spun out much farther, with tips so attenuate that it is impossible to tell where they really do end.

They continue to increase in length until they finally touch

the body-wall, or that of the intestine, to which they fasten themselves. They then function as muscle by contracting and pulling together the parts to which they are attached.

While they remain free no trace of striation can be seen in the cells, but we have to remember that we are looking at them through the pilidium wall, which, however clear it may be, is not perfectly diaphanous. Hence there might exist a fine striation without our being able to detect it. But as soon as the cells become fixed in position granules appear in the cell cytoplasm, and the thread-like branches become distinctly fibrillar in structure. No amitotic division stages were found, as noted by Montgomery in the free mesenchyme cells of the adult worm (37). Occasionally the branches of two cells anastomose before becoming attached, and may be seen to contract, at first irregularly, but later rhythmically, like similar cells in opisthobranch Gastropods (cf. 49). After the cell becomes fastened to the pilidium walls these rhythmic pulsations cease, and the cells become regular muscles, contracting only when stimulated. The muscles developed from these macromesenchytes are considered under the following heads:

1. Retractor Muscle of the Apical Plate.—This is usually the first muscle formed. Soon after the intestine has turned down posteriorly mesenchyme cells are seen along the apex of the bend beneath the apical plate (figs. 8, 9). One or more of them become stationary at about the position of the future muscle.

It then sends out spin-threads which reach, and fasten themselves to, the apical plate, the wall of the intestine, and sometimes the aboral wall of the pilidium. Other cells in floating about come in contact with these fixed ones, and are arrested. They in turn send out processes to the apical plate, the intestine, or the wall of the pilidium, according to their position. Other processes are then sent out which anastomose with those already formed, making a coarse network (fig. 11).

The strands of the network are then pulled around by the

formation and attachment of new processes and the letting go of old ones, until they are approximately parallel (fig. 14). The strands then come together and fuse into larger ones, while the cell bodies, which now contain little beside the nuclei, travel slowly along the strands, and seem finally to lie on the under surface of the apical plate, or upon the wall of the intestine.¹

The removal of the nuclei leaves the strands in the condition of clear muscle-fibres (fig. 15). Occasionally the body of a cell is all used up in forming processes, and then the nucleus may be flattened slightly and retain its place in the fibre.

The muscle is thus fastened first to the wall of the intestine (fig. 13), and is so figured by Verrill (46, p. 417).

But it soon divides and passes down on either side of the intestine, and fastens to the anterior border of the lappets, separating into fine fibres at the point of junction (fig. 15).

In a good light the fibres may be seen to be attached to delicate papillæ, which are raised slightly from the inner surface of the ectoderm cells. The muscle is now no longer connected with the stomach, for a strong contraction draws the apical plate down until it almost, if not quite, touches the stomach wall. This is the longest, the largest, and the strongest muscle in the pilidium, as well as the first one to be formed, and it is chiefly through its violent contractions that the cells of the pilidium wall are pulled asunder under irritation.

In such a case, after the muscle has shortened and thickened all its structure will allow, a still further shortening is produced by the assumption of a corkscrew shape, exactly as in the contractile stem of *Vorticella*. This is the only means by which the muscle can draw the apical plate down far enough to touch the stomach wall.

2. Interparietal Muscles.—The first of these consists of a single cell, which lodges usually just in front of the apical plate (fig. 17). Long processes are developed at

¹ Mrs. G. F. Andrews kindly gave me this final location of the nuclei, from her own observations upon *Cerebratulus*.

either end of this cell, which extend across and fasten to the pilidium wall.

At first the fibres are simple, and contraction results in pulling the pilidium walls closer together; but in later development they may be joined by other fibres, and the motion then becomes compound, producing a general shrinking of the body-walls.

There are also one or more cells which sometimes accompany the large retractor muscle, but whose fibres only extend from the apical plate to the wall of the intestine (fig. 15).

These are insignificant in size and strength, and probably play an equally insignificant part in the motions of the larva.

Finally, there are muscles, consisting mostly of single cells, which run from different points of the pilidium wall to that of the intestine (figs. 13, 15). These seem to develop wherever the cell is finally lodged, and their contraction produces movement in both the walls to which they are attached.

Being formed from a single cell, the body of the cell usually remains visible for some time, but later it may travel along to one wall or the other, and leave a simple strand stretched across the intervening space. Here, then, we witness the transformation of a cell, at first independent of all the rest of the larva save the liquid in which it floats, into a muscle-fibre fixed at both ends, and capable of contracting under stimulus.

3. *Cæsoophageal Muscles*.—There are two sets of these:

a. *Gastro-cæsoophageal*, consisting of delicate fibres running diagonally between the adjacent walls of *cæsophagus* and stomach.

Most of them consist of a single macromesencyte and its branches; they do not anastomose, and are so far apart that they cannot fuse (fig. 14). They are not formed until the seventh or eighth day, and are used chiefly in the dilation (antero-posterior) of the *cæsophagus*. They are weak, and scarcely worth a separate classification.

b. *Post-cæsoophageal*, a thin muscular sheet, triangular in shape, connecting the oral ectoderm with the posterior

wall of the œsophagus along its mid-line. Sometimes the sheet is divided, and attached along either side instead of in the mid-line.

In fig. 14 several mesenchyme cells are seen just fastened in place and putting out processes; in later development (fig. 15) the individual cells have coalesced into a broad triangular sheet of muscle. One side is attached to the œsophagus from the mouth nearly to the stomach; a second side is attached to the ectoderm from the mouth back to the angle between the lappet and the oral surface; while the third side, somewhat concave, hangs free. The bodies and the nuclei of the individual cells composing this muscle can be seen for a long time as swellings irregularly distributed through the muscle sheath.

The œsophagus is ordinarily dilated laterally, so that the contraction of this muscle dilates it antero-posteriorly, and, when followed by a contraction of the muscular walls of the œsophagus itself, aids materially in generating the currents of water which take in the food particles and eject the waste matter.

The motion thus produced corresponds also to the breathing movements in the adult worm, and it does not seem rash to suppose that the larva also breathes in this way, and that the muscle under discussion is one of the muscles of respiration.

4. Circumoral Muscle.—This consists of a strong muscular ring which surrounds the mouth, and of muscle bands which extend backward and forward from the ring to the edge of the lappets (fig. 15). The elliptical mouth extends from the centre of one lappet to that of the other, and across the space intervening between the lip and the anterior and posterior angles of the lappets numerous muscle-fibres are developed. At the side are usually found large cells, which send out fibres reaching to the extreme anterior and posterior walls of the pilidium, as well as shorter lateral ones. These cells are well developed, and their contraction tends to draw the borders of the oral surface in toward the centre. The ring around the mouth is developed into a well-defined

sphincter, whose contraction can almost close the mouth opening. These ring and band muscles form an excellent support for the attachment of the other muscles, notably those of the lappets and apical plate, and for the support of the primitive intestine. In fact, they serve as a sort of centre for the whole body musculature; and this seems an important use under normal conditions. They also restore the œsophagus to its normal shape after dilation, and, next to the apical muscle, are the most strongly constricted under irritation. They have the advantage of being situated close to the source of supply of mesenchyme cells, and in other species they are retained during metamorphosis, and develop into the strong lip muscles of the adult Nemertean.

The second kind of mesenchyme given off by the entoderm consists of much smaller cells than the first. Very soon after the appearance of the large cells these smaller ones may be seen coming off in the same locality. The difference in size is shown in fig. 9, and is not diminished by subsequent growth. These micromesencytes do not float about like their larger predecessors, but remain close to the body-wall (fig. 14).

They do move about, however, in a curious way.¹

After being warped about in different directions they each settle down at some particular spot, and become permanently attached, to form the fifth group of muscles. Conn, in his study of *Thalassema* (17), found two kinds of mesenchyme cells, one of which became distinct muscles, while the other consisted of branching cells of the same origin, but more like "connective tissue corpuscles scattered at random in the body-cavity, but quite close to the body-wall. In the older larvæ they are more abundant, and unite to form quite a continuous layer." Their similarity in origin, form, and position to the micromesencytes of *Cerebratulus*, and the fact that they are ultimately joined in a continuous layer, suggest that they may have a similar function.

¹ In a verbal communication Mrs. G. F. Andrews states that she has seen these cells warping themselves about by means of protoplasmic processes.

5. Parietal Muscles.—These consist of single micro-mesenchytes scattered over the entire inner surface of both ectoderm and entoderm (fig. 16). Their fibres anastomose freely with one another and with the interparietal muscle-fibres, and form an irregular network, which is attached closely to the inner surface of the pilidium walls. Their contraction may assist the motion produced by other muscles, or may produce a local shrinkage something after the manner of the so-called "goose-flesh" on our own skin under the influence of cold.

Certain of the cells on the walls of the œsophagus are arranged with more or less regularity transversely, and form constrictor muscles. It is possible that some of the macro-mesenchytes assist in the formation of these constrictors, since some of them are attached in the right position and afterward disappear, but the matter could not be definitely determined.

These muscles are usually incorporated in the tissue of the intestine wall during subsequent development, and together with many of the macromesenchytes which have remained isolated are transferred to the adult Nemertean during metamorphosis, as has been shown in other species by Bütschli (11). All the remainder of this quite intricate musculature disappears.

The parietal network forms a layer separating the ectoderm from the central gelatine, and assists the other muscles in pulling asunder the cells of the pilidium walls under irritation.

We thus see in the musculature of the larva which is temporary, and the bulk of which disappears during metamorphosis, a curious foreshadowing of the function of dismemberment which is so prominent in the adult.

6. Lappet Muscles.—These muscles necessarily await the development of the lappets, and are thus the latest to appear, coming about the eighth day. The cells from which they originate are almost of the same size, and become stationary close to the cilia ring, forming a row just inside the cilia cells (fig. 81).

Each cell then sends out a process which develops into a muscle-fibre. There are two sets of these lappet muscles.

a. Radial Muscles of the Lappets.—These consist of fine fibres extending radially from the edge of the lappets to the circumoral ring (fig. 15). They are all of the same size, and are arranged at approximately equal distances from one another, each micromesencyte forming but a single fibre.

They anastomose little, if at all, but each fibre at the edge of the lappets divides into from two to five fibrils.

Each fibril is attached to a fine mammillary process on the inner surface of a cilia cell, which looks like a miniature of one of the papillary muscles of the chordæ tendineæ of the human heart. These muscles correspond to the "large muscles of the lappets" noted by Salensky in *Lineus* (45), but differ from them in that they do not radiate from a single point.

There is a small group (fig. 15) radiating from the same point as in Salensky's figure, but it does not constitute an important part of the muscle. The actual process of attachment by which one of the muscle fibres is fastened to the pilidium wall is difficult to watch, but it is easy to determine in these lappet cells that the muscle fibrils are connected with the cytoplasmic reticulum. When one of the threads sent out by a mesenchyme cell comes in contact with an ectoderm cell it first flattens out a little on the surface of that cell.

The substance of the thread, which is actively moving protoplasm, then fuses with the ectosarc of the cell, and through it becomes attached to the reticulum in the interior. That it is certainly thus attached is seen upon the disruption of the pilidium under irritation, when muscle fibrils may sometimes be found with a single ectoderm cell still attached to either end.

These of course were interparietal muscles. If now the cells be held in position by pressure of the cover-glass the muscle-fibre will go on contracting for some time.

By increasing the power used until the reticulum of the

cell becomes visible, it can be seen that the threads of this reticulum are apparently continuous with the fibrils, and that every contraction of the latter pulls the reticulum adjacent to the point of attachment out of place. As soon as the contraction ceases the reticulum returns to its former shape. The ground substance of the cytoplasm is apparently affected only as it is compelled to accommodate itself to the changes of shape in the reticulum. The cytoplasm of the thread, therefore, at first fuses imperceptibly with that of the cell to which it is being attached, but on becoming fibrillated the fibrils attach themselves to the more substantial reticulum.

These radiating fibres are very contractile, and may often be seen to assume the same corkscrew shape as the apical muscle when excessively contracted. They serve to produce the opening and closing motion of the lappets already described.

b. Locomotor Muscles of the Cilia Rows.—These correspond closely to the circumoral muscles in origin and mode of development. The cilia rows lie at the junction of the aboral and oral ectoderm where the mesenchyme cells originate.

When the lappets first start some of these cells are taken along with them in their downward growth, and retain their original position just inside the cilia cells (fig. 11). From a portion of these micromesenchytes are developed the radial muscles just described, but most of the fibres unite to form a muscle strand running along inside the cilia cells. This strand increases as the lappets enlarge, and unites at either end with the circumoral muscle (fig. 77). Its fibres divide into fibrils which terminate in the individual cells of the cilia rows.

The strand can be plainly seen in all longitudinal or diagonal sections which cut through the edge of the lappets, and it may be detected in specially perfect cross-sections, where of course the fibres appear as dots. These are the only muscles of the larva distinctively for locomotion (cf. p. 159).

But not all the mesenchyme is employed in the manufacture of muscle. Certain of the macromesencytes do not develop processes or exhibit amœboid movements, but divide and subdivide actively. As fast as they are used up in this way others take their place, so that they may always be found scattered about in the gelatine. In the living larva they appear yellowish, and they always stain more deeply than the muscle cells. Evidently they are the source of the gelatine itself, and probably correspond to the isolated cells which Bütschli showed (11) were transferred to the adult Nemeritean. If their development could be followed in this species it would doubtless be found that they share the same fate.

Summary.—1. The mesenchyme originates from large entoderm cells situated at the junction of entoderm and ectoderm.

2. Its cells are of two kinds, called macromesencytes and micromesencytes respectively, the former being several times larger than the latter. At first macromesencytes are given off alone, then both kinds appear together. From micromesencytes are developed the parietal and lappet muscles; from macromesencytes all the other muscles of the pilidium.

3. In this muscle development both kinds of cells may either remain single, forming delicate fibres, or may anastomose into a complex network, or several cells may fuse into a larger strand.

4. At first the macromesencytes float about freely and exhibit slight amœboid changes of form. Then they put out slender pseudopodia branches which arrest their motion. These pseudopodia do not show any contractile movements, but only a streaming motion of granules and cytoplasm. They are lengthened until they come in contact with something to which they can be fastened.

5. As soon as they are fastened the structure changes from that of normal cytoplasm into typical fibrillated muscle. This is accompanied by a corresponding change in activity; the streaming ceases, and the fibrils become contractile and function as muscles.

6. Prior to fixation two macromesencytes sometimes anastomose with the same change in structure and activity, but they pulsate more or less rhythmically instead of contracting in the ordinary manner. As soon as they fasten to the larval walls, however, the pulsations cease, and their subsequent contractions are like those of other muscles.

7. The cytoplasm of the macromesencytes is exhausted in the formation of branches. The nucleus retains its original position until the muscle-fibres are formed; it may then become flattened and incorporated in situ in the muscle tissue, but more frequently it migrates along the fibre to the pilidium wall.

8. The micromesencytes do not float about, but remain close to the pilidium walls, upon which they creep along to their final position by means of "protoplasmic activities."

9. The ends of the thread-like pseudopodia sent out by both kinds of mesenchyme, on coming in contact with a cell of the pilidium wall, at first fuse with its ectosarc, but after they become fibrillated the fibrillæ are attached to and are apparently continuous with the cell reticulum.

10. The ectoderm and the entire musculature of the larva, except the parietal muscles of the intestine and a few isolated macromesencytes, disappear during metamorphosis.

11. When irritated the larval muscles contract violently and pull in pieces the walls of the pilidium, thus showing the same tendency toward dismemberment that is manifested in the adult.

Conclusions.—The simple fact that circumstances combine so favourably for a study of the musculature in the pilidium would give it considerable interest. And when we remember how closely it approaches in primitive simplicity to the archetype of several of the largest groups of Invertebrates, it becomes doubly interesting, and we are enabled to draw several suggestive conclusions.

1. The muscles of the pilidium are metamorphosed pseudopodia.

The pseudopodia of the mesenchyme cells are the exact

counterpart of the spin-threads sent out from the polar bodies and from the blastomeres during segmentation. Some at least of those spin-threads were contractile, while these mesenchyme spin-threads actually develop into typical muscles. The same thread which at first exhibits a visible streaming of its cytoplasm afterwards becomes contractile and shortens just as visibly.

2. The transition from pseudopodium to muscle-fibre consists essentially in a striation or fibrillation of a portion of the cytoplasm, and the gradual assimilation of the non-fibrillated remainder.

Such a striation of cytoplasm is nothing new. It has been observed by Flemming and many others in the living cells of cartilage, epithelium, connective-tissue and other animal cells, in which the fibrillæ form a sort of loose network. It has been seen by G. F. Andrews in living cells of many Protozoa and Metazoa (4, 5), where it was plainly correlated with contractile activities. In preserved material striation is shown in the pancreas cells of *Necturus* (51) and in the beautiful preparations of ciliated cells from *Anodonta* and *Cyclas* (20).

But the very best examples are those given by Heidenhain (24) of the radiating system of fibres in the leucocytes or wandering cells of the salamander, and by Zimmermann (52) of similar radiating systems in the pigment cells from the epidermis of fishes. Here the cytoplasm not only becomes fibrillar, but both authors believe it to represent the contractile elements by means of which the cells change their form and creep about (51).

In all these cases the cytoplasm becomes fibrillar inside the cell, but that ought not to exclude the possibility of its repeating this tendency outside the cell in the pseudopodia.

Conn states (17) that in the mesoderm formations of *Thalassema* the cells which are budded off from the entoderm near the blastopore do not become true wandering cells, but are immediately transformed into muscles. Each muscle is

unicellular, consisting of a cell body with a distinct nucleus, and with muscle-fibres extending from it in two directions. Here, then, the branches become fibrous as well as the body of the cell.

When the streaming movement necessary to the sending out of spin-threads is stopped by contact with something, the threads at once become striated. At first the striæ are hardly visible and some distance apart, but they rapidly increase in size and distinctness until finally they occupy nearly all the muscle strand. It seems probable that this increase in fibrillation consists largely of an assimilation of the non-fibrillated portion. During this transformation the whole cell body is often conveyed out into the incipient muscle strand, where it is converted into muscle fibrillæ.

3. Fibrillation appears to start in a rearrangement of the cytoplasmic reticulum, whereby its threads, instead of forming an irregular network, become parallel.

We can see how a streaming of the cytoplasm along the spin-thread pseudopodium would help such an arrangement, for the fibrillæ are longitudinal. Several other facts support such an origin of muscle fibrillation. The familiar radiating fibrillæ in the asters of dividing cells, when followed outward, can be traced into the cytoplasmic reticulum, and they are so continuous with its threads that it is impossible to tell where the fibril ends and the reticulum begins, or vice versa.

Again, the muscle fibrillæ under favourable conditions can be followed into the cell to which they are attached, and terminate there in the cytoplasmic network, with which they are so completely fused, that once more it is impossible to tell where one ends and the other begins. Furthermore, in a study of columnar epithelium it may often be noticed that the cytoplasm in the outer zone of the cell has been arranged in more or less parallel fibrillæ along the long diameter of the cell. No reticulum is visible in this part of the cell except that formed by the fibrillæ. In figures of

ciliated epithelium given by Englemann (20) the fibrillæ are almost perfectly parallel, and not only correspond exactly in number with the cilia, but are just opposite to them. We can hardly escape the conclusion that the external cilia are prolongations of the internal fibrillæ. If so, then the difference between cilium and muscle-fibre is that the former consists of a single fibrilla, while the latter is made up of several bound together.

Finally the fibrillæ, when they first appear, are not upon the surface of either cell or spin-thread, but are distributed throughout their substance. Hence they cannot be regarded in any sense as "surface secretions," but are more intimately associated with the cytoplasmic structure. If not formed by a rearrangement of the reticular network, they at least bear the same relation to the remainder of the cytoplasm that such threads would.

4. The first contractions of the changing pseudopodia represent the combined action of all cytoplasmic energy, pulling in a single definite direction instead of in different directions.

Originally the cytoplasm possesses perfect internal mobility, and its first movements are amoeboid in character. Then follow spinings, or the putting out and withdrawal of pseudopodia in different directions. Some of these become permanent, and the whole contractile energy of the cell is then concentrated upon them. As the cytoplasm is pushed out farther and farther it becomes more and more limited in the direction of its movement. And when the pseudopodia are once fastened and fibrillation has begun it can move only in one direction, along the axis of the pseudopodia.

The energy which is at first expended in different directions, some of them antagonistic to others, becomes concentrated along the axis of the pseudopodium. Hence the resultant cytoplasmic contractions gain as much in strength and rapidity as they lose in mobility, and become capable of producing what we call a muscular contraction. The initial contractions are noticeably weak, and the intervals between

them are longer than in later development, but they do not stop here.

5. The muscle-fibres thus formed increase both in size and contractile power through exercise.

When first formed the fibres are simply fibrillated pseudopodia of single mesenchyme cells, hence all their substance must come from this one cell. And yet there is a perceptible increase in the size of the fibres, even after the entire body of the cell has gone out into them. This increase is most rapid and hence most apparent in those muscles which are most often contracted, e. g. the apical and circumoral muscles.

The increase in strength is admirably shown in the lappet muscles, each of whose single fibres scarcely shortens at all in its initial contractions. But after several days' development it can contract so vigorously as not merely to shorten, but also to assume the characteristic corkscrew shape.

6. Fibrillation and the consequent change from potential to kinetic contractility occurs only after the pseudopodium has attached itself to something outside the cell.

We found the same thing true of the spin-threads sent out by the polar bodies and the segmenting blastomeres.

The simplest explanation of this fact is that the constant movement of the cytoplasm in pushing out the spin-thread prevents contraction, but as soon as spin-thread or pseudopodium becomes attached the flow ceases, fibrillæ appear, and contraction ensues.

It is worthy of note that the nature of the contractions depends somewhat on the kind of attachment. When attached to a cell of the pilidium wall the contractions in the resultant muscle-fibre are like those of ordinary muscle. When threads from two cells anastomose without becoming attached to anything else, they contract in rhythmic pulsations like cardiac muscle.

This rhythm is shown even better in the muscles formed from mesenchyme cells in the veliger larvæ of certain nudi-

branch molluscs, and has been described elsewhere (49). Finally, in those cells where the cytoplasm becomes fibrillar without forming any connection at all outside the cell, as in ciliated epithelium, the contractions are in the form of rhythmic vibrations.

Sometimes it happens that the pseudopodia from two cells which have anastomosed, and have been contracting in rhythmic pulsations, become attached later to the pilidium wall. In such a case the nature of the contractions also changes, and they cease to be rhythmic, and become in all respects like ordinary muscle.

Histology.

Methods.—A pilidium larva is nearly as hostile to preservation as the medusa to which it is often compared. After a trial of many different preservatives the best was found to be platinum chloride, used either alone or in equal parts with acetic acid. Corrosive acetic can also be recommended, but is exceptionally difficult to wash out of the tissues.

For staining, Delafield's hæmatoxylin, followed by eosin or Orange G, gives good differentiation.

Blastula.—A segmentation cavity appears very early, and increases until the blastula consists of but a single layer of cells surrounding this cavity. These cells are elongated at right angles to the surface of the blastula, and vary greatly in size and shape, so that they project unequally into the central cavity, making the inner surface very rough.

The cells at the inferior pole are longer and narrower than the superior ones, so that there is thus early a differentiation into ectoderm and entoderm. The nuclei are spherical, comparatively large and uniformly granular; they are nearly always excentric in position, being much nearer the external end of the cell. The cytoplasm contains so much yolk material as to be opaque at first, but clears rapidly and becomes transparent enough to show the central cavity before gastrulation (fig. 55).

This cavity contains one or more loose cells which have been given off from the entoderm cells where they join the ectoderm. The loose cells are mesenchyme, and so far as observed none of them originate from the ectoderm.

Gastrula.—As soon as the cells begin to multiply for invagination and the formation of the intestine they become equal in size, and their inner ends are evened. The mesenchyme still continues to come off from the entoderm, and the latter is now clearly differentiated from the ectoderm (fig. 69).

The ectoderm consists of a single layer of epithelium. On the aboral surface it is a pavement epithelium made up of cubical cells, which are small at the superior pole, grow larger toward the equator, and then grow smaller near the border of the oral surface. By a comparison of different stages we find that the cells around the apical plate are the first to become transparent (fig. 70). Large clear spaces like vacuoles appear in these cells; but they are not empty spaces, for they react to stains in the same way as the gelatine which fills the body-cavity. These spaces gradually extend down toward the oral surface, until by the time the lappets are formed they can be found in every cell of the aboral ectoderm (fig. 73). In individual cells they are at first spherical, but quickly elongate parallel with the ectoderm surface. Then together with the cells they increase in area at the expense of their thickness, leaving the nuclei embedded in cytoplasm on the inner border of the cells.

The oral ectoderm is much thicker, and composed of cylindrical cells in which no clear spaces can be seen. These cells have larger nuclei than those in the aboral ectoderm, and are more active. From them are developed the lappets, the cilia row which surrounds the edge of both oral surface and lappets, and the invaginations which form the amnion and the ectoderm of the adult Nemertean (13).

The entoderm is much thicker than the ectoderm, but consists of a single layer of cells, cylindrical in form and similar to those of the oral ectoderm. They are more irregular in shape and overlap somewhat, so that they give

in some sections the appearance of a double layer. They retain their large blastula nuclei, and are quite active; they also remain opaque, with the exception of those on the anterior wall of the oesophagus, which are cleared in a different manner.

THE PILIDIUM.

The aboral ectoderm, which was a pavement epithelium in the gastrula, has now become typically squamous, the cells being strongly flattened. As the cells increase in superficial area they lose the rounded form of the gastrula and become more and more angular, until they finally assume an irregular four- to six-sided form. The number of the cells remains practically constant, except at the border of the oral surface.

These facts, compared with the increase of clear areas in the gastrula, show that the pilidium grows largely, if not wholly, by a flattening of the aboral cells. The aboral "umbrella," as it is called, is simply a protective covering for the young embryo, to be thrown away at the time of metamorphosis. Hence its cells, when once formed, remain until final dissolution, simply flattening more and more to give the necessary increase in size. Sometimes the flattening is carried so far in the old pilidium that the body of the cell becomes thinner than the nucleus, and the latter bulges out into the body-cavity. Meanwhile the clear spaces have increased until they occupy nearly all the cell, leaving but little cytoplasm around the nucleus (fig. 72). The thinning and clearing of the ectoderm, combined with the "glass-clear" gelatine between ectoderm and entoderm, gives the pilidium great transparency. But we should not expect the individual cells to be held together very firmly, since they are in contact only along their thin edges, and hence they pull asunder easily under irritation.

But the oral ectoderm takes an active part in the development of the future Nemertean, and it is the only ectoderm except the apical plate that shows karyokinetic figures.

Its cells are smaller, but the nuclei are about the same size, and not being flattened the cells are held together more securely.

Both oral and aboral ectoderm are thickly covered with fine cilia, which are longer and stouter at the apical plate and the cilia row.

The apical plate is an invaginated thickening of the ectoderm. Metschnikoff regarded it "als eine Art indifferentes Gehirn," and the fibres going from it as a nerve commissure (36).

Bütschli later maintained that the fibres must be regarded as muscle, and that it was doubtful whether this plate really was the central organ of the nervous system (11).

Salensky considered Metschnikoff's assumption probable from a morphological standpoint, since the apical plate can be regarded as the homologue of that formed in the trochophore larva. But he added that it was unlike this in its simpler form, and it takes no part in the formation of the brain, and hence must be regarded as a rudimentary plate (45). He then gives the first, and, as far as known, the last account of the histological structure of the plate, closing with these words: "The question as to the nature of the bundle (of fibres connected with the plate) must be settled by a study of the development history of the plate and the fibres." We have just given the development history of the fibres, and have found that they are undoubtedly muscle. The plate originates in two or more cells found near the apical pole in a median section of a blastula. These cells stain more deeply than the others, and occasionally show karyokinetic figures (fig. 69); otherwise they are like the remaining ectoderm cells. But they divide and subdivide actively at right angles to the surface of the blastula and form a group of cells, one layer thick, a little anterior to the pole on the median line.

The cells are cylindrical in form, and of the same diameter throughout. Their nuclei are small at first, but become relatively large as the cells diminish, and are always situated close to the inner end of the cell. Their cytoplasm is more

compact, and hence not quite as transparent as the rest of the ectoderm. These plate cells divide slowly but steadily, while the surrounding ectoderm cells do not divide at all; hence they are pressed inward as an invagination into the body-cavity. Neither this invagination nor that of the intestine is quite symmetrical, the former being inclined toward the anterior end of the pilidium, and the latter toward the posterior end. As they invaginate the plate cells become smaller and more conical or wedge-shaped, the bases pointing inward toward the body-cavity (fig. 70). These changes proceed slowly, so that for two or three days the plate projects but slightly into the central cavity as a rounded swelling (fig. 71). But it grows more and more convex, until it acquires a thimble or nipple shape by the sixth day.

In preserved specimens the apical muscle is usually contracted, and the thimble is pulled out into a cone, and by comparing longitudinal with transverse sections it can be seen that the cone is nearly symmetrical in outline (cf. figs. 72 and 73).

A median section shows that the plate is composed of small, crowded conical cells, whose bases show through the ectoderm as distinct circles (fig. 74). The cells are shorter around the margin and longer toward the centre, each containing a large spindle-shaped nucleus and sometimes a highly refractive nucleolus.

Both cells and nuclei stain more deeply than the adjacent ectoderm, showing a corresponding difference in their activity.

The outer ends of the nuclei are usually pointed, and sometimes prolonged into a short, slender, thread-like process (fig. 76); but the inner ends are not so prolonged as Salensky has figured for *Lineus* (45), they are well rounded and plump.

A muscle fibril connects with the inner end of each of the cells near the centre of the plate, but not with those toward the margin. These fibrils can be seen to enter the plate through the structureless membrane which covers the whole plate, and are lost sight of in the substance of the cytoplasm.

If Salensky's figure be compared with this one of *Cerebratulus* (fig. 76) it will be noticed that in his figure (45, fig. 8) the plate is pulled in so far that fully one half the depression is formed of aboral ectoderm. Whether this is a normal condition in *Lineus* I am unable to say, but I have found a similar condition in *Cerebratulus* only when the apical muscle was strongly contracted. If this were true in *Lineus* the separate fibrils of the apical muscle when contracted would naturally pull out the inner ends of the cells to which they were attached, and may have produced the apparent prolongation.

The long stout cilia arise in bunches of four to six, from near the centre of the outer ends of the cells (fig. 76). Near the border of the plate they are finer and shorter than at the centre.

In life they are gathered into a compact bundle, looking like a single large flagellum, but in preserved specimens they are always separated and usually broken (cf. figs. 10 and 74).

Both surfaces of the plate are covered by a fine structureless membrane, through which cilia and muscle fibrils pass.

There are usually in the angle between the plate and the ectoderm mesenchyme cells whose function is unknown. They are yellowish or sometimes dark brown in colour in the living larva, and no processes can be detected coming from them. It is possible that they may be of the same nature as the so-called "eye-spots" of annelid larvæ, but this could not be determined.

The plate, therefore, is developed from ectoderm cells, which are smaller in size, less transparent, bear longer and more sensitive cilia, and whose nuclei are relatively larger, but which are otherwise undifferentiated from the remaining ectoderm.

None of these things necessarily indicate the formation of anything like nervous tissue; and, in view of the fact that the fibres connected with the plate are undoubtedly non-nervous in origin, structure, and function, we must conclude

that in *Cerebratulus* there is no nervous tissue in or connected with the apical plate. This plate differs from its morphological homologue in annelid larvæ in being made of a single layer of undifferentiated ectoderm instead of containing two layers more or less modified. In the trochophore the plate contains nervous tissue, which afterwards develops into the supra-œsophageal ganglion of the adult; in the *Cerebratulus pilidium* the plate is thrown away with the rest of the aboral ectoderm during metamorphosis, and we find no trace of any nerves at all.

The Cilia Rows.—These are rows of large cilia running along the border of the oral surface and around the edge of the lappets, and they are the chief organs of locomotion.

We can distinguish ectoderm wall cells, cilia cells, and a well-developed locomotor muscle system (fig. 75).

The ectoderm cells are similar in structure to other ectoderm, but increase in thickness as they approach the cilia cells, those on the aboral surface being thicker than the oral.

Hence the upper border overhangs the under one, and acts as an organ of protection to the cilia, as noted by Salensky (45).

The cilia cells are smaller than the wall cells, and are arranged in three rows between the latter along the extreme edge of the lappets. They are wedge-shaped or pyramidal, with their apices turned inward. Their cytoplasm and nuclei are similar to those of the apical plate, and they are also covered on the exterior with a structureless membrane, through which the cilia pass. The latter are distributed over the entire surface of the three rows of cells, but show a tendency to gather in bundles. On the inner surface of the cilia cells, and between the wall cells, lie the locomotor muscles (fig. 77). These consist of a strong muscle band and of scattered mesenchyme cells. The band is made up of stout parallel fibres, which originate in the mesenchyme cells and terminate in the cilia cells (fig. 79). It is continuous with the circumoral muscle both anteriorly and posteriorly (fig. 77), and stains deeply with hæmatoxylin. It thus corresponds

exactly with the ring of muscle fibres and cells which lie at the base of the ciliated band in the trochophore larvæ.

The cells are small, and look like micromesenchytes, except that they are mostly unipolar, the single pole giving off a long fibrous process. The row of cells can be followed from the lappets around the border of the body, but the muscle band blends with the circumoral muscle, and loses its individuality.

This locomotor muscle lies in exactly the position assigned by Salensky to the "nerve-ring;" fig. 79 is almost identical with fig. 4 of his description. But we have called them muscle for the following reasons. Salensky states that "the nerve-ring passes along the cilia row, and thus becomes the homologue of the nerve-ring in the annelid larvæ described by Kleinenberg." But he fails to note that Kleinenberg also describes a ring of muscle cells at the base of the ciliated cells, which is used by the larva in locomotion (29).

If either of these sets of locomotor apparatus are to be developed in so primitive a larva as the pilidium at the expense of the other set, the presumption is strongly in favour of the muscle. We would scarcely expect to find the nerve well developed, as Salensky claims, and no trace whatever of the muscle.

Again, borax carmine, orange G, and hæmatoxylin stain these fibres exactly the same as the other pilidium muscles, and no difference is perceptible in their structure or texture.

Another proof is that the cells whence the fibres originate are exactly like those from which the radial fibres arise.

It has never been doubted that the latter are anything but muscle cells; they, too, are unipolar or multipolar, as Salensky claims for the "nerve-cells," and his argument from form would apply equally well to both. Finally, this strand is continuous with the circumoral muscle (fig. 77), and if one is nerve, the other must be also; but if we concede that the circumoral ring is muscle, then the strand must also be muscle.

These facts, no one of which, perhaps, is sufficient alone,

when taken together furnish strong evidence that the fibres are muscle. Whether the strand also contains nerve-fibres must remain an open question; none can be seen, and pilidiums kept for days in water impregnated with methylene blue showed no trace of coloration.

Anteriorly the cilia rows, in passing from the lappets to the oral surface, invaginate in a large loop (fig. 82), which projects into the central cavity in the same manner as the apical plate.

The two loops are composed of the same sort of cells as the rest of the cilia rows, and appear undifferentiated. They appear about the sixth day, and increase in size up to the eighth or ninth day, after which they remain unchanged as long as I have succeeded in keeping any larvæ—about six weeks.

I believe these to be the first pair of invaginations which are to form the adult Nemertean, but, of course, have been unable to prove the matter.

The Intestinal Canal.—In the mature pilidium this is composed of two parts, each consisting of a single layer, and well differentiated. At first the intestine is composed throughout of large cylindrical cells, but as soon as the inner end begins to turn down posteriorly the constituent cells begin to differentiate. Those on the anterior and lateral walls of the œsophagus flatten out, increase in superficial area, and become transparent in a very similar manner to the aboral ectoderm.

But the process is not carried so far, and the cells never lose their vitality. The flattening is not uniform, so that the cells grow thinner from the stomach toward the mouth, where they pass insensibly into the oral ectoderm.

The posterior wall of the œsophagus is thicker, its cells are smaller in area, more cylindrical in form, and do not become as transparent. They are also depressed along the mid-line into a shallow groove (fig. 82), which forms a channel for the food particles.

The stomach wall is thicker than that of the œsophagus, its component cells are larger and less transparent, and are

of two kinds, distinguished by the intensity with which they are stained.

Wall-cells.—These are more numerous, are prismatic in shape, and contain smaller nuclei. They do not stain very deeply, and are evidently the true entoderm.

Gland-cells.—Between the wall-cells are others scattered over the stomach, but most numerous at its anterior end (fig. 80). They are larger than the wall-cells, and are flask-shaped, with the narrow neck of the flask pointing inward, while the rounded body contains a large nucleus. They stain very deeply, and are evidently gland-cells as first stated by Metschnikoff (33) and later by Bürger (13), and not nerve-cells as claimed by Salensky (45).

The inner surface of both stomach and oesophagus is covered thickly with fine cilia, which are slightly longer in the stomach than in the oesophagus. At the base of the cilia is another structureless membrane, covering the whole interior of the intestine.

At the junction of stomach and intestine is the large sphincter muscle already described. It allows free passage of food particles when relaxed, but closes the opening entirely when contracted. Since the muscles are usually contracted in preserved specimens, it often happens that sections are obtained which appear similar to those given by Hubrecht (25); but watching the living larva for a few moments is sufficient to do away entirely with any idea that the stomach ends blindly at both ends. At about the sixth day a swelling is noted on the superior wall of the stomach posterior to the pyloric valve. This develops into a shallow evagination whose walls are made up of cells smaller and more crowded than the adjacent stomach entoderm. But this evagination was carried no further in the oldest pilidium reared, and so its ultimate purpose could not be determined.

Summary.—1. A segmentation cavity appears very early, and increases until the blastula consists of a single layer of cells elongated at right angles to the surface and surrounding this cavity.

2. The ectoderm is a one-layered pavement epithelium, made up of cubical cells on the aboral surface and cylindrical cells on the oral surface. The entoderm is also one-layered and made up of cylindrical cells, but it is thicker and more opaque than the ectoderm, and its cells overlap considerably.

3. The aboral ectoderm remains constant after being formed, and the increase in size is accomplished by a strong flattening without cell division. This, together with a gradual clearing of the cell protoplasm, gives the pilidium great transparency.

4. The apical plate is an invaginated thickening of the ectoderm, made up of conical cells whose bases turn inward toward the body-cavity. The nuclei are pointed and sometimes prolonged into thread-like processes on the outer ends, but are rounded and plump on the inner ends. The component fibrils of the apical muscle connect with the inner ends of all cells near the centre of the plate.

5. The long stout cilia which form the apical tuft arise in bunches of four to six from the centre of the inner ends of the cells, and in life are gathered into a central bunch which looks like a single large flagellum.

6. The cilia cells, whence arise the large cilia running along the border of the oral surface and around the edge of the lappets, are arranged in three rows. The cilia themselves are given off in bunches from the outer ends of the cells.

7. Just inside the cilia cells is a strong band of locomotor muscle-fibres and scattered mesenchyme cells. A careful study of their origin and development, the development of the plate itself, its histological structure and staining, all go to prove that both fibres and cells are muscle, and that there is no nervous tissue in the plate or connected with it.

8. The anterior wall of the œsophagus becomes partially flattened and cleared in the same manner as the aboral ectoderm, but the posterior wall retains its original thickness. It is grooved along the mid-line to form a channel for the food.

9. The stomach walls contain numerous gland-cells, which are flask-shaped, with the neck of the flask pointing inward. The inner surface of both stomach and intestine is covered with cilia, and at their junction is a large sphincter muscle which controls the passage of the food particles and waste material.

ADDENDA.

Since the foregoing went to the printer I have received an article entitled "Development of the Pilidium of Certain Nemerteans," by W. R. Coe.

This excellent paper discusses briefly the segmentation, gastrulation, and pilidium stages in *Micrura cæca*, *Cerebratulus Leidyi*, and *C. marginatus*.

Together with the present paper it was practically finished before either author became aware that the other was working upon the subject. The close agreement in the results obtained is all the more gratifying in view of their entire independence.

I wish briefly to mention the following points :

1. In segmentation *C. lacteus* transposes the second and third cleavage planes of the other three species, making the second horizontal and the third vertical. Otherwise the four agree in all essential features of segmentation and gastrulation.

2. While Coe has not given the development of the apical plate and the muscular system in detail, it is evident from his drawings that this development in both cases is almost identical with that here given. The arrangement of the parietal muscles, especially in *Micrura cæca*, is somewhat different from that in *C. lacteus*, as might be expected. But the mesenchyme cells from which they are formed are evidently smaller than those which form the other muscles, and correspond to the micromesenchytes in *C. lacteus*.

3. The statements in reference to the presence of nervous tissue are wisely cautious, but it is easy to see that Coe does

not put much faith in Salensky's interpretation (45). He distinctly states (p. 253) that the so-called "nerve-cells" in the entoderm "are obviously nothing but gland-cells, which are partially filled with a deeply staining secretion and have no sensory function whatever."

In all four of these species, without exception, the fibres connecting the apical plate with the oral ectoderm are muscular in origin. Also the elements which Salensky describes as nerve-cells and nerve-fibres are found to stain easily with common muscle stains, while they do not differentiate at all with methylene blue or any other distinctive nerve stain. This should make us somewhat cautious in accepting the apical plate of the pilidium as an exact homologue of that in the trochophore larva of Annelids.

BIBLIOGRAPHY.

An excellent bibliography will be found in Bürger's monograph (13), which contains a brief abstract of every paper mentioned. Only those papers are mentioned here to which actual reference is made in the text.

1. AGASSIZ, A.—"The Embryology of *Autolytus cornutus*," 'Boston Journ. Nat. Hist.,' vol. vii, 1863.
2. ANDREWS, E. A.—"Activities of the Polar Bodies of *Cerebratulus*," 'Archiv f. Entwickl.,' Bd. vi, Heft 2, 1898.
3. ANDREWS, E. A.—"Filose Activities in Metazoan Eggs," 'Zool. Bulletin,' vol. ii, No. 1, 1898.
4. ANDREWS, G. F.—"The Living Substance as such, and as Organism," 'Journ. Morph.,' vol. xii, 1897.
5. ANDREWS, G. F.—"Some Spinning Activities of Protoplasm in Star-fish and *Echinus* Eggs," *ibid.*
6. BEATTIE.—"On the Reproduction of *Nemertes Borlassii* (Lineus longissimus)," 'Proc. Zool. Soc.,' London, Part xxvi, 1858.
7. BARROIS, JULES.—"Mémoire sur l'embryologie des Némertes," 'Ann. Sc. Nat.' (6), tome 6, 1877.

8. VAN BENEDEN, M.—"Recherches sur la Faune littorale de Belgique," 'Mém. d. l'Acad. des Sc. Belg.,' tome xxxii, 1861.
9. VAN BENEDEN, E.—"Recherches sur la Maturation de l'Œuf, la fécondation et la division cellulaire," 'Archiv de Biol.,' tome iv, 1883.
10. BENHAM, W. B.—"Fission in Nemertines," 'Quart. Journ. Micr. Sci.,' vol. xxxix, 1896.
11. BÜTSCHLI, O.—"Einige Bemerkungen zur Metamorphose des Pilidium," 'Archiv für Naturgesch.,' 1873.
12. BÜTSCHLI, O.—"Vorläufige Mittheilungen über Untersuchungen betreffend die ersten Entwicklungsvorgänge im befruchteten Ei von Nematoden und Schnecken," 'Zeit. f. wiss. Zool.,' Bd. xxv, 1875.
13. BÜRGER, OTTO.—"Die Nemertinen des Golfes von Neapel," 'Fauna u. Flora d. Golfes v. Neapel,' 22te Monographie, 1895.
14. BUSCH, W.—"Beobachtungen über Anatomie und Entwicklung einiger wirbellosen Seethiere," 1851.
15. COE, W. R.—"On the Anatomy of a Species of Nemertean (*Cerebratulus lacteus*, Verrill), with remarks on certain other species," 'Trans. Conn. Acad.,' vol. ix, 1895.
16. COE, W. R.—"The Maturation and Fertilisation of the Egg of *Cerebratulus*," 'Zool. Jahrb.,' Bd. xii, 1899.
17. CONN, H. W.—"Life History of *Thalassema*," 'Stud. Biol. Lab. Johns Hopkins Univ.,' vol. iii, No. 7, 1886.
18. DESOR, E.—"Embryology of Nemertes," 'Proc. Boston Nat. Hist. Soc.,' vol. vi, 1848.
19. DIECK, G.—"Entwicklungsgeschichte des Nemertinen," 'Jenaische Zeitschrift,' Bd. viii, 1874.
20. ENGLEMAN, T. W.—"Zur Anatomie und Physiologie der Flimmerzellen," 'Archiv ges. Phys.,' Bd. xxiii, 1880.
21. VON ERLANGER, R.—"Entwicklungsgeschichte des Nematoden," 'Biol. Centralb.,' Bd. xvii, Heft 4, 1898.
22. GEGENBAUR, C.—"Bemerkungen über *Pilidium gyrans*, etc.," 'Zeit. f. wiss. Zool.,' Bd. v, 1854.
23. GAGE, S. H.—"The Life History of the Toad," 'Teacher's Leaflet,' No. 9, Coll. Agric., Cornell Univ., 1898.
24. HEIDENHAIN, M.—"Cytomechanische Studien," 'Archiv f. Entwickl.,' Bd. i, Heft 4, 1895.
25. HUBRECHT, A. A. W.—"Zur Embryologie der Nemertinen," 'Zool. Anz.,' 1885.
26. HUBRECHT, A. A. W.—"Contributions to the Embryology of the Nemerteans," 'Quart. Journ. Micr. Sci.,' vol. xxvi, 1886.

27. HUBBRECHT, A. A. W.—“Report on the Nemertines,” ‘Reports of the Challenger Expedition,’ 1887.
28. KROHN, J.—“Ueber Pilidium und Actinotrocha,” ‘Müller’s Archiv,’ 1858.
29. KLEINENBERG, N.—“Sull’ origine del sistema nervosa central degli Annelidi,” ‘Mem. Accad. Lincei Roma,’ tome x, 1881.
30. LEE, A. B.—“La Spermatogenèse chez les Némertiens, à propos d’une théorie de Sabatier,” ‘Recueil zu Suisse,’ tome iv, 1887.
31. LEUCKART UND PAGENSTECHEK.—“Untersuchungen über niedere Seethiere,” ‘Müller’s Archiv,’ 1858.
32. MARK, E. L.—“Maturation, Fecundation, and Segmentation of Limax campestris,” ‘Bull. Mus. Comp. Zool.,’ Harvard College, No. 6, 1881.
33. MCINTOSH, W. C.—“Notes on the Development of Lost Parts in the Nemerteans,” ‘Journ. Linn. Soc.,’ vol. x, 1870.
34. MCINTOSH, W. C.—‘Marine British Annelids, Nemertea,’ 1873–4.
35. METSCHNIKOFF, E.—“Studien über die Entwicklung der Echinodermen und Nemertinen,” ‘Mém. Acad. Imp. Pétersbourg,’ series vii, tome xiv, No. 8, 1870.
36. METSCHNIKOFF, E.—“Vergleichend embryologische Studien,” ‘Zeit. f. wiss. Zool.,’ Bd. xxxvii, 1882.
37. MONTGOMERY, T. H.—“On the Connective Tissues and Body-cavities of the Nemerteans, with Notes on Classification,” Spengel’s ‘Zool. Jahrb.’ (Anat. Abth.), Bd. x, 1897.
38. MÜLLER, JOH.—“Pilidium gyrans,” ‘Archiv für Anat. und Phys.,’ 1847.
39. MÜLLER, JOH.—“Ueber verschiedene Formen von Seethieren,” ‘Müller’s Archiv,’ 1854.
40. RANDOLPH, H.—“The Regeneration of the Tail in Lumbriculus,” ‘Zool. Anzeiger,’ Jahrg. xiv, 1891.
41. RENIER, ST. A.—‘Prospetto della Classe dei Vermi,’ 1804.
42. SABATIER, A.—“La Spermatogenèse chez les Némertiens,” ‘Revue Sc. Nat. Montpellier’ (3), tome ii, 1883.
43. SALENSKY, W.—“Zur Entwicklungsgeschichte der Borlasia vivipara,” ‘Biol. Centralb.,’ Bd. ii, No. 24, 1883.
44. SALENSKY, W.—“Recherches sur le développement du Monopora vivipara,” ‘Archiv. de Biol.,’ tome v, 1884.
45. SALENSKY, W.—“Bau und Metamorphose des Pilidiums,” ‘Zeit. f. wiss. Zool.,’ Bd. xliii, 1886.
46. VERRILL, A. E.—“The Marine Nemerteans of New England,” ‘Trans. Conn. Acad.,’ vol. viii, 1892.

47. WATASÉ, S.—“Studies on Cephalopods: I. Cleavage of the Ovum,” ‘Journ. Morph.’ vol. iv, No. 3, 1891.
48. WHITMAN, C. O.—“The Embryology of Clepsine,” ‘Quart. Journ. Micr. Sci.’ vol. xviii, 1878.
49. WILSON, C. B.—“Activities in Mesenchyme Cells of Certain Larvæ,” ‘Zool. Bull.’ vol. ii, No. 1, 1898.
50. WILSON, E. B.—“Observations on the Early Developmental Stages of some Polychætous Annelids,” ‘Stud. Biol. Lab. Johns Hopkins Univ.’ vol. ii, 1882.
51. WILSON, E. B.—‘The Cell in Development and Inheritance,’ The Macmillan Company, New York, 1896.
52. ZIMMERMANN, K. W.—“Studien über Pigmentzellen, etc.,” ‘Archiv f. micros. Anat.’ Bd. xli, 1893.

EXPLANATION OF PLATES 9—11,

Illustrating Mr. Chas. B. Wilson’s paper on “The Habits and Early Development of *Cerebratulus lacteus* (Verrill).”

KEY TO LETTERS.

am. Apical muscle. *ani.* Anterior invagination. *bv.* Blood-vessel. *c.* Intestinal cæca. *cc.* Cilia cells. *cm.* Circular muscles. *com.* Circumoral muscle. *ct.* Connective tissue. *dvm.* Dorso-ventral muscles. *ec.* Ectoderm. *en.* Entoderm. *gc.* Gelatine cell. *glc.* Gland-cell. *gr.* Groove for food. *im.* Interparietal muscle. *lam.* Lappet muscles. *lm.* Longitudinal muscles. *lom.* Locomotor muscles. *o.* Ovary. *œ.* Œsophagus. *pm.* Post-œsophageal muscle. *s.* Stomach. *sc.* Sperm mother-cell. *t.* Testis. *wc.* Wall-cell. *yc.* Yolk-cell.

PLATE 9.

FIG. 1.—*Cerebratulus* swallowing a *Nereis* five minutes after dismembering the posterior half of its body. Photograph from preserved specimen, one eighth life size.

FIG. 2.—*Cerebratulus* with regenerating papilla. Photograph from life, one eighth life size.

FIG. 3.—Male (left) and female (right) *Cerebratulus*, the latter showing normal anal papilla. Photograph from life, one eighth life size.

FIG. 4.—*Cerebratulus* with proboscis sheath cut open to show how the proboscis is coiled when withdrawn. Photograph from preserved specimen, one eighth life size.

All the remaining figures, with the exception of Nos. 11, 53, 54, and 59, have been drawn with a camera lucida on a Leitz microscope. The magnification is indicated by giving the Leitz numbers of the eye-piece and objective used. The figures have then been reduced one half in making the plates.

FIG. 5.—Gastrula, showing shape and arrangement of ectodermal cells and beginning of cilia rows. 3 and 7.

FIGS. 6 and 7.—Successive stages in the process of escaping from the egg membranes. 3 and 3.

FIG. 8.—Gastrula just escaped from the membranes, thirty-eight hours old. Cilia and flagella drawn the exact length seen. 1 and 7.

FIG. 9.—Larva forty-eight hours old, first stage in formation of apical muscle. ²⁵⁰1 and 7; tube drawn 60 mm.

FIG. 10.—Same, fifty-four hours old, second stage; side view.

FIG. 11.—Same, ninety-six hours old, third stage. Zeiss camera lucida, magnified 575 diams.

FIG. 12.—Same, 108 hours old, fourth stage; end view. 1 and 7; tube drawn 60 mm.

FIG. 13.—Same, 120 hours old, fifth stage; side view, showing apical muscle attached to dorsal wall of œsophagus.

FIG. 14.—Same, six days old, sixth stage, showing apical muscle divided and extending down on either side of the intestine to fasten to the oral surface anterior to the mouth. This figure shows also interparietal, post-œsophageal, and circumoral muscles.

FIG. 15.—Same, ten days old, seventh stage. Apical muscle fully developed; post-œsophageal muscle forming a triangular sheet; radiating lappet muscles well developed.

FIG. 16.—Same, twelve days old; surface view showing parietal muscles.

FIG. 17.—Transverse interparietal muscle attached to apical plate, from larva six days old. 1 and 7.

FIG. 18.—Eggs taken from ripe ovary and examined before they have touched any water. 3 and 3.

FIG. 19.—Same after immersion in salt water three minutes.

FIG. 20.—A ripe, freshly laid ovum, unfertilised, showing membranes and attachment protuberance. 1 and 7.

FIG. 21.—Transverse section of a regenerating papilla very near its posterior end, showing ventral grooves and beginning of the lateral nerve-cords. 1 and 3.

FIG. 22.—Same farther forward, showing lateral nerve-cords migrating toward their normal position.

FIG. 23.—Same still farther forward; nerve-cords nearly in their normal position, and circular muscles well developed.

PLATE 10.

FIG. 23*a*.—Fertilised egg, showing flattening of the superior pole previous to the giving off of the polar bodies. 1 and 7.

FIGS. 24—36.—Maturation of the egg and formation of the polar bodies, with the beginning of filose activities. 1 and 7, tube drawn 60 mm. These drawings are all from the same egg, and were taken at the following intervals:—11.05 a.m., 11.065, 11.08, 11.21, 11.216, 11.22, 11.228, 11.235, 11.24, 11.27, 11.28, 11.335, and 11.40.

FIG. 37.—A second egg, showing abnormal activities during completion of the polar bodies. 1 and 7; tube drawn 60 mm.

FIG. 38.—A third egg with unequal papillæ and slightly abnormal activities. Magnification the same.

FIG. 39.—Egg with polar bodies pressing against the inner membrane and bulging it outward. 1 and 7; tube drawn 60 mm.

FIG. 40.—Polar bodies of egg shown in Figs. 24—36, taken at 11.36. 3 and 7; tube drawn 60 mm.

FIG. 41.—Same, first polar body at 11.17.

FIG. 42.—Polar bodies and sperm at beginning of first segmentation. 3 and 7.

FIG. 43.—Same at close of first segmentation.

FIG. 44.—Polar bodies during 64-cell stage. 3 and 7; tube drawn 60 mm.

FIG. 45.—Same in 128-cell stage.

FIGS. 46—50.—First segmentation, showing filose activities of polar bodies and blastomeres. All figures from the same egg at the following intervals:—12.06 m., 12.065, 12.09, 12.11, 12.16. 1 and 7; tube drawn 60 mm.

FIG. 51.—Egg in which blastomeres were almost entirely separated, and in which they showed perceptible motion during flattening. Same magnification.

FIG. 52.—Same egg as in Figs. 46—50, in the 4-cell stage (12.30). Central opening crossed by spin-threads.

FIG. 53.—Four-cell stage, top view. Enlarged from a camera lucida sketch of living egg.

FIG. 54.—Eight-cell stage, showing dextral twisting of the upper cells. Enlarged from camera lucida sketch of living egg.

FIG. 55.—Blastula with differentiated ectoderm and entoderm, and mesenchyme cell separating from the latter. 3 and 7, from a preserved and mounted specimen.

FIG. 56.—Section showing nuclear spindle parallel with surface subsequent to giving off of first polar body. 3 and 3.

FIG. 57.—Same with spindle diagonal after extrusion of second polar body.

FIG. 58.—Same with segmentation spindle for first segmentation.

FIG. 59.—Sperms, enlarged from camera lucida sketch, cf. Fig. 42.

PLATE 11.

FIG. 60.—Longitudinal horizontal section of a regenerating papilla, showing formation of sexual pouches and intestinal cæca; anus terminal. 3 and Tolles 1-inch objective.

FIGS. 61 and 62.—Longitudinal horizontal sections of male and female; immature genital pouches scattered through the connective tissue. Killed in April. 1 and 3.

FIG. 63.—Transverse section of female killed in April, showing relation of developing egg-pouches to inner longitudinal muscle layer. 3 and 3.

FIG. 64.—Portion of immature ovary from Fig. 62, enlarged to show method of egg development. 1 and 7.

FIG. 65.—A single egg pouch of Fig. 62, enlarged to show egg cells, yolk cells, and glycerine cells. The walls are formed from connective tissue. 1 and 7.

FIG. 66.—A single sperm pouch of Fig. 61, enlarged to show formation of sperm mother-cells. The connective tissue here extends into the pouch, and the sperm cells are supported upon it. 3 and 3; tube drawn 60 mm.

FIG. 67.—A small portion of Fig. 66, enlarged to show the way in which the sperm cells are borne on the mesoderm strands. 3 and 7; tube drawn 60 mm.

FIG. 68.—A single sperm pouch magnified still farther to show transformation from sperm mother-cells into sperms. 3 and one twelfth oil immersion.

FIGS. 69—73.—Vertical sections of a late blastula and four gastrulas in different stages of development, showing the origin and development of the apical plate, the formation of mesenchyme cells, and clearing of ectoderm. 1 and 7; tube drawn 60 mm.

FIG. 74.—Longitudinal vertical section of pilidium; apical plate fully developed with apical muscle attached; aboral ectoderm much flattened and perfectly transparent; oral ectoderm thicker, more opaque, and beginning to invaginate anteriorly; micromesenchytes scattered over the inner surface of both ectoderm and entoderm. 1 and 7.

FIG. 75.—Transverse section of lappet; three rows of cells bearing long cilia; locomotor muscles. 3 and one twelfth oil immersion.

FIG. 76.—Longitudinal section of apical plate, showing arrangement of flagella in bunches and the connection of the muscle-fibres. 3 and one twelfth oil immersion.

FIG. 77.—Longitudinal vertical section through the lappet, the œsophagus wall, and the stomach. The locomotor muscle band (*lom.*) is here seen to be continuous with the circumoral muscle (*com.*). 3 and one twelfth oil immersion.

FIG. 78.—Longitudinal vertical section of the lappet through the wall cells of the cilia rows, with a portion of the locomotor muscle band and the mesenchyme cells forming the radial muscles of the lappets. 3 and one twelfth oil immersion.

FIG. 79.—Longitudinal vertical section as in Fig. 77, showing the locomotor muscle band composed of cells and fibres. 3 and one twelfth oil immersion.

FIG. 80.—Longitudinal vertical section of stomach, showing ordinary entoderm and gland cells. 3 and one twelfth oil immersion.

FIG. 81.—Same as Fig. 77, but showing more plainly the row of mesenchyme cells which form the radial lappet muscles.

FIG. 82.—Longitudinal horizontal section just above the mouth, showing the two anterior invaginations with mesoderm attached; the walls of the œsophagus with a central groove posteriorly for the food particles. 3 and 8; tube drawn 60 mm.

23.

24.

27.

30.

25.

28.

31.

39.

26.

29.

32.

40.

41.

42.

46.

49.

47.

50.

48.

51.

53.

23 a

24.

27.

30.

25.

28.

31.

26.

29.

32.

39.

40.

41.

42.

46.

49.

47.

50.

48.

51.

52.

53.

33.

35.

37.

34.

36.

38.

43.

44.

45.

58.

54.

56.

57.

55.

59.

60.

61.

62.

63.

66.

68.

67.

72.

73.

74.

77.

79.

With the Author's Regard

REPRINT

FROM

BIOLOGICAL BULLETIN

VOL. I. No. 4

BOSTON, U.S.A.

GINN & COMPANY, PUBLISHERS

The Athenæum Press

1900

BIOLOGICAL BULLETIN.

OUR NORTH-AMERICAN ECHIURIDS.

A CONTRIBUTION TO THE HABITS AND GEOGRAPHICAL
RANGE OF THE GROUP.

CHAS. B. WILSON.

ONLY four species of Echiurids, representing three of the five known genera, have been reported from the North American coast up to the present time. These are as follows: *Thalassema mellita* Conn was found at Beaufort, Va., living in empty sand-dollar tests, and its structure and morphology were most admirably worked out (2). *Thalassema viridis* Verrill has been reported from nodules of blue clay at a depth of seventy-seven fathoms off Head Harbor, Campobello Island (16). *Bonellia sühmii* Selenka was dredged from deep water off the coast of Nova Scotia and was described and named in the *Challenger Reports* (12).

The fourth species, *Echiurus chrysacanthophorus* Pourtales, has been reported by several authors from various localities on the New England coast. Each of these four was established as a new species by its discoverer and has been found nowhere else. The *Bonellia* species was based upon a single badly mutilated specimen, *T. viridis*, and the species of *Echiurus* upon a very limited number of specimens, no one of which in the latter species was perfect, leaving *T. mellita* to stand alone beside the well-known and thoroughly studied European forms.

In the present contribution I am able to add American localities for two of the well-known Old World species, and when

the results of the recent Harriman Alaskan Expedition are published another even better known European form will be found among them.

It is hoped also to clear up the cloud of doubt which has hung about the questionable American *Echiurus chrysacanthophorus*, for the reports on this species have contained so many gross errors and conflicting statements, and so little accurate description, that the determination of the exact species has been impossible.

This has been due to a variety of causes, chief among which may be mentioned two. First, it is essentially a shore species, frequenting muddy shallows where the water is too deep or too roily for the shore collector and not deep enough for dredging. Consequently only a limited number of specimens have been obtained.

Again, so far as known, every one of these was so mutilated in the getting as to render a full description impossible. The part most easily injured is the delicate proboscis. This breaks off upon the slightest provocation, and leaves no scar that can be detected even with a good hand lens.

Hence it is difficult to obtain a specimen with the proboscis intact even under favorable circumstances, and absolutely impossible by dredging. It was this denudition of the proboscis with no resultant scar which led the discoverer of the species, Coutouy, to mistake it for a holothurian, and to describe it as *Holothuria chrysacanthophora* in 1838 (3).

The same mistake was made by Gould in 1841 (5), who says: "This is not unlikely to be *H. forcipata* of Fabricius. Several specimens which I have seen were all taken from fishes' stomachs in a mutilated state. Some of the essential characters, therefore, remain yet undetermined. The surface is light colored and appears to be naked, except that there are several long, flexible, sharp-pointed spines about the mouth¹ of a shining golden yellow. One specimen is five or six inches in length."

Pourtales rectified this mistake in 1851 and located it correctly among the Gephyrea, giving it a name which it has since

¹ Really the anus.

borne, *Echiurus chrysacanthophorus* (8). But he also adds: "I have seen but a single specimen of this species. The one I have before me answers very well to the characters assigned to *Echiurus Gaertneri* by Quatrefages. It wants likewise the spoon-shaped appendage," *i.e.*, the proboscis (*ibid.*).

But Quatrefages himself admitted in 1865 that the species *Gaertneri* was based "upon individuals which had been rolled about by the wind," and he adds: "It is very possible that the appendage was broken off" (10). This proved to have been the case, and in 1880 Greef included the species *Gaertneri* as one of the synonyms of *E. Pallasii* Guerin, but he retained the doubtful species *chrysacanthophorus* (7).

A species of *Echiurus* has been dredged by Professor Verrill at various points along the New England coast, and has been reported conditionally as *E. chrysacanthophorus*. But Verrill wrote me in 1895 that in all his dredging (over 1000 localities) he had met with this species "in very few instances, and *never*¹ a perfect specimen." Hence he wisely refrained from attempting any detailed description of it, and from any comparison with foreign species.

Finally Shipley, in 1896 (13), and again in 1899 (14), rejects the species altogether as being inadequately described, and the locality, "North Atlantic," which he assigns to *Echiurus Pallasii*, doubtless signifies the Norwegian and Greenland shores, from which it has been reported by other authors.

Such being the condition of affairs, it seems fitting to describe the species accurately, to determine it definitely, and to add a few observations upon its habits which may be of generic interest. This is rendered possible by the fact that it has been the good fortune of the author to obtain a large number of absolutely perfect specimens and to keep some of them under observation in aquaria for several weeks, while others were successfully preserved,—a by no means easy task.

The material was all obtained at Casco Bay, on the Maine coast, during the summers of 1895-98. It is also hoped that the photographs which accompany these notes may prove of assistance in locating the species.

¹ The underscoring is his.

Habits. — This species lives in the mud near and below ordinary low-water mark. It can be best obtained during the few days of each month when the tides run lowest, at which time it can be dug in the same way as the common clam (*mya*).

It is most abundant in close proximity to mussel beds where the mud is soft and very black with organic matter.

I am aware that this habitat is radically different from that given by Greef and others for *E. Pallasii*, but I find a ready explanation in the fact that sand beaches are the rare exception rather than the rule along the Maine coast, so that the animal has simply accommodated itself to its environment.

Its home is a simple burrow formed by pushing aside the mud. The manner in which this is done was repeatedly observed both in its native haunts and in an aquarium.

If not already in that position, the animal turns until it rests upon its ventral surface. This brings the two large anterior setae in contact with the mud. The proboscis is now turned upward and backward, until it lies along the dorsal surface of the body, with its own ventral surface outermost, but protected somewhat by a rolling in of its edges. The proboscis remains inert in this position and *takes no part whatever in the burrowing*. This is in strong contrast to the active locomotor use of the proboscis described by Rietsch in a specimen of *Bonellia minor* (11). By a series of muscular contractions, which include both the longitudinal and circular muscles of the body walls and the special muscles which move the ventral setae, these latter are thrust forward until they project in front of the body almost horizontally.

At the same time the base of the proboscis is drawn backward and somewhat upward, so that the anterior end of the body becomes wedge or chisel shaped, the ventral surface being flattened and extending farthest forward, with the two setae projecting from its anterior edge. These setae are then turned downward and thrust into the mud as far as possible. Being curved, they furnish an excellent leverage, and the body is drawn toward them by a contraction of the longitudinal muscles.

This contraction passes slowly backward along the body until the posterior end is reached, which is moved forward

thereby half or three-quarters of an inch. The two anal rows of setae now serve to hold it in position, while the anterior end is again thrust forward and downward into the mud, and the ventral setae are fastened in a new position. This process is repeated until the animal finally disappears beneath the surface, leaving a circular opening equal in diameter to the body at its greatest lateral contraction. The whole process is extremely slow, and fully forty minutes are consumed in getting the posterior end of the body out of sight beneath the surface.

The burrow proceeds diagonally downward for ten to eighteen inches, then runs horizontally from six inches to two or three feet, and finally turns vertically upward again toward the surface.

When the animal reaches the surface the anterior end of the body is pushed out far enough to free the proboscis. This is then restored to its normal position and the body is withdrawn again into the burrow.

Spengel notes (15) that each burrow of the species (*E. Pallasii*) observed by him at Nordenay possessed two openings close together and each surrounded by a low wall. But those burrows were made in hard sand, while these are in soft mud, and consequently we should expect to find differences. These burrows at first have two openings, but the original entrance soon fills up through the caving in of its walls and the washing in of mud from the surface. The entire diagonal portion is often filled in this way and is never opened again, leaving this end of the burrow blind. These burrows also, when first formed, have low walls around the openings, caused by the pushing aside of the mud, but they quickly disappear.

The Echiurus assumes a position just below the surface, holding itself in place by the two rows of anal bristles (*cf.* Shipley). The mud then washes into the burrow and forms a plug one to two inches thick, with a small opening about the size of a lead-pencil at the center. Through this opening the proboscis is thrust out in search of food when the tide is in, and is then the only portion of the animal which is visible. It is capable of great extension, as was the proboscis of *B. viridis* described by Eisig, and often reaches a length of five or six inches. The

free end moves about in every direction and carefully searches the surface around the opening. Having found a particle of food, the edges are rolled in ventrally toward each other, if not already in that position, and form a more or less closed tube. The whole ventral surface (which is now the interior of the tube) being ciliated, there is generated a current which quickly carries the food toward the mouth. The proboscis often assumes a similar tubular shape when it is not elongated, as can be seen in Fig. 2, so that the curling inward of the edges is independent of the strong contraction of the circular muscles which produces the extension.

Often also it rolls itself into a tight coil, commencing at the tip and curling over ventrally as though it were grasping some object, but nothing save a few food particles is to be found in it, which are much too small to occasion any such effort.

The proboscis is very sensitive over its entire surface, but especially so on the ciliated ventral portion, and the slightest irritation there results in a quick withdrawal.

As would be inferred, such an appendage is of extreme importance to the animal, and yet it breaks off upon the slightest provocation. Whether such a separation is necessarily fatal or not, and whether the animal possesses the power of regenerating its proboscis, could not be definitely determined.

It hardly seems probable, however, that the animal could live for any length of time without it. But it was found that the proboscis itself was so highly innervated that it retained its vitality, and to a marked degree its sensitiveness also, for a long time after separation, a week or more if kept in fresh sea water. When the tide goes out, though there is always water left in the burrow, the proboscis is withdrawn and all indications point to the conclusion that the animal retreats to the lower part of its burrow.

Like other gephyreans, this species secretes a thick mucus, which lines the burrow walls and penetrates the mud for some distance, giving it greater firmness and solidity.

This mucus, as in so many other cases, oxidizes the iron in the mud, so that the walls of the burrow are a rusty brown color and stand out in sharp contrast to the surrounding black.

Movements and Locomotion. — In life, even when out of its burrow, the creature is constantly altering its outward form by energetic contractions of the skin muscles, as noted by Greef (6). Deep constrictions appear at various places, which move now forward, now backward, that portion of the body just in front of or behind the constriction increasing proportionately in size. The proboscis is also kept in constant motion, coiling up and uncoiling, rolling inward from the edges and unrolling or stretching out to a considerable distance and then being withdrawn. In its burrow the animal cannot turn around, but can move either forward or backward at will and with equal rapidity. This motion is accomplished by a series of wave-like contractions and relaxations in the circular and longitudinal muscles of the body wall, the one alternating with the other, and both together producing a fairly rapid gliding motion. The necessary rigidity is given to that portion of the body wall which for the time being serves as a fulcrum, by the pressure of the liquid in the body cavity, as first noted by Quatrefages (9). Andrews has clearly stated (1) the essential factors in the mechanism of *Sipunculus Gouldii* which bring about such "hydrostatic locomotion," and several authors have described similar motion in other gephyreans.

But no one, so far as known, has suggested any other mode of moving about. Indeed, one of the best recent text-books distinctly states that "the gephyrea are only capable of a very slow creeping motion" (Parker and Haswell, p. 461).

It seems never to have been suggested to any one, the present author included, that this same rhythmic contraction of the body walls would furnish an excellent means for swimming.

Hence it was quite a surprise, on visiting an aquarium after dark during the second summer, to find three or four specimens swimming about in it freely. The body was elongated to twice its ordinary length, while the proboscis was elongated even more in proportion and its edges were rolled downward and inward so as nearly to meet along the median line and form a long narrow tube which seemed to take an active part in the swimming.

The resultant motion was peculiar, being gyratory or cork-

screw-like, the anterior end always moving ahead, but it was perfectly free in any direction and quite rapid.

Besides assisting in locomotion the proboscis also seemed to serve as a steering organ, and its extreme sensitiveness rendered it very effective in avoiding obstacles.

The fact that this swimming took place only at night suggests that these animals are more or less nocturnal in their habits, and it may be that they can move about much more freely than has been hitherto supposed. At all events this is probably the mode of locomotion used at or near the breeding season, and it readily explains the large numbers of specimens which are thrown up on the beach after a storm at such seasons.

This species is well known to the clam-diggers along the coast and is sometimes used for bait in deep-sea fishing, but not often, and is never sought designedly for that purpose.

Determination of Species.—After a careful comparison of the descriptions given by Couthouy and Pourtales with that of *E. Pallasii* by its discoverer and subsequent zoölogists, and with the description which follows, there seems no possible doubt that those authors fell into the same error concerning our American species which trapped Quatrefages on the European form, *viz.*, they described an *Echiurus Pallasii* which had lost its proboscis as a new species. Accordingly *Holothuria chrysacanthophora* Couthouy, 1838, and *Echiurus chrysacanthophorus* Pourtales, 1851, must go to swell the long list of synonyms already appended to *Echiurus Pallasii* Guérin-Ménéville.

Echiurus Pallasii Guérin-Ménéville.—Synonyms: *Holothuria chrysacanthophora* Couthouy, 1838. *Echiurus chrysacanthophorus* Pourtales, 1851.

External Morphology.—Body like that of all known echiuroids, spindle-shaped, tapering slightly at either end; 10–30 cm.¹ long (including the proboscis, 3–6 cm. long) and 3–6 cm. in diameter at the center (Figs. 1 and 2).

¹ This figure is much larger than that usually given for *E. Pallasii*, but is the result of careful measurement and is good evidence in favor of Shipley's statement (13). "It seems probable that *E. forcipatus* of Reinhardt is identical with *E. Pallasii*, though bigger" (*cf.* p. 175).

Color uniform gray or grayish-yellow, shading into a deep orange on the interior of the proboscis. Entire surface of the body rough from being covered with small blunt papillae, which are unequal in size. The larger ones are more globular and are quite regularly arranged in transverse rows in which the individual papillae are so close together that they touch one another. There are twenty-two or twenty-three of these rows, and between them are scattered the smaller papillae, which are more conical in shape and seldom show any arrangement in rows.

Both kinds of papillae are more sharply defined and nearer together toward the ends of the body. There is also usually a bunching of the papillae around the anterior setae where they are larger than elsewhere on the body.

There is a pair of large, shining yellow, hooked setae, one on either side of the ventral mid-line, 16–20 mm. behind the base of the proboscis. These setae are about 20 mm. long and curve toward the posterior end of the body. They are retractile and can be almost wholly withdrawn into the body cavity. The posterior end of the body is surrounded by two rows of yellow setae, somewhat shorter than the anterior pair and perfectly straight. They also are retractile, and in most preserved specimens are withdrawn into the body cavity. In the animal shown in Fig. 4, however, they were extended to their full length. The rows are quite near together (3–5 mm.) and not more than 4 mm. from the anus, which is central and terminal. These posterior setae incline backward and assist the animal in moving about. The anterior row is made up of eight or nine setae, the posterior one of seven or eight.¹

Reserve setae are present for both rows and for the ventral pair. The setae alternate in the two rows, but neither row is entire, a space being left on the ventral mid-line.

In the posterior row this space corresponds to the omission of one seta, in the anterior row to the omission of three.

There is a papilla around the base of each seta, much larger than those on the body. The spaces between these basal papil-

¹ The fact that these different numbers may be found in individuals otherwise exactly alike is still further evidence that Reinhardt's species, *forcipatus*, is not well grounded.

lae and the intervals on the ventral surface, up to within 1 mm. of the mid-line, are filled in with ordinary large papillae.

Proboscis large, 3-6 cm. long and 1-3 cm. wide. It is capable of being extended to 12 cm. with a corresponding diminution of its width. It is cylindrical at the base, but quickly opens into a half tube which is broadened at the tip into a shovel form (Fig. 1). The exterior is a brighter yellow than the body and perfectly smooth. The interior is rich orange and completely ciliated, but in most specimens examined it lacks the longitudinal brown stripes noted by Greef in *E. Palasii* (6). In several specimens, however, they showed up faintly against the orange background.

The skin also on the interior of the proboscis is thrown up into longitudinal ridges, the intervening furrows between which are darker in color than the ridges themselves (Fig. 3). The mouth opens through the center of the cylindrical base. A well-defined ridge runs outward from the mouth along the dorsal mid-line toward the tip of the proboscis. This ridge is somewhat brighter in color than the rest of the interior, but is completely concealed unless the proboscis is opened. The tip of the proboscis sometimes has a well-marked chocolate-brown edge.

The ventral nerve cord and blood vessel show plainly through the skin (*cf.* Figs. 1 and 2), and when the body is extended the dark-colored intestine can be seen at points where it touches the inner surface of the body walls. The sexes are alike externally, with no appreciable difference in size (*cf.* Figs. 1 and 2).

But when sexually ripe, Greef says that the golden eggs or the white semen in the nephridia show through the body wall enough to distinguish the males from the females (6).

Internal Morphology like that of all echiuroids. The alimentary canal is several times the length of the body and is looped irregularly. It is suspended from the body walls by thin muscular strands instead of a continuous mesentery, and upon the slightest perforation of the body walls it is extruded through the orifice by a violent contraction of the muscles.

This alimentary canal may be divided into three regions or parts, called respectively the fore, mid, and hind gut.

The foregut is very short, and contains a pharynx and oesophagus which are often bright orange in color like the inside of the proboscis. The remainder of the foregut is usually larger in diameter and has been called the crop. The midgut constitutes the bulk of the alimentary canal and is distinguished by a groove lined with vibratile cilia which runs along its dorsal side. Opening into this groove at either end is a collateral intestine, much smaller in diameter than the midgut and seemingly analogous to that in echinoderms.

The hindgut is somewhat larger than the midgut and forms near the anus a cloaca into which open two anal vesicles, one on either side. These are quite long, simple sacs, light brown in color, which vary greatly in length in different individuals (40-70 mm.). They open into the body cavity by ciliated funnels, which are most numerous near the base of the sacs, and one of which is terminal.

Both males and females have two pairs of nephridia, which open on the ventral surface on either side of and close to the nerve cord. The mouths of these nephridia are raised into large papillae on the external surface of the body, and can be plainly seen, the anterior pair just behind the ventral setae, and the second pair 5 or 6 mm. farther back.

At the base of each nephridium on the inner side is a ciliated funnel opening into the body cavity, through which the sexual products enter the nephridium when sufficiently ripe.

They are then discharged through the external papillae into the water. When free from eggs the nephridia are 15-20 mm. long and spindle-shaped, with a diameter of 3-5 mm. at the center. Probably when filled with ripe eggs or sperm they increase proportionately in size.

The *Sexual Products* are doubtless formed, as stated by Greef, from small cells near the posterior end of the ventral nerve cord, which are covered with peritoneum. But reproduction certainly does not take place in this locality (Casco Bay) in July and August, as well as in midwinter, *viz.*, it does not occur twice a year. All my specimens were secured in June to August, and not one of them contained ripe sperms or eggs.

But two specimens were obtained September 4 and placed in an aquarium. One of these, which proved to be a female, was injured in the digging, and while being put into the aquarium some nearly ripe eggs escaped through the rent in her side. These furnished the necessary stimulus for the uninjured male and he soon sent out ripe sperms in large quantity from the nephridia.

This would indicate a breeding season for that locality of September to November.

In the female just mentioned the nephridia were perhaps one-eighth full of eggs; all the rest of the eggs were free in the body cavity. This was the only specimen in which any eggs were found in the nephridia, but they may sometimes be found in the body cavity in June, and probably require a long time for development. When ripe (*i.e.*, those from the receptacles) the eggs are spherical, about 0.3 mm. in diameter and nearly opaque, but until fertilization the large germ nucleus can be plainly seen through the yolk granules.

The spermatozoa have a peculiar bullet-shaped head, a short cylindrical middle piece, and a long, very delicate tail. Their vibratory movements are rapid and very strong, and they retain the power of motion for a long time after being discharged into the water.

Just enough description has been here given to fix the species definitely, but considerable work has already been done on the morphology and histology of the body organs and on the origin of the sexual products, and it is expected that the near future will afford an opportunity for a careful study of the complete life history of this interesting species.

Through the courtesy of Dr. W. R. Coe, of the Sheffield Biological Laboratory at Yale University, I have received specimens of an *Echiurus* secured by him in Alaska, while on the Harriman Alaskan Expedition during the summer of 1899.

This species was found abundantly at many different localities along the Alaskan coast south of the Peninsula and on adjacent islands, nearly always in rich black mud.

It is of considerable interest to note that it proves to be the same species here described, *viz.*, *Echiurus Pallasii*, and that

its habits, so far as observed, correspond exactly with those just given. Its burrow is horseshoe-shaped, the two ends opening at the surface, and around each is a little mound formed by the pushing aside of the mud. The iron ingredients of the mud in the walls of the burrow are also discolored by the mucus secreted by the animal and show as a rusty brown.

In size the Alaskan specimens surpass those from Casco Bay, and the same shovelful of mud often reveals giants and pigmies of the species side by side. But this is simply in accordance with the general results of the expedition, for gigantic specimens of nearly every native species were found.

The number of setae in the anal rings of four specimens selected at random were counted. In three of these there were eight setae in the anterior ring and seven in the posterior, but in the fourth specimen the numbers were nine and eight respectively.

The fact that specimens from two such widely separated localities agree perfectly in carrying the maximum of size beyond 30 cm. and also in the variation of the number of setae in the anal rings, is a third argument, and quite a strong one, against the validity of the species *forcipatus*.

There seems to be no discernible connection between the number of the setae in the anal rings and the size of the animal; a small specimen is just as likely to possess the larger number.

On the contrary, there is something of a connection between the size of the individual and the temperature of its environment; in general, the colder the water the larger the average of the species. Such a fact strongly corroborates the statement made by Shipley (14) that "this genus is a denizen of the colder seas," and indicates that an Arctic environment is most congenial to its development.

These two new localities also go far toward rendering this species cosmopolitan. It has already been reported from the North Sea, where it was originally discovered, the English Channel, and the coasts of Norway, Sweden, Denmark, Holland, and Belgium. To these can now be added the American North Atlantic and North Pacific, and it may be expected as

one of the results of further investigation in the Asiatic North Pacific.

Thalassema erythrogrammon Max Müller. — I obtained a specimen of this *Thalassema* through the kindness of Dr. E. A. Andrews of Johns Hopkins University.

It was taken at Green Turtle Cay, off Great Abaco Island, the Bahamas, in the summer of 1886, and when alive was of a flesh color with reddish longitudinal stripes, the proboscis lighter in color, the papillae whitish. The body was raised into longitudinal ridges between the muscle bundles whose prominence varied with the degree of contraction. The specimen was hardened in Perenyi's fluid, and yet the muscle bands show a decided pink-brown color at the present time and stand out very distinctly, as can be seen in the photograph (Fig. 5).

It was excellently preserved in a normal condition and measures 16 cm. in length (including the proboscis, 3 cm. long) and 2.4 cm. in greatest diameter. Body spindle-shaped, with bluntly rounded ends, and after preservation *not* perceptibly furrowed by the longitudinal muscle bands. Papillae in dense plaques at the posterior end of the body; no smooth area in the immediate vicinity of the anus. Longitudinal muscles in sixteen bands about 1.5 mm. wide, with interspaces 4.5–7 mm. wide at the center of the body, except the two bands on either side of the ventral mid-line which are close together.

Proboscis so fleshy as to be nearly a solid cylinder, 1 cm. in diameter at the base, thus bringing the mouth to the extreme ventral surface; less fleshy and not broadened toward the tip.

The two setae were so far withdrawn into the thick skin as to be wholly invisible from the external surface, but could be all the more plainly seen on the interior.

The specimen proved to be a ripe male, and the three pairs of nephridia were enormously swollen and packed with sperm.

They increased in size from in front backward, the respective lengths being 3.2, 4.5, and 8.2 cm. The two posterior pairs were constricted at intervals and looked much like a string of sausages; the anterior pair opened 3 mm. in front of the ventral setae, and all three pairs were furnished with spirally coiled internal openings.

Anal glands 9 cm. long, simple, very thin walled, and *without* visible funnels. Intestine filled with the powdered shells of small lamellibranchs.

The chief interest in this specimen centers in the new locality. It has been reported hitherto only from the Red Sea, the Isle of Bourbon, the Malay Peninsula, and New Guinea, about as far distant as possible from the Bahamas. But it evidently belongs to the West Indian fauna and adds one more to the Atlantic species of this genus. Again, this is one of the species in which the number of muscle bands has been given as invariable and fourteen in number. The occurrence of sixteen bands in the present specimen shows that, like most of the other species, the number varies within narrow limits. The position of the anterior nephridia in front of the anal setae, as in *T. caudex* Lampert, is also worthy of note.

STATE NORMAL SCHOOL,
WESTFIELD, MASS.,
March 8, 1900.

LITERATURE CITED.

1. ANDREWS, E. A. Anatomy of *Sipunculus Gouldii* Pourtales. *Stud. Biol. Lab. Johns Hopkins Univ.* Vol. iv.
2. CONN, H. W. Life History of *Thalassema mellita*. *Stud. Biol. Lab. Johns Hopkins Univ.* Vol. iii. 1884-87.
3. COUTHOUY, J. P. Description of New Species of Mollusks and Shells. *Bos. Journ. Nat. Hist.* Vol. ii. 1838.
4. FORBES AND GOODSIR. Natural History of *Thalassema* and *Echiurus*. *Edinburg New Phil. Journ.* Vol. xxx. 1841.
5. GOULD, A. A. Report on the Invertebrata of Massachusetts. Boston, 1841.
6. GREEF, R. Die Echiuren (*Gephyrea armata*). *Acta Ac. German.* Vol. xli, pt. ii. 1879.
7. GREEF, R. Ueber Echiuren und Echinodermen. *Archiv für Naturgesch.* 46 Jahrg. 1880.
8. POURTALES, L. Gephyreans of the Atlantic Coast of North America. *Amer. Asso. Adv. Sci. for 1851.* Vol. v. 1852.
9. QUATREFAGES, M. DE. Mémoire sur l'Echiure de Gaertner. *Annal. des Sci. Nat.* Ser. 3, T. vii. 1847.

10. QUATREFAGES, M. DE. *Histoire Naturelle des Anneles*. T. ii, Géphyreens. Paris, 1865.
11. RIETSCH, M. Études sur les Géphyriens armés ou Échiuriens. Thesis, Geneva, 1886.
12. SELENKA, E. *Challenger Reports*. Vol. xiii. 1885.
13. SHIPLEY, A. E. Gephyrea and Phoronis. *Camb. Nat. Hist.* Vol. ii. London, 1896.
14. SHIPLEY, A. E. On a Collection of Echiurids from Loyalty Islands, New Britain, and China Straits, with an Attempt to Revise the Group and to Determine its Geographical Range. *Zoöl. Results*, etc. Camb. Univ. Press, pt. iii. 1899.
15. SPENGEL, J. W. Ueber die Organization des E. Pallasii. *Zoöl. Anz.* Bd. xl.
16. VERRILL, A. E. Recent Additions to the Marine Invertebrata of the Northeastern Coast of America. *Proc. U. S. Nat. Mus.* Vol. ii. 1879.

FIG. 1. — A male (right) and female (left) *E. Pallasii* in a normal state of contraction in sea-water. $\times \frac{1}{2}$. Photographed from life.

FIG. 2. — The same pair in the same position, but with the female contracted under irritation. $\times \frac{1}{2}$. Photographed from life.

FIG. 3. — Ventral view of proboscis and anterior body. Photographed from preserved Alaskan specimen. Life size.

FIG. 4. — Anal rows of setae. Photographed from preserved specimen. Life size.

FIG. 5. — *Thalassema erythrogrammon*. Photographed from preserved specimen. $\frac{2}{3}$ actual size.

DRAGONFLIES OF THE MISSISSIPPI VALLEY
COLLECTED DURING THE PEARL MUSSEL
INVESTIGATIONS ON THE MISSISSIPPI
RIVER, JULY AND AUGUST, 1907

BY

CHARLES BRANCH WILSON

Department of Biology, State Normal School, Westfield, Massachusetts

No. 1692.—From the Proceedings of the United States National Museum,
Vol. XXXVI, pages 653-671

Published June 19, 1909

Washington
Government Printing Office
1909

DRAGONFLIES OF THE MISSISSIPPI VALLEY
COLLECTED DURING THE PEARL MUSSEL
INVESTIGATIONS ON THE MISSISSIPPI
RIVER, JULY AND AUGUST, 1907

BY

CHARLES BRANCH WILSON

Department of Biology, State Normal School, Westfield, Massachusetts

No. 1692.—From the Proceedings of the United States National Museum,
Vol. XXXVI, pages 653-671

Published June 19, 1909

Washington

Government Printing Office

1909

DRAGONFLIES OF THE MISSISSIPPI VALLEY COLLECTED DURING THE PEARL MUSSEL INVESTIGATIONS ON THE MISSISSIPPI RIVER, JULY AND AUGUST, 1907.

By CHARLES BRANCH WILSON,

Département of Biology, State Normal School, Westfield, Massachusetts.

INTRODUCTION.

Many opportunities were afforded for the collection of dragonflies in connection with the pearl mussel investigations on the Mississippi River and its tributaries during the summer of 1907. So far as practicable these opportunities were improved and a list is here presented of the different species obtained, with their geographic and seasonal distribution. Some of the territory visited had been previously worked over by dragonfly investigators in a more thorough and satisfactory manner, but much of it also was new and is here reported upon for the first time.

Then, too, all the previous work had been disconnected, confined to a single State or even a single locality, and hence there was not the same chance for correlation and comparison.

The present is the first attempt, so far as known, to collect from any considerable extent of the Mississippi River and its tributaries; and while it is confessedly deficient in many particulars, it nevertheless affords a general outlook that may be of some value. The itinerary of the trip, so far as dragonfly collecting was concerned, was as follows:

The time between July 6 and 12 was spent at St. Paul in examining some of the numerous small lakes with which that city and Minneapolis are surrounded. Leaving St. Paul on the 12th, a run was made down the Mississippi to Prescott, Wisconsin, where the party remained until the 15th. On that date the St. Croix River was ascended as far as Stillwater, Minnesota, where a stop of twenty-four hours was made, during which time dragonflies were collected from both banks of the river and from a small lake in the outskirts of the town. Returning to Prescott the next forenoon and continuing down the Mississippi, the party stopped at La Crosse, Wisconsin.

from the 20th to the 22d, and reached McGregor and Prairie du Chien on the 25th.

From Prairie du Chien on the 26th the Wisconsin and Kickapoo rivers were ascended as far as Wauzeka, where the banks of the Kickapoo and the marshy land adjacent to them were thoroughly examined for dragonflies. A return was made to McGregor the same afternoon. Again continuing down the Mississippi, the party stopped at Muscatine, Iowa, for twenty-four hours and reached Burlington in the same State on August 3. Here a stop was made until the 6th, and again both banks of the river were thoroughly examined for specimens.

From Burlington the Mississippi was descended to Grafton, Illinois, which was reached on the 11th. On the 12th the Illinois River was ascended as far as Hardin, Illinois, and a return was made on the 13th, collecting along both banks.

On the 13th also a run was made down the Mississippi to the mouth of the Missouri River, which was ascended for a few miles and back again, the party reaching St. Louis on the evening of the 13th. Leaving there the morning of the 14th, a long run was made down the Mississippi to Cairo, Illinois, at the mouth of the Ohio River, which was reached on the 19th.

During this entire run not a solitary dragonfly was seen except one or two specimens of *Libellula pulchella* Drury flying across the river.

The Ohio was then ascended on the 20th to Paducah, Kentucky, at the mouth of the Tennessee River. The next day the party started up the Tennessee and reached Riverton, Alabama, on the 24th. Here a stop was made till the 26th and considerable collecting was done. We started back down the river on the 26th for Paducah, where the trip ended on August 30.

The Mississippi River was thus covered from St. Paul to Cairo through the States of Minnesota, Wisconsin, Iowa, Missouri, and Illinois, and there were included also 40 miles of the St. Croix River, 20 miles of the Wisconsin and Kickapoo rivers, and 40 miles of the Illinois River. The Ohio River was then covered from Cairo to Paducah, between the States of Illinois and Kentucky, and the Tennessee River through the States of Kentucky and Tennessee into Alabama, making in all a distance of nearly 2,000 miles.

With the exception of a partial duplicate series, which the author was kindly allowed to retain and for which his sincere thanks are tendered to the honorable Commissioner of the Bureau of Fisheries, all the specimens collected are now in the U. S. National Museum and admit of ready reference.

A few notes descriptive of the general physical characteristics are given under such of the localities as seem to demand them. Where

they are omitted it is to be understood that the conditions were those usually found along the river—high and heavily wooded banks with a cleared area at the immediate margin of the river, more or less covered with tall grass and weeds.

LIST OF SPECIES.

I. LAKE AMELIA, MINNEAPOLIS, MINNESOTA, JULY 6 AND 7.

This is a small lake west of Minneapolis which serves as one of the feeders of the Minnehaha River. It is surrounded by high and dry banks which are entirely cleared, leaving only here and there a bush or tree. The immediate shores are covered with a dense growth of grass and weeds, back of which are cultivated fields.

1. *ANAX JUNIUS* (Drury).
Common around the shore and inland half a mile or so; a very strong flier and hard to capture except when mating.
2. *TETRAGONEURIA SPINIGERA* (Selys).
Common flying along the shore and very close to it inland; frequently alights and can then be easily captured.
3. *LIBELLULA PULCHELLA* Drury.
Common not merely around the lake but far inland over the potato and corn fields; too wary to be easily caught.
4. *LIBELLULA EXUSTA* Say.
A single male captured near the shore, the dorsal surface of whose abdomen was already (July 6) deeply pruinose.
5. *GOMPHUS SPICATUS* Hagen.
A single male captured in the grass along shore; no others seen, although carefully searched for.
6. *LEUCORHINIA INTACTA* (Hagen).
Abundant everywhere along shore and for some distance inland.
7. *CALOPTERYX MACULATA* (Beauvois).
Found in the gorge of the Minnehaha River, the outlet of Lake Amelia, below the falls; fairly common.
8. *CALOPTERYX ÆQUABILIS* Say.
Found in the same gorge, but not as common as *C. maculata*.
9. *LESTES INEQUALIS* Walsh.
Two specimens seen and one captured; not common.
10. *LESTES UNCATUS* Kirby.
A single male captured in the grass near the shore.
11. *ISCHNURA VERTICALIS* (Say).
Fairly common in the grass alongside the lake; only orange females found, no black one.
12. *ENALLAGMA EBRIUM* (Hagen).
Found in company with the preceding species everywhere, even at a distance from the lake shore in the woods and cultivated fields; females as common as the males.
13. *ENALLAGMA HAGANI* (Walsh).
Found everywhere, fairly swarming in the grass along shore and for some distance inland; eaten by *Gomphus spicatus*.

II. LAKE PHALEN, ST. PAUL, MINNESOTA, JULY 8.

This is a small lake northeast of St. Paul and partially outside the city limits. Its western and northern shores are covered with primeval woods, while the southern and eastern banks are low and swampy in places and clothed with dense underbrush. At the northwest corner the lake is connected with another much smaller lake or pond by a short stream which winds through an intervening strip of low marshy ground.

The banks of the smaller pond are densely wooded, except a narrow strip along the shore and around the outlet.

On the stream connecting the two bodies of water and around the shores of the smaller pond the dragonflies were especially abundant, and most of the species recorded were collected there.

The species of *Tetragoneuria* was the one most abundant on Lake Phalen itself.

1. ANAX JUNIUS (Drury).

Fairly common around the shore; several seen closely enough for satisfactory identification, but none captured.

2. ÆSHNA JUNCEA VERTICALIS (Hagen).

Fairly common; a female caught off the side of the trolley car just as it stopped; body very beautifully colored when alive, but fades almost immediately after death; actively feeding along the shore rather than over the water.

3. LIBELLULA PULCHELLA Drury.

Very common; sexes about equally abundant; two females captured by hand, which had evidently recently emerged from their pupa cases.

4. LIBELLULA QUADRIMACULATA Linnaeus.

Two females secured along the shore; the only ones seen.

5. CELITHEMIS EPONINA (Drury).

A single pair captured, which were the only ones seen.

6. GOMPHUS VILLOSIPIES Selys.

Common, squatting on the bare ground, logs, and rocks; found in company with *G. spicatus*, but is considerably larger; strong and pugnacious, catches and eats the smaller dragonflies like *Leucorkinia* and *Symphetrum*.

7. GOMPHUS SPICATUS Hagen.

Three captured, all females; smaller than preceding but habits similar; feeds largely on damselflies, like *Enallagma* and *Ischnura*.

8. TETRAGONEURIA CYNOSURA (Say).

Common everywhere; all secured were males; hovers over the water but rarely alights; very pugnacious, attacking and driving away *Gomphus* and even *Æshna*. No *spinigera* seen at this lake, no *cynosura* at Lake Amelia.

9. ERYTHEMIS SIMPLICICOLLIS (Say).

Two pairs secured, both sexes in full color and not yet beginning to become pruinose.

10. LEUCORHINIA INTACTA (Hagen).

Common everywhere, the sexes about even in numbers.

11. *LEUCORHINIA PROXIMA* Calvert or *FRIGIDA* Hagen.

Both sexes secured. Males with yellow spots along the back of the thorax and the first five abdominal segments; seventh, eighth, and ninth segments much dilated; two large yellow spots on the ventral surface of second segment; lower appendages fused with a much shallower notch between them than in *intacta*. Females with the basal half of the wings, or at least to the inclosing of the triangle, colored red; dorsal yellow spots like the male but not as distinct; ventral surface of second to seventh segments becoming pruinose.

12. *SYMPETRUM RUBICUNDULUM* (Say).

A single pair secured; no others seen; easily distinguished even at a distance by its brilliant red color.

13. *ENALLAGMA SIGNATUM* (Hagen).

Quite common flying about the floating algae.

14. *ENALLAGMA CARUNCULATUM* Morse.

Fairly common, but not as plentiful as *E. ebrium* and *E. hageni*.

15. *ENALLAGMA EBRIUM* (Hagen).

Both sexes very common in the grass along shore.

16. *ENALLAGMA HAGENI* (Walsh).

Most common of all the damselflies; both sexes found everywhere in the grass and weeds along shore.

17. *ENALLAGMA ANTENNATUM* (Say).

Rare, only a few seen; found on rushes over the water.

18. *ISCHNURA VERTICALIS* (Say).

Quite common in company with *Enallagma hageni*; both sexes secured.

19. *LESTES INEQUALIS* Walsh.

Rare, only a single female secured.

20. *LESTES VIGILAX* Hagen.

A little more numerous than *L. inequalis*; mostly males.

III. BEAVER LAKE, ST. PAUL, MINNESOTA, JULY 10.

Nearly east from St. Paul, a small lake with a portion of the banks high and sandy and a portion low and swampy, everywhere covered with a dense growth of vegetation, underbrush, weeds, and grass. The two dragonflies which were most abundant were found on the high sandy banks, while the damselflies were captured in the low and wet places.

1. *LIBELLULA EXUSTA* Say.

Abundant everywhere, most common with *quadrimaculata* in the undergrowth close to the shore. When it alights it squats like a *Gomphus* on the rocks, stumps, and even on the ground. It is gregarious, as many as fifteen or twenty alighting on the same spot; it is also inquisitive and many were caught that actually alighted inside the net as it was being carried. The males are predominant and are all pruinose thus early, even the two antehumeral stripes showing clear white.

2. *LIBELLULA QUADRIMACULATA* Linnæus.

Everywhere in company with the preceding; when it alights it does not squat but perches on a twig, holding its body horizontal even if the twig is vertical. It is gregarious, like the preceding species, from

twelve to fifteen or twenty alighting on the same stalk or twig. It is not wary, but neither is it inquisitive like the preceding species. These two species of the genus were present in great numbers, the others but sparingly.

3. *LIBELLULA PULCHELLA* Drury.
Only a few seen and none of them secured.
4. *LIBELLULA LUCTUOSA* Burmeister.
Two females secured in fine color.
5. *ANAX JUNIUS* (Drury).
A single pair secured close to the shore.
6. *TETRAGONEURIA SPINIGERA* (Selys).
Common everywhere, but not in great numbers like *Libellula exusta* and *L. quadrimaculata*.
7. *LEUCORHINIA INTACTA* (Hagen).
Common, but in small numbers; at Curve Lake, which is badly polluted by drainage from some harvester works in the immediate vicinity, this was the only dragonfly to be seen.
8. *LEUCORHINIA PROXIMA* Calvert, or *FRIGIDA* Hagen.
This is the same species as was found at Lake Amelia; only a few specimens were seen, and these were all secured.
9. *ENALLAGMA HAGENI* (Walsh).
Very common; hundreds secured by a single sweep of the net through the long grass along shore.
10. *ENALLAGMA EBRIUM* (Hagen).
Not as common as the preceding; about in the proportion of one to ten.
11. *NEHALENNIA IRENE* (Hagen).
Both sexes fairly common, but not in such numbers as *Ischnura posita*.
12. *ISCHNURA POSITA* (Hagen).
Found in company with *Enallagma hageni* and *E. ebrium* everywhere; not as plentiful as the former, but more so than the latter.

IV. MISSISSIPPI RIVER, BETWEEN ST. PAUL AND HASTINGS, JULY 12.

1. *LIBELLULA PULCHELLA* Drury.
Not common; only a few seen flying across the river.
2. *LIBELLULA QUADRIMACULATA* Linnæus.
Common on the bluffs on the east bank of the river; both sexes secured.
3. *LIBELLULA LUCTUOSA* Burmeister.
Both sexes captured upon the same bluffs on which *L. quadrimaculata* was taken.
4. *PLATHEMIS LYDIA* (Drury).
Not common, only two specimens secured, both females.
5. *GOMPHUS FRATERNUS* (Say).
A couple of males were secured from the river bank just below St. Paul.
6. *LEUCORHINIA INTACTA* (Hagen).
Common everywhere along both banks of the river.
7. *LEUCORHINIA PROXIMA* Calvert or *FRIGIDA* Hagen.
The same species as previously recorded, obtained from the bluffs along the east side of the river.
8. *TETRAGONEURIA CYNOSURA* (Say).
Common everywhere, flying over the water and along the banks.

9. *TETRAGONEURIA SPINIGERA* (Selys).

As common as the preceding; some dead ones seen floating in the water, with fish jumping for them.

10. *ARGIA APICALIS* (Say).

Both sexes found around the heaps of clam shells on the east bank of the river near Pleasant Farms.

11. *ARGIA MÆSTA PUTRIDA* (Hagen).

Both sexes found in company with *A. apicalis*.

12. *ÆSHNA JUNCEA VERTICALIS* (Hagen).

Many seen flying across the river and along the east bank.

13. *ANAX JUNIUS* (Drury).

Many seen flying across the river and along both banks.

It was noted that the species of *Tetragoneuria* mated most often during the hour preceding sunset. Many couples could then be seen flying over the water, and they would approach the boat and even alight on it. *Gomphus*, *Anax*, and *Æshna* were each seen plunging into the water after insects. *Anax* went in like a kingfisher, submerging its whole body and evidently grasping the insect with its feet. None of them apparently wet its wings while doing this, at least not enough to hinder it at all in its flight.

V. PRESCOTT, WISCONSIN, JULY 13 TO 15.

1. *LIBELLULA PULCHELLA* Drury.

Not common, only a few seen flying across the river.

2. *LIBELLULA QUADRIMACULATA* Linnaeus.

Only four individuals of this species seen.

3. *ÆSHNA CONSTRICTA* Say.

Common flying about in the woods near the St. Croix River; four females secured. It alights on the sides of tree trunks or hangs vertically downward from the underside of a twig or a leaf, and in this position quietly munches the insect it has secured. It is more active toward night, coming out of the woods and flying about over the water.

4. *GOMPHUS VASTUS* Walsh.

Common on the rocks along the shore of the river; all that were secured proved to be males.

5. *GOMPHUS FRATERNUS* (Say).

Not as common as *G. vastus*; the two that were secured were females.

6. *DIDYMOPS TRANSVERSA* (Say).

Two males caught in the woods along shore, others seen but only in a single restricted locality.

7. *ARGIA MÆSTA PUTRIDA* (Hagen).

Both sexes common along the rocky shore close to the water.

8. *ARGIA VIOLACEA* (Hagen).

Both sexes common in company with *A. mæsta putrida*.

9. *LESTES RECTANGULARIS* Say.

Three males taken in the grass along the banks some distance from the water, where it was shady; four other males were taken along a slough on the opposite side of the river.

10. *GOMPHUS EXTERNUS* Selys.

A single male taken on the river bank in front of the town.

11. *LIBELLULA LUCTUOSA* Burmeister.
Both sexes found at a small pond south of the town.
12. *PLATHEMIS LYDIA* (Drury).
Both sexes found at the same pond with *Libellula luctuosa*.
13. *CALOPTERYX ÆQUABILIS* Say.
A single pair seen in the slough opposite Prescott.
14. *HETÆRINA AMERICANA* (Fabricius).
A single specimen seen on the island opposite the town.
15. *ENALLAGMA HAGENI* (Walsh).
Sparsely scattered along the river's edge.
16. *ENALLAGMA EBRIUM* (Hagen).
A few found with *E. hageni*.

VI. STILLWATER, MINNESOTA, JULY 15.

On the St. Croix River; the banks of the river are high and dry and well wooded, except an area just opposite the town where formerly stood a large sawmill. The refuse accumulating from this mill has formed a terrace along the river's edge elevated well above the water and without a shred of vegetation anywhere upon it.

1. *LIBELLULA QUADRIMACULATA* Linnæus.
Found by the hundreds in the old lumber yard on the bank of the St. Croix opposite Stillwater; every stick, stub, and bush alive with them. They were very tame, alighting not merely on the net but also on the hand and arm and all over the clothing. This and the other four species here listed were the only dragonflies seen.
2. *LEUCORHINIA INTACTA* (Hagen).
Common, but not nearly as numerous as *Libellula quadrimaculata*.
3. *ARGIA TIBIALIS* (Rambur).
Both sexes flying about in the open sunshine in company with *Libellula quadrimaculata* and *Leucorhinia intacta*.
4. *ARGIA APICALIS* (Say).
A few males found in company with *A. tibialis*.
5. *PLATHEMIS LYDIA* (Drury).
Both sexes found on the river bank a little below the lumber yard.

VII. LILY LAKE, STILLWATER, MINNESOTA, JULY 16.

A small sheet of water on the high ground to the west of the town; its western and northern banks are covered by dense underbrush, the eastern and southern banks cleared and occupied by dwellings. From the southeast corner proceeds a small outlet, winding about through soft, marshy land. The dragonflies were most abundant along this outlet and on the margin of the lake in its immediate vicinity.

1. *EPICORDULIA PRINCEPS* (Hagen).
A few seen patrolling the shore; one male captured.
2. *LIBELLULA LUCTUOSA* Burmeister.
Both sexes quite plentiful in one restricted area at the northwest corner of the lake.
3. *LIBELLULA PULCHELLA* Drury.
Common, many of the females just out of their pupa cases.

4. *ERYTHEMIS SIMPLICICOLLIS* (Say).

Common everywhere.

5. *PLATHEMIS LYDIA* (Drury).

Fairly common, many of the females just emerged from their pupa cases.

6. *LEUCORHINIA INTACTA* (Hagen).

Common everywhere; the most numerous species seen.

7. *TETRAGONEURIA SPINIGERA* (Selys).

A single female taken and one or two others seen.

8. *DOROCORDULIA LIBERA* (Selys).

Several seen flying about over the small stream which serves as the outlet to the lake; distinguished readily by its inflated abdomen; hard to catch, but both sexes secured.

9. *LIBELLULA QUADRICACULATA* Linnæus.

Found in company with *Dorocordulia libera* and quite common; but it is very wary here, and it was extremely difficult to secure even a single specimen.

VIII. RED WING, MINNESOTA, JULY 17.

1. *LIBELLULA PULCHELLA* Drury.

Several seen flying across the river.

2. *ANAX JUNIUS* (Drury).

Many seen patrolling the river banks.

3. *PLATHEMIS LYDIA* (Drury).

Both sexes seen along the river bank just above town.

4. *GOMPHUS EXTERNUS* Selys.

A single pair captured on the river bank.

5. *GOMPHUS VASTUS* Walsh.

Common everywhere; most of the specimens secured were males.

6. *GOMPHUS CRASSUS* Hagen.

A single female secured in company with *G. vastus*.

7. *GOMPHUS FRATERNUS* (Say).

Both sexes fairly common.

8. *GOMPHUS AMNICOLA* Walsh.

A single female secured in company with *G. fraternus*.

9. *LESTES INEQUALIS* Walsh.

Both sexes common in shady places near the woods.

10. *ARGIA TIBIALIS* (Rambur).

Both sexes common along the river bank.

11. *ARGIA APICALIS* (Say).

Found in company with *A. tibialis*, but not as plentiful.

12. *ARGIA MÆSTA PUTRIDA* (Hagen).

A few individuals found along the river bank.

13. *ENALLAGMA HAGENI* (Walsh).

Found in the grass along the river bank.

14. *ENALLAGMA EBRIUM* (Hagen).

Found in company with *E. hageni*.

IX. WINONA, MINNESOTA, JULY 19.

1. *LIBELLULA PULCHELLA* Drury.

Several seen flying across the river.

2. *PLATHEMIS LYDIA* (Drury).
Both sexes taken along the river bank.
3. *ARGIA MÆSTA PUTRIDA* (Hagen).
A few in the open spaces close to the water's edge.
4. *ISCHNURA POSITA* (Hagen).
A few taken in company with *E. hageni* and *E. ebrium*.
5. *ENALLAGMA HAGENI* (Walsh).
Fairly common in the tall grass along the river banks.
6. *ENALLAGMA EBRIUM* (Hagen).
Found with *E. hageni*, but not so numerous.

X. HOMER, MINNESOTA, JULY 20.

Very few dragonflies or damselflies seen; a few individuals of *Libellula pulchella* Drury, *Anax junius* (Drury), and *Plathemis lydia* (Drury) observed flying across the river. *Lestes vigilax* Hagen, *L. rectangularis* Say, and *Argia moesta putrida* (Hagen) taken in small numbers along the river banks.

XI. REEDS LANDING, MINNESOTA, JULY 18.

1. *ANAX JUNIUS* (Drury).
Common patrolling the shore or flying over the water.
2. *GOMPHUS FRATERNUS* (Say).
Both sexes captured along the sandy shores.
3. *GOMPHUS VASTUS* Walsh.
More specimens, including both sexes, of this species were here secured than at any other locality on the river; the banks of the river with alternating reaches of sand and gravel seemed peculiarly attractive to these dragonflies.
4. *SYMPETRUM ALBIFRONS* (Charpentier).
Both sexes were captured in the tall weeds along the edge of the woods; they seem to prefer shady spots.
5. *SYMPETRUM RUBICUNDULUM* (Say).
A single male was found in company with *S. albifrons*.
6. *CALOPTERYX MACULATA* (Beauvois).
Both sexes common along the steep banks where the grass reaches to the water's edge and there is a swift current.
7. *CALOPTERYX ÆQUABILIS* Say.
Both sexes of this damselfly were found in company with *C. maculata*, but were not so numerous.
8. *LESTES VIGILAX* Hagen.
Both sexes found in the tall weeds and grass back from the water; not very common.
9. *LESTES RECTANGULARIS* Say.
Both sexes secured in company with *L. vigilax*.
10. *ARGIA MÆSTA PUTRIDA* (Hagen).
A few specimens seen along the river banks.

XII. LA CROSSE, WISCONSIN, JULY 20 TO 22.

Just to the north of the city the banks of the Mississippi are low and swampy and traversed by numerous streams and bayous. The

railroad tracks cross and recross this region in many directions and afford a convenient means of reaching localities that would otherwise be inaccessible. Much of the collecting was done along these railroad tracks.

1. *LIBELLULA PULCHELLA* Drury.

Common everywhere around the outskirts of the town.

2. *PLATHEMIS LYDIA* (Drury).

A single colony, including both sexes, of this species was discovered at a small pond just north of the railroad tracks; none was seen anywhere else.

3. *ANAX JUNIUS* (Drury).

Very common over the marshes and along the La Crosse River above the city.

4. *EPICORDULIA PRINCEPS* (Hagen).

A few seen patrolling the banks of the La Crosse River.

5. *SYMPETRUM RUBICUNDULUM* (Say).

A few individuals secured in the edge of the woods back of the railroad tracks.

6. *GOMPHUS FRATERNUS* (Say).

Both sexes captured on the gravel along the river bank.

7. *GOMPHUS VASTUS* Walsh.

In company with *G. fraternus* and more numerous.

8. *PERITHEMIS DOMITIA* (Drury).

Both sexes obtained at the lake in the park.

9. *ENALLAGMA HAGENI* (Walsh), *E. EBRIUM* (Hagen), and *E. SIGNATUM* (Hagen).

Found together in the long grass and weeds along the river bank; the first-named species the most abundant.

10. *LESTES RECTANGULARIS* Say and *L. VIGILAX* Hagen.

Found a little distance back from the water, near the woods.

11. *ARGIA MÆSTA PUTRIDA* (Hagen) and *A. APICALIS* (Say).

Found in the shrubbery along the water's edge, the last mentioned the most abundant species.

12. *ISCHNURA VERTICALIS* (Say).

A few found in company with the species of *Enallagma*.

XIII. BROWNSVILLE, WISCONSIN, JULY 23.

After leaving La Crosse the only Neuroptera seen were at Browns-ville, Wisconsin, Crosby's Slough, Minnesota, and Victory, Wisconsin. At each of these places the high and wooded banks yielded three species of *Argia*, namely *mæsta putrida* (Hagen), *tibialis* (Rambur), and *apicalis* (Say), their relative abundance being in the order named.

Where the shores became sandy and less steep two species of *Gomphus*, *vastus* Walsh and *fraternus* (Say) were predominant, flying over the water and patrolling the banks. Apparently these two genera did not intermingle to any extent, but each was colonized by itself.

XIV. LANSING, IOWA, JULY 24.

Only two species of *Gomphus*, *vastus* Walsh, and *externus* Selys, were seen at this station or along the river above and below it.

XV. PRAIRIE DU CHIEN, WISCONSIN, JULY 25.

Again only two species of dragonflies seen, *Gomphus externus* Selys, and *Plathemis lydia* (Drury); both of these were fairly common. The river banks were low, flat, and sandy, and in the scattered weeds were obtained *Argia tibialis* (Rambur), *A. apicalis* (Say), and *Ischnura verticalis* (Say), none of the three at all common.

XVI. HORSESHOE LAKE, OPPOSITE MCGREGOR, IOWA, JULY 26.

Another excellent example of colonization, *Perithemis domitia* (Drury), was found here by the hundreds, the males out on the lily pads in the open lake, the females in the weeds along the shore. This species was seen at only a few other places, and then only sparingly. *Epicordulia princeps* (Hagen), and *Libellula pulchella* Drury were the only other dragonflies seen; the former were much the more numerous and were patrolling the pickerel weed and rushes along the shore. The lily pads and rushes were further tenanted by three species of *Enallagma*, *hageni* (Walsh), *ebrium* (Hagen), and *signatum* (Hagen), none of them at all numerous. In addition there were a few specimens of *Ischnura verticalis* (Say).

XVII. WAUZEKA, WISCONSIN, JULY 26.

This was 15 miles up the Wisconsin River and a half mile up the Kickapoo River, on the banks of the latter. The ground was all marsh land, soggy and wet, with standing water everywhere. Here was found a colony of *Plathemis lydia* (Drury), both sexes of which were present in large numbers, flying about over the water. The only other dragonflies seen were *Gomphus externus* Selys, a pair of which were captured in one of the dry spots on the marshes, while others were seen flying over the water and along the flat, dry banks of the Wisconsin River. There were also a few males of *Perithemis domitia* (Drury) seen on the marshes, and *Libellula pulchella* Drury flying over the fields farther back from the water. Of the damselflies, *Heterina americana* (Fabricius) was found along the grassy banks of the Wisconsin River in limited numbers, while *Lestes vigilax* Hagen was found in the rushes on the marshes.

XVIII. GUTTENBURG, IOWA, JULY 27.

Here was a flat, dry shore, raised considerably above the water and covered thickly with weeds. On it were found *Libellula luctuosa* Burmeister and *Gomphus externus* Selys, while flying about over the water were *Epicordulia princeps* (Hagen) and a few males of *Perithemis domitia* (Drury). Of damselflies there were found *Enallagma hageni* (Walsh), *Ischnura verticalis* (Say), and *Lestes rectangularis* Say.

XIX. CLINTON, IOWA, JULY 30 AND 31.

From Guttenburg to Clinton the shore was dry and sandy and yielded nothing but *Argia tibialis* (Rambur) and *Argia apicalis* (Say), and the two species of *Gomphus*, *vastus* Walsh and *externus* Selys.

At Send Prairie, Illinois, the sand was raised in high bluffs along the shore, and here the two species of *Gomphus* were specially abundant. Elsewhere even the species of *Argia* were scarce and no other kinds were seen. At several of the landings just above Clinton not even a single specimen of dragonflies or damselflies could be found by careful and long-continued hunting. Taken all in all, this was the most barren section of the river encountered during the entire season, except that between St. Louis and Cairo.

XX. LE CLAIRE, IOWA, JULY 30.

The shores at this place were high, dry, and sandy, and there were very few dragonflies or damselflies to be seen. *Epicordulia princeps* (Hagen), *Tetragoneuria cynosura* (Say), *Perithemis domitia* (Drury), and *Argia tibialis* (Rambur) comprised all that could be found, and of the first three only a single specimen was seen.

XXI. MUSCATINE, IOWA, AUGUST 1.

Here the shore was low and covered with a rich growth of weeds, in which there was the greatest variety of dragonflies and damselflies, in the smallest space, of any locality on the river.

Only a few moments could be spent in collecting, but in that time 14 species were secured.

1. *ÆSHNA JUNCEA VERTICALIS* (Hagen).

Two specimens taken in the high bushes back from the shore.

2. *EPICORDULIA PRINCEPS* (Hagen).

A single specimen seen patrolling the river bank.

3. *LIBELLULA PULCHELLA* Drury.

Common everywhere along the banks and over the water.

4. *LIBELLULA LUCTUOSA* Burmeister.

A few males found in the weeds along shore.

5. *GOMPHUS AMNICOLA* Walsh.

A single pair captured on the rocks at the water's edge.

6. *ERYTHEMIS SIMPLICICOLLIS* (Say).

Males common on the river bank, but only a few females seen.

7. *PACHYDIPLAX LONGIPENNIS* (Burmeister).

A single specimen taken in the thick undergrowth.

8. *PERITHEMIS DOMITIA* (Drury).

A single female captured at the water's edge; no others seen.

9. *SYMPETRUM VICINUM* (Hagen).

Fairly common along the edge of the woods back from the river bank.

10. *ARGIA MÆSTA PUTRIDA* (Hagen).

Common everywhere in the dry and open places on the banks.

11. ARGIA TIBIALIS (Rambur).

Found in company with *A. mæsta putrida*, and about as common.

12. LESTES VIGILAX Hagen.

A single specimen taken in the thick weeds.

13. ISCHNURA VERTICALIS Say.

Also rare; a few specimens secured in a patch of long grass.

14. ENALLAGMA GEMINATUM Kellicott.

Rare; a few found in company with *I. verticalis*.

At a landing a couple of miles above the town on the river bank an hour's search revealed nothing but *Argia mæsta putrida*, and seemingly the locality was fully as favorable as this other one.

XXII. BURLINGTON, IOWA, AUGUST 3 TO 6.

1. ANAX JUNIUS (Drury).

Several seen and one found mutilated on the shore.

2. ÆSHNA CLEPSYDRA Say.

A single male captured in the woods near the river.

3. TETRAGONEURIA CYNOSURA (Say).

Several seen along the water's edge.

4. LIBELLULA PULCHELLA Drury.

Common everywhere, particularly along the western bank of the river.

5. PLATHEMIS LYDIA (Drury).

Rare; only a few males seen.

6. GOMPHUS DESCRIPTUS Banks.

A couple of females secured on the rocks near the river.

7. ERYTHEMIS SIMPLICICOLLIS (Say).

Common on both banks near the water.

8. PERITHEMIS DOMITIA (Drury).

A single pair taken on the west bank.

9. PACHYDIPLAX LONGIPENNIS (Burmeister).

More common on the eastern bank of the river.

10. SYMPETRUM RUBICUNDULUM (Say).

Found in company with *Pachydiplax longipennis* on the eastern bank of the river.

11. ISCHNURA VERTICALIS (Say).

Common everywhere in the grass along the water's edge.

12. ARGIA TIBIALIS (Rambur).

Found in the more open places and very common.

13. ARGIA APICALIS (Say).

Found with *A. tibialis* and nearly as common.

14. ARGIA MÆSTA PUTRIDA (Hagen).

Common on the western bank, but none could be found on the eastern side; prefers the rocks and sand along the water's edge.

15. ENALLAGMA ANTENNATUM (Say).

A single male secured in company with *Ischnura*.

16. HETÆRINA AMERICANUA (Fabricius).

A single male was secured from O'Connell slough which had escaped from its pupa case so recently that its color was not yet defined.

There was no evidence of colonization here, but a fairly even distribution of all the species. Several individuals of *Libellula pul-*

chella Drury were observed going to roost for the night in the tall ironweed along a dried-up overflow bottom. When roosting they flatten back against the vertical stem of the weed instead of holding their bodies horizontal as is done when they alight in the daytime, possibly as a protection against rain. This was not the right kind of a shore for *Gomphus*, and hence only the single pair was seen.

XXIII. QUINCY, ILLINOIS, AUGUST 9.

Only a half-hour could be spent here, and in that time the following species were either seen or secured: *Libellula pulchella* Drury, *Aeshna juncea verticalis* (Hagen), *Pachydiplax longipennis* (Burmeister), *Gomphus amnicola* Walsh, *Argia tibialis* (Rambur), and *A. mæsta putrida* (Hagen).

XXIV. HANNIBAL, MISSOURI, AUGUST 10.

Two hours in the afternoon and the same period the next forenoon were spent here in collecting, but with limited results. There were hundreds of *Libellula pulchella* Drury flying across the river and over the inland fields, but the only other species found were *Gomphus externus* Selys, *G. amnicola* Walsh, *Pachydiplax longipennis* (Burmeister). *Argia mæsta putrida* (Hagen), *A. tibialis* (Rambur), and *A. apicalis* (Say), and of these there was only a single specimen of each of the first three.

XXV. THE ILLINOIS RIVER, AUGUST 12.

In passing up the river from Grafton to Hardin two distinct colonies of *Erythemis simplicicollis* (Say) were found. The first was 10 miles above Grafton, where the east bank of the river was covered with hundreds of this species, including both sexes, while many were flying across the river.

The other colony was 4 miles farther up the river, at the head of an island. Here the island seemed to be the headquarters from which the dragonflies flew out in every direction.

Just below Coon Creek an abundance of *Libellula pulchella* Drury was observed, and they could be seen flying over the inland fields. Repeated observations seemed to indicate that in general the flight was from the shady to the sunny side of the river, from east to west in the forenoon and from west to east in the afternoon.

XXVI. COON CREEK, ILLINOIS, AUGUST 12.

This was between the colony of *Libellula* and one of *Erythemis*, and there were found here, naturally, these two species, though in limited numbers, and beside them *Pachydiplax longipennis* (Burmeister), fully as numerous as either of the preceding, *Celithemis eponina* (Drury), *Tetragoneuria cynosura* (Say), and *Gomphus plagiatus* Selys.

Of damselflies there were the two species of *Argia*, *apicalis* (Say) and *tibialis* (Rambur).

XXVII. HARDIN, ILLINOIS, AUGUST 12 AND 13.

Here were found a few specimens each of *Libellula pulchella* Drury, *Tetragoneuria cynosura* (Say), *Anax junius* (Drury), and *Gomphus amnicola* Walsh, together with large numbers of *Ischnura verticalis* (Say), and a few males of *Enallagma piscinarium* Williamson.

XXVIII. MISSISSIPPI RIVER FROM GRAFTON TO CAIRO, ILLINOIS, AUGUST 13 TO 20.

No stops were made between Grafton and the mouth of the Missouri River, but the dragonflies and damselflies were as common as they had been and could be seen along either bank flying over the water or in the bushes. A run was made up the Missouri for 8 or 10 miles and back, but not a solitary dragonfly was seen, and this continued all the way down to Cairo.

Repeated landings were made and the banks diligently searched for specimens, but without finding even one. This abrupt demarkation is no doubt due to the muddy water poured in by the Missouri River. No dragonfly larva could rightly be expected to live in such a medium, and their absolute refusal is what might naturally be looked for.

XXIX. JOHNSONVILLE, TENNESSEE, AUGUST 21.

On ascending the Ohio River the dragonflies began to appear again, and were as numerous as ever on reaching Paducah, at the mouth of the Tennessee River. For the entire length of this latter river to Riverton, Alabama, *Gomphus* was particularly abundant and could be seen at all hours of the day flying over the water. The first stop for collecting was made at Johnsonville, and here were found *Libellula pulchella* Drury, *Macromia taniolata* Rambur, *Erythemis simplicicollis* (Say), *Pachydiplax longipennis* (Burmeister), *Plathemis lydia* (Drury), *Argia mæsta putrida* (Hagen), *A. tibialis* (Rambur), *A. violacea* (Hagen).

The shore at this particular place was not suitable for *Gomphus*, and none was secured.

XXX. SAVANNAH, TENNESSEE, AUGUST 23.

Here the shores were favorable for *Gomphus* and three species were caught—*vastus* Walsh, *notatus* Rambur, and one undetermined. No other dragon flies seen.

XXXI. RIVERTON, ALABAMA, AUGUST 24 TO 26.

The banks of the river were high and dry, except in one place in the outskirts of the town, where were a few small swampy ponds.

Here were found large numbers of *Libellula pulchella* Drury with *Plathemis lydia* (Drury) and a species of *Macromia*.

Along the river bank *pulchella* was not as numerous, and there were associated with it *Erythemis simplicicollis* (Say), *Pachydiplax longipennis* (Burmeister), *Macromia tæniolata* Rambur, *Gomphus vastus* Walsh, *G. notatus* Rambur, two species of *Heterina*, one of which was *americana* (Fabricius), *Argia tibialis* (Rambur), *Argia violacea* (Hagen), and a species of *Anax*, of which none could be obtained.

SUMMARY.

Certain facts must be kept in mind while endeavoring to summarize these observations.

1. With few exceptions the examination of each locality was confined to a period of only a few hours duration. Hence the species obtained would represent the fauna of the locality for that day only, and would give but few suggestions in reference to its fauna at other times, or to seasonal changes.

2. The dates for each of the localities examined were different. While this would have little practical influence for neighboring localities visited within a few days of each other, it would mean a great deal when the interval was increased to a month, or even two months.

3. There was a continual progress in the localities visited from Minnesota, one of the extreme Northern States, to Alabama, one of the extreme Southern. Hence the geographic changes would cause considerable differences in the fauna, irrespective of the seasonal changes, and by thus combining the two their separate influence would be much augmented.

In spite of these difficulties, however, there are certain conclusions which may be fairly drawn from the observations which have just been recorded.

1. A small fresh-water lake or pond, surrounded by shrubbery and vegetation, furnishes the ideal breeding place for dragonflies and damselflies, with which even such a river as the Mississippi, with its numerous sloughs and bayous, is scarcely worthy of comparison. The larvæ of these insects evidently prefer clean to muddy water as a medium in which to live; in witness whereof may be cited the fact that not a solitary specimen of the Neuroptera was seen on the Missouri River or on the Mississippi between the mouth of the Missouri and the mouth of the Ohio.

2. Only a single species was found in all the localities visited. This species, *Libellula pulchella* Drury, may therefore be taken as the most widely distributed in the Mississippi Valley, both geographically and seasonally. A close second was furnished by *Pachydiplax longipennis* (Burmeister), which appeared in nearly all the localities. Furthermore, neither of these species was found colonized anywhere.

3. The genus *Gomphus* is chiefly the guardian of the river. The species may be seen at all times of day patrolling the river's surface with tireless vigilance or squatting upon the shore and watching their surroundings intently, and woe betide the luckless insect that comes within their reach. All of the species observed are remarkably alike in their habits so that it is practically impossible to distinguish them until after they are caught. This genus also was found universally distributed and not colonized.

4. The other dragonflies and the damselfs, on the contrary, were found in colonies, each made up of a few closely related species that harmonize well with one another and restricted in its area with fairly well-defined borders. A few of these colonies are worthy of special mention.

A. The first was at Beaver Lake in St. Paul and was made up of *Libellula exusta* Say and *L. quadrimaculata* Linnæus for the dragonflies, and *Enallagma hageni* Walsh for the damselfs. The lake is small and surrounded by a scattering growth of underbrush and rank grass. There were hundreds of the dragonflies among the bushes and shrubs, while the tufts of grass were so loaded with *Enallagma* that a single sweep of the net secured over two hundred. While other species were found, as given in the list, it was only after long and careful search and in such small numbers as to count for nothing beside the myriads of the three species mentioned.

B. Another colony was found on the bank of the St. Croix River, opposite Stillwater, Minnesota. Here had been formerly a large saw-mill, and the river bank for a long distance was packed with sawdust, bark, and edgings to the depth of several feet. Flying about over this area and alighting on the projecting sticks were swarms of *Libellula quadrimaculata* Linnæus, sometimes a dozen or more on the same stick, and with them were numerous specimens of *Argia tibialis* (Rambur), particularly along some piles of old slabs back from the water. The most careful search revealed only three other species, and in such small numbers that they could only be regarded as stragglers.

C. A third colony was found in Horseshoe Lake, a part of the river surrounded on three sides by islands and opposite the town of McGregor, Iowa. This was a colony of *Perithemis domitia* (Drury), and *Epicordulia princeps* (Hagen), the former flying over the lily pads by the score, the latter patrolling the pickerel weeds and rushes along the shore. The only other dragonfly seen after long and careful search was *Libellula pulchella* Drury, which had evidently come across from the mainland.

D. Special mention should also be made of the two colonies of *Erythemis simplicicollis* (Say) observed on the Illinois River, one

10 miles above Grafton and the other 4 miles farther up the river. These have already been referred to on page 667.

This isolation of species into colonies prevailed throughout the entire length of the various rivers visited and in some of the small lakes. It is a very different condition from what is found in other lakes where fifteen or twenty species, or even more, can be secured in a single afternoon; witness Lake Amelia and Lake Phalen. It leads naturally to the next conclusion—

5. With the exception of such genera as *Gomphus* and *Anax* and such species as *Libellula pulchella* Drury, the individual range of any dragonfly or damselfly is in all probability very small.

The members of one of these colonies just noted are probably natives of the locality. They were born there, they spend their lives in hunting the insects that surround the water, they lay their eggs in the same water, and then die. Continued observation of such a colonized area for many years would doubtless reveal much that would be of interest in its bearing upon colonization in general, as well as upon the distribution of species.

7.
CARD 1945
THE JOHNS HOPKINS UNIVERSITY
BALTIMORE

NOTES
ON
DRAGONFLIES OF JAMAICA

BY
C. B. WILSON

[REPRINTED FROM THE JOHNS HOPKINS UNIVERSITY CIRCULAR
FEBRUARY, 1911]

DRAGONFLIES OF JAMAICA*

BY CHARLES B. WILSON

The dragonflies of Jamaica are subject to peculiar environmental conditions which exert an important influence on their distribution and abundance. Nearly all of the Odonata demand quiet fresh water for the laying of their eggs and the rearing of their young. But such bodies of water are comparatively rare on the island, are widely scattered with long intervals between, and are usually small and densely filled with aquatic life, both animal and vegetable.

All the rivers of Jamaica and most of the streams have far too swift a current for dragonfly larvæ except close to the ocean, and only one or two species frequent them. The first result is that practically the entire dragonfly fauna is confined to the immediate vicinity of the isolated ponds and quiet streams.

Hence there is much crowding and as a second result some of the dragons like *Trithemis umbrata* and *Orthemis ferruginea* utilize almost any pool of water they can find, in company with the mosquitoes and gnats. And they may often be seen depositing their eggs in the tiny rain pools which collect in the hollows of the honeycombed limestone rocks.

Again some of the damsel flies like *Micronympha ramburii* and *Anomalagrion hastatum* frequent for the same purpose the water pools formed inside the wild pines (*Bromelia*).

There is always plenty of water here and enough mosquito and gnat larvæ to furnish the damsel nymph with an abundance of food. But the water in the rock pools frequently dries up, and it is doubtful whether any of the dragon larvæ, hatched in those pools, are ever transformed into adults.

* Notes from the Johns Hopkins University Laboratory at Montego Bay, Jamaica. B. W. I., summer of 1910.

Perhaps the most striking peculiarity of the adults is their quiet coloration. Hardly a single example of really brilliant colors was noted during the entire season, and this absence was especially apparent among the damsel flies where ordinarily there is such a rich variety of hues.

They were all, dragons and damsels alike, dressed in rather sober reds and browns or grays and blacks, with little of the iridescent and metallic colors.

Another unexpected character was the entire absence of the larger species of both dragon and damsel flies. Not a single representative of such genera as *Anax*, *Aeschna*, *Gomphaeschna*, *Boyeria*, *Macromia*, *Gomphus*, or *Libellula* was seen during the season, and practically the same may be said of the damsel genera *Calopteryx*, *Heterina*, *Argia*, and *Lestes*. A single specimen of *Heterina bipartita* has been reported from the Island by Carpenter (Journal Jamaica Institute, II, p. 261), but has never been seen by others. Calvert's new genus *Ortholestes* is one of the larger damsel flies, but *Lestes spumarius* is only of medium size.

On the other hand the smaller species were everywhere in evidence; the tiny dragons *Trithemis justiniani* and *Micrathyria aequalis*, together with the small damsels *Ceratura capreola* and *Micronympha ramburii* were especially abundant.

Another remarkable fact in connection with these Odonata is that they show almost exclusive neotropical affinities.

There is not a single nearctic or sonoran dragon fly in the list, and only a few that are sonoran as well as neotropical. There is but one species peculiar to Jamaica, *Ortholestes clara*; six are confined to the West Indies, viz: *Trithemis justiniani*, *Macrothemis celeno*, *Dythemis rufinervis*, *Scapania frontalis*, *Micrathyria didyma*, and *Lestes spumarius*. The other eighteen are found on the mainland of South, Central, or North America, with the preponderance decidedly in favor of the first mentioned.

Thus the statement made by Kolbe (Archiv für Naturgeschichte, LIV, p. 153) that the West Indian Neuroptera show marked South American affinities is again substantiated by these Montego Bay Odonata.

LIST OF SPECIES

- Ortholestes clara* Calvert. Confined to Jamaica, where apparently it is found only on the eastern end of the island. Two males were secured at Cinchona on the summit of the Blue Mountains, 5,000 feet above sea level; not seen elsewhere.
- Lestes spumarius* Selys. Confined to the West Indies; fairly common around the ponds and along the dead water of the rivers.
- Telebasis dominicana* (Selys). Found on several of the West Indies and in Guiana; rather rare at the large pond on the Jarrett sugar estate; not found elsewhere.
- Ceratura capreola* (Hagen). Recorded from several of the West Indies and Brazil; "almost the smallest species known" (Hagen); extremely common at the large pond on the Jarrett estate, but not seen elsewhere; both orange and green females were secured with the males; two of the orange females have only a tiny blue spot on the ninth segment.
- Micronympha ramburii* (Selys). Recorded from several of the West Indies and on the continent from the northern United States to Peru and Venezuela. Orange, olivaceous, and black females were secured with the males; some of the males have the ninth segment entirely blue on the dorsal surface like *fluvialis*, but the appendages are those of *ramburii*.
- Enallagma doubledayi* (Selys). Found in Cuba and in North America from Florida to Massachusetts; fairly common at the small pond on the Hale estate, but only one specimen seen elsewhere.
- Enallagma coecum* (Hagen). Recorded from Cuba and St. Thomas, but not before from Jamaica; rather rare and found only at the pond on the Jarrett estate.
- Enallagma civile* (Hagen). Found in several of the West Indies, all over the United States, in Canada, Mexico and Texas; not previously recorded from Jamaica; fairly common at all the ponds.
- Amphiagrion vulneratum* (Hagen). Confined to the West Indies, where it has been recorded from Cuba and Porto Rico, but not before from Jamaica; comparatively rare and found only at the pond on the Jarrett estate.
- Amomalagrion hastatum* (Say). Recorded from Cuba, but not hitherto from Jamaica; found also in Venezuela and in the United States from Florida to Maine; both black and orange females found with the males; very abundant at the pond on the Jarrett estate.

- Acanthagyna septima* (Selys). Recorded only from Cuba, Jamaica, and Brazil; extremely rare, but a single female being seen during the season; this was secured on a wood road at some distance from the water.
- Pantala flavescens* (Fabricius). Found in the West Indies and all parts of the tropics of both hemispheres; "no other species occupies so many countries" (Hagen); quite rare at Montego Bay, only two individuals being seen, one of which was caught.
- Tramea abdominalis* (Rambur). Found on many of the West Indian islands; fairly common at Montego Bay around the small ponds, but sticks closely to the water.
- Miathyria marcella* (Selys). Recorded from Cuba, Brazil and Mexico; only a few specimens seen at Montego Bay and but a single male secured.
- Trithemis umbrata* (Linnaeus). Found on many of the West Indies and in North America from Mexico to Georgia; extremely abundant in tropical South America; the most common dragon fly in Jamaica; found everywhere around small pools as well as the ponds and at long distances from any water. A single female was secured, whose wings were blotched with black like those of the male.
- Trithemis justiniani* (Selys). Confined to Cuba and Jamaica; a very common species around the shores of the ponds and on the vegetation in shallow water; flavescent spots on the wings of the male conspicuous during flight.
- Trithemis ochracea* (Burmeister). Common in meridional America and recorded from Cuba, but not hitherto from Jamaica; very rare at Montego Bay, only two males seen along a ditch by the railroad track, both of which were captured.
- Orthemis ferruginea* (Fabricius). Very common throughout the West Indies and in tropical America; abundant everywhere in Jamaica, preferring the ponds, but found also in the vicinity of small pools and at long distances from water.
- Macrothemis celeno* (Selys). Confined to the West Indies; common along the rivers in the Blue Mountains in company with *Scapanea frontalis*, but not seen down nearer the sea level; a typical river species and not found around the ponds.
- Dythemis rufinervis* (Burmeister). Confined to the West Indies; comparatively rare at Montego Bay, being found at only the largest of the ponds and there in small numbers.
- Scapanea frontalis* (Burmeister). Confined to the West Indies; common along the rivers in the Blue Mountains, even at a considerable elevation (4,500 feet) above the sea; also found along the dead water at the sea level; another typical river species.
- Lepthemis verbenata* Hagen. Found in Cuba, Brazil, and Venezuela, but not before reported from Jamaica; comparatively rare at Montego Bay, sticking closely to the ponds; the most difficult of all the Jamaica Odonata to capture.
- Lepthemis vesiculosa* (Fabricius). Found on many of the West Indian islands, and on the continent from Mexico to Brazil; fairly common in Jamaica, with habits very similar to those of *Mesothemis simplicicollis*, frequenting the denser portions of the reeds and rushes, where it is difficult to manipulate a net.

Microthyria aequalis (Hagen). Found in Cuba and also in Mexico and Grenada; a small species quite common around the ponds and preferring the vegetation that grows in deeper waters; this species patrols the center of the ponds, while *T. justiniani* hunts along the shores.

Microthyria didyma (Selys). Confined to the West Indies; comparatively rare at Montego Bay and found only in the vicinity of the larger ponds; considerably larger than the preceding species and both of them very active and agile flyers.

5421 1945
CABOT

DRAGON FLIES OF THE CUMBERLAND VALLEY IN KENTUCKY AND TENNESSEE

BY

CHARLES BRANCH WILSON

Of the Department of Biology, State Normal School, Westfield, Massachusetts

No. 1928.—From the Proceedings of the United States National Museum,
Vol. 43, pages 189-200

Published September 7, 1912

Washington
Government Printing Office
1912

DRAGON FLIES OF THE CUMBERLAND VALLEY IN KENTUCKY AND TENNESSEE

BY

CHARLES BRANCH WILSON

Of the Department of Biology, State Normal School, Westfield, Massachusetts

No. 1928.—From the Proceedings of the United States National Museum,
Vol. 43, pages 189–200

Published September 7, 1912

Washington
Government Printing Office
1912

DRAGON FLIES OF THE CUMBERLAND VALLEY IN KENTUCKY AND TENNESSEE.

By CHARLES BRANCH WILSON,

Of the Department of Biology, State Normal School, Westfield, Massachusetts.

INTRODUCTORY.

During the summer of 1911 the author traveled nearly the entire length of the Cumberland River in the interests of the United States Bureau of Fisheries. While the party was studying especially the fresh-water mussels of the river, there were frequent and excellent opportunities for collecting the Odonata.

These opportunities were improved as far as possible, and a list is here presented of the different species obtained, together with their observed range and habits. This is the first attempt, so far as known, to report the dragon flies of this particular locality, and it must of necessity be very incomplete, but it is hoped that it may at least form a foundation for future observation, and give a general idea of the odonate fauna of the region. Having had previous experience with river collecting, a small .22-caliber rifle and cartridges loaded with dust shot were provided in addition to the usual collecting outfit. Such species as could not be secured in any other way were brought down with the dust shot. These were usually mutilated and of no use for museum purposes, but scarcely one of them was injured enough to render it incapable of identification, which is all that is required for determining the fauna of the valley. The general itinery of the trip, so far as the Odonata were concerned, was as follows: Starting at Jellico, Tennessee, June 28, 1911, on the Clear Fork of the Cumberland River, the party worked the upper portion of the river as far down as Burnside, Kentucky, from various railroad centers. Thence they proceeded by boat down the river through Kentucky and into Tennessee as far as Clarksville, a distance from Jellico of about 600 miles. Side trips were also made up all the tributary rivers, streams, and creeks of any size. Constant watch was kept for both dragon flies and damsel flies, and specimens were collected at different places on the river bank in addition to the specimens taken from the

boat all the way along. The specimens of dragon flies were identified on the spot, that there might be no fading of colors, and were then shipped by mail. One large box, containing specimens from the lower part of the river, was lost in transit. While a list of the species had fortunately been kept, the exact localities and dates were lost. These have been supplemented so far as possible from the notebook, but there is still somewhat of a dearth of localities from the lower river, which did not really exist.

For the opportunities thus enjoyed, as well as for permission to publish the present paper, the author tenders sincere thanks to the honorable Commissioner of the Bureau of Fisheries.

LIST OF SPECIES.

1. TACHOPTERYX THOREYI (Hagen).

A male and a female of this large species were obtained near the Great Falls of the Cumberland, one on July 5, the other on July 8. The former, the male, was captured on the bank of the river; the latter was 10 miles away in a sunny place beside the stage road and at a considerable elevation among the mountains. Both were easily captured while resting, for there is no difficulty in approaching them at such times, as has been noted by Williamson and others. But while hunting their prey they are strong and swift fliers, and their habits much resemble those of *Aeshna* or *Anax*. From these and other large species they can be distinguished, even while flying, by their brown markings in place of blue or green or yellow. Many besides those captured were seen while driving 14 miles along this same road.

2. GOMPHOIDES OBSCURA (Rambur).

This species was very common on the Clear Fork of the Cumberland River at Jellico, Tennessee, June 28, and a dozen of each sex were obtained. Another single specimen was captured on the Big South Fork of the Cumberland near Parkers Lake post office July 9. Both sexes rest much of the time upon the sand on the river bank in the bright sunshine. They are easy to approach and capture at such times and are not as swift fliers as many of the gomphines.

3. GOMPHUS VASTUS Walsh.

One female was taken at the Great Falls of the Cumberland, July 6, and a male and female were obtained on July 18 at Indian Creek Landing, Russell County, Kentucky. The greatly dilated seventh, eighth, and ninth segments and the bright yellow on the sides of the ninth segment are conspicuous even in flight.

The species was common at least down to the State line between Kentucky and Tennessee. It is quite active and the males are hard to capture, since they persist in alighting amid the brush near the water's edge.

4. *GOMPHUS NOTATUS* Rambur.

A single male was captured at the Great Falls of the Cumberland, July 5. It was flying up and down the river over the swift water just above the falls. It is a very strong flier and is exceptionally active, remaining a long time on the wing. Indeed, this one did not alight at all during the hour that it was watched. The species is comparatively rare, since no other specimens were seen during the summer.

5. *GOMPHUS SPINICEPS* (Walsh).

A single female was captured in the long grass on the banks of Greasy Creek in Russell County, Kentucky, July 17. Quite a number of specimens were present in the immediate vicinity, but it was practically impossible to detect any of them before they flew up out of the grass. The one obtained was caught accidentally while sweeping the grass for damsel flies. It is a strong flier and frequents the vicinity of riffles, where the water flows rapidly over small stones. It is recorded by Williamson from Tennessee.

6. *GOMPHUS DILATATUS* Rambur.

A single female was taken at Jellico, Tennessee, June 28, on the Clear Fork of the Cumberland. This is one of the larger species, but did not prove so difficult to capture, since it may be approached with comparative ease while at rest. Several other specimens were seen at the same locality, but it was not found anywhere else during the summer.

7. *GOMPHUS PLAGIATUS* Selys.

This species was common all along the river from Burnside, Kentucky, to Nashville, Tennessee. It frequents the riffles, flying back and forth over the swift current, and is seldom seen in the long stretches of quiet water between. Frequently it dives into the water for its prey, plunging entirely beneath the surface. It immediately comes forth, spreads its wings, and flies away into the very top of one of the tallest trees along the river bank, there to enjoy its meal in quiet security.

It very seldom alighted on the shore and proved difficult to capture, all the specimens having to be shot either while hovering over the water or while munching their prey in the trees.

It may be recognized when flying near at hand by the reddish-brown posterior end of the abdomen, which stands out in good contrast to the darker color of the rest of the body. About a dozen specimens were obtained at various riffles on the river in Russell, Cumberland, and Monroe Counties, Kentucky, and Clay and Jackson Counties, Tennessee. In hovering over the water the abdomen is not elevated, as in the following species, but is held nearly horizontal.

8. GOMPHUS PALIDUS Rambur.

This species was also fairly common at the riffles, but unlike *plagiatus* it frequently alighted on the river bank and was then comparatively easy to capture. Several teneral were secured at Cloyds Landing, Monroe County, Kentucky, that had just emerged on the morning of July 23. Four of the larvæ crawled out on the boat during the night, and the soft imagos were found alongside the exuviae the next morning.

This species first appeared at some riffles about 30 miles below Burnside, but quickly became common.

It flies comparatively slowly and hovers a great deal; its wings have a yellowish tinge, very visible when hovering; it often plunges entirely beneath the water when capturing its prey, and then mounts high in the air and seeks the tops of the tallest trees. When it alights on a pebbly beach it hovers a moment and apparently feels the rock, testing it before settling, and meanwhile holding its abdomen pointing upward. It then settles down slowly, lowering the abdomen until it is flat against the rock. In this position its colors harmonize so well with its surroundings that it can be seen only in a favorable light. It also frequently alighted on the boat, holding its abdomen elevated at an angle of about 45°.

9. DROMOGOMPHUS SPINOSUS (Selys).

This species was common on the upper part of the river from the Great Falls down to the State line. It was also obtained on the Big South Fork, opposite Parker's Lake post office, in Pulaski County, Kentucky. On the main river specimens were obtained at Burnside, Mill Springs, Indian Creek Landing, Cloyd's Landing, and Black's Ferry. It is quite active but alights frequently along the shore and can then be captured. It is not confined to the vicinity of rapid water like the two preceding species, but is found anywhere in sunny localities, usually on rocky ledges. Like the preceding species it dives into the water for its food, but is satisfied with ordinary underbrush or even the rocks as a dining place. In ovipositing the females skim along very swiftly close to the surface of the water, which they touch with the tip of the abdomen at long intervals, without visibly checking their speed, after the manner of *Macromia*.

A male taken at Black's Ferry had the dorsal surface of the tenth segment washed with greenish-yellow like the female.

The newly emerged imago has a decidedly yellow dorsal stripe; this then becomes olive, and in the old males gradually disappears leaving the abdomen almost entirely black.

10. BOYERIA VINOSA (Say).

A single male was captured July 5 at the Great Falls, and two other individuals were seen in the immediate vicinity. It was also

found sparingly at different points on the river, notably at Indian Creek Landing, July 19, and Black's Ferry, July 24.

It frequented the thicker woods where the trees overhung the water. Here both sexes were found attached to the under side of twigs in close proximity, after the manner of *Macromia*, and when disturbed they returned to the same spot again and again.

11. *MACROMIA ILLINOIENSIS* Walsh.

The most common of all the dragon flies, it is seen everywhere up and down the river, in quite sunny places as well as at the riffles.

It is a very rapid flier, especially when frightened, or when chasing its prey or other dragon flies, and it never hovers and rarely alights. When two of them come together from opposite directions a fierce fight often takes place, and one of the contestants is sometimes thrown into the water. They are constantly upon the wing in search of food, and they fly so rapidly and dodge so quickly that it is next to impossible to catch one in a net. But they have a habit of congregating in favorite spots among the low bushes, often in company with *M. tæniolata*. Here they hang by their legs from the under side of the branches, sometimes several individuals occupying the same branch. Even then it is difficult to get up to them with a net, but they can be easily approached near enough for shooting.

In this way a dozen specimens of this and the following species were obtained within 20 minutes in the low bushes beside the wagon road leading to the ferry at Cairo, Wilson County, Tennessee, August 19. A curious habit was also noted: About sunset they resort to the cornfields on the river bottoms and patrol them until dark. In doing this they fly between the rows of corn about 3 feet above the ground, going up one row and down the next with remarkable regularity. This habit was observed on many different occasions; indeed, scarcely a cornfield was visited at that time of day without seeing one or more of these *Macromias*.

12. *MACROMIA TÆNIOLATA* Rambur.

This larger species in every way resembles the smaller preceding one. When on the wing the two show scarcely any difference except their relative size. These larger ones are veritable hawks, intensely rapacious, swift enough to catch and strong enough to overpower and eat almost any insect, even some of the *Gomphus* species already mentioned. They not only congregate with *M. illinoiensis*, but their habits are exactly the same. Two of the specimens mentioned above were brought down with one shot, while hanging so close together that they almost touched. On examining them one was found to be a *tæniolata* and the other an *illinoiensis*. Different species of dragon flies do not usually mingle thus intimately, especially when there is such a disparity in their size.

Like *illinoiensis*, this species was found the entire length of the river below Burnside, not numerous at any one place, but evenly distributed throughout.

13. *SOMATOCHLORA TENEBROSA* (Say).

A single female was captured near the Big South Fork, opposite Parkers Lake post office, July 9. Ten or a dozen specimens of this species were patrolling back and forth just after sunset in one corner of an old pasture near a small brook at the foot of the mountains. They were strong and rapid fliers and extremely difficult to capture. They moved gracefully up and down and in and out, weaving together their paths of flight like the intricate mazes of an old-fashioned dance. But never for an instant could they be caught off their guard. At the first attempt of the net they all retired precipitately, and it was a long time before they returned again. This is a northern species and its presence in Kentucky is probably explained by the high altitude of the region where it was found and the proximity of the mountains.

14. *EPICORDULIA PRINCEPS* (Hagen).

A single specimen of this species was seen on the afternoon of July 20 near Burkesville, Kentucky. It suddenly appeared, apparently from nowhere, and alighted on the boat within arm's length of the author; but, of course, at the first movement it was gone, and it did not return.

15. *ANAX JUNIUS* (Drury).

Several specimens were seen at long intervals, one at Indian Creek Landing, July 15; another at Sandersville Ferry, just above Nashville, Tennessee, August 18; a third at Lock No. 5, Wilson County, Tennessee; and a fourth near Clarksville, Tennessee, August 27.

Each was patrolling the bank of the river, but none of them was captured.

16. *PANTALA HYMENÆA* (Say).

A male and female were captured at the Great Falls, July 7. They were very common around the falls and congregated in considerable numbers over the swift water after sunset. They fly rapidly and are agile dodgers. Apparently they never alight except for the night, but continue moving about restlessly and eating whatever they catch while still flying. One could often be seen to catch an insect and eat it while looking for more.

Occasionally one would mount spirally into the air until lost to view, and of course it was impossible to tell whether that one came back again to continue the hunt; but at all events the numbers did not diminish until they all disappeared at about the same time. This species was also seen at various places along the whole length of the river.

17. *TRAMEA ONUSTA* Linnæus.

A single female was captured at Fishing Creek, Kentucky, July 15. Several others were seen in the vicinity, the dark bases of the posterior wings serving to identify them when everything else in sight had hyaline wings.

18. *PERITHEMIS DOMITIA* (Drury).

This tiny dragon fly was first seen on the river at Fishing Creek, Pulaski County, Kentucky. Afterwards it appeared every now and then all the way down the river to Clarksville, Tennessee, becoming more numerous after passing the State line.

The males were seen upon the main river, while the females were on the side creeks or in the fields at some distance from the water.

19. *LEUCORHINIA INTACTA* (Hagen).

This dragon fly, familiarly known as "Johnny White-face," was found only around the fresh-water ponds or on the side creeks; there were none on the river. Some of the localities where specimens were taken were Fishing Creek, Greasy Creek, Indian Creek, and Cloyds Landing, in Kentucky; Roaring River, Spring Creek, and Marrowbone Creek, in Tennessee; and around the pond at Sandersville Ferry, Tennessee.

20. *ERYTHEMIS SIMPLICICOLLIS* (Say).

Like the preceding, this species was found only around ponds, and its presence was always indicative of a pond or swamp in the vicinity. It was fairly common at Indian Creek Landing, and at that time (July 17) the males had not become pruinose.

At Sandersville Ferry large numbers of the species were congregated around the pond and even along the river bank for some distance above and below. By this time (August 17) the males had become entirely pruinose.

21. *PACHYDIPLAX LONGIPENNIS* (Burmeister).

Found in considerable numbers at Jellico, Tennessee, on the Clear Fork of the Cumberland River, June 28, and even at this date all the males were wholly pruinose. The species was subsequently taken on the Big South Fork near Burnside, at Greasy Creek, Cloyd's Landing, Butler's Landing, Carthage, Nashville, and Clarksville.

22. *LIBELLULA LUCTUOSA* Burmeister.

A single male was captured and several specimens of both sexes were seen at Indian Creek Landing, July 17, around the small pond. The species were seen at each of the other ponds visited, but none were found on the river.

23. *LIBELLULA CYANEA* Fabricius.

Two males were captured on the Clear Fork at Jellico, Tennessee, June 28, and another male at the small pond at Indian Creek Landing, Kentucky, July 17. One or two females were seen in inaccessible places where they could not be captured.

24. *LIBELLULA PULCHELLA* Drury.

This large and well marked species was seen but very few times during the season, once on the Big South Fork near Burnside, July 11, a second time near the small pond at Indian Creek Landing, July 17, a third time near Gainesboro Landing, and finally near Hartsville, August 15. It seems remarkable that a species so cosmopolitan as this should be so little in evidence for the whole length of the river.

25. *PLATHEMIS LYDIA* (Drury).

This species was found everywhere, not on the river but up the tributary creeks and around the little pools and ponds in the pastures and fields. The first one was taken at Jellico, Tennessee, June 28, and the last one at Clarksville, Tennessee, August 30. Specimens could have been secured at every stopping place in Kentucky and Tennessee, but the males are so easily distinguished while flying as to obviate the necessity of their capture. It is seen only rarely on the river banks.

26. *AGRION MACULATUM* Beauvois.

Common along all the smaller shaded creeks running into the Cumberland, but never appearing on the main river. Among the localities from which specimens were obtained are Williamsburg, Kentucky, June 29; Big South Fork, Beaver and Greasy Creeks, Cloyd's Landing, Roaring River, Carthage, Hartsville, and Ashland City, Tennessee, August 27. Probably every creek and run between these geographic and time extremes would have yielded specimens. A great difference was noted in the ease with which this species could be approached at the different localities. At Williamsburg and on Beaver Creek and at Hartsville one could walk up and seize them with his fingers. At Roaring River and Ashland City it was almost impossible to get near enough to catch them with the net.

27. *HETÆRINA AMERICANA* (Fabricius).

This species was common everywhere along the upper portion of the river in the vicinity of swiftly running water. It is especially fond of shallow rocky ripples, either in the main river or in any of its tributary streams. Some were captured at practically every one of the ripples visited, but the numbers diminished in descending the river, until at the State line there were comparatively few. The last one seen was secured at Rome in Smith County, Tennessee. As *americana* diminished and finally disappeared the following species, *H. tricolor*, appeared, increased in numbers, and finally took the place of *americana*.

Both of these species fly until October, so that this difference in their distribution can not be attributed to seasonal changes, but must be geographical.

H. americana is a species whose range extends to the north and so frequents the upper portions of the Cumberland River among the mountains.

28. *HETÆRINA TRICOLOR* (Burmeister).

This species first appeared at Celina, Tennessee, a little way below the State line. It then rapidly increased in numbers and gradually replaced *americana*, becoming the most common agrionine of the lower portions of the river.

It does not assemble in such large numbers as *americana*, and is much more difficult to capture, but otherwise is almost identical in its habits, and it frequents similarly the bushes along shallow rocky ripples. It is a southern species and so is found on the lower portions of the river among the lowlands.

29. *LESTES RECTANGULARIS* (Say).

The only species of the genus *Lestes* seen during the season was captured on the shore of the small pond at Indian Creek Landing. Both sexes were found in the dense underbrush on the shores, which they seemed to prefer.

30. *ARGIA MOESTA PUTRIDA* (Hagen).

This is one of the three common species of *Argia* found everywhere along the entire length of the river and on such of its tributaries as were visited. It does not occur in as great numbers as the following species, and is not so conspicuous in consequence of the lack of blue at the tip of the abdomen.

But it is much like them in habits and frequents sunny places on the river bank, usually alighting on the ground, on sticks, or on stones. The younger females are pale brown, in such contrast to the blue head and thorax of the fully matured adult that they look like a different species.

31. *ARGIA APICALIS* (Say).

This is by far the most common damselfly on the river, and during the whole season it was found in great numbers wherever the Odonata were hunted. It was as abundant on the upper river among the mountains as farther down in the lowlands.

It seems to prefer a floating chip or a board at the level of the water for oviposition. Around such places the pairs congregate, the females grasping the edge of the chip and thrusting their abdomens as far as possible beneath the water, the males holding themselves erect and perfectly straight above the neck of the female. Often the chip is covered so completely that there is not room for even one more couple. It then looks as if it were covered with a dense growth of moss, having spots of bright blue on every stem. This species was not seen to submerge itself while ovipositing as is frequently done by the preceding species.

32. *ARGIA TIBIALIS* (Rambur).

Not as abundant as *apicalis* but occurring in about the same numbers as *putrida*. The three were found everywhere together, but *tibialis* seemed to prefer vegetation more than the other two, and did not stick so closely to the open sunny spots. The fact that

only two of the posterior segments are blue dorsally renders this species less conspicuous than *apicalis*.

It was rather more common during July on the upper portions of the river, and diminished somewhat in numbers during August on the lower river.

33. *ARGIA TRANSLATA* Hagen.

Found in company with the three preceding species, but preferring shady and secluded spots amongst dense vegetation rather than the sunny open. This is rather more of a southern species than the others, but did not occur in such abundance as *apicalis*. Furthermore none were seen ovipositing in company with the other species, but always in secluded places by themselves. A few specimens were found in every locality the whole length of the river, but it seemed more plentiful during August on the lower river.

34. *ARGIA SEDULA* (Hagen).

This bright-colored species was found in dense vegetation along the banks of small creeks and streams, often in company with *Agrion maculatum*. It was never found in any numbers—only straggling specimens—but was universally distributed throughout the river and during the entire summer. It is a more showy species than even *apicalis*, the wide black stripes on the blue thorax standing out conspicuously.

35. *CHROMAGRION CONDITUM* (Hagen).

Two females were taken in company with *Agrion maculatum* at Ashland City, Tennessee. They were on the shady bank of a small creek flowing into the Cumberland River, and were the only specimens seen during the entire season.

36. *ENALLAGMA EXSULANS* (Hagen).

Only two lots of this species were taken, one on the Big South Fork, July 9, and the other at Nashville, Tennessee, August 21.

The latter was near a small pond; the former was on the river bank. This highly-colored species, therefore, does not seem very common since it could hardly escape notice if present at any of the other localities visited.

37. *ENALLAGMA GEMINATUM* Kellicott.

A single specimen of this small species was taken on the Big South Fork in company with the preceding species, and none were seen at any of the other localities.

38. *ISCHNURA POSITA* (Hagen).

This tiny damselfly was found only around the small ponds at Indian Creek Landing, Kentucky, and near Nashville and Clarksville, Tennessee. Both sexes were taken at each of these localities, but none were seen on the river or any of its tributaries.

39. *ISCHNURA VERTICALIS* (Say).

Found at the small pond near Nashville, Tennessee, August 21, and also near Clarksville, one week later. It was not found anywhere on the river or on any of its tributaries.

SUMMARY.

Certain facts must be carefully considered before any conclusions of real value can be drawn.

1. While collecting was done at all times of day, from early dawn until long after sunset, yet the examination of any one locality was confined to a few hours, or at the most to a day or two.

The results, therefore, will be general, applicable to the whole river or large portions of it, rather than specific for any locality.

2. The collecting did not begin until the very last of June (the 28th); almost the whole of the best dragon fly month of the year was thereby lost, and thus the author failed to obtain some species at least that must have been present earlier in the season.

3. There was a continual progress in the localities visited, seasonally, from late in June until early in September, and geographically from the Jellico and Pine Mountains in the extreme eastern part of Kentucky through the Cumberland plateau of central Kentucky and Tennessee to the lowlands of the western portion of the latter State. Such a combination of different localities, different dates, and different elevations would preclude any data with reference to seasonal distribution. My conclusions, therefore, must be general rather than specific, geographical rather than seasonal, and must deal with the habits and habitat of the various species, and not so much with their local distribution or relative abundance. In accordance with these suggestions the following may be fairly deduced:

1. Of the dragon flies here named it may be stated that the river is entirely patrolled by the two species of *Macromia*, by two of the *Gomphus* species, *plagiatus* and *pallidus*, and by *Dromogomphus spinosus*.

2. The two species of *Macromia* are to be found everywhere, over still water as well as at the ripples, on the river, along the banks, and in the fields at some distance from the water. Although not as numerous as some of the other dragon flies, nor bunched together in restricted areas like the species of *Gomphus*, the large size of these *Macromias* and their superior agility easily give them the supremacy, and they are admittedly the king dragon flies of the Cumberland Valley.

3. At the ripples the species of *Gomphus* are very much in evidence, the dark-colored *plagiatus* and the light-colored *pallidus* far surpassing all the others in their geographic range, as well as in actual numbers at any one place. They are the patrols of the swift water and are almost never seen except in its immediate vicinity. While not as powerful nor as active as the *Macromias*, yet their influence is greatly enhanced by this habit of congregating in considerable numbers at definite localities.

4. The function of *Dromogomphus* is that of a filler-in or supple-
menter. Along the quiet reaches of the river it completes the work
of the *Macromias*, at the ripples that of the two species of *Gomphus*,
and everywhere it makes good the deficiencies and omissions of these
other dragon flies. Although often far more numerous than the
Macromias, its inferior size and agility compel it to be satisfied with
second place. And at the ripples, while it could hold its own with
either species of *Gomphus* on equal terms, it is always greatly out-
numbered.

5. Among the damsel flies the two species of *Heterina* occupy the
same position as the *Macromias* among the dragon flies. While they
are found in greater numbers near swift water, they nevertheless
cover practically the entire river. But there is this difference, that the
species are separated, *americana* occupying the upper portions of the
river among the mountains, while *tricolor* is found in the lowlands
farther down. The species, therefore, can not be counted as two in
comparison with those of *Macromia*, but only as one.

6. Four of the species of *Argia*, namely, *moesta putrida*, *apicalis*,
tibialis, and *translata*, correspond very well with the two species of
Gomphus.

While they are not confined to the vicinity of swift water, like those
dragon flies, they do congregate in considerable numbers at favorable
localities.

7. The odonate fauna of the Cumberland River is thus made up
practically of these five dragon flies and six damsel flies, and all the
other species here enumerated are in a measure incidental or acces-
sory.

8. The general course of the Cumberland River is a crescentic
curve, convex toward the south, so that the mouth is practically on
the same parallel as the source. Nevertheless the combination of
mountains, an elevated plateau, and lowlands results in a correspond-
ing combination of northern, cosmopolitan, and southern species in
the odonate fauna.

CARD 1945

DEPARTMENT OF COMMERCE AND LABOR.
BUREAU OF FISHERIES.

Economic Circular No. 3 : : : : : : : : : : Issued October 26, 1912

MUSSELS OF CENTRAL AND NORTHERN MINNESOTA.¹

As a part of the series of mussel investigations conducted by the United States Bureau of Fisheries, the lakes and rivers of central and northern Minnesota were examined in 1912 to ascertain the kinds and quantity of mussels they contained. As this was a preliminary survey or reconnoissance, no attempt was made to locate all of the mussel beds or to determine their exact boundaries. The results which are of interest to mussel fishermen and pearl-button manufacturers may be summarized as follows:

GENERAL CONDITIONS.

Practically all this portion of Minnesota is covered with boulders, gravel, sand, and clay mixed indiscriminately, left by the melting of a great glacier which formerly swept over the State, and the inequalities of distribution of this glacial material have determined the location of most of the lakes and river valleys. Furthermore, the grinding action of the ice cut down the hills and filled in the valleys to a great extent, leaving a comparatively level surface. As a result, all the rivers and streams are very winding and have a rather slow current. The lakes are full of sand and gravel bars, and the bottom of both lakes and rivers is largely composed of sand and gravel, with a comparatively small proportion of mud. These conditions exert a marked influence on the mussels, and, taken in connection with the fact that the water is full of lime and clear, except in the rivers that drain from the Mesabi Iron Range, they make the entire region an exceptionally good one for mussel development.

For convenience the lakes and rivers are considered in six groups.

LAKE SUPERIOR DRAINAGE.

This contains no mussels of commercial value and practically none at all. From the St. Louis River, the largest in this drainage, mussels and fish are effectually shut out by the dam and falls at Carlton. And even if the fish had a clear passage, no mussels could thrive in the river below Floodwood on account of the immense number of logs driven down its waters every year.

¹By Charles B. Wilson and Ernest Danglade, whose complete report will be published by the Bureau later.
62484—12

ST. CROIX DRAINAGE.

Fish carrying mussels find a free passage from the Mississippi up the St. Croix and into its various tributaries. One of these, the Snake River, in Pine County, is full of fine mussels, as are also Cross Lake and Pokegama Lake, through which it flows. There are found here in great abundance the fat or grass mucket, the pocketbook, the butterfly, the three-ridge and the warty-back. The fat muckets are remarkably thick shelled and have a fine luster. In the latter part of July there were about two carloads of shells on each lake awaiting shipment. Although this locality has been reported as exhausted, the fishermen at work there had no difficulty in obtaining from 400 to 600 pounds of shells a day. It is also an exceptional region for pearls, many large and valuable ones having been obtained. Rush, Bald Eagle, White Bear, and Forest Lakes, in the same drainage, contain no mussels of commercial value.

There is a small blank factory in Pine City which uses most of the odd lots of shells obtained from the two lakes and Snake River.

RED-RIVER-OF-THE-NORTH DRAINAGE.

When the great ice sheet melted, a large lake was formed which filled the Red River Valley as far north as Lake Winnipeg. Its outlet was through Traverse and Big Stone Lakes, down the valley of the Minnesota River into the Mississippi. This lake is estimated to have lasted about a thousand years, and during that period the mussels had ample opportunity to migrate from the Mississippi up into the Red River. The latter was examined above and below Fergus Falls, at the outlets of West Lost and Ottertail Lakes, between Pine and Rush Lakes, between Little Pine and Pine Lakes, and at the inlet to Little Pine Lake. An abundance of good button shells was found at each of these places except the last. They included the fat or grass mucket, the pocketbook, the Wabash pig-toe (*Quadrula rubiginosa*), and the round pig-toe (*Q. coccinea*). A carload of these shells was shipped from Fergus Falls two years ago and proved to be good material. There are many more carloads available in the long stretches of river between the lakes of Ottertail County, and they are easily gathered, since the water in the river is nowhere very deep. The conditions in this river and in most of the lakes through which it flows are very favorable for commercial species of mussels. And there is every probability that other and more valuable species would thrive well if introduced here. For example, there are plenty of sand bars for the yellow sand-shell, gravel beds and running water for the common mucket, and excellent situations for the washboard, the niggerhead, the butterfly, and the pig-toes.

MINNESOTA RIVER DRAINAGE.

The Minnesota River itself is full of button mussels, as are most of its large tributaries, and many carloads are shipped from Granite Falls, Mankato, and other centers. These shells contain a large percentage of blue-points and three-ridges, and many of them are also spotted or thin at the tips, hence they do not appeal quite so strongly to the shell buyers.

And yet there is an abundance of good material here that is well worth utilizing. A blank factory at one or two of the central points on the main river would be able to use many tons of spotted and partially thin shells that are now rejected as not being worth the heavy freight rates down to Wisconsin and Iowa. Many of the lakes in Grant and Douglas Counties drain into the Minnesota River, but none of the 20 or more that were visited contained any commercial shells. Several of them, however, afford most desirable conditions for the propagation of valuable button mussels, as will be noted later.

MISSISSIPPI RIVER DRAINAGE.

The upper Mississippi includes by far the most important lakes and tributary rivers in the State. Beginning at the north there is an abundance of good button shells around Bemidji, both up the river above Lake Irving and down the river between Lake Bemidji and Cass Lake. One man collected 3 tons of fine muckets and pocket-books in a very small area at the outlet of Lake Bemidji, and 2 or 3 carloads could be obtained with little difficulty. The shells are of good size and luster and very few of them are spotted. Here again is an excellent location for a blank factory.

Cass, Winnebigoishish, and Leech Lakes contain no commercial mussels, but two of the tributaries of Leech Lake were reported by a mussel fisherman to be full of good button shells. The first was Linda River, which runs through a lake of the same name and empties into Leech Lake on the south. The other was Laura River, the outlet of Laura Lake, which empties into the east arm of Leech Lake. The shells found were muckets and pocketbooks.

Prairie River rises near Hibbing and flows down in Itasca County, through Prairie Lake into the Mississippi just below Grand Rapids. Both the lower river and the lake were examined and found to contain an abundance of fat muckets of excellent quality. They are of good size and fine luster, and are not spotted. Fully two-thirds of the shell could be utilized for buttons. Farther up the river there are large beds containing the common mucket and the pocketbook, as well as the fat mucket.

The Crow Wing River, together with its tributaries, the Fishhook, Shell, Redeye, Leaf, and Long Prairie Rivers, form practically one continuous bed of mussels. These vary somewhat in the different localities examined, but are usually abundant and of excellent quality. Two or three carloads have been shipped from the Shell River at Menahga and proved to be of extra value—large and thick and fine-lustered muckets, fat muckets, and pocketbooks. Two fishermen are now at work endeavoring to get another carload before cold weather. One peculiarity of these mussels is that the best ones are found under a mass of algæ and water weeds, and sometimes buried in the sand 2 feet or more, facts which offer a good suggestion for investigation of other localities. Another peculiarity is the thickening of the shells, even the paper shells and floaters being almost thick enough to cut buttons. Much of this river system is so far from railroads that the shells can hardly be used profitably, especially because, after hauling them to the railway, the freight charge of \$5 a ton to the nearest factory leaves very little return for the fishermen.

In talking the matter over with some of the musselmen, however, a way was suggested of obviating these difficulties. For \$200, the freight on a single car of shells, one could build and equip a small house boat for sawing out blanks. Floating with this down the river all the material could be used where it was obtained, spotted shells and shells with thin tips being as available as any others so long as there would be no freight to pay. For such an outfit the Crow Wing River system would furnish material for many years. It could be used also on the Prairie River, the Sauk River, and the upper Mississippi.

The Sauk River was visited at two places and found to be full of shells of fine appearance—muckets and pocketbooks. These are found all the way from Sauk Center to the Mississippi, a distance of 50 miles by the river. Upon testing, however, these shells proved to be brittle and unfit for buttons.

Clearwater Lake has some fine muckets and pocketbooks at the lower end, near the outlet; the Clearwater River, emptying out of it, was not visited, but was reported to be full of similar shells of fine quality and luster.

ISOLATED LAKES.

A large number of isolated lakes were visited, but no mussels of commercial value were found in any of them. Ideal conditions for the propagation of some of the most valuable mussel species exist, however, in several of the lakes. Buffalo and Pleasant Lakes in Wright County, Rice and Koronis Lakes in Stearns County, Osakis

Lake in Todd County, Battle Lake in Ottertail County, and Lake Minnewaska at Glenwood in Pope County are very favorably situated as regards railroad facilities, natural surroundings and conditions, and the proper fish to serve as hosts for the young mussels. The State of Minnesota has a fish hatchery at Glenwood, on the shore of Lake Minnewaska. Every spring when the wall-eyed pike are seined out of the lake to get their spawn there are always caught with them in the net large numbers of sunfish and yellow perch. These are the best fish that could be obtained for carrying young mussels belonging to the mucket (*Lampsilis*) group. It would be a simple matter to load these fish with the young of some mussel possessing high commercial value before putting them back into the lake. It is confidently believed that in this way the lake could be stocked in a few years with an abundance of good button mussels, and it would be a simple matter to keep up the supply when once it was established. If the experiment proved successful at Glenwood, the other lakes could be similarly stocked. It is the isolation of these lakes and the fact that fish could not get into them out of the rivers at the proper season of the year that has prevented the mussels from becoming naturally established there.

RECOMMENDATIONS.

As a direct result of the information obtained during this preliminary survey, the following recommendations can be made:

1. Suitable fishways should be provided for the free passage of fish around the 35-foot power dam 4 miles below Fergus Falls on the Red River, around all the dams within the city itself, and around the power dam across the Mississippi 9 miles below Bemidji. Mussels multiply well only where there is an abundance of fish. If the fish are stopped by a dam the mussels above the dam may not be able to multiply, and hence will disappear after the first generation.

2. It will be advisable to try the introduction of certain mussels into such of the more conveniently situated lakes as seem best suited for them. The United States Biological Station at Fairport, Iowa, and the local State hatcheries can profitably combine in this. The successful introduction of valuable shells into even a few of Minnesota's countless lakes would not injure the fishing at all, but rather improve it, and would add materially to the resources of the State.

3. It would be advisable, by the introduction of valuable button shells, to increase the present percentage of mucket and pig-toe mussels in the Red River of the North and in the St. Croix and Minnesota River drainages. Only muckets could be propagated in the upper Mississippi, since the Falls of St. Anthony at Minneapolis

have formed a natural barrier to the pig-toe mussels, and there are probably no fish suitable to carry them in the upper river.

4. Small local blank factories, like the one at Pine City, should be encouraged. They utilize otherwise unmarketable material, clean up the small and odd lots of shells, and open up localities that could not be reached from the larger centers.

If made in the form of a house boat, such a blank factory would render available the rich resources of several river systems that otherwise must remain absolutely unattainable.

1945-
DEPARTMENT OF COMMERCE AND LABOR.
BUREAU OF FISHERIES.

Economic Circular No. 1 : : : : : : : : : : Issued February 13, 1912

MUSSEL BEDS OF THE CUMBERLAND RIVER IN 1911.¹

As part of a series of such investigations by the Bureau of Fisheries, the mussel beds of the Cumberland River were examined in 1911 with reference to the quality and quantity of their yield of shells. For information of mussel fishermen, pearl-button manufacturers, and other persons especially interested in the subject the principal results of the examination are summarized in the following preliminary report.

LOCATION AND PRODUCTIVITY OF BEDS.

The Cumberland River rises in the extreme southeastern corner of Kentucky, flows westerly through portions of Kentucky and Tennessee, and empties into the Ohio at Smithland, Ky. It is navigable during high water from its mouth to Burnside, a distance of 525 miles, and a system of locks in process of construction will make navigation possible during the entire year.

Cumberland Falls, in Whitley County, Ky., form an impassable barrier for mussels and much of the other life in the river, and above the falls the ladyfinger (*Unio gibbosus*), which has no commercial value, is practically the only species. The lower river, from the pool at the foot of the falls to the mouth, abounds with mussels, as do all the tributaries. From Cumberland Falls to Celina, Tenn. (175 miles), mussels are fairly abundant and the beds are well distributed, but the percentage of unmerchantable shells, small species and "pinks," is too high, and there is no clamming for button-making purposes, though pearling is carried on in many places with good success. The best beds for commercial purposes are those at Indian Creek Bar, where the southern mucket is quite abundant; Selfs Bar,

¹ By Charles B. Wilson and H. Walton Clark, whose complete report will be published by the Bureau later.

from which several tons of shells have been taken by the pearlers; and Biggerstaff Bar, where there is a marked increase in merchantable species, notably the southern mucket, butterfly, three-ridge, and Ohio pig-toe.

In the second stretch of river, from Celina to Nashville, Tenn. (190 miles), more commercial shelling is carried on and not as much pearling. There are about 30 important beds of mussels distributed with considerable regularity in this portion of the river. About 3 miles below Butlers Landing, 7 tons of merchantable shells, mostly Ohio pig-toes and southern muckets, were collected a year or two ago and left on the river bank. At Dycus Landing clammers were at work in 1911, but had not collected enough shells to permit an estimate of their value. Below Carthage, at the foot of Goodalls Island, is a large bed of fine shells, upon which both clammers and pearlers were actively at work with fair results, and an Ohio River company is said to have taken 200 tons of good mussels from this locality. Half a mile below Cedar Bluffs 12 tons of shells were collected and cribbed a year ago, but were held for a higher market. There is also a fine bed at the head of Hills Island which has not been worked, at least not recently.

The third stretch of river, from Nashville to Dover, Tenn. (105 miles), has been thoroughly worked by clammers, and the location of all the beds, together with their size and relative value, are well known, largely because a factory for sawing blanks at Clarksville, Tenn., has furnished a ready market for the shells. The largest and most valuable bed of shells on the Cumberland is located at Gowers Island, 25 miles below Nashville. It is $3\frac{1}{2}$ or 4 miles in length and contains many fine niggerheads and yellow sand shells. Gaissers Bar, near Clarksville, has been worked for 10 years by from three to five boats, and was said to be as good as ever by clammers working on it in 1911. From the beds below Clarksville an enormous number of shells, estimated at 500 or 600 tons, have been taken during past years.

The remaining portion of the river from Dover to the Ohio (85 miles), while it has not been worked as much as the preceding portion, probably contains as many and as valuable mussels. There are numerous beds near Dover, Tenn., and at Linton, Donelsons Creek, Canton, and Kuttawa, all in Kentucky. In these beds there is a noticeable increase in the percentage of niggerheads, while the proportion of Ohio pig-toe remains about the same.

From Lock 21, situated 27 miles below Burnside, Ky., to Carthage, Tenn., a distance of 200 miles, the river is still in its natural state, abounding in riffles and shoals, and the current is strong enough to permit the use of brails in collecting mussels. Those por-

tions flooded by backwater from the locks have no current, and tongs are required, but the quiet water forms a favorable breeding place for mussels and the beds grow faster and thrive better than in a swift current. Unlike the upper Mississippi, there is little or no independent clamming on the Cumberland. In most cases the clambers do not own their outfits, but collect the mussels by contract for the person furnishing the boats.

On account of the high percentage of pink shells, clamming is not very profitable in the upper portion of the Cumberland, but if the southern mucket were artificially propagated there it would soon reduce this percentage and make the mussel beds commercially valuable.

THE IMPORTANT SHELLS.

Eighty-six species of mussels are now known from the Cumberland River, of which only about 17 can be used for button making, the rest being too small or too thin. Among these 17 there are but 5 really important species—the niggerhead, the Ohio River pig-toe, the southern mucket, the butterfly, and the yellow sand shell.

The niggerhead (*Quadrula ebena*) is the most important shell on the lower river, but the means of propagating it have not yet been discovered. It is doubtful whether it would succeed in any but the lower part of the river, as it requires rather deep water, and it has probably extended its range up the river as far and as abundantly as it found conditions favorable.

The Ohio River pig-toe (*Quadrula obliqua*) is the most common commercial shell in the central portion of the river. While a good button shell, it is considerably inferior to the niggerhead, and since better shells are easily procurable, this one would not make a particularly desirable species to propagate in the river unless the conditions were especially favorable.

The southern mucket (*Lampsilis ligamentinus gibbus*) is an unusually good button shell, fully equal to the best of the niggerheads. It is quite flat and uniform in thickness, so that there is little waste. It could be easily propagated, since it has a long breeding period, and the glochidia fasten themselves readily to sunfishes, perch, and bass. It will thrive also in a great variety of situations, so that, everything considered, it would be much superior to any other species for the restocking of the river.

The butterfly (*Plagiola securis*) is rather common throughout the whole length of the river. Near the mouth of the river the shells are badly stained, but above Canton, Ky., they have an excellent white nacre. The species reaches a large size in the Cumberland, and the sexes are strongly marked, the females being humped and

inflated. Next to the preceding species, this would be the most desirable to plant in the river, and it also has a long breeding season.

The yellow sand shell (*Lampsilis anodontoides*) which is the most valuable of fresh-water shells, occurs occasionally in the Cumberland, and was quite common at Meeks Spring Bar. These shells are generally exported to be manufactured into knife handles, etc., and are thus of interest to shippers rather than to local manufacturers.

The "washboard" also occurs in most of the mussel beds, but is usually badly stained, and its shells are always sorted separately and sold as second grade. It reaches a large size, but is not as immense as in the Wabash or Mississippi.

CARD 1943

DEPARTMENT OF COMMERCE AND LABOR

BUREAU OF FISHERIES

GEORGE M. BOWERS, *Commissioner*

THE MUSSEL FAUNA OF THE MAUMEE RIVER

Bureau of Fisheries Document No. 757

WASHINGTON
GOVERNMENT PRINTING OFFICE

1912

DEPARTMENT OF COMMERCE AND LABOR

BUREAU OF FISHERIES

GEORGE M. BOWERS, *Commissioner*

THE MUSSEL FAUNA OF THE MAUMEE RIVER

Bureau of Fisheries Document No. 757

WASHINGTON
GOVERNMENT PRINTING OFFICE

1912

THE MUSSEL FAUNA OF THE MAUMEE RIVER

By H. WALTON CLARK and CHARLES B. WILSON

Bureau of Fisheries Document No. 757

CONTENTS.

	Page.
Introduction.....	3
Geology and geography of Maumee and upper Wabash Basins.....	4
Biology of Maumee River.....	8
Mussel survey.....	10
Headwaters of Maumee and Little Wabash Rivers.....	10
St. Marys River and Spy Run.....	11
St. Joseph River and feeder canal.....	18
Maumee River.....	25
Discussion of mussel species.....	39
General distribution of shells in Maumee River.....	55
Food of Maumee mussels.....	57
Parasites of Maumee mussels.....	61
General conclusions.....	71

THE MUSSEL FAUNA OF THE MAUMEE RIVER.

By CHARLES B. WILSON and H. WALTON CLARK.

INTRODUCTION.

This report embodies the results of an investigation of the mussel fauna of the Maumee River, carried on under the auspices of the United States Bureau of Fisheries during the summer of 1908, and it represents a part of the series of investigations undertaken by that Bureau looking toward means of continuing the supply of mussel shells. Upon this supply, which had begun to show signs of serious depletion, depends one of the important industries of the country, the pearl-button industry of the Mississippi Valley.

The scope of the inquiry embraced whatever appeared to be closely related to mussel life, such as the history and character of the river and its present mussel supply as regards abundance, quality, and species. It was desirable also to ascertain where good breeding stock might be obtained, the location, character, and condition of mussel beds, and circumstances in which different species appeared to thrive. Such features of general life history as food, habits, time and manner of spawning, enemies, and parasites were also noted whenever opportunity offered.

In the choice of the area to be studied, the features to be emphasized during the investigation, and similar details we have had the direction and advice of Dr. Barton W. Evermann, Chief of the Division of Scientific Inquiry of the Bureau of Fisheries. His counsel has been of great assistance in the preparation of this report.

In addition to the Maumee River, the upper part of the Wabash Basin was also investigated, in order that the two basins might be compared where they are close together. This latter part of the work also yielded many interesting results, especially in the spawning habits of mussels and the life history of parasites. The results of the Wabash investigation are frequently referred to briefly where they carry on lines left incomplete by the Maumee studies.

The authors had as an associate in the work Mr. Donald M. Earll, of Washington, D. C., to whom is due much credit for the results.

During the Maumee investigations, not only the main river, but also the two streams which unite to form it, the St. Joseph and St. Marys, were examined for the last few miles of their course, and the other principal affluents, the Tiffin and the Auglaize, were likewise investigated for a short distance above where they join the Maumee. Other bodies of water flowing into the Maumee or closely related to its basin, such as the feeder canal at Fort Wayne and its reservoir, and Spy Run, a small tributary to the St. Marys not far above its mouth, were studied. Below Defiance, Ohio, the Miami and Erie Canal runs parallel with the river, and was followed to avoid the riffles and difficulties of navigation to be encountered in the main stream. It offered a favorable subject of research in itself and the Maumee could readily be examined from time to time, as that river was never any great distance away.

During the trip to the United States fish hatchery at Put-in Bay, Ohio, opportunity was taken to examine the mussel fauna of that region. This gave data for inference as to which species had probably ascended the Maumee from Lake Erie and which had entered more recently from the Wabash system. It also furnished a basis for comparison between the river and the lake mussels as regards size, etc.

The authors are about equally responsible for the work. To Mr. Clark belongs the credit for the final determination of the mussel species, all of the observations on the food of mussels, and most of those upon the parasites. Dr. Wilson supervised the work and has furnished the geological and geographical distribution and most of the notes upon the various stations.

GEOLOGY AND GEOGRAPHY OF THE MAUMEE AND UPPER WABASH BASINS.

Although the Maumee River flows into Lake Erie and is therefore a part of the great St. Lawrence system, while the Wabash flows into the Ohio and thence to the Mississippi, the basins of the two rivers have been so intimately connected in their geological history and topographical features, as well as by the artificial connections established during the existence of the Wabash and Erie Canal, that they are practically one. Even at the present day the headwaters of the Little Wabash River approach within 3 miles of the St. Marys River and still nearer to small affluents of that stream, and when the white settlers first came to Fort Wayne they found this point an important portage for the native Indian tribes. There is no perceptible divide between the two basins, and a large open country ditch still unites them through an old flat lake plain known locally

as "the prairie." A careful examination of this ditch revealed no mussels at all, and it is not likely they could live in the mucky bottom, though it is possible that glochidia might be carried through the stream by migrating fishes.

During the glacial period the entire region was buried under the ice, and every form of molluscan life was exterminated. At the melting of the ice sheet great bodies of water were formed which could find no outlet to the eastward on account of the still unmelted ice, and therefore all the water was compelled to drain toward the south and west into the Ohio and Mississippi Valleys. The old channels can still be traced and are represented on the geological maps of the region. The geologists tell us that at first there were two of these lakes entirely separated from each other. The easternmost one, Lake Maumee, covered the present basin of the Maumee River and the upper part of the Wabash Basin and was 100 feet higher than Lake Chicago, which lay to the west. Lake Maumee drained through the Maumee and Wabash Valleys into the Ohio, while Lake Chicago found an outlet along the Des Plaines and Illinois River Valleys.

The restocking of the region with mussels must have been effected by migration through these respective outlets. At this period several of the more hardy species came up through the Wabash Basin into Lake Maumee, as is attested by the finding of their shells among the fossils of the period. At the beginning, therefore, the Maumee Basin was restocked with Ohio Valley species of mussels, which came to it by way of the Wabash River.^a

After the ice had retreated far enough northward to reveal the surface features of the region under discussion, it exposed the valley of an ancient preglacial river, sometimes called the Huronian River, and now known as the Saginaw-Grand Valley. This river valley runs east and west across the southern part of the State of Michigan and became a channel connecting the two lakes just mentioned. The opening of this channel gradually lowered the water in Lake Maumee to the level of that in Lake Chicago. A series of terminal moraines which had formed along the southern margin of Lake Maumee were enabled by this lowering of the water to assert themselves and close the Wabash outlet. These moraines are known to geologists as the Mississinewa Moraine, to the south and west of which lies the Mississinewa River, the Salamonie Moraine, to the north and east of the Salamonie River, the Wabash Moraine to the north and east of the main branch of the Wabash River, the St. Joseph-St. Marys Moraine to the east of those two rivers, both of which drained originally into the Wabash, and the Defiance Moraine

^a For an interesting discussion of this subject, see Simpson, *American Naturalist*, vol. xxx, p. 379-384.

to the east of the Tiffin and Auglaize Rivers. The former drainage of the St. Joseph and St. Marys Rivers through the Wabash is indicated by the peculiar turn they make at Fort Wayne, where they unite to form the Maumee. This sudden change, of course, is so striking a feature that it has excited comment by almost everyone who has considered the topography of the region. The situation is well expressed by Mr. Simpson who says:

The St. Josephs, St. Marys, and Auglaize Rivers, tributaries of the Maumee, flow in the direction of the Wabash; the two former join at Fort Wayne and flow partly backward as the Maumee, the whole looking like a tree with its branches broken down and hanging against its trunk.^a

From the time of the closing up of the Wabash outlet until the St. Lawrence was reopened, the only outlet for Lake Maumee was through the Huronian channel into Lake Chicago, and thence into the Des Plaines and Illinois Rivers. All the mussels, therefore, which took part in restocking Lake Maumee during this period belonged to the Illinois River fauna and entered the lake by this roundabout channel. The Unionidæ are essentially inhabitants of shallow water and would have spread along the margin of these glacial lakes. As the level of the lakes was gradually lowered and the present system of drainage was established, the mussels naturally followed the retreating waters, and thus finally found their way into the river beds where they now live.

This account of the origin of the present mussel fauna in the Maumee and upper Wabash Basins is adapted from several geological reports of the States of Indiana and Michigan and from an excellent paper on the "Distribution of the Unionidæ in Michigan" by Bryant Walker.^b

From the foregoing account of the manner in which the stocking of the Maumee Basin took place, it would naturally be inferred that in the lists of species of mussels obtained at the various stations on the Maumee and Wabash Rivers by the party, there should be more than the usual amount of similarity between those from the headwaters of the two rivers, and this similarity should decrease the farther down the respective rivers the comparison is made. Such we find to be actually the case. (See p. 38.)

But there is another factor which may at least claim a share of the credit for the correspondence in species.

The Wabash and Erie Canal was in active operation between these two rivers for nearly half of the last century. Starting at Toledo, Ohio, it ran along the bank of the Maumee for the entire length of that river to Fort Wayne. There it crossed the narrow strip of country between the headwaters of the two rivers, ran along

^a American Naturalist, loc. cit.

^b Author's separate of a paper read before the Michigan Academy of Science, March, 1899.

the edge of the old lake plain or "prairie," near the Indian portage and at no great distance from the Little Wabash, struck the main Wabash below Huntington, Ind., and then followed the latter river down to the Ohio. This canal was fed from the two rivers and opened into them at various points along its course.

There was thus established a channel of communication which, during its half century of existence, must have resulted in the exchange of many species of mussels, as well as other portions of the fauna of the two rivers.

Such a canal furnishes an excellent breeding ground for mussels, as is well shown in the case of the old feeder canal at Fort Wayne (p. 19) and the Miami and Erie Canal still in existence between Defiance and Toledo (p. 34).

This artificial opportunity for interchange of species, occurring so recently, must have greatly supplemented the original similarity due to the former identity of the drainage basins. It would also go far toward destroying any local peculiarities that might have developed since the two basins were separated.

The Maumee Basin is situated in the northeastern part of Indiana and the northwestern part of Ohio, and covers an area of 6,500 square miles. There are no large hills in or around it, it being a flat glacial plain, covered with moraines and low ridges. The basin abounds in clay and solid subsoil, so that the river is rather muddy most of the time. The water is also quite hard, furnishing an abundance of lime to the mussels for their shells. In the upper part of the river, as far down as Defiance, Ohio, there is considerable sand and gravel bottom, but below Defiance a good deal of the bottom is solid bedrock. As already stated, the Maumee is a very young river in point of geological time, yet, next to the Detroit River, it is the largest tributary of Lake Erie and is one of the largest rivers within the State of Ohio. The Maumee is formed by the junction of the St. Joseph and St. Marys Rivers, just beneath the Columbia Street Bridge in Fort Wayne, and flows northeast to Lake Erie at Toledo, Ohio. From origin to mouth is about 100 miles in a straight line, but as a result of the angular or crescentic form of the glacial moraines which separate the Maumee from the Wabash Basin, the river winds greatly, especially that portion of it above Defiance, and thus adds fully 50 miles to its length.

As might be expected, the current is not very swift except during high floods, since the river falls but 164 feet in its entire course, or a trifle over a foot a mile, and much of this is accumulated in a series of riffles at Defiance and Grand Rapids. Elsewhere the river is made up of long, sluggish stretches, alternating with short riffles of varying lengths, and it is in the vicinity of the latter that most of the mussels are found.

Through the removal of most of the forests which once covered the area about its headwaters, the current and depth of water are not so constant as they once were, but the river rises and falls more suddenly, and is usually considerably more turbid or muddy than formerly. The height and activity of the river in times of flood are strikingly manifested by the tangled piles of drifted logs and brush up on the flood plain high above the normal surface of the river.

This change in the steadiness of flow of the river, with the accompaniment of a more shifting bottom, has probably had considerable effect on the mussel life of the stream.

BIOLOGY OF THE MAUMEE RIVER.

Through the abandonment of the Wabash and Erie Canal, which took place nearly 30 years ago, and the draining and gradual drying up of the old lake plain or prairie, the Maumee River has become isolated from the Wabash, so that there has been no transference of species for some time.

In the course of our work our attention was devoted chiefly to the mussel fauna. The general features of the river and its inhabitants, both plant and animal, undoubtedly have many important relations to the mussels, but, on account of the limited amount of time at our disposal and the impracticability of carrying on several lines of work at once, only such features were noted as appeared to have some evident bearing on mussel life. In the St. Marys River and about the region of Fort Wayne, where conditions were favorable, the river was more thoroughly explored than elsewhere, the flora and fauna were noted, and the stomach contents and parasites of the mussels were examined. All along the way stomach contents and parasites were preserved for future study.

A valuable addition to our knowledge of the biology of the Maumee Basin has been furnished by a report of the investigations made by Philip H. Kirsch during the summer of 1893 and published in the Bulletin of the United States Fish Commission (vol. xiv, for 1894). This report refers to an abundance of algæ in various places, and furnishes a list of 87 species of fishes, 3 species of mussels in the Maumee, 4 species of crawfishes, 7 of batrachians, 6 of snakes, and 6 of turtles. In this report the remark is made that mussels are common.^a They are, however, only incidentally mentioned, so that

^a The mussels obtained by Kirsch during these investigations were later turned over to Mr. C. T. Simpson for examination. In an interesting discussion concerning the "Mississippi Valley Unionidæ found in the St. Lawrence and Atlantic drainage areas," in the American Naturalist, vol. xxx, p. 379-384, Mr. Simpson remarks of these shells:

"This changing of characters" [a number of changes have just been discussed] "has been well illustrated in a lot of Unionidæ recently submitted for examination by Prof. B. W. Evermann, of the U. S. Fish Commission. * * * *Unio luteolus* Lam., *U. subrostratus* Say, *U. circulus* Lea, *U. phaseolus* Hild., *U. multiplicatus* Lea, *U. multiradiatus* Lea, and *Anodonta grandis* Say, are so dwarfed and stunted and changed in color as to be scarcely recognizable, while the same species from the Wabash from which these have no doubt all been derived, are as vigorous and finely developed as any in the Mississippi Valley."

Kirsch's report and the present one may be regarded as supplementary to each other.

The following general observations were made concerning the biology of the stream:

Among the aquatic plants, *Oscillatoria* was abundant in the St. Marys River and the upper portion of the Maumee down as far as Kern Reservation, 7 miles below Fort Wayne. In the St. Marys this plant was found floating in large blackish or blue-green bunches on the surface of the river; ^a farther down much of the floating *Oscillatoria* seemed recently washed in. Filamentous algæ, probably *Cladophora*, grew on the rocks in the bottom and occasionally on the shells of the mussels. Wild celery (*Vallisneria spiralis*) was abundant on the bottom of the St. Marys at Fort Wayne, but was not conspicuous farther down. The dense-flowered water willow (*Dianthera americana*) fringed the edges of the river and lower portions of the canal all along the way and was one of the plants most constantly seen. During the latter part of the cruise along the Miami and Erie Canal this plant was covered with large tangled clumps of dodder, so that the prospect either way along the canal was lined with great masses of yellow here and there. Algæ of many sorts grew in great abundance in the Maumee below the dam at Defiance. Portions of the canal from Napoleon, Ohio, to the locks below were covered with a dense scum of delicate little water fern, *Azolla caroliniana*. Along the lower stretches of the canal *Ceratophyllum* was abundant in stretches of quiet water. *Typha latifolia*, the narrow-leaved cat-tail, formed a dense hedgelike growth along the edge of the canal in places. The spatterdock, *Nymphæa advena*, was fairly common along the lower reaches of the canal and the white water lily, *Castalia odorata*, occasional. Duckweeds were common in the canal, but not noted in the river.

As to animal life, various species of protozoa were very abundant in one place in the St. Marys, as will be described later on. (See p. 13.) They were not noted farther down the river; however, there was little opportunity to examine carefully for them. No plankton was taken, but the material examined from the stomachs of mussels probably gives a fair notion of the nature of the smaller free plankton elements. Sponges and flatworms were rather common on rocks and shells the whole length of the river. In addition to the mussels, various mollusks such as *Pleurocera*, *Ancylus*, and *Sphærium* were common. Crawfishes were abundant everywhere in the river, but were not often noted in the canals. Aquatic insects and larvæ were not

^a Further observations show that the presence of *Oscillatoria* and other minute organisms is a periodic phenomenon. They accumulate during periods of low, stagnant water but altogether disappear during periods of high water with rapid current.

especially abundant, except below the dam at Defiance. According to residents of the region along the river, fishing was in general rather poor, although in a few places, as several miles above Defiance and below Defiance Dam, angling was enthusiastically carried on by men wading out in the stream in high boots and casting. In the autumn of 1907 a good deal of angling was observed in the St. Joseph River just above its mouth, at Fort Wayne. The anglers there were catching a good number of the wall-eyed pike, or pike perch, *Stizostedion vitreum*, which they called "pickerel." We did not see many fishes in the water during most of the cruise, although at Fort Wayne, where we had opportunity to examine carefully, a number of species were observed, and all along the Maumee the small-mouthed black bass seemed fairly common. The darting fishes frequently struck the boat with resounding whacks and occasionally jumped over the boat or even over our heads as we sat in the boat. They frequently jumped against different members of the party and fell back into the water, and 6 examples, most of them quite large and fine, jumped into the boat and were captured. At one place, a little above Woodburn, Ind., we passed through a large school of basking gars.

Among aquatic birds and waders, kingfishers (*Ceryle alcyon*) were fairly common, green herons (*Ardea virescens*) and the great blue heron (*Ardea herodias*) were quite abundant, the former along shore or on branches of trees and the latter standing statuesquely on rocks in midstream and rising with a low level flight as we approached. We saw several small flocks of wood ducks (*Aix sponsa*) which seem to be summer residents. Sandpipers were common along shore and flocks of killdeer occasional on bars. On account of the northern latitude it is perhaps worthy of note that the song of the Carolina wren came to us frequently from the woodlands along the upper stretches of the river.

No aquatic mammals were seen, although occasional shell piles gave evidence of the presence of a few muskrats.

MUSSEL SURVEY.

HEADWATERS OF MAUMEE AND LITTLE WABASH BASINS.

The region in and around Fort Wayne is of peculiar interest, since it is the borderland between the two river basins, and also furnishes much evidence of the influence of the old Wabash and Erie Canal upon the mussel fauna. For this reason, considerable time was spent here before beginning the specific work upon the basins themselves. Most of the localities reported upon were worked over several times

in order that there might be a reasonable certainty that all the resident species had been found. A careful study was made of the species themselves and data collected as regards food, parasites, etc. The localities examined include the St. Marys and St. Joseph Rivers, Spy Run, a small tributary of St. Marys, and an old feeder canal and its reservoir which was formerly connected with the St. Joseph River.

The Aboit and Little Wabash Rivers, which belong to the Wabash system, were also examined. The stations at these localities are designated by letters, those on the main river by numbers. The relative abundance of the different species at each station is indicated by giving the number of examples obtained, or by remarks.

ST. MARYS RIVER AND SPY RUN.

In the St. Marys River the shells are scattered irregularly everywhere, so that along the bank a few dead shells may be found every now and then, or an occasional live mussel seen in the water. There are a few shell beds, all of small size, however, where conditions appear to have been exceptionally favorable for the development of molluscan life, and at such places the mussels are fairly abundant.

Station A. Above the Bluffton Road Bridge, at Fort Wayne.—The highest point at which the St. Marys River was examined was above the Bluffton Road Bridge, about 4 miles from the mouth of the river. At this place there were riffles and the remains of an old dam, and the point lies above the entrance of most of the sewage of the city. The water was shallow and the bottom covered with gravel, sand, or mud, according to the rapidity of the current. At the date examined (June 26) the water was quite turbid and nothing could be seen on the bottom. We had heard reports of a goodly number of shells there, but by wading about considerably we found only a few. The living mussels were hard to find, partly because of the stony bottom and partly because of their actual scarcity. A man fishing at the place was offering boys who were swimming near by 5 cents apiece for mussels, which he wished to use for bait, and it was noteworthy that although the boys were searching diligently the fisherman was not oversupplied. We found a fair number of dead shells on the shore, representing 18 species.

The little *Truncilla sulcata*, which seemed on the whole a rather rare shell, and of which during the entire summer's work we found only 1 live example (although scattered valves were occasionally found along the river bank), seemed unusually common here; we obtained 4 entire shells and 10 valves. None of the larger species of mussels were present in sufficient numbers to be of commercial value,

while all of the others were either too small or so discolored as to be unfit for use.

The river was followed from this point down to Swinney Park, a distance of about a mile and a half, but practically no shells were seen, and men wading in the river fishing for crawfishes with dip nets knew of none. From Swinney Park down to the riffles, soon to be discussed, the river had been examined fairly well during the previous year, and no shell beds of any importance had been found. Occasionally dead shells had been seen scattered along shore and in one place a few large *Lampsilis ligamentinus*, which had probably been killed by fishermen for bait.

Station B. Riffles, St. Marys River below the Van Buren Street Bridge.—The most important bed found in the St. Marys River was at the riffles, about an eighth of a mile below the Van Buren Street Bridge and across from the city waterworks pumping station.

The riffles are conveniently near the residence of Miss Elizabeth J. Bowman, at 719 Michael Avenue, who very kindly gave us the use of her house and grounds as a laboratory headquarters for the work in and around Fort Wayne. Being so favorably situated, this station was repeatedly visited and the mussels obtained were carefully examined for food, parasites forming pearls, etc.

As the opportunity for doing laboratory work is rather rare in moving field parties, and as it was supposed that this mussel bed would be fairly typical of others we would encounter but would not have opportunity to study fully, this bed was investigated and the observations noted in considerable detail.

The stretch of river above the mussel bed was about 8 feet deep at its greatest depth and 60 or 80 feet wide, with a sandy bottom, and was used by the boys as a swimming-hole. A large quantity of sand for building purposes had been hauled out of the river at this place and screened some little distance from the river bank. Among the screenings was a fair number of mussel shells of different species and shells of *Pleurocera* and *Sphærium*. The species of mussels represented by the shells among the screenings were *Quadrula rubiginosa*, *Q. undulata*, *Pleurobema clava*, *Unio gibbosus*, *Symphynota complanata*, *Anodonta grandis*, *Lampsilis gracilis*, *L. rectus*, *L. ligamentinus*, and *L. luteolus*. There were not many live mussels to be found in this stretch of the river, probably on account of disturbances caused by the hauling of sand.

There were also few found below the riffles, as the stones were too thick in the river bed to furnish any foothold. The shell bed itself was therefore on a slope between the shallower portion of the riffle and the deeper sandy bottom upstream. The bottom on which the

mussels were located was composed of mingled sand and pebbles. The water over the mussel bed was shallow, averaging about 2 feet in depth during the period of observation, and the current was moderate, 3 or $3\frac{1}{2}$ miles per hour. The water varies considerably in depth and turbidity at different times; even a small local shower raises the surface perceptibly and makes the water very muddy, after which it slowly abates in volume and becomes clear. While this mussel bed was under observation it was occasionally rendered unworkable for a few days by local showers. On the other hand, the water was sometimes found clear enough to see the bottom with a fair amount of distinctness.

The life conditions of the riffles and the swimming hole just above it were studied in considerable detail. The river flora did not appear to be particularly rich. The only conspicuous alga was a species of *Oscillatoria*, which was very abundant on the surface in large floating blue-black patches from which the filaments radiated in every direction. Of phanerogams, the only aquatic plants growing in the river at this place were eelgrass or wild celery (*Vallisneria spiralis*) and the dense-flowered water willow (*Dianthera americana*).

The animal life was rich and rather varied. One of the most abundant animals was a *Vorticella*-like protozoan, probably *Epistylis*, which thickly covered with a uniform hoary coating the blades of *Vallisneria* and the branches and leaves of willow which dipped into the water. The same or a similar protozoan grew in great abundance on the crawfishes of all sizes, especially thickly on the antennæ, which were rendered quite white and plumose. Examples of the protozoan taken from the crawfishes showed the zooids thickly clustered at the apex of a long nonretractile dichotomously branching stem. On account of the nonretractility of the stem, this white coating can not contract into a mass when irritated as can colonies of *Vorticella*. A small colony of *Vorticella* was found clustered on an *Atax* taken out of a mussel. A species of fresh-water sponge was very common below the shell bed, frequently coating the inside of dead valves with an expanded thick feltlike covering. The brown hydra (*Hydra fusca*) was quite abundant, and numerous examples were seen attached to the back of shells of *Ancylus*. Leeches did not seem to be abundant; the only one noted was a fish leech attached to a sunfish caught in the river.

In addition to the mussels, discussion of which will be reserved till the end of the description of the locality, various univalves such as *Pleurocera*, *Physa*, and *Ancylus* were common.

The crawfishes were so abundant at this place as to deserve special mention. So far as examined the species was *Cambarus virilis*

Hagen, and the river bottom appeared to be almost overpopulated with them. The young were often seen crowding up close to the shore. As noticed above, many were thickly covered with a growth of protozoa, and some of the young were covered with a green algal growth. In the mussel bed the crawfishes were seen sunning themselves on the rocks which projected out of the water, lifting themselves high upon the pincers in a most peculiar fashion. Upon wading out to a large projecting rock situated in the river about in the middle of the mussel bed they were found to be clustered thickly on the sloping surface of the rock just at the water line, their heads projecting out of the water. Many were found living in dead mussel shells just below the bed; indeed, it was hardly possible to pick an old shell or tin can out of the water without obtaining a crawfish. Some of those thus captured were of very large size. The crawfishes were frequently observed devouring the flesh of dead mussels, but it is doubtful whether they were able to kill any, especially the larger ones. They may possibly be an intermediate host of some of the mussel parasites. The crawfishes were caught in considerable numbers, either by dip nets or minnow seines, for fish bait and were used in the St. Joseph River. On July 2 a man was observed seining crawfishes just below the mussel bed at the riffles. The seine was drawn over the bottom, which was covered with rounded pebbles about the size of hen's eggs or larger, and the ends of the brails poked about among the rocks. The crawfishes, of which it seemed there was one under nearly every stone, backed up into the net and were caught in great numbers. The fisherman wanted only the soft-shells and "peelers" (crawfishes about to molt) and threw the rest back. A great number were molting at the time. The "peelers" can be easily distinguished from other crawfishes by pressing the sides of the carapace, which arches up free from the body. They also have a somewhat different color. The molted carapaces of crawfishes and gastroliths associated with them were quite common along the shore of the river.

No crustaceans except crawfishes were noted in the river itself, though small Entomostraca were abundant at the edge of the river, in overflow pools.

Aquatic insects and larvæ did not appear to be particularly abundant so far as species were concerned; a few forms, however, were quite common. The red "blood worm" (a *Chironomus* larva) was present in large numbers, and along shore, just under the water surface and attached to submerged objects by a short slender pedicel, was a great number of small gelatinous pear-shaped objects full of minute dots, probably egg bunches of *Chironomus*. Midges were abundant, emerging in great numbers; on the morning of June 21

there were many exuviae on the water surface and on objects along shore. Many of the insects died shortly after emerging.

On the first visit to the swimming-hole, the afternoon of June 14, a large number of johnny darters (*Boleosoma nigrum*) and a few minnows were observed dead along shore. All the fishes were quite small, apparently the young of the year. It is very likely that some sudden pollution of the river about that time was the cause of the death of the fishes as well as that of a great number of large crawfishes on shore and mussels in the water. Some time during the summer it was reported that dyestuff had been poured from the knitting mills some distance above into the river and had caused a wholesale destruction of fishes, which died in such numbers as to render portions of the city along the river scarcely habitable. In addition to the dead fishes mentioned above, the following species were observed: Catfishes (young, probably *Ameiurus natalis*), mad toms (*Schilbeodes gyrinus*), golden shiners (*Abramis crysoleucas*), carp (*Cyprinus carpio*), and sunfishes (*Eupomotis gibbosus*). In the previous year a number of small black suckers (*Catostomus nigricans*) were seen at this place.

Of reptiles, a few painted turtles (*Chrysemis marginata*) were found. There were no indications of aquatic mammals, such as tracks or piles of shells along the shore. Late in autumn, however, a good many crawfishes were seen along shore with backs bitten open, and this may have been done by a muskrat or a mink.

As has been said, although a few mussels could be found above the main bed, the greater number were to be obtained just at the head of the riffles in a fairly compact bed. The mussel bed itself is quite small, probably not more than 2,000 square feet in extent, and commercial operations would clean it out in a very short time. On several occasions the water was clear enough to see the bottom and the distribution of the mussels fairly well. The mussels did not appear to be moving. They were headed mostly downstream, the natural position for feeding mussels, and were not deeply buried; about half of the shell projected out of the mud. The projecting portion was more or less stained and frequently covered with an algal growth.

On June 20 this bed was gone over with considerable thoroughness and a number of mussels collected. These were placed on shore, counted, and sorted over, and, after a number of representative shells such as were desired for specimens were picked out, the rest were thrown back. All the shells, especially *L. rectus* and *L. ligamentinus*, were large and fine. A number of the living animals were measured and weighed, with the results shown on the next page.

MEASUREMENTS AND WEIGHTS OF ST. MARYS RIVER MUSSELS.

Serial No.	Species.	Length.	Height.	Thickness.	Weight.
		mm.	mm.	mm.	Ounces.
1	<i>Quadrula undulata</i>	115	85	48	10.75
2	do.....	104	77	45	8.25
3	do.....	102	82	44	8.50
4	do.....	86	67	35	4.75
5	do.....	80	60	35	3.75
6	do.....	76	60	31	3.50
7	do.....	72	57	30	3.00
8	<i>Lampsilis rectus</i>	158	70	50	13.75
9	do.....	159	67	47	14.50
10	do.....	134	60	40	7.75
11	do.....	150	66	47	13.75
12	do.....	153	74	48	12.75
13	do.....	141	66	42	12.50
14	do.....	154	68	50	8.75
15	<i>Lampsilis ventricosus</i>	126	90	54	13.75
16	do.....	110	80	45	8.25
17	do.....	83	67	40	4.75
18	<i>Lampsilis ligamentinus</i>	137	83	53	16.50
19	do.....	135	84	55	15.50
20	do.....	145	88	58	18.25
21	do.....	135	83	55	15.75
22	do.....	131	82	58	14.75
23	do.....	132	80	49	13.75
24	do.....	130	80	49	11.75
25	do.....	126	79	51	12.00
26	do.....	131	79	52	12.75
27	do.....	122	79	48	12.25
28	do.....	115	79	48	10.75
29	do.....	97	63	40	5.25
30	do.....	120	75	55	11.75
31	do.....	122	80	45	10.00
32	<i>Lampsilis luteolus</i>	124	70	46	9.25
33	do.....	127	73	52	10.75
34	do.....	134	71	49	11.00
35	do.....	127	74	56	11.75
36	do.....	126	76	50	10.75
37	do.....	118	69	51	9.25
38	do.....	102	60	48	6.50
39	do.....	92	60	37	4.90
40	<i>Symphynota costata</i>	123	68	36	6.75
41	do.....	95	56	28	3.25
42	do.....	111	65	31	4.75
43	do.....	113	66	38	5.75
44	do.....	95	55	27	3.00
45	do.....	111	60	33	5.25
46	do.....	101	55	29	3.50

Below the mussel bed and also in it were a large number of dead shells. These were covered with water and appeared to be still as good for commercial purposes as ever, since they retained their original texture and luster. Some of the shells that had been longest dead were stained black, perhaps from iron in the water, but this color was superficial and could have been easily ground off. The mussels appeared at the time of our visit to be dying in some numbers, for a good many still retained the position they had during life and the flesh was still clinging to the interior of the shell. Some of the larger living shells were diseased and stained brown or green in the neighborhood of the cardinal teeth.

The stomachs usually contained considerable mud, in which was scattered a few diatoms, *Scenedesmus*, *Phacus*, etc.; the amount of organic material was quite small. The results of studies of stomach

contents are given in detail under the general heading at the close of this report. (See p. 57.)

When examined in June these mussels were strikingly barren. The only gravid individual noted was an example of *Lampsilis ventricosus* with the shell of a marked female contour very much inflated, and this was partly barren, the gills appearing shrunken. Subsequent investigations showed that the sterility of this bed was due partly to the season. As we went downstream and the season advanced we noticed gills of various species beginning to take on a dusky tinge at the margin and filling up with fertilized eggs and glochidia. Moreover, on a visit to this mussel bed on September 21, of 28 examples of *L. ligamentinus* procured 8 were gravid. The other species procured in September were: *Quadrula tuberculata*, 1; *Q. rubiginosa*, 1; *Q. undulata*, 3; *Symphynota complanata*, 1; *Lampsilis rectus*, 3; *L. luteolus*, 2; none gravid. The percentage of breeding mussels was hardly as great as one might expect under favorable conditions. No small shells were found, the smallest being of medium size and apparently several years old. The conditions on the whole seem to indicate that this mussel bed is dying out. It would have been possible to secure a number, perhaps a half ton, of good shells here without disturbing the mussels.

The riffles were incidentally visited in November, and although the water was quite cold the protozoa were still abundant on crawfishes and dead leaves in the water, and the conditions bore considerable resemblance to those observed earlier in the year.^a

None of the mussels was badly parasitized.^b *Atax ypsilophorus*, *Aspidogaster conchicola*, and *Cotylaspis insignis* were rather common, but not abundant. The marginal cyst distomid was rather frequent, and it was here we obtained material with which we were able to associate this organism with pearl formation. It was most common in *Lampsilis ligamentinus*.

From the riffles down to the mouth of the river mussels appeared to be quite scarce.

^a On June 26, 1909, as opportunity permitted, this place was revisited. It was during a long period of high water. The river, though turbid, was not filthy and appeared reasonably clean. At the riffles it was racing at a rapid rate and the current could hardly be stemmed when about breast-high, but would sweep one off his feet. No Protozoa were seen, and only a few young crawfishes, which were very active and alert. A few gray-back minnows were swimming about on the surface, and schools of small minnows darted from shore. By wading about a great deal only two live mussels (*L. ligamentinus*) were found, though there were a number of dead shells. There were no evidences of unhealthy conditions or overcrowding; on the contrary, the conditions seemed to be those of an ideal mussel stream. This visit served to emphasize the fact that during periods of high water sewage is comparatively innocuous and that while the water of the river has great variation the river population is fairly constant; in periods of low water the stream is overpopulated and, to use a chemical phrase, the inhabitants are almost precipitated out.

^b The parasites are more fully discussed and described at the end of the report.

Station C. Spy Run.—Spy Run is the name of a small shallow stream which enters the St. Mary's about a half mile above its mouth. The bottom is of fine sand and the water at the time visited was quite clear. There were many small fishes, chiefly the johnny darter (*Boleosoma nigrum*), a few golden shiners (*Abramis crysoleucas*) and chubs (*Semotilus atromaculatus*), and a number of crawfishes all free from Protozoa. No living mussels were found, but about a dozen dead shells, all of which, except fragments of one *Lampsilis iris*, were *Anodontooides ferussacianus subcylindraceus*.

ST. JOSEPH RIVER AND FEEDER CANAL.

The St. Joseph River, more commonly known by the shortened local name St. Joe, is a larger and clearer stream than the St. Marys, and since only the very lowest portion of its course enters the city, it is much freer from sewage.

Station D. St. Joseph River at Robinson Park, 6 miles north of Fort Wayne.—The highest point at which the St. Joseph River was examined was at Robinson Park, a pleasure resort about 6 miles above the city. This point could easily be reached by trolley. Considerable change had taken place in the river here within the last few years. At the time the park was established there was a dam in the river which had kept the feeder canal, just above, full of water. This had raised the water of the river and had expanded it somewhat into a quiet, pondlike basin. The breaking of the dam had reduced the water to its normal height and emptied the canal.

At the time of our visit the river was rather high and turbid from recent rains. We procured a boat and rake at the park and rowed up to the riffles about half a mile above the park, examining the river and shore.

There was a fair number of shells scattered along here, all of which were large and of excellent luster. The large shells found at the park itself had been dead some time, and may have been killed by the lowering of the water when the dam broke; the *Lampsilis luteolus* were exceptionally large and fine. Farther up the stream large dead shells were collected on the bank, chiefly *Quadrula undulata*. They were freshly dead and had probably been killed for bait. On investigating the river it was found full of snags in some places; in others the bottom was of hard clay, too compact for mussels to live in. In the beds of gravel where mussels were likely to be found the bottom was full of sharp rocks which in the turbid water were difficult to distinguish from mussels, so that collecting the latter was uncertain. We found very few live shells, but were told that they were easy to obtain when the water was low and clear.

The manager of the boathouse at Robinson Park told us of having seen a good bed of mussels here during clear low water. He also reported that where he used to live on the Ohio River they ate the "small sweet mussel," but the larger kinds were too tough for food, except that they could be used for flavoring soup.

Station E. Feeder canal from Robinson Park to Fort Wayne.—In the days of the Wabash and Erie Canal, the dam mentioned above was built across the St. Joseph River just below what is now Robinson Park, and a feeder canal was dug to convey the water from above the dam to the main canal at Fort Wayne. After the main canal had fallen into disuse this feeder was still used as a source of power for mills at the outskirts of the city, and the water was turned back into the St. Joseph River.

When Robinson Park was established the canal formed a charming water lane leading from the city out to it. About the summer of 1906 or 1907, however, the dam in the river broke and let the water out of the canal.

The dry canal bed offered one of the most remarkable opportunities possible for the study of mussel distribution within a small area. It was 6 miles in length and, with the exception of a few places below the general level, it dried up so quickly that the mussels are still left in their original positions in the mud on the bottom of the canal. The shells are half to two-thirds buried in the dried mud, the great majority of them with the posterior end directed northward—that is, against the current when the canal was full of water—and with the valves nearly closed, just as the animals died.

This region had been visited and preliminary studies made in the autumn of 1907, and it presented the same features that it did early in the summer of 1908—a long, dry, and cracked mud flat forming a vista of projecting shells, the short tracks the mussels had made during life being still distinct. In the canal bed it was possible to study all the species that had lived there, their abundance, distribution, and the like. Many of the young shells of *Lampsilis luteolus* exhibited brilliant rays; they appear to have been exceptionally highly colored.

Toward the upper end of the canal, in a place where the bottom was 15 feet wide, the mussels were counted for a stretch of 10 feet along the canal bed and the following species noted: *Quadrula rubiginosa*, 11; *Q. cylindrica*, 1; *Q. undulata*, 86; *Anodonta grandis*, 6; *Ptychobranchus phaseolus*, 1; *Lampsilis ligamentinus*, 5; *L. luteolus*, 6. The width taken was the total width of the bottom of the canal and was considerably wider than the space occupied by the mussels.

About a mile farther down the canal a space 10 feet square was measured off in the bottom of the canal and the following species

were found: *Quadrula rubiginosa*, 6; *Q. undulata*, 60, all rather small; *Pleurobema clava*, 1; *Alasmodonta truncata*, 2; *Symphynota complanata*, 2; *S. costata*, 5; *Anodonta grandis*, 15; *Obovaria circulus*, 4; *Lampsilis ligamentinus*, 5; *L. luteolus*, 1; *L. ventricosus*, 4. This gave a little over 1 shell per square foot. In 1908, in a square meter of bottom near the Rod and Gun Club, the following species were noted: *Quadrula rubiginosa*, 9; *Q. undulata*, 36; *Symphynota complanata*, 1; *Anodonta grandis*, 17; *Obovaria circulus*, 11; *Lampsilis iris*, 2; *L. ligamentinus*, 2; *L. luteolus*, 3, giving a total of 81 per square meter. In addition to these shells there were many small *Sphaeriums*, the ground being paved with them, 34 *Campelomas*, and 23 *Pleuroceras*. The square meter referred to above represents, as nearly as could be judged, an average number rather than either extreme.

The general impression obtained concerning the abundance of various species is given in the table on page 37.

Figure 2, plate 1, represents a portion of the dried canal bed near its upper end. It shows admirably the mud cracks formed on drying and the mussel shells still protruding in situ.

Realizing the value of an opportunity to study so extensive a tract with the mussels still in their original positions and in plain sight, several visits were made to the canal, and as a result the following conclusions were reached:

1. Each of the species found was well distributed throughout the entire canal; that is, there was no marked gathering together or colonizing of any one species to the exclusion of others. So fully was this true that a careful examination of a few rods of the canal bed anywhere was reasonably certain to yield specimens of all the species, except possibly one or two that were very rare. In this connection it must be kept in mind that the bed of the canal was very different from that of a river, in that it was practically the same throughout its entire length. It was all shallow mud, with little sand or gravel; the water was of nearly uniform depth, and the current was of uniform rapidity. In short, there was almost nothing except the consistency of the mud upon which a mussel could base any preference of locality. Slight differences in this respect caused an increase in the numbers of mussels in some places, but affected all the species equally.

2. The number of mussels which can find accommodation under fairly favorable conditions upon a definite area in the canal bottom may be judged by the counts on measured areas given above.

3. A canal makes an excellent breeding ground for mussels, as was particularly attested by the presence of a large number of younger examples among the adults, showing all stages of growth. The current in the canal appears to have been just fast enough, food material

Fig. 1.—Bed of Maumee River just below Columbia Street bridge, Fort Wayne, Ind., showing mussels killed by sewage from city gas works.

Fig. 2.—The dried bed of the Feeder Canal, showing mud cracks and mussel shells in situ.

Fig. 3.—Pile of shells, chiefly mucklets, *Lampsilis ligamentinus*, containing 25 tons, gathered from the Maumee River near Fort Wayne, Ind.

constant and ample, the supply of water uniform the year round, and the bottom seems to have been well suited to a great variety of species. This gives the mussels a uniformly large size, while the shells at the same time are of extra quality and luster.

4. These facts would indicate that a canal would furnish one of the best locations that could be obtained for artificial propagation of mussels. Furthermore, the water in a canal can be drawn down from time to time without much trouble, thus allowing examination of the mussels. Examples suitable for breeding or for commercial purposes could then be selected easily and rapidly without in any way disturbing the others. Such possibilities are at least worthy of a careful consideration in future attempts at the artificial propagation of mussels.

The last visit to the canal was made on July 27, after a series of heavy rains. The canal bed was at this time under water for nearly its entire length, and was covered with grass and weeds that had sprung up in a short time and effectually concealed the shells. This visit threw light on a phenomenon which had proved quite puzzling during previous visits. Occasionally, shells of *Quadrula undulata*, only recently dead and with bits of flesh still clinging to them, had been found in dry places in the canal bed some distance from any pool. At the time it was hard to understand how they came to be there, as it seemed impossible that they could have "mudded up" and survived the long period following the breaking of the dam. This visit showed that during the high water of winter or spring the whole canal bed had probably been submerged, and that the mussels had migrated from the deeper portions at that time.

During our previous visits, also, a number of pools, comprising the deeper portions of the canal bed, were observed, and a few live mussels, chiefly *Anodonta grandis* and *Quadrula undulata*, had been noted near the edges, but the pools were not fully investigated.

On this last visit the pools were thoroughly investigated and were found to contain an abundance of molluscan life. Fine examples of the following species of mussels were secured: *Quadrula coccinea*, 1; *Q. rubiginosa*, many, deeply buried; *Q. cylindrica*, 1; *Q. undulata*, many; *Alasmidonta truncata*, 1; *Symphynota costata*, several; *Anodonta grandis*, a few; *Strophitus edentulus*, a few; *Ptychobranhus phaseolus*, 1; *Obovaria circulus*, 1; *Lampsilis iris*, 1; *L. rectus*, 2; *L. ligamentinus*, many, large and fine; *L. luteolus*, several; and *L. ventricosus*, 1, large. Among other mollusks, *Ancylus* was abundant and large, usually attached to the shells of living mussels. Algæ of various species were common, covering the water surface. In one place *Hydrodictyon* was exceedingly abundant.

This investigation was interesting and important, as it showed that mussels will live for long periods in shallow pools where they once

have obtained foothold, even though the conditions under which they once thrived and multiplied have ceased. While it is true that mussels die rather quickly when placed in foul water or unfavorable conditions, both our investigations here and our experiments in transplanting elsewhere indicate that they can live for long periods where they probably would not naturally develop, and that they can easily be stored in pools of limited size.

Station F. Reservoir of the feeder canal.—This is an artificial pondlike area at the lower end of the canal and within the outskirts of the city of Fort Wayne. This reservoir, which originally connected with the canal, covers about an acre, and the water, which at the time of our visit was only a foot deep at most, probably never gets much deeper, as it can easily drain into the river below. The bottom of the reservoir is of a bare, yellowish clay, and there is a great deal of miscellaneous trash over it, indicating that it has been used to some extent as a sort of dumping ground. There were quite a number of mussels in this pond. *Quadrula rubiginosa* was common in the warm shallow water near shore, and on the date of our first visit (June 30) was remarkably active, almost every example being at the end of a long, curved track. They were quite high up out of the mud, and several had fallen over and were lying on their sides. *Quadrula undulata* and *Anodonta grandis* were also common, and there were a few *Lampsilis luteolus*. Some dead *L. glans* and one dead *L. ventricosus*, which quite closely resembled *L. capax*, were found along shore. More very young mussels were seen here than anywhere else. They were at the end of long, narrow tracks resembling snail tracks, in the shallow water along the north shore of the pond, and were nearly buried in the mud, only the posterior tip of the shell slightly projecting. Their presence indicates that the reservoir was used quite actively as a breeding ground for the mussels. There were a few fishes in the reservoir, chiefly carp and suckers, and boys were occasionally seen fishing there. Other mollusks, especially large *Campelomas*, were abundant.

The mussels of this place, especially the *Anodontas*, were more heavily infested with parasites than those obtained anywhere else, with the exception of some *Lampsilis alatus* taken at Grand Rapids, Ohio, which contained *Atax* in great numbers. The common mussel parasites, *Atax*, *Cotylaspis*, and *Aspidogaster*, were present in nearly every individual examined.

The reservoir was again visited on July 23, and it was found that the *Quadrula rubiginosa*, which on the previous visit were high up out of the mud and actively moving about, had by this time buried themselves deeply. It was also noticed that at the same date, in the pools of the canal itself, they were likewise deeply buried. It is probable that their great activity during our first visit was due to

restlessness caused by the warmth of the shallow water and that their action of deeply burying themselves was in anticipation of the drying up of the reservoir. A number of the *Anodontas* obtained at this time were examined as to food and parasites, with the following results:

No. 1.—Parasites: *Atax*, 3, in gill axils; *Cotylaspis insignis*, 1, in axil of inner gills; *Aspidogaster conchicola*, 2, in pericardial cavity. A small patch of *Plumatella polymorpha* on each valve. Gills empty, but ova in the body. Stomach contents ample, brownish green in mass, containing a few *Scenedesmus* and numerous globular organisms, probably *Trachelemonas*.

No. 2.—Parasites: *Atax*, 27, in axils of gills; *Cotylaspis insignis*, 8, in axils of inner gills; *Aspidogaster conchicola*, 8, in pericardial cavity. Shell deeply stained a salmon color on the inside, with a tadpole-shaped blister on the left valve near the siphonal opening. Considerable *Plumatella polymorpha* on the outside of the valve. Stomach contents fine greenish brown in mass, mostly of unrecognizable material, and containing several *Scenedesmus*, 1 *Pediastrum pertusum*, and 1 shell of rotifer *Anuræa cochlearis*.

No. 3.—Parasites: *Atax*, 43, between and among the gills, chiefly in the axils; *Cotylaspis insignis*, 2, axils of inner gills; *Distomum* of Osborn about 248, on outside of mantle, between mantle and shell; *Aspidogaster conchicola*, 8, in pericardial cavity; Sporocysts (*Distomum* of Osborn) innumerable, distributed thickly throughout the mantle. Stomach contents, chiefly minute green and black globules, probably *Cryptomonas*, and 1 diatom, *Pleurosigma*.

No. 4.—Parasites: *Atax*, 8 large, 2 small, in gill axils. The large ones were full of eggs. *Distomum* of Osborn, 58, 30 on the right side near the umbo ("right shoulder") and 28 on the left; *Cotylaspis insignis*, 9, in axils of inner gills; *Aspidogaster conchicola*, 2, in pericardial cavity. Stomach and intestine almost empty, but contained *Trachelemonas*, *Gamosphæria aponia*, and a spindle-shaped *Euglena*-like organism. Nacre stained a deep salmon color, with a good deal of *Plumatella* on the outside.

No. 5.—Parasites: *Distomum* of Osborn, 33 on the "left shoulder" and 35 on the right; sporocysts of that species innumerable throughout the mantle, the cercariæ escaping from them and present in large numbers; *Atax ypsilonphorus* 32; *Atax*, small species, 18, between gills; *Cotylaspis insignis* 11, in axils of inner gills; *Aspidogaster conchicola*, 5, in pericardial cavity. The intestine contained numerous minute dark-green globules (*Trachelemonas*?), which were moving about actively. It also contained the *Euglena*-like organism, and *Anuræa cochlearis*, 1 empty shell.

No. 6.—Parasites: *Distomum* of Osborn, 23 on the "right shoulder" and 12 in the left; *Atax* 50, in the axils of the gills; there were many *Atax* eggs, which are minute yellow objects, on the inner side of the mantle. Two species of *Atax* present, a large and a small, both full of eggs. The eggs in the mantle were hatching, and the larvæ were present in the different stages of development; *Cotylaspis insignis* 4, in the axils of inner gills, and *Aspidogaster conchicola* 13, in the pericardial cavity. The shell had considerable *Plumatella polymorpha* attached; the nacre was stained a deep salmon, and there was a raised ridge on the right valve from the umbo downward and backward.

No. 7.—Parasites: *Atax intermedius* 14, in axils of gills, and with the eggs scattered on the inside surface of the mantle; *Distomum* of Osborn about 100, on the "shoulders"; *Cotylaspis insignis* 9, in the axils of the inner gills; *Aspidogaster conchicola*, 2, in pericardial cavity. The alimentary canal of this example was empty. Interior of the shell with a row of four salmon-colored

groups of knobs opposite each "shoulder" and extending from the hinge two-thirds of the way to the edge of the shell. Three straight ridges, also salmon-colored, on the left valve, radiating from the distal end of the row of knobs. The salmon marks in the nacre corresponded exactly with the position of the distomids in the mantle. There were three bunches of distomids corresponding to the three ridges on the left side.

No. 8.—Parasites: *Distomum* of Osborn, about 200 on the outside of the mantle at the "shoulders," but no sporocysts present. *Atax intermedius* 14, *Atax aculeatus* 3, and several examples of *Atax ypsilophorus*. The *Atax* contained large eggs, and all the animals were located between the gills; *Cotylaspis insignis* 2, in the axils of the inner gills; *Aspidogaster conchicola* 5, in the pericardial cavity. There was a good deal of *Plumatella polymorpha* on the shell. The color of the nacre was pretty uniform, but somewhat more intense in the region of the unbones, where the distomids were also thickest. Alimentary canal full of *Trachelemonas*, with a few diatoms and *Scenedesmus*. The *Trachelemonas* were very actively swimming about, although they had been in the stomach of the mussels for at least 36 hours.

No. 9.—Parasites: *Atax* 23, between the gills; the eggs abundant, and some young hatched; *Distomum* of Osborn 3, on "shoulders" as usual; *Cotylaspis insignis* 3, in axils of inner gills; *Aspidogaster conchicola* 7, in pericardial cavity. The alimentary canal contained rather numerous *Scenedesmus*, 1 *Pediastrum pertusum*, 4 *Anuræa cochlearis*, and 1 spindle-shaped *Euglenalike* object.

In a day or two after the visit to the reservoir in which these mussels were obtained, it was revisited. The pond was covered with a green scum, but there was no opportunity to examine it more fully.

The collections at this place were particularly interesting because of the knowledge obtained concerning stages in the life history of the distomid of Osborn, sporocysts of which were especially abundant in mussels no. 3 and 5. These matters are more fully discussed under our notes on parasites toward the end of this report. (See p. 61.)

Station FF. Feeder canal between the reservoir and the Maumee River.—The feeder canal with its reservoir may be regarded as a sort of auxiliary channel of the St. Joseph River from Robinson Park down to the city. The mussels were, however, much more evenly distributed in the canal bed than in the river bed. The latter was examined from the reservoir of the canal down to the mouth of the river, but only occasional mussels were obtained above Wagner Street Bridge.

Station G. St. Joseph River at Wagner Street, Fort Wayne.—At Wagner Street there was a very good shell bed, which was examined pretty thoroughly. The river here is shallow, with a gravel bottom, and the current during ordinary stages of the water is about 2 or 2½ miles an hour.

A little below this station there appeared to have been a fair bed of mussels; but sand was being hauled from the river in large quantities, and the disturbance was unfavorable to molluscan life.

The men hauled many shells with the sand. A fine example of *Lampsilis ventricosus* was observed spawning here on July 20. Just above where the men were hauling, *Quadrula rubiginosa*, a few *Symphynota costata*, some *Lampsilis luteolus*, and a large number of *L. ligamentinus* were seen. Where the men were at work a number of the rarer shells, *Pleurobema clava* and *Truncilla sulcata*, were obtained.

Station H. St. Joseph River just above its mouth.—One of the finest beds was just at the mouth of the St. Joseph River, extending upstream about 20 rods, and as the condition of the river was quite favorable this was examined several times. The bottom was of fine sand and the water from a few inches to about $3\frac{1}{2}$ feet deep, and quite clear, so that the mussels on the bottom could be seen fairly well. There was nearly a bushel of shells on shore, which had been crushed by boys in search of pearls.

The mussels had been moving about to some extent and appeared to be, on the whole, quite active. While most of them were deeply buried and were headed downstream in their natural feeding position, a few were transverse to the current, and none showed the sharp line of demarcation on the shell that is usually found where the animals occupy the same position for a long time. Of this collection recorded in the table, 9 species, *Q. rubiginosa*, *Q. pustulosa*, *Q. undulata*, *S. complanata*, *P. phaseolus*, *L. rectus*, *L. ligamentinus*, *L. luteolus*, and *L. ventricosus*, represented by 208 shells out of a total of 341, were good button shells. This is a considerably lower percentage than a little farther down in the Maumee, as the proportion of marketable shells is considerably reduced by the abundance of the comparatively worthless *Symphynota costata*. The merchantable species were easy to obtain and also of large size and excellent quality. While we were at work on this shell bed on July 21, the clammers who had been working in the Maumee below entered the mouth of the St. Joseph. This date, therefore, marks the beginning of clamming operations on this river. The clammers had at the time about 800 pounds of shell in their boat, chiefly *Lampsilis ligamentinus*, which they had secured in the Maumee below.

MAUMEE RIVER.

During the autumn of 1907 preliminary investigations were made along the first few miles of the Maumee. Shells appeared to be fairly abundant, but were for the most part ignored by the local inhabitants. In general, no attention was paid to them except that they were occasionally used for fish bait, and people knew little about them. A considerable pile of scattered shells was seen in a yard adjoining the river, and the owner of the place said he had gathered the mussels to feed his ducks, which were very fond of

them. Among the shells found in the yard were some fine *Lampsilis ligamentinus*, and a rather thick ventricose form of *L. alatus*. There was no clamming for button shells in the river and little or no pearling.

In the summer of 1908 a prospecting trip along the first few miles of the Maumee discovered a clammer's camp, which will be spoken of more fully later on. (See p. 27.) The camp was visited several times during preliminary field work.

The boat was launched July 29 just below the Columbia Street Bridge in Fort Wayne, which marks the head of the Maumee, and August 9 we reached Miami, Ohio, 7 miles above Toledo, where the river enters Maumee Bay. The party proceeded downstream by easy stages, examining the river's bottom for mussels wherever there were indications of their presence, stopping overnight at one of the towns or villages along the river or at a convenient farmhouse. Defiance and Grand Rapids, Ohio, were the only places where any stay was made. At Defiance the Tiffin and Auglaize Rivers enter the Maumee, each of them nearly as large as that stream itself, and three days were spent examining them. At Grand Rapids an extra day was devoted to the long riffles below the dam. The old Miami and Erie Canal is still in operation from Defiance to Toledo. This afforded a way of getting past the dams and riffles and gave promise of being itself rich in mussels. As it kept so close to the river that the latter could be visited easily at any time, the party chose the canal for the remainder of the trip. The following is a summary of the stations with the species found at each and their relative abundance.

As previously stated, the stations were numbered consecutively, and the numbers appearing with the species represent the specimens of each that were obtained.

Station 1. Maumee River at its source.—This includes the first 2 or 3 miles of the river and the clammer's camp.

At the very head of the river, just below the Columbia Street Bridge, an immense bed of dead shells was found, forming banks and bars. The entire bottom of the river and the south bank for some distance out of the water were literally paved with shells, chiefly muckets (*Lampsilis ligamentinus*).

Some idea of the number of these shells can be obtained from figure 1, plate 1, in which every one of the objects upon the bank is a dead shell. In all probability these mussels had been killed by the refuse from the gas works which are situated on the bank of the St. Marys a few rods above its junction with the St. Joseph. Spots of tar were found on dead mussels some distance below this point. The water was covered with an oily scum in places and a tarry odor was perceptible for several miles down the river.

The bottom of the river at its head is Devonian limestone, and the banks are of white clay; the average depth of the channel at the time examined was about 3 feet and the current about a mile an hour.

A mile and a half down the river was the clammer's camp. This was the only one on the river and had been established but a short time. The owner, Mr. H. S. Birge, had formerly lived on the Wabash, where shelling operations are active, and had done considerable clamming there. He had come to Fort Wayne to work on the construction of a canal, and finding this work slack at times, had naturally turned to the river and begun investigating its clamming possibilities. He reported clamming "fairly good but not as good as one might expect from the looks of the river." As the bottom was rough and stony with occasional snags and the water fairly shallow, he procured shells in the same fashion that they are obtained in parts of the lower Wabash—by scooping them up with a coal fork, the operator standing waist deep in water. In three weeks' time, with the help of his brother and two young boys, the clammers had gathered 25 tons of first-quality shells, mostly "muckets" (*Lampsilis ligamentinus*), with a sprinkling of good "long johns" or "black sand shells" (*Lampsilis rectus*), a few "pocketbooks" (*L. ventricosus*), etc. The shells were remarkably uniform in size and quality. There were few culls or worthless shells—less than a bushel. They consisted chiefly of *Lampsilis alatus*, a few *Quadrula tuberculata*, and an occasional *Unio gibbosus*.

Figure 3, plate 1, shows a pile of shells, with the cleaning table in the background, and gives a fair idea of their size. In the matter of pearls and baroques this lot of shells gave very meager returns; there were no baroques worth saving, and only two small and comparatively worthless pearls in the whole lot. Mr. Birge was impressed with the size and fine quality of the muckets of this region.

Station 2. Five miles below Fort Wayne.—A fair bed of mussels was found here, with many dead shells along the bank. The water was shallow with almost no current, the bottom muddy with an abundance of algæ.

Station 3. Kern Reservation.—There was here a large bar projecting out of water and covered with dead shells which had evidently been washed out during river floods. The river was free from sewage and the water was quite clear, about 3 feet at the deepest, and with very little current. The bottom was of rounded gravel well covered in places with algæ, and many good-sized sponges. There were also large numbers of flatworms on the stones and many *Ancylus*, while crawfishes were numerous and hostile.

The mussels were well bedded and quite abundant, but not very large. A sample collection was preserved, after which the others were thrown back. This was the first station at which *Q. pustulosa*

was obtained in abundance, although a few fair-sized examples were found in the feeder canal in 1907. Mr. Kern, whose farm extends along the river here, says that the mussels appear to be dying off more rapidly than formerly, due, he thinks, to increased pollution of the river by sewage.

Station 4. Near New Haven, Ind.—Just above the New Haven Bridge is a long stretch of the river with clear shallow water and gravelly bottom. Here a fairly thick bed of mussels was found. The crawfishes were especially numerous and pugnacious, and many of them were seen eating small mussels. It could not be ascertained whether they had killed the mussels or were merely feeding on some that had died from other causes. All the shells obtained were rather small. The *Q. undulata* were peculiar in that the ridges were considerably broken up into isolated portions somewhat resembling tubercles.

Symphynota complanata, which was one of the characteristic shells of the feeder canal and of which we obtained examples in the mouth of the St. Joseph, may have been introduced into the Maumee River through the agency of the Wabash and the Erie Canal. At the town of New Haven we were told of a remarkable shell that some boy had found along the river several years before, and which had been preserved as a curiosity. An examination proved it to be a characteristic specimen of this species. This was the farthest down the Maumee it was seen or heard of.

Station 5. Below New Haven, Ind.—This station was near a sand bar just below a long riffle. The water was from a few inches to 3 feet deep, and the bottom sandy, with many pebbles. There was an immense number of crawfishes here, one of which was eating a dead *Q. undulata*. Only a few live mussels were found. Among the dead shells were one *Alasmodonta truncata*, one *Strophitus edentulus*, several *Obovaria circulus*, and several *Lampsilis rectus*.

Station 6. One mile below station 5.—A small pile of shells was found on the river bank opposite a house owned by a man named Nieter. Some boys had been searching for pearls and had thrown the emptied shells together. Upon examination we found only three species.

Station 7. Four miles above Woodburn, Ind.—After leaving station 6 no indications of shell beds were noted until we reached the vicinity of Woodburn, Ind. Four miles above that town is a large gravel bar on the north bank of the river, overflowed at high water and covered with dead shells. Several live mussels were found in a pool on the bar and one or two were out of water and still alive, showing that they had come there during the recent high water. The list includes both living and dead shells.

Station 8. Woodburn, Ind.—Near Woodburn is a long series of riffles known as Bull Rapids, where shells appear to be abundant, but would be difficult to obtain, except during very low water, on account of the rocky bottom and the swiftness of the current. There was a long bar here covered with dead shells, but although we waded about everywhere over the coarse sand and rocks of the bottom, covering a large area, we found only a few live mussels. The party stopped for the night with a Mr. Armbruster, just below this station, and he reported finding in his cornfield on the south bank of the river a large pile of mussel shells some distance from the water, and made up of the same kinds as those found in the river. The presence of bones and stone implements among the shells left no doubt that this was an Indian kitchen midden, and that the aborigines had used these mussels for food.

Station 9. Maumee Center Bridge.—Just above Maumee Center Bridge some men were busy hauling gravel out of the river bed. There was a fair number of shells in the gravel, though by no means enough to indicate a shell bed, and the men were of the opinion that there were not many in the river. The water was turbid at the place, the bottom of gravel, and the depth $3\frac{1}{2}$ to 4 feet. The species noted were found in the sand along the shore.

Station 10. One mile below Antwerp, Ohio.—The next place at which the river was examined was about a mile from Antwerp, Ohio. Just below the town the river has a width of 250 or 275 feet, with low banks, and there is a long series of riffles. The bottom is covered with coarse gravel and loose rocks. There were many dead shells on bars alongshore, while the live mussels were rather scattered and deeply buried among the rocks and pebbles.

Station 11. Five miles below Antwerp, Ohio.—This station was along the bed of the river opposite the farm of a man named Curtis. A long sand bar with a number of dead shells was seen. On the bar were noted a few *Quadrula rubiginosa*, several *Q. cylindrica*, a few *Q. undulata*, a large number of *Pleurobema clava*, a few *Unio gibbosus*, a few *Obovaria circulus*, several *Lampsilis iris*, a few *L. rectus*, and a large number of *L. ligamentinus*, which was the most common shell. Just above the bar the water was deep and sluggish and below it was shallower and swifter. In the deeper water the shells were widely scattered and deeply buried and consequently difficult to find. In the shallow water on the slope of the bar they were also well scattered, but had been actively crawling about and were easily found at the end of the tracks they had made.

Station 12. Ten miles above Defiance, Ohio.—The water was quite deep here and the river banks steep; the place was used as a swimming hole. The bottom was rather solid, composed of fine mud and sand and covered with a growth of algæ, among which was a large

handsome species of *Chara*. No shells were seen on shore, and after examining a large area of the bottom only 3 live mussels could be found: 1 *Unio gibbosus*, 1 *Lampsilis alatus*, and 1 *L. luteolus*.

Station 13. Tiffin River, just above Defiance, Ohio.—Tiffin River is a large stream entering the Maumee about a mile and a half above Defiance, Ohio. We had heard that there were mussels in the stream, and Kirsch^a has reported them as abundant in the lake at the head of the river, although he says nothing of the river itself. The back-water of the Maumee, caused by the dam below Defiance, extends for about 2 miles up this river, so that it was a very sluggish stream with almost no current. A light-green thin scum, resembling *Euglena*, flowed slowly down, streaking the central portion of the river.

The banks and bottom were yellow clay, the water turbid, and so far as we could observe aquatic vegetation was lacking. We ascended the river about 2 miles. No shells were seen on shore and considerable dredging brought up only 3 live mussels, 1 *Lampsilis alatus*, 1 *L. ligamentinus*, and 1 *L. ventricosus*. The river was full of brush and snags which frequently entangled the dredge. It is quite likely that mussels are more abundant higher up beyond the dead water.

Defiance, Ohio, was reached August 2. Here the Maumee and Cincinnati Canal goes southward through the State. At the time of our visit this canal was nearly empty, as the locks were being repaired. This canal was followed on foot for some distance into the country, but no traces of mussels of any kind could be seen along the shore or in the mud in the bottom.

Station 14. The Auglaize River, 2 miles above Defiance, Ohio.—The Auglaize River is fully as large as the Maumee, and joins the latter at Defiance, the old Indian fort for which the city is named having stood upon the point of land between the two rivers. The water is considerably clearer than that of the Maumee, and the dead water backs up the river for some distance. Just beyond the dead water is a series of short riffles. Here the water was quite shallow and the bottom composed of a slippery horizontal shale which had been used to some extent in the manufacture of cement. The river is further broken up by a number of small islets and pools. Many large dead shells were found on the bars. The mussels could obtain no foothold in the bottom of the main portion of the river, since it was of bare shale, but were found in the sand and gravel bars along the banks. Here they were congregated into dense beds. Nearly the whole surface of the bars was covered with dead and living shells, even among the roots of the water willows and other aquatic plants. The water was clear and the current moderate, making the collection

^a Bulletin U. S. Bureau of Fisheries, loc. cit.

of specimens easy. Shells of all the species found were large, some of them exceptionally so, being the largest of their kind we had yet seen. This was notably true of *Symphynota costata* and *Alasmidonta truncata*. The shells were also of the finest quality and best luster, making them very desirable material for commercial purposes.

The *L. ventricosus* were buried rather deeply and were comparatively hard to dig out. *Quadrula pustulosa*, which had been dwarfed thus far in the Maumee, was here of good size. It will be noted that several species were found here which had not been encountered before, viz, *Quadrula lachrymosa*, *Plagiola donaciformis* and *elegans*, and *Obliquaria reflexa*. (See fig. 5, pl. II.)

Station 15. The Auglaize River, 4 miles above Defiance.—The success at station 14 determined us to try the river again 2 miles farther upstream. The bottom was much the same as at the previous station, except even more slippery and with fewer islets; and the only place the mussels could obtain any foothold was in sheltered coves along-shore, now on one side and now on the other, according to the current and swing of the river. The coves differed somewhat as to bottom, some being sandy or gravelly and others muddy. The shells found here included more of the smaller species than at the preceding station, although there were also some very large ones. On one of the fine gravelly bars a number of mussels, chiefly of the smaller species, were very actively crawling about in the shallow water; a recent shower had probably moved them out of their places and they were readjusting themselves. Here was found the only living example of *Truncilla sulcata* seen during the whole summer's work. In the protected coves with muddy bottom *Anodonta grandis* was the most common shell. *Lampsilis ligamentinus* was just beginning to show an approach to the gravid condition; the lower edges of the outer gills were becoming faintly distended and margined with black. *Ptychobranchus phaseolus* was considerably further advanced, the gills being thrown into wavy folds. There were many small schools of minnows here, which kept nibbling at our feet and ankles when we waded into the stream and which clustered eagerly about bits of bread which we threw into the water.

Among mussel parasites the marginal-cyst distomid was quite common, and there were a few *Atax* and *Cotylaspis* present. The *Anodontas* were heavily infested with *Atax* and the distomid of Osborn.

Station 16. Maumee River, 4 miles below Defiance.—Four miles below Defiance a State dam, 7 feet high, crosses the river. This dam, known also as the Independence Dam, was built by the State of Ohio to make the river a feeder to the Miami and Erie Canal, which enters the river at this point. In the palmy days of the

canal the town of Independence was located here at the dam, but when the railroad superseded the canal the town moved elsewhere. The water above the dam backs for 7 miles up the Maumee and about 2 miles up the Tiffin and Auglaize Rivers and forms a charming lakelike body of water below Defiance. This water is navigable for small boats and launches, of which there were a considerable number. The river is some 600 feet wide at the dam, and at the time of our visit a thin sheet of water was pouring over. We had been informed while at Defiance that there were many fine mussels below the dam. (See fig. 4, pl. II.)

Examination of the place proved the accuracy of our informant and showed that this locality was the richest collecting ground and supported a greater variety and abundance of life than any other stretch of the river. The river bed below the dam is a broad valley with a limestone bottom, the river being broken up into a great number of pools and channels dotted with little islands overgrown with willows. The water, sparkling and fresh after its race over the dam, seemed to make conditions exceptionally favorable for all sorts of aquatic life. The shores of the pools were edged with water willows, and the stones on the bottom were covered with a rich growth of algæ of various species and hues, some growing in long ropy masses; there were especially large clumps of *Cladophora*, lending a green color to the bottom, and numerous larvæ of caddis and stoneflies gluing the pebbles together. Many crawfishes were seen, and Bryozoa were common on the rocks. There were many anglers in high boots wading about in the racing currents. Flocks of black tern were flying overhead, the first we had seen.

Fringing the edges of the pools and islands were many rather small shells, chiefly *Plagiola elegans* and young *Quadrula lachrymosa* that had apparently been killed by fishermen for bait. By feeling about in the sand in the shallow water shells could be found in great numbers, and they were of fine quality and very large size. The *L. ventricosus* were the largest we had seen. Everything considered, these are the most important mussel beds in the river, and this is one of the places worthy of future study.

It was at this place we found a couple of pearls, which, on account of their minute size, were of no market value. They were, however, of considerable interest, as, on account of their position, they served to intensify the suspicion already entertained that pearl formation may be excited by the presence of the marginal cyst. We are of the opinion that this is an exceptionally favorable location for the carrying on of investigations along this line.

At the Defiance Dam we entered by means of a lock into the first stretch of the canal, which runs from Defiance to Grand Rapids, Ohio.

The canal has a moderate current and is a picturesque waterway, with a winding towpath on one side and a country road on the other.

Station 17. Maumee River at Florida Bridge, Ohio.—This is 4 miles below the dam, and the river had very much the same character as at the previous station, except that there appeared to be more water than at the very foot of the dam. There was not a great deal of current, and the water was clearer than any we had yet seen; the mussels could be clearly distinguished in 18 inches of water. The bottom was still of flat rock, so that it was only in favorable places that the mussels could anchor. They were fairly abundant, but considerably smaller than at the dam.

Station 18. Miami and Erie Canal, near Texas, Ohio.—Near a small village named Texas considerable dredging was done in the canal. The uniformity of bottom and absence of rocks or snags made the dredging very easy. The bottom was of soft black mud and the water about 5 feet deep with a moderate current. We found here a scattered bed of *Quadrula undulata*; every dredge haul brought up a few examples. These were large and rather plump, with a black epidermis, and approached more nearly to the form of *Q. plicata* than the very compressed brownish examples we had been finding hitherto. These shells bore colonies of *Plumatella polymorpha*. Below Texas there are two tedious locks in the canal, after which we entered the broad expanse of the Maumee above Grand Rapids Dam. At the last lock we saw valves of *Q. lachrymosa*.

Station 19. Maumee River above the Grand Rapids Dam.—Here, as at Defiance, the dam backs up the water for several miles, and at this place the river is widened to 2,000 feet or more. Mussels were reported plentiful in this dead water and a few hauls with the dredge verified the correctness of the report. The water here is 18 feet in depth and the bottom is covered with mud in which are patches of sand and rocks, and it is very good dredging, being free from snags. Only three species were obtained, but they were all large, fine shells.

Station 20. Maumee River below the Grand Rapids Dam.—This dam, like the one at Defiance, was built by the State of Ohio as a feeder for the Miami and Erie Canal. It is 5 feet in height and a little over 1,800 feet in length and interrupted at the center by an island 350 feet in width, known as Purdys Island. At the time of our visit (Aug. 17) no water was running over the dam, all the surplus escaping by the canal on the north bank of the river and a mill race on the south bank. The river bed below the dam is broken up into numerous channels separated by islands covered with water willows and other plants much as it was below Independence Dam at Defiance. Here, however, the bottom is a fine-grained sandstone which has been largely quarried for building purposes, with the

result that the channels are broken by long deep ruts and numerous pools. The water was very clear and in the shallower portions of the pools the shells could be seen distinctly. In one of the pools especially the mussels, crowded together and interspersed with numerous crawfishes, showed up so clearly that they made a recognizable impression on a photographic plate through about a foot of water.

The mussels here evidently have a hard time finding enough soil to hold them in place, and many appear to be washed out and down the river during high water. Several were seen lying on their sides on the bare ledges. (See fig. 4, pl. II.)

There was some pearl excitement at Grand Rapids, but it appeared to be confined chiefly to boys. The mussels can be very easily obtained, and shells, cut open by the pearlers, were strewed in large numbers over the rocks about the edges of the pools. Several of the boys that we saw had vials of small irregular slugs or baroques to sell, but they contained nothing of any value. The inhabitants of the place told us that button men had been there prospecting for shells and had offered \$40 per ton for a species which we judged from their description to be the black sand shell, *Lampsilis rectus*. The shells of that particular species were so uncommon, however, that nobody thought it worth while to hunt for them.

There was some fishing in the pools below the dam, and mussels, especially small *Quadrula pustulosa*, were used for bait.

Station 21. Miami and Erie Canal at Grand Rapids, Ohio.—At the end of the dam opposite Grand Rapids we entered into the second stretch of canal, which leads from Grand Rapids to Toledo, Ohio. At the very head of the canal we dredged and examined the shores for signs of mussels. We obtained only one *Anodonta grandis* on the dredge, and this was heavily infested with the sporocysts of the distomid of Osborn. A few dead *Plagiola elegans* and *Obliquaria reflexa* were found on shore, probably left there by a muskrat. The canal is a pleasant stretch of water without any obstructions, running parallel with the river. (See fig. 6, pl. II.)

Station 22. Miami and Erie Canal, 4 miles below Grand Rapids.—About 4 miles down the canal, where a long fringe of upland forest borders the canal opposite the towpath, we came upon half a bushel of shells at the end of a burrow occupied by a mink or muskrat. The shells were all small. The *P. donaciformis* were of fine color and unusually large size. The finding of this pile of shells was a fortunate circumstance, as it contained a good number of shells belonging to species which we could not find in any quantity and which are not readily obtained by the dredge. Indeed, considerable dredging in the canal opposite the shell pile yielded only *Q. undulata* and *Q. lachrymosa*.

Fig. 4.—The Maumee River below the State Dam, Defiance, Ohio, the richest collecting ground in the river.

Fig. 5.—The Auglaize River, 2 miles above Defiance, Ohio, showing the small islets and pools containing dense beds of mussels.

Fig. 6.—A stretch of the Miami and Erie Canal, an excellent breeding ground for mussels, and an ideal place for artificial propagation.

As a usual thing, the muskrat appears to feed on other material, chiefly vegetables, during the summer, beginning its mussel diet more extensively in the autumn, and the first mussels killed are usually small.

From this station on, piles of shells along the shore indicated moluscan life, which would otherwise have escaped notice, and also the presence of muskrats.

Station 23. Miami and Erie Canal, 8 miles below Grand Rapids, Ohio.—Here, opposite a farm belonging to Mr. Neifer, a few hauls were made with the dredge, and a single *Quadrula pustulosa* and 15 to 20 *Q. undulata* were obtained.

Station 24. Maumee River, 4 miles above Waterville, Ohio.—The river here is much wider than at Grand Rapids; there are broad riffles and the bottom is mostly of flat limestone. There are only a few patches of sand in the bottom among the numerous islands, which are covered with willows, water willows, etc. Shells were fairly plentiful where they could obtain a foothold. There are many dead shells on the islands and a few small *U. gibbosus* and *P. elegans* on shore freshly killed, probably by a muskrat.

Station 25. Miami and Erie Canal, opposite station 24.—Two dredge hauls were made in the canal opposite the last station on the river, but only a single example of *Anodonta grandis* was obtained.

Station 26. Miami and Erie Canal, 1 mile east of Waterville, Ohio.—Just below the bridge which crosses both the canal and the river, 1 mile east of Waterville, Ohio, two dredge hauls were made. The canal here was about 6 feet deep and the bottom was of a rather soft black mud. The *Q. undulata* were rather inflated, with black epidermis and well covered with the bryozoan *Plumatella*, like those taken near Texas, Ohio.

Station 27. Miami and Erie Canal at Westcott, Ohio.—At Westcott, Ohio, a small village above Miami, a few dredge hauls were made in the canal, but only one *Quadrula lachrymosa* and a few *Q. undulata* were obtained.

At Miami, which is only 7 miles from Toledo, the Maumee was wide, with but few islands, and deep enough to be navigable for launches, of which there were many in evidence. There were large patches of *Nelumbo lutea* scattered about in the river. The shore was examined for a considerable distance but no shells were found. During low water the riffles are said to extend from Grand Rapids to within a quarter of a mile of Miami; the shells, therefore, would probably be about the same for the entire distance.

Station 28. Miami and Erie Canal below Miami, Ohio.—About a mile below Miami a temporary dam had been thrown across the canal to allow the making of certain repairs in the locks below. This dam

stopped all the water except a small overflow stream which trickled along the very deepest part of the canal. At one place, where a small stream came rushing over a miniature cataract, a dense school of young fish, which appeared to be the skipjack, *Pomolobus chrysochloris*, were crowded together making frantic efforts to leap up the fall.

In the shallow water of the canal many mussels were found alive, while along the exposed portions of the canal bottom an opportunity was presented for studying mussel distribution similar to that in the feeder canal at Fort Wayne.

By far the larger part of the bed of the canal was open to observation, the central stream being very narrow. At one place the canal when full had overflowed at one side, forming a large lagoon or backwater, in which the water had been from 6 inches to a foot in depth. The bottom of this lagoon was nearly covered with dead shells.

It was noticeable that *Quadrula undulata* and *Q. pustulosa* withstand a scarcity of water better than most of the other species. There were more of these two species alive in the water than all the others together, and in several places on the exposed sides of the canal examples of one or the other of these two species were found with the flesh still adhering to the shells, showing that these mussels had withstood drying up longer than associated species. The little *Anodonta imbecillis* was found for the first time in considerable numbers at this place, both in the deeper and shallower parts of the canal. The conditions of the canal also gave an excellent opportunity to get very young shells of some of the smaller species, such as *Plagiola elegans* and *P. donaciformis*.

In connection with the last station on the river may be considered shells obtained on the beach of Put-in Bay Island in Lake Erie. These represent species of the lake into which the Maumee flows and from which that stream may have received some members of its mussel fauna. No live mussels could be obtained at Put-in Bay except a few occasionally washed up by waves. About a mile below the bathing beach a number of dead shells were obtained, representing the species given in the table.

In this list the words "common" and "few" refer only to the relative number of shells found. Considered as a whole, shells at Put-in Bay were rather rare, and all seen were much dwarfed.

TABLE SHOWING DISTRIBUTION OF MUSSELS IN MAUMEE RIVER.

[NOTE.—Abun.=abundant; Com.=common; numbers denote the actual number of specimens found.]

Mussel species.	Lettered stations.								Numbered stations.										
	A	B	C	D	E	F	G	H	1	2	3	4	5	6	7	8	9	10	11
Quadrul atuberculata (purple warty-back)	2				Few.		1	1	Few.	1	5	2			7	Few.	Com.	4	1
Quadrula coccinea	1				Few.		2	15	Few.	7	107	1			2	Few.	Few.	2	2
Quadrula rubiginosa	Com.	4		Com.	Com.	Com.	16		Few.			2	2				Few.	Few.	Few.
Quadrula pustulosa (pimple-back; warty-back)		1					1	1	Few.		45	2	1		6	1	Few.		
Quadrula cylindrica (rabbit's-foot)	1				Few.														Few.
Quadrula undulata (three-ridge; blue-point)	Com.	9		Com.	Abun.	Com.	11	78	Few.	Com.	7	2		Few.	Few.	1	Abun.	2	1
Pleurobema clava	1								Few.	Few.		2			Abun.	Few.	Few.	2	Com.
Unio gibbosus (spike)	Few.						5	9	Few.			2			Com.		Few.	9	7
Alasmidonta truncata					Com.		1	2	Few.		2		1		Few.		Few.		
Symphynotacomplanata (heel-split-ter; hackle back)					Com.			1											
Symphynota costata (fluted-shell; squaw-foot)	Abun.	7			Com.		13	86	Few.	2	22	22	6		Com.		Few.	1	
Symphynota compressa								1											
Anodontoides ferrussacianus subcylindraceus			11																
Anodonta grandis				Com.	Com.	Com.		9									Few.		
Strophitus edentulus (squaw-foot)	1	1			Few.		2	2			1		1						
Pychobranchus phaseolus	1				Com.		7	18				2					2	Few.	7
Plagiola securis (butterfly)									1										
Obovaria circulus	Com.				Com.		2	2	Few.	1	5	1	5		Few.	Few.	2	1	Few.
Lampsilis gracilis (paper-shell)								11	Few.	2	2	1	1		1	1	1		1
Lampsilis alatus (paucake)					Few.	Few.	1	5			1		1						
Lampsilis glans					Few.			1											
Lampsilis iris	Com.		1		Few.	Few.		2		4		1			Com.	Few.	Few.		Few.
Lampsilis rectus	1	18			Few.		1	9	Few.		6	2	7		Few.		2		Few.
Lampsilis ligamentinus (mucket)	Com.	72			Com.		36	60	Com.	Com.	24	71	4	Few.	Com.	Com.	Com.	Com.	23
Lampsilis tuteolus (fat mucket)	Com.	14		Com.		Few.	11	22	Few.	8	1	3			1	1	Few.	1	4
Lampsilis ventricosus (pocketbook)		4			Few.		5	8	Few.	2		12	2	Few.	Com.	Com.	Few.		1
Lampsilis multiradiatus	1				Few.			1											
Micromya fabalis					Com.														
Truncilla sulcata	Com.				Few.			3	Few.		1	1			Few.				

DISCUSSION OF MUSSEL SPECIES.

1. *Quadrula tuberculata* (Rafinesque). Purple warty-back. This is not a very common species of mussel in the Maumee or its tributaries, only a few occasional examples having been taken. It was most abundant in the upper portions of the river, near Fort Wayne, and down as far as Maumee Center Bridge. No living examples were obtained below Defiance, Ohio, and only a very few dead shells were picked up below here, the last one being obtained at Waterville, Ohio. All specimens seen were kept, and only about 52 were obtained in the Maumee system altogether. The range of this species is given by Simpson^a as "Mississippi drainage generally; southern Michigan; San Saba County, central Texas." While it is in the main a Mississippi form, it is one of those species which occur occasionally within the St. Lawrence Basin, and although not usually a lake-dwelling species a few old valves were found along the shore of Put-in Bay, The Maumee examples show very little variation. Although most of them were rather small, some of the shells seen at the clammer's camp near Fort Wayne were quite large. The few mussels of this species obtained alive usually contained small baroques in the dorsal region.

This mussel is of no value for buttons on account of its color. In addition to being purple, the luster is usually dull. The epidermis, which is commonly brown, is somewhat tinged with green in examples from Maumee Center Bridge. In some places the distomid of Kelly, associated with dorsal baroques, is a common parasite. The examples found in the Maumee River, however, are comparatively free from this parasite.

2. *Quadrula coccinea* (Conrad). This species is not as common in the Maumee Basin as *Q. tuberculata*, only about 31 specimens having been obtained. It was more abundant in the upper course of the river, but dwindled out and finally disappeared; the greatest number (10) was obtained at Kern's Reservation, not far below Fort Wayne, and the last one was taken at Florida, Ohio, in the riffles below the bridge. It is a species common to both the Mississippi and the St. Lawrence drainage. The larger number of examples seen were white naced, though a few were rosy.

The larger white-naced specimens would make excellent button shells, classing with the pig-toes, though considerably thinner.

3. *Quadrula rubiginosa* (Lea). *Quadrula rubiginosa* is one of the most widely distributed of our fresh-water shells and occurs in a great variety of situations; it is found in lakes as well as in rivers. It is fairly common all along the Maumee and its tributaries (except the Tiffin, which was not thoroughly examined and in which few

^a Proceedings U. S. National Museum, vol. XXII, p. 795.

shells of any species were found). It was very abundant in the feeder canal and in its reservoir. A number of shells of this species were also found on the shore of Put-in Bay Island, Lake Erie.

Although during the summer's collection we obtained material exhibiting considerable variation, all examples found within the Maumee Basin were fairly constant in form, though some were short and humped. This species very closely resembles *Quadrula coccinea*, the only apparent difference being in the prominence of the ridge on the posterior umbonal slope; hence some specimens are difficult to classify.

Young shells of this species exhibit faint rays which disappear with age. The specimens obtained in the reservoir differed from most of the others in having a very satiny epidermis. The greater number of the shells have a white nacre, although in some cases it is yellowish or rosy. None of our examples are as rosy, however, as *Q. coccinea* frequently becomes. The flesh of this species varies from salmon or orange to deep red, the richness of its color probably varying with the nearness to the breeding season and the abundance of ova present; these latter are of a bright carmine color. Some specimens were found becoming gravid and one nearly ripe in the feeder canal July 27. On account of its commonness not all of the shells seen were collected; however, we obtained 112 examples from the Maumee Basin.

What seemed a peculiarity in the action of this mussel was the habit of burying itself in the early summer. On a visit to the reservoir of the feeder canal on June 30, the mussels were all projecting far out of the mud and actively moving about, while on July 23, at the same place, they were buried quite deep, and hard to find. They were also deeply buried in the feeder canal pools about the same date.

A probable explanation of this peculiar action is that the reservoir was quite shallow and the water became warm. The water becomes low during drouths, and the mussels may have gone down into the mud in anticipation of the pool going dry.

This species is sometimes more or less affected with *Atax*, though not badly. Those found in the reservoir were more affected than others.

Although its small size is something of a disadvantage, this species would make a fair button shell. It has good luster, and its comparative flatness would permit its being worked up economically.

Though there are a number of river shells superior to it, it is one of the best if not the best button species that would thrive well in ponds. A considerable number were weighed and measured, and the largest, obtained at the Defiance Dam, was 88 millimeters high by 306 millimeters long, and the dry shell weighed 101 grams.

4. *Quadrula pustulosa* (Lea). Pimple-back; warty-back. *Quadrula pustulosa* is another of the widely distributed mussels common to both the Mississippi and St. Lawrence drainage systems; but, although thus widely distributed, it is somewhat choice of its habitat. It shows a distinct preference for more or less sandy or gravelly bars with a live current. It does not usually form beds, but is generally more or less mixed in with other species. It was found throughout the length of the river, but most abundantly in the central portion. A few examples, some of them of good size, were found at Fort Wayne, especially in the feeder canal. The greatest number taken at one place was at Kern's Reservation, where 46 were obtained in a shallow bottom of sandy gravel. All these examples, and, indeed, nearly all found in the Maumee until we reached the Auglaize River, were small, dwarfed shells; those found in the Auglaize River and near the dam at Grand Rapids were of considerably larger size. A few of the shells were almost devoid of pustulations, and one small smooth shell, much produced forward and rounded, bore considerable resemblance to *Obovaria retusa*. The two largest examples obtained were 85 millimeters long and weighed (dry shell) 145 grams.

This is one of the species commonly used in button making, and where it reaches large size is fairly well adapted to that purpose. In the Maumee, on account of both their small size and their fewness, they are not an important item. Most of the examples secured were retained and numbered in all 156 shells.

5. *Quadrula lachrymosa* (Lea). Stranger; monkey-face. This species was found only in the lower courses of the river; none were encountered above the Auglaize. In that stream three examples, the first seen, were secured. From this point they were occasionally met with all the way down the river, and in the canal. Thirteen specimens were taken below the Defiance or Independence Dam, and below the dam at Grand Rapids, Ohio, 24 were obtained. This is the greatest number for any locality. The largest one seen was obtained here; its length was 115 millimeters and its weight (dry shell) 221 grams. All examples seen were retained, the total number being 46.

This shell is used in button making, and ranks in this respect along with the three-ridges. The irregular sulcation of the valves, however, puts it to some disadvantages in cutting, so that while it is an interesting and well-marked shell, it does not possess enough favorable qualities from the commercial point of view to make it desirable for propagation.

6. *Quadrula cylindrica* (Say). Rabbit's-foot. This has been regarded as a species of the Mississippi drainage, belonging principally to the Ohio, Cumberland, and Tennessee River systems. Only a few examples were found and these were in the feeder canal and upper

parts of the Maumee. It is therefore probable that they represent the result of migrations by way of the Wabash and Erie Canal. One example was found in the St. Marys River and four in the Maumee in the vicinity of Antwerp, Ohio; a few dead valves were occasionally seen, but not more than two or three at the most. None were found below the point just mentioned. In the feeder canal, where conditions were particularly favorable for a study of the fauna, four examples were found, and two fine valves, not mates, were obtained in the mouth of the St. Joseph. The shells found in the feeder canal were of an elegant compressed form with numerous triangular tubercles on the anterior portion, and represent the subspecies *strigillatus* B. H. Wright, which is considerably more attractive than the type form. They are rather dark in color, with green triangles, as is usual, and fine capillary rays. One example contained two *Atax*. This attractive species is not well suited to button making on account of its form and the fact that the nacre is frequently diseased; hence it is practically unknown to the trade.

7. *Quadrula undulata* (Barnes). Three-ridge, blue-point. With the exception of *Lampsilis ligamentinus*, *Quadrula undulata* is the most abundant species of mussels in the Maumee Basin. All the undulate mussels found were referred to this species except those at Put-in Bay, Lake Erie. Notwithstanding the statement made in nearly all the literature at hand that "the two species^a are perfectly distinct and there is no need of confusing them," many examples were found that were hard to place. Different authors do not agree perfectly as to the differences between these species and, generally speaking, the characteristics given are rather vaguely expressed, a fault not due to the carelessness of describers but to the nature of the case. All descriptions seem to agree in stating that the umbones are more inflated in *plicata*, but we find this feature as variable as any other. In the large collection of shells of the Bureau of Fisheries belonging to these two types we have many intermediate forms and several series exhibiting almost perfect transition from one species to the other.

This species, as we have it, is exceedingly variable, so much so that in looking over the entire summer's collection it was possible to give the locality of a number of shells simply from their appearance.

Q. undulata was found to be fairly common along the river where there were any shells at all, and on account of its abundance only a small proportion of the shells seen were retained. Fourteen were obtained at the riffles in the St. Marys, where it was fairly common. In the St. Joseph River at Robinson Park and in the feeder canal it was abundant and attained large size; 10 examples were obtained from the St. Joseph and 23 were taken of the large number seen in the feeder canal. It also thrived in the reservoir of the feeder canal.

^a *Q. undulata* and *Q. plicata*.

Very few were found in the upper Maumee. None were noted in the shell pile collected by the clambers near Fort Wayne and only 10 were obtained in the river above Defiance, Ohio. In the Auglaize River the species is quite abundant and 52 specimens were secured. It was fairly common in the Maumee below Defiance. Ten examples were secured at the Defiance Dam, 6 in the canal at Texas, and 16 near the dam at Grand Rapids. It was the most abundant shell in the canal below Grand Rapids.

From Defiance down the river and in the canal these shells were blacker and considerably more inflated than those above; the specimens found in the feeder canal at Fort Wayne were usually quite compressed and brownish in color, while those below Defiance were full and black, suggesting *Q. plicata*. These latter shells were usually overgrown with patches of the bryozoan *Plumatella polymorpha*.

This is one of the staple species used in button making, the nacre having a good luster and the shell being thick and heavy. The small end is beautifully iridescent and frequently of an attractive blue color.

This species, along with its relatives, is in good repute among pearl hunters. We found a few minute pearls and small rough baroques, but no more than in other shells. It is fairly free from parasites; a very few *Atax* were found. The nacre is frequently stained brown. As the species is hardy and thrives in a variety of conditions, especially in canals, it might be a good sort of propagate where better species would not thrive. The total number of examples obtained in the river was about 180.

In Lake Erie, at Put-in Bay, we found a dwarf species of shell, *Q. plicata hippopæa* (Lea), resembling this.

8. *Pleurobema clava* (Lamarck). Simpson^a regards this as a shell of the Mississippi drainage and gives its range as "Ohio, Cumberland, and Tennessee River systems, reported from Iowa City, Iowa, St. Peters River, Minn., and from Nebraska." Call reports it from the St. Marys and from another stream in Indiana (St. Joseph) of St. Lawrence drainage. In the Maumee Basin it was nowhere abundant, but fairly well distributed along the upper course of the river. One was found above Bluffton Road Bridge, and in the St. Joseph River two dead shells were found, one quite large. Two shells were found in the Maumee near Fort Wayne, while at Maumee Center Bridge we obtained 12 moderate-sized specimens. At Antwerp two small shells were seen, and dead shells were still fairly common several miles below that place. None were seen as far down as Defiance, nor any below there, nor were any found in Lake Erie at Put-in Bay. The whole number of specimens obtained

^a Synopsis of the Naiades, Proceedings U. S. National Museum, vol XXII, p. 746.

was 20. The Maumee specimens are brightly polished and can be distinguished by this feature from the rest of the summer's collection.

This is an exceedingly handsome shell, but of no commercial importance, as both its small size and peculiar form are disadvantageous. The nacre, though usually white, is occasionally of a beautiful warm pink.

9. *Unio gibbosus* (Barnes). Spike. *Unio gibbosus* was fairly common the whole length of the river. It is one of the species of wide distribution and considerable variability. Our specimens do not exhibit much variation, however. Most were of the solid, shortened, somewhat humped type. The long examples, which have procured for the species the name "spike," sometimes closely resemble *Lampsilis rectus*, from which they can be distinguished by the sculpture of the umbones and by the shape of the lateral teeth, while the short humped form is frequently almost indistinguishable from *Ptychobranhus phaseolus*; about the only way to tell them apart is by observing the color and texture of the epidermis, that of *U. gibbosus* usually being darker, and by the shape of the body cavity. One shell was found in the St. Marys, two in the St. Joseph near its mouth, and three in the Maumee near Fort Wayne. It was most abundant in the central portion of the river from Maumee Center Bridge to the bridge at Florida, Ohio, and was common in the Auglaize River. Lower down the Maumee it gradually disappeared, the last few shells having been seen at Grand Rapids, Ohio, below the dam. In all, 63 shells were obtained in the Maumee Basin. It appears to be one of the common shells in Lake Erie, 16 having been found on the shore of Put-in Bay Island. Both purple and white nacre forms were present. The greater number, about two-thirds, had white nacre, one had rosy nacre, one had purple nacre, white at the edges, and the others were intermediate between white and purple. Young examples showed delicate rays.

This species is of no commercial value, as even the white forms have the nacre quite dull. In some localities the distomid of Kelly, associated with dorsal baroques, is a common parasite, but they are not abundant in the Maumee.

10. *Alasmidonta truncata* (B. H. Wright). This is not an especially common shell in the Maumee Basin. According to Simpson^a it is a Mississippi Valley species which has migrated into the upper parts of the St. Lawrence Basin. It is rather variable in form and is sometimes difficult to distinguish from *Strophitus edentulus*. It was found in the feeder canal and St. Joseph River at Fort Wayne. Occasional examples were encountered along the course of the river, as 2 at Kern Reservation, 1 at Maumee Center Bridge, 1 at Antwerp, Ohio. Three large ones were obtained in the Auglaize River

^a Synopsis of the Naiades, Proceedings U. S. National Museum, vol. XXII, p. 671.

and three in the Maumee below the Independence Dam. The last example was found below the dam at Grand Rapids, Ohio. In all, 15 specimens were taken.

This shell is handsome and odd, brightly splashed with blue or green and greatly inflated. It is of no commercial importance on account of its thinness. The nacre is usually whitish, though frequently with a bluish tinge and occasionally a beautiful pink or rosy.

11. *Symphynota complanata* (Barnes). Heel-splitter; hackle-back. This species is common about Fort Wayne, being especially abundant in the feeder canal, where it was one of the most conspicuous members of the mussel fauna. Of the great number seen in the feeder canal 18 fine examples were taken; 2 were secured in the reservoir of the feeder canal and 5 in the St. Joseph River near its mouth.

This species is evidently an overflow from the upper Wabash drainage. Only one specimen was obtained in the Maumee River and that was at the very head near Fort Wayne; one which had been found at New Haven, about 7 miles below Fort Wayne, had been kept and was shown as a curiosity.

This shell was formerly not much used in button making, as it is usually rather thin for that purpose. Its broad flat surface and fair luster, however, are greatly in its favor, and more buttons can be cut out of one of its valves than from any other species except the large *Quadrula heros*. It appears to breed abundantly and bring forth large numbers of young. Gills of examples obtained in the Little Wabash River near Fort Wayne, September 26, 1906, were full to bursting with glochidia, which are brownish and give the whole mass a distinct brown color.

The species appears to have bred successfully in the feeder canal, as there were a great many young shells there. It would probably not thrive well in ponds, though a healthy example was seen in the reservoir of the feeder canal. It is not found in lakes, but is frequent in small streams with rather muddy bottoms, and is somewhat similar to *Anodonta* in habits. It is frequently the host of *Atax*, and is one of the species especially susceptible to infection by the parasite *Aspidogaster conchicola*, which inhabits the pericardial cavity, without, however, doing much apparent harm.

As this species lives where there is rather little current and thrives on a muddy bottom, it would probably be a valuable subject for cultivation. Its abundance in the canal suggests that it would respond well to artificial conditions.

12. *Symphynota costata* (Rafinesque). Fluted-shell; squaw-foot. This mussel was fairly common in the Maumee River throughout most of its length. One example was found in the St. Marys River

above the Bluffton Road Bridge, and 11 were obtained at the riffles. In the feeder canal 2 examples were secured. It was probably not uncommon there, but on account of its general abundance no more were taken. From 1 to 3 were found at most of the stations on the Maumee, so that it would be unnecessary and tedious to give its occurrence in detail. It was common in the Auglaize, where 13 examples were secured, and abundant in the Maumee below the dam at Grand Rapids, Ohio, where we obtained 23. One was found in the canal just below Grand Rapids. Some of the examples are beautifully rayed. The nacre is usually of a peculiar and pleasing yellowish shade. On account of the usual thinness of the shell, however, the species is commercially unimportant, few or none being used in the button business. Altogether we obtained in the Maumee Basin 125 shells belonging to this species.

13. *Symphynota compressa* (Lea). In the Maumee Basin we found only one example of this widely distributed species. This was found in the St. Joseph River near its mouth. The species is rather small and thin, and of no commercial importance.

14. *Anodontooides ferussacianus subclyindraceus* (Lea). This subspecies was found in only one locality in the Maumee drainage, and there it was the only species found except one fragment of *Lampsilis iris*. This was in a small stream, Spy Run, which enters the St. Marys at Fort Wayne. In this stream seven examples were found, all small dead shells. This species is of no commercial importance on account of the thinness of the shell.

15. *Anodonta grandis* (Say). This species delights in a muddy bottom and a slow current. It was rather common in such places as the feeder canal and its reservoir, and a few large examples (dead shells) were found along the St. Joseph River near Robinson Park. It was found only occasionally in the rivers; 5 were obtained at the riffles of the St. Marys River; 10 were taken of many found in the feeder canal; 12 were collected in the reservoir of the feeder canal. We found 8 in the St. Joseph River near its mouth. In the Maumee it occurred rather sparingly, 1 example having been obtained at the Maumee Center Bridge, 10 in the Auglaize River, 1 in the Maumee below the dam at Defiance, 5 below the dam at Grand Rapids, and 2 in the canal below Waterville. A number were seen below the dam in the canal at Maumee. Only a few of the examples seen were collected; the total number taken was 51.

The specimens from the feeder canal were unusually thick, appearing as if a second nacreous layer had been deposited.

Of all the species of mussel encountered, *Anodonta* was the richest in parasites, harboring the greatest number of species, and (except in the case of some *Lampsilis alatus* obtained at Grand Rapids which

contained great numbers of *Atax*) the largest number of individual parasites.

Most of the shells obtained were more or less stained red interiorly. This stain, caused by a parasite, the distomid of Osborn, varied greatly in extent, beginning in the umbonal cavity and extending from that region in two diverging lines, one anteriorly and the other posteriorly, ventrad. The V-shaped area thus formed gradually fills in with red until the whole surface is involved. This process has been quite fully described by H. L. Osborn^a and by H. M. Kelly.^b The minute distomids, showing pink against the mantle, were present in numbers varying from a few to several hundred.

Occasionally mussels of this species were found in which the distomids mentioned above had not yet escaped from the sporocysts. The shells of such mussels frequently had the nacre raised in sharp pearly projections, and in some cases the sporocysts seemed to have been overgrown with the nacre of the shell.

In addition to the distomid of Osborn, *A. grandis* also usually has a number of *Aspidogaster conchicola* in the pericardial cavity, several individuals of *Cotylaspis insignis* in the axils of the inner gills, and one or more species of *Atax* among the gills; even leeches are frequently found within the shells. The leeches are no doubt parasitic, as is evidenced by the fact that where a pile of freshly cleaned shells killed by muskrats were found under water on another occasion (at Lake Maxinkuckee) the leeches almost covered the insides of the valves.

On account of the thinness of its shell, *Anodonta grandis*, and indeed all the species of this genus, are of no value commercially.

16. *Anodonta imbecillis* (Say). This species has not heretofore been reported from the Maumee Basin. It was only infrequently found; one specimen was obtained on the shore of the St. Marys River, at Fort Wayne. After this none were seen until at the very end of the investigation, in the canal at Maumee, Ohio, below the dam; at this place 38 examples were taken. Their abundance here indicates that they were probably abundant also throughout the length of the canal, but do not "bite" at the dredge hooks. As none were found in the bottom of the feeder canal, it is probable that they do not occur there. This is a very pretty species, but it is of no commercial value.

17. *Strophitus edentulus* (Say). Squaw-foot. This species is not common in the Maumee Basin. Examples were occasionally found in the St. Marys River at Fort Wayne, in the feeder canal, and in the St. Joseph and upper Maumee Rivers. One was obtained at Grand

^a Zoological Bulletin, vol. i, no. 6, 1898.

^b Bulletin Illinois State Laboratory Natural History, vol. v, p. 406, 1899.

Rapids, below the dam. None were seen in the Auglaize River, nor in the Maumee at Defiance. One shell was found on the shore of Put-in Bay, Lake Erie. In all, only 8 examples were obtained in the Maumee Basin. It is of no commercial importance.

18. *Ptychobranhus phaseolus* (Hildreth). This species was not abundant anywhere in the Maumee Basin, but was scattered all along the length of the river. In the autumn of 1907 a fair number were obtained in the feeder canal. We found 16 good specimens in the St. Joseph River at Fort Wayne, 2 in the Maumee near its head, and 2 or 3 at occasional stations along the river. It was fairly common in the river below Antwerp, Ohio, where 10 shells were obtained at one station. Nine examples were secured in the Auglaize River, 2 in the Maumee below the dam near Defiance, and 3 at the bridge at Florida, Ohio, and 2, the last seen, were taken below the dam at Grand Rapids, Ohio. The examples obtained in the Auglaize August 8 were beginning to become gravid. In all, 53 specimens were secured from the Maumee Basin. Shells of this species were fairly common on the shore of Put-in Bay, where it was small but beautiful in color, luster, and form. The outer gills of gravid examples are remarkable for their folded and plaited appearance; the gills look like nests from which insect larvæ, like "wigglers," are ready to emerge. The nacre of some of the young shells is of a beautiful faint pink, but that of all the large old shells was white.

This shell has not been used to any extent, if at all, probably on account of the scarcity of supply, and it is not known to the trade. Its flatness, nearly uniform thickness, and excellent luster would make it worthy of experimentation in the button business. It would probably rank with the "butterfly," *Plagiola securis*, in that respect. The presence of a number of young shells in the feeder canal indicates that it might be easy to propagate in artificial channels.

19. *Obliquaria reflexa* (Rafinesque). Warty-back. This species was first encountered in the Auglaize River, where 1 example was secured. Below the Defiance Dam 3 were obtained; 1 was found at Florida Bridge, and 3 at Grand Rapids below the dam. In the stretch of canal below Grand Rapids it was apparently abundant. One was picked up on the shore at the very entrance of the canal and 22 in a pile left by a mink or muskrat along the side of the canal. A few were found in the canal below the dam at Maumee. This species, being quite thick and of good luster, is used to some extent commercially, but on account of its small size a shell yields only a few buttons.

20. *Plagiola donaciformis* (Lea). The first example of this species was obtained in the Auglaize River. No others were seen until we reached Grand Rapids, Ohio, where 1 was found in the Maumee below the dam. In the stretch of canal near Grand Rapids it ap-

peared to be fairly common; 10 shells were taken from a pile left by some predaceous animal, and of a large number seen in the canal below the dam at Maumee 14 were secured, some of them quite young and small.

This is one of the most beautiful of our fresh-water shells, and the markings are very attractive. It is too small to be of any importance commercially.

21. *Plagiola elegans* (Lea). Deer-toe. No examples of this species were seen until the Auglaize River was reached, where we found 10. It was fairly common in the river and canal below this point. Living mussels and shells of some recently killed were very common in the Maumee below the dam near Defiance.

Of many examples seen we obtained 17 shells here. Below the dam at Grand Rapids, Ohio, we secured 6 shells, and at the pile of shells near the canal bank, which has been frequently referred to, we obtained 49 shells of this species. Some were seen along the shore of the Maumee 4 miles above Waterville, and it was common in the canal below the dam at Miami.

This is one of the prettiest of our fresh-water bivalves, but it is too small to be used much for buttons, though the largest examples are sometimes utilized. By clammers it is called the "deer-toe." It is fairly constant in form, but varies considerably in color and markings, the ground color being sometimes yellowish and sometimes green. The rays are often broken up into V-shaped blotches. The total number of examples collected was 97.

22. *Plagiola securis* (Lea). Butterfly. Of this species only 1 example, a large coarse specimen closely resembling some of the shortened and flattened forms of *Lampsilis ligamentinus*, was secured. This is a species belonging to the Mississippi drainage, and it is one of the most valuable shells for buttons. The specimen was obtained at the clammer's camp near Fort Wayne and was from the upper part of the Maumee.

23. *Obovaria circulus* (Lea). There appears to be considerable confusion among authors regarding the three so-called species *Obovaria circulus*, *O. lens*, and *O. leibii*, and by some authorities the two last named are regarded as subspecies of the first. We obtained the small inflated *O. leibii* on the shore of Put-in Bay Island. In the Maumee we obtained flatter, larger shells, which are similar to those in the collection of the Bureau from the Ohio and Tennessee Rivers. This species (*circulus*) occurs occasionally throughout the length of the Maumee. Three examples were found in the St. Marys River at Fort Wayne. It was fairly common in the feeder canal, where 16 specimens were secured, and in the St. Joseph River near its mouth, where we obtained 10. Six examples were obtained at Kern Reservation, five at Maumee Center Bridge, and 14 in the

Auglaize River, in addition to occasional shells picked up here and there. The last one seen was at Grand Rapids below the dam. The whole number obtained in the Maumee Basin was 60. This species is frequently infested with the distomid of Kelly, and contains small dorsal baroques. Diseased shells with one or both valves roughened and yellow on the inside were quite common. The shell is usually too small to be of much use commercially, but it has a beautiful luster, which continues in dead shells when exposed to the weather longer than in any other species observed. The nacre is usually white, though in some instances it is pink or rosy.

24. *Lampsilis gracilis* (Barnes). *Lampsilis gracilis* is fairly common and well distributed in the Maumee Basin, but is nowhere particularly abundant. Seven examples were obtained at the riffles in the St. Marys River and three in the St. Joseph near its mouth. In the upper part of the Maumee River it is rather scarce; only 1 was taken near Fort Wayne, 1 at Maumee Center Bridge, and 1 below Antwerp, Ohio. In the Auglaize River it was fairly common; 13 were obtained there. In the Maumee below the dam near Defiance it was rather abundant, 19 being found at that place. It was also abundant at Grand Rapids below the dam; here 16 were secured, and 2 in the canal below Grand Rapids. It was quite common in the canal below the dam at Miami, Ohio, though none were collected there.

In all, 63 examples were secured, and 10 additional dwarfed specimens on the shore of Put-in Bay Island, where it was quite common. This is one of the most iridescent shells we have, the posterior portion shading into a fine rainbow blue and purple. It is of no commercial value, however, on account of the thinness of the shell, which usually cracks badly in drying.

25. *Lampsilis alatus* (Say). Pancake. This species is of occasional occurrence in the Maumee Basin, but not abundant. Along the upper parts of the basin they were rather rare. Three were obtained in the St. Joseph River at Fort Wayne, and 1, small, in the Maumee, not far below its source. In 1907 several examples were obtained in the Maumee near Fort Wayne. A few scattered specimens were found below Antwerp, Ohio, and 1 in the Tiffin River a half mile above its mouth. Three were taken in the Auglaize and 11 large ones below the dam near Defiance, where it was beginning to become common. Three were found at Florida Bridge. Below the dam at Grand Rapids, Ohio, it was one of the most common shells and great numbers that had been opened by pearlery were seen on the rocks. We secured 23 examples here. A few were found in the second stretch of canal and in the Maumee above Waterville, Ohio. It was common in the canal below the dam at Miami, Ohio. In all, 56 specimens were taken in the Maumee Basin. At

Put-in Bay Island, Lake Erie, 10 small dwarfed examples were found; it appears to be common there.

The Maumee Basin examples, especially those obtained in the upper course of the river, differ from the usual type of the upper Mississippi River specimens in being considerably thicker, shorter, and more inflated. *Aspidogaster conchicola* is a fairly common parasite in the pericardial cavity, and the examples seen at Grand Rapids were infested with *Atax* to a remarkable degree, some individuals harboring nearly a hundred of the mites apiece.

There is a great deal of variation in the color of the nacre of this species, from pink to rich coppery red. Some of the shells were beautifully iridescent. On account of its color and the thinness of the shell it is of no use for buttons.

In the upper Mississippi, where this species thrives in great numbers, it forms the bulk of the cull shells left on shore, and on beds devoted to commercial purposes would probably be regarded as a nuisance. Richly colored baroques, usually of small size, occasionally occur in this species.

26. *Lampsilis glans* (Lea). This small, inconspicuous species is very likely to be overlooked in collecting, and is probably more common and more generally distributed than reports would indicate. It inhabits both ponds and rivers. In the Maumee Basin only 6 examples were secured—4 in the feeder canal, 1 in the reservoir, and 1 in the St. Joseph River near its mouth. All were dead shells picked up on shore.

27. *Lampsilis iris* (Lea). This attractive little shell does not appear to be common in the Maumee Basin. Two examples were secured in the St. Marys River above Bluffton Bridge, 4 in the St. Joseph near the mouth, 2 in the feeder canal, and 1 at Maumee Center Bridge, making 7 in all. It is probably more common than collections would indicate, as it is frequently found in abundance late in the fall after muskrats have begun collecting, where it has been difficult to find in numbers before this. It seems to be one of the favorite articles of diet with the muskrat.

28. *Lampsilis rectus* (Lamarck). While not particularly abundant, this is a fairly common and well-distributed shell in the Maumee Basin. Its distribution is so general that it is unnecessary to give details. It was quite common in the riffles in the St. Marys, and present in the feeder canal, St. Joseph River, along the Maumee, and in the Auglaize. Nearly every example seen was kept. In all, 63 were taken in the Maumee Basin and 3 in Lake Erie at Put-in Bay. Only a few young were seen, and a few gravid ones were obtained. The young are more or less distinctly rayed; in the adult the epidermis is about uniformly black, but the rays are represented by fine

platings. The female shells are more or less inflated and produced postero-ventrally, so that the ventral outline is somewhat arched.

Generally speaking, the color of the nacre is variable in this species; in some localities many of the shells are pink or purple. The great majority of the shells in the Maumee Basin are white, though the cardinal teeth may be pinkish, pinkish-purple, or purple. *Cotylaspis* is a frequent, and *Atax* an occasional, parasite. In a number of examples the nacre near the cardinal teeth was black and diseased. *L. rectus* reaches quite a large size in this basin; the largest example was 172 millimeters long and the dry shell weighed 375 grams.

On account of its relative scarcity the value of this species as now occurring in the river would not amount to much. It is, however, the most valuable indigenous species so far as price per ton of shell is concerned. In luster it is not greatly inferior to *L. anodontoïdes*, the most valuable of the fresh-water mussels. Its elongate form makes it as well suited to the manufacture of knife handles as *L. anodontoïdes* and for pocket knives the purple or pink nacre shells would not be so objectionable as in the manufacture of buttons, so that the advantage the other species has lies chiefly in the attractive color of its skin. At Grand Rapids we were told that a price of \$40 per ton was offered for these shells. As this species lives under widely different conditions, such as rivers, canals, and even lakes and ponds (though it is usually dwarfed in lakes), it would be one of the most, if not the most, promising species with which to attempt artificial propagation in the Maumee.

29. *Lampsilis ligamentinus* (Lamarck). Mucket. This is by all means the most common shell in the Maumee Basin, occurring so frequently in the river that it would be both needless and tedious to go into details. At Fort Wayne it was common in all three rivers—the St. Marys, St. Joseph, and the Maumee—and in the bed of the feeder canal. It formed the great mass of the 25 tons of shells collected by the clambers at the head of the Maumee. At Fort Wayne it reached its maximum development, and though not actually immense, it was quite large and heavy, as heavy indeed as could be worked up profitably. The shells decrease in size as we go down the river, so that those in the middle portion are of only medium size. Those in the Auglaize River were fairly large. Although *L. ligamentinus* was found at most of the points examined for the whole length of the river, it became scarcer and showed a tendency to disappear from the lower stretches. It was not common in the second stretch of canal, though a few were seen in the canal bed below the dam at the very end of the trip. Only a small portion of the great number seen were taken; however, we saved 282 examples. A number of the shells were measured and weighed, of which the largest was

145 millimeters long and weighed 467 grams. The nacre of all the shells was white.

L. ligamentinus, the mucket, while not the very best of button shells, is not greatly inferior to the best, and on account of its commonness and favorable shape and size is the most common species in commercial use. In the upper Mississippi it occasionally has to be discarded on account of its pink nacre, but this feature is wholly absent from Maumee shells. Perhaps 90 per cent of the shells of the Maumee Basin that possess commercial value are *L. ligamentinus*.

This species is rather free from parasites. A few *Atax* frequently occur, but *Cotylaspis*, *Aspidogaster*, and the other parasites found so frequently in the thin-shell mussels, are usually rare or absent here. Encysted distomids are fairly common, though hardly so common as in *L. ventricosus*. They are usually found about the edge of the mantle, though they may also be distributed throughout the body. The common form, designated in this report as the marginal-cyst distomid, is of especial interest in this species, as it is occasionally the cause of the formation of pearls.

This species was not usually found gravid until late in the season. At the beginning of the Maumee investigation, in June, only a few examples were gravid, but the greater number were barren. As we proceeded down the river, it was noticed that in the Auglaize River, August 8, the gills had begun to fill with glochidia and had a faint blackish edge. On a visit to the riffles of the St. Marys on September 27 a large number of the mussels were found to be gravid.

Lampsilis ligamentinus is one of the most easily propagated of fresh-water mussels, and where it produces a heavy shell and white nacre, as it does in the Maumee, is one of the most valuable species for propagation.

Although well-marked specimens of *L. ligamentinus* are easily distinguished from the following species, *L. luteolus*, one frequently finds shells which are difficult to identify, apparently standing somewhere between the two.

30. *Lampsilis luteolus* (Lamarck). Fat mucket. *Lampsilis luteolus* was found in about the same situations as *L. ligamentinus* but not in such abundance. Most of the examples seen were collected and the number of shells in our Maumee collection is 134. None of our specimens are of the variety *rosaceus*, which is a form belonging to the St. Lawrence drainage.

Unlike *L. ligamentinus*, this species is usually abundant in lakes, as well as being an inhabitant of rivers. It is indeed one of our characteristic lake shells. We obtained a number from Put-in Bay Island, Lake Erie, but they were rather small, as is usual with lake-dwelling individuals. The examples found in the St. Joseph River and the feeder canal were remarkably large and fine. This species

appeared, like many of the others, to become smaller as we proceeded downstream.

L. luteolus is subject to infection by the same parasites as those which attack *L. ligamentinus*, viz, *Atax* and occasionally *Cotylaspis*. One example obtained in the mouth of the St. Joseph River contained a number of *Bucephalus polymorphus*.

This shell has nacre of about the same quality as that of *L. ligamentinus*, but the shell is usually smaller, and has more lateral curvature, so that it can not be worked up so advantageously in making buttons. It is well adapted to the manufacture of fancy buckles, however.

31. *Lampsilis multiradictus* (Lea). This very attractive little mussel was not common in the Maumee Basin, and nearly all those found were dead shells, so nothing was learned concerning its habits. Only 9 examples were found, and these were in the upper two-thirds of the river basin, in the St. Marys, St. Joseph, and Maumee Rivers, and in the feeder canal. In 1907 a fair number were found in the feeder canal, and it had apparently thriven there to some extent. It is of no commercial importance. The species is a resident of lakes as well as rivers.

32. *Lampsilis ventricosus* (Barnes). Pocketbook. This shell, though not especially common, occurs rather frequently in the Maumee Basin. At the riffles of the St. Marys 7 large examples were found. Very fine examples were also obtained in the feeder canal. In the reservoir of the feeder canal a fine but small specimen was found, pretty closely resembling *L. capax*. In the mouth of the St. Joseph River 18 were secured. Occasional examples were obtained all the way down the Maumee; in the Auglaize 14 fine specimens were taken. The largest ones found were in the Maumee below the dam at Defiance, and it was also common below the dam at Grand Rapids, and 2 more were secured in the Maumee above Waterville, Ohio. Altogether 83 examples were obtained.

This shell also lives in lakes and 12 were obtained in Lake Erie at Put-in Bay, all dwarfed.

Although well-marked specimens of this species are easily recognized, it has many deviations from the typical form. Some closely approach *L. capax*, and we have seen shells from Lake Maxinkuckee which seem to lie between this species and *L. luteolus*. In other localities it appears to run into a species which in its typical form is known as *L. ovatus*. However, in the Maumee Basin it is well marked and fairly uniform.

L. ventricosus is used to some extent in the button business, but it is quite frequently too thin for this purpose.

In spawning season this is a very striking shell, the breeding mussel projecting long vividly colored flaps from the mantle and mov-

ing these with a spasmodic motion, while the animal lies on its back. The spawning season does not appear to be strictly confined to any particular season of the year, but spawning individuals can occasionally be found throughout the summer. One was observed in the St. Joseph River at Fort Wayne on July 20.

The principal parasites of *L. ventricosus* are *Atax*, usually few in number, the distomid of Kelly which is frequently present but never numerous, and the marginal-cyst distomid, which is occasionally present in great numbers in the margins of the mantle and throughout the body.

33. *Micromya fabalis* (Lea). This is the smallest and one of the most attractive of fresh-water mussels. It is rather rare in collections, on account of its small size being easily overlooked. It was exceedingly abundant in the Feeder Canal; in 1908 we obtained a half dozen examples, and in 1909, by going over the ground thoroughly in search of this particular species, several hundred were secured.

34. *Truncilla sulcata* (Lea). Scattered valves of this species were seen along the shore of the St. Marys and Maumee, and now and then whole shells. Shells and valves were found on the shore of the St. Marys above Bluffton Street Bridge, along the St. Joseph near its mouth, and in the Auglaize River. Only 1 living example was found, and this was in the Auglaize. In all only 15 shells were obtained.

Truncilla triquetra was not found in the Maumee Basin, but we picked up several vales on the shore of Put-in Bay Island.

GENERAL DISTRIBUTION OF SHELLS IN MAUMEE RIVER.

In general, as to distribution of mussels in the Maumee River, certain species were found to diminish in number or size, or both, in a downstream course.

Quadrula tuberculata diminishes in both number and size until in the lower part of the river only a few dead and rather small shells were obtained. Dwarfed specimens were also found at Put-in Bay.

Q. coccinea gradually diminishes and finally disappears at Grand Rapids, Ohio; it was found at Put-in Bay.

Q. rubiginosa greatly diminishes in numbers, but a few remain until the very last.

Q. cylindrica, sparingly present around Fort Wayne, was not found far below Antwerp, Ohio; no living specimens were obtained in the Maumee.

Pleurobema clava diminishes in numbers and disappears at Defiance, Ohio.

Symphynota complanata was common and large in the feeder canal and is occasional in the St. Joseph at Fort Wayne. One speci-

men was seen at New Haven, Ind. We ourselves found none in the Maumee, except at its very head.

Ptychobranchus phaseolus decreases in numbers and disappears at the very last near Miami, Ohio. Dwarf examples were found at Put-in Bay.

Obovaria circulus diminishes rapidly in numbers, and the last one was found in the Auglaize River at Defiance, Ohio.

Lampsilis multiradiatus, fairly well distributed in the upper part of the river, wholly disappeared at Defiance.

L. ligamentinus decreased in number more than in size, but diminished considerably even in size.

Truncilla sulcata, never very common, was not found below Defiance, Ohio.

The following species increase in number or size, or both, with the descent of the river:

Quadrula pustulosa increases both in number and size until it is fairly common below Grand Rapids, Ohio.

Q. lachrymosa first appears in the Auglaize a little above Defiance and becomes quite common in the lower part of the Maumee and in the canal.

Unio gibbosus increases both in size and number and becomes one of the most common forms in the lower part of the river.

Anodonta imbecillis appeared in considerable numbers at the very last, in the canal below the dam at Miami, Ohio.

Obliquaria reflexa first appeared in the Auglaize River, near Defiance, and became fairly common below there; the same may be said of *Plagiola donaciformis* and *Plagiola elegans*.

Lampsilis gracilis shows considerable increase both in numbers and size. The same may be said of *Lampsilis alatus*, of which very few were found at Fort Wayne, while it was abundant in the lower stretches of the river.

The following species are of about equal size and distribution throughout the entire length of the river:

Quadrula undulata was fairly common everywhere. It prefers a solid bottom overlaid with a thin stratum of rather soft mud, and wherever these conditions were encountered it was pretty sure to be found.

Symphynota costata was also fairly common everywhere; it increased somewhat in size as we descended the river, the examples found in the Auglaize being the largest obtained.

Anodonta grandis was nowhere abundant, but was found at nearly every station. It prefers a soft muddy bottom.

Lampsilis iris was rare everywhere, but was found all along the river.

L. rectus was nowhere found in abundance; the examples collected near Defiance were especially large and of fine quality.

L. ventricosus was nowhere abundant, but was found occasionally all along the river.

Of exceptionally rare shells, *Plagiola securis* was represented by only 1 specimen, obtained at the clammer's camp near Fort Wayne. In searching over the pile of shells found in the poultry yard referred to in the early part of this paper, it is believed that an example of *Unio crassidens* was seen, but as the shell does not appear in our collections its presence in the river can not be predicated with certainty.

In his paper on "The hydrographic basins of Indiana and their molluscan fauna,"^a Dr. Call gives a list of 27 species of Unionidæ from the Maumee River; of these, 5 species, viz, *Quadrula heros*, *Alasmidonta calceola*, *Obovaria retusa*, *Obovaria ellipsis*, and *Lampsilis subrostratus*, were not seen by us.

FOOD OF THE MAUMEE MUSSELS.

The character of the food of mussels may be better appreciated after a short account of the method of feeding.

If one looks at a mussel in its natural position in the water one of the first things to attract the attention is two openings, one large and usually conspicuously fringed with elongate papillæ, the other smaller and fringed or not, according to the species. These openings project from the posterior or sharp end of the mussel which is directed upward from the bottom. The larger fringed opening is toward the ventral portion of the mussel and is an incomplete tube formed by portions of the mantle placed together. This is the inhalent opening, and here water is taken into the gill chambers by means of waving cilia which beset the gills, mantle, and other parts of the body bordering on the mantle chamber. The water thus brought in contains oxygen and food particles. The small cilia move the particles up to the anterior end of the body between the large labial palps or lips, which form a sort of funnel to the mouth. Here the food passes through the short gullet into the stomach, and thence into a long convoluted alimentary canal, which finally ends at the smaller of the two openings noted above, the exhalent aperture.

There are minute pores in the gills, and through these the water is forced by cilia into the exhalent aperture, from which it returns to the lake or stream in which the mussel lives. Large robust mussels are able to produce quite a strong current, but this is usually not visible in the rippling water where they naturally live. It can be best observed in large river mussels removed from their native stream

^a Proceedings Indiana Academy of Sciences, 1896, pp. 248-257.

and placed in the calm shallow waters of a lake. It is probable that these mussels breathe extra heavily in the less highly oxygenated lake water. The current from the exhalent siphons boils up violently and is ejected intermittently at more or less regular intervals.

In many mussels there is no direct communication between the gill chamber into which the water, bearing solid particles, enters, and the suprabranchial chamber from which it is ejected through the exhalent aperture. Some mussels have the gills free above posteriorly, so that the two chambers have direct communication, and in these it is possible for the mussels to shunt solid particles directly from the gill chamber to the chamber above without passing through the alimentary canal. We have no evidence, however, that this is ever done. The mussel probably exercises little choice as to the nature of its food. The papillæ which fringe the edge of the inhalent orifice are supposed to be water-testing organs, and the mussel can close itself against foul water or against positively objectionable material. In the feeding mussel, as observed in the stream or lake, there is no appearance of nicety or fastidiousness as to the particles swept in; the wide open, immobile, and expressionless lips admit the general current and its diverse minute population with a catholic impartiality. The alimentary canal of the mussel is usually filled with a sort of impalpable or sometimes gritty mud, and mixed in with this are found scattered organisms of various sorts which serve as food.

The impalpable mud usually corresponds closely in color and general appearance with the bottom in which the mussels are found; in rivers with yellow clay bottoms it is yellowish; in dark, muddy bottoms it is dark. It consists of fine particles which have been held in suspension in the water. In turbid streams it consists of the material which gives the water its turbidity, in clear ponds with bottoms of fine mucky silt it is black, and in those still waters full of diffused minute algæ and flagellates, which are common in ponds and pools, it is predominantly organic and of a greenish cast. In the latter case it usually consists almost entirely of colonies of plankton-scum (water bloom) algæ, which are frequently inclosed in clear vacuolelike spaces.

The moderately long alimentary canal suggests that the ingested material contains a low amount of nutriment; observations also seem to indicate that the digestive powers of the mussel are slow and feeble. In mussels which had been kept for several days *Scenedesmus* was found as fresh and green as ever, and in one mussel obtained in the reservoir of the feeder canal green flagellates were still alive and active after having been at least 36 hours in the mussel. While in these instances it is possible that digestion was delayed by the capture of the mussel and placing in changed surroundings, there are other indi-

cations that digestion is normally slow and imperfect. In mussels taken from the beds, washed, and immediately examined, diatoms found at the posterior end of the alimentary canal are frequently alive and exceedingly active; they appear to be even more active than when taken from open water, and the form and color of the chromatophores are unchanged. It is possible that in these cases the mussel obtains some nutriment from the outer coating of the diatom and that the removal of this makes the latter especially active.

The organisms found in the alimentary canal of mussels vary considerably with the places in which the mussels live, but, so far as observed, do not differ much, if at all, among the various species. They consist of such planktonts as are small enough to be taken in, and not active enough to resist the force of the inward current produced by the mussel. The largest and most active planktont taken to any extent was the entomostracan *Bosminia*. This was found with considerable frequency in lake-dwelling mussels, but as all seen were dead, and many were simply empty shells, it was not possible to ascertain whether the mussel had taken in the living animals or not. Actively moving flagellates are quite frequently ingested. In the gill chamber of some *Quadrula tuberculata*,^a a species with an exceptionally large inhalent opening, we found such objects as *Chironomus* larvæ and one small mature dipterous insect.

There are several organisms which are likely to be found in mussels wherever taken. Species of *Scenedesmus* are almost invariably present, as is also *Navicula* along with other diatoms and species of *Pediastrum*, such as *P. pertusum* with great frequency, *P. boryanum* rather commonly, and *P. ehrenbergii*, which appears to be a rare species everywhere, only occasionally. The rotifer *Anuræa cochlearis* is also found frequently and under all sorts of conditions, in lakes, ponds, and rivers. The part usually found is the empty lorica. Another common object found in the alimentary tract of mussels is a club-shaped, several-celled, brown object, probably the spore of a fungus or lichen.

With the exception of those just mentioned the organisms found within mussels are very diverse, and the creatures seem to be quite omnivorous within the limits of what they can capture. Just as in any stream one finds various types of plankton aggregates from the extreme type of "potamoplankton" or characteristic river plankton of the mid-current, recognizable by the scarcity of water-bloom algæ, to well-developed types of "limnoplankton" or lake plankton in the quiet sloughs and bayous, so in these different portions of the stream one finds different sets of organisms in the mussels. In lakes full of diffused water-bloom algæ, the material which forms the mudlike matrix of the food in river mussels is to some extent replaced by the

^a Not in the Maumee River, however, where few were examined.

water-bloom algæ. These may serve also as food. The stomach contents of such mussels, when placed in vials of preservative, differentiate into a lower stratum of black mud and an upper flocculent stratum of fairly pure algæ.

The mussel may be regarded as a sort of living filter, feeding upon the filtrate it separates from the water. It would be worth investigating to ascertain whether they arrest and destroy pathogenic bacteria and thus become efficient purifiers of water. They are valuable aids in plankton investigations, capturing many minute organisms which escape methods of collection ordinarily in use. Though at the outset it hardly looks as if they could cope with the problem, their capacity for ingesting water-bloom algæ (*Clathrocystis*, *Lyngbya*, etc.) suggests that it might be worth while to investigate their efficiency as reducers of plankton scum.

The water bloom, as is well known, frequently becomes a nuisance. It collects in noisome masses of scum along shores of otherwise attractive lakes and reservoirs. Its taste and odor renders the water of reservoirs undrinkable, and for a remedy of this condition the copper sulphate treatment has been devised. Its presence in large quantities along the shores of our most beautiful lakes renders them unattractive during the late summer season, and in many places brings the bathing season to an early close. Aside from the filthy appearance of the water, many persons claim to be actually poisoned by the water bloom, and there are instances on record of live stock being fatally poisoned by drinking water covered with plankton scum. In addition to this, the great amount of decaying material in the water is said to take up oxygen, making the lower strata uninhabitable for fish. It is possible that by planting large numbers of mussels, supplemented by planting egg masses of *Chironomus*, which appear to hatch easily and the larvæ of which eat the coarser algæ, that the plankton-scum nuisance can be greatly abated.

The stomach contents of mussels taken from the main current of the St. Marys, St. Joseph, and Maumee Rivers were rather noteworthy for their paucity of organic material. Through the large mass of muddy matrix filling the stomach were usually scattered a few *Scenedesmus*, various diatoms, and an occasional *Pediastrum* or *Cosmarium*. At the riffles small brown cystlike objects, which may have been a species of *Trachelemonas*, were quite common; with the exception of this the mussel contained very little. Among the organisms noted were *Scenedesmus caudatus*, *Cœlastrum microsporum*, *Pleurosigma*, several forms of *Navicula*, *Phacus longicaudus*, *Pediastrum bryanum*, *Gomphonema*, a sponge spicule, and an active *Euglena*-like organism. The stomach contents of mussels taken elsewhere along the river and in its tributaries, as in the Auglaize at Defiance and the Maumee at Grand Rapids, were not essentially dif-

ferent. One of the examples of *L. ligamentinus* taken in the Auglaize, however, contained many very minute cylindrical objects with rounded ends, which were probably bacteria.

The stomach contents of the mussels found in the reservoir of the feeder canal, a shallow pondlike body of water, bore considerable contrast to that of the river. This reservoir was well populated with small green monads and similar organisms, and during the last days of our observation became covered over with a green scum. It was "puddle plankton" rather than that which is characteristic of either lakes or rivers. The stomach contents of the mussels were greenish in mass, and were found to consist of various organisms, mostly green in color and actively moving.

The main mass consisted of small globular and thick celled, green or brownish flagellates, probably *Trachelemonas lagenella*. Among other organisms were species of *Phacus*, several species of *Scenedesmus*, *Pediastrum pertusum*, *Gomphonema*, several species of *Navicula*, a little *Botryococcus brauni*, *Anurea cochlearis*, *Cosmarium*, small fragments of a *Conferva*-like alga two or three cells long, fragments of the test of *Ceratium hirundinella*, and the brown objects resembling fungus spores. There were numerous narrow curved objects which were probably loricas of *Trachelemonas*.

PARASITES OF THE MAUMEE MUSSELS.

During the progress of the Maumee River investigations the parasites encountered were noted and examples saved for further study.

Generally speaking, *Anodontas* and other thin-shelled mussels are more heavily parasitized than the species having thick shells, and parasites are more abundant in shallow, warm, and quiet pools than in rivers.

The mussels of the feeder canal reservoir were more heavily parasitized than those of the main streams. The following parasites were observed:

1. *Cotylaspis insignis* Leidy, a small organism, which to the naked eye resembles a pale leech. The body is trumpet shaped, and the ventral surface has a large ovate disk cut up by partitions. By this disk the animal adheres to its host, and it usually inhabits the axils of the inner gills. It was most common in *Anodonta grandis* and occurred occasionally in most other species of mussels examined. An example of *Lampsilis rectus* obtained at the riffles contained the surprisingly large number of 67 of these parasites. So far as could be ascertained, this parasite produces no marked physiological effect upon the host and appears to do no particular harm.

2. *Aspidogaster conchicola* Von Baer bears a close general resemblance to the above, but is considerably larger, and the adhering

disk, which is larger and more complicated, has been aptly compared to the sucking disk of *Remora*.

This parasite affects various species of mussels, but its favorite hosts are species of *Anodonta*, *Symphynota complanata*, and *Lampsilis alatus*, in which considerable numbers were found. It usually inhabits the pericardial cavity of the host, though when considerable numbers are present they may be found in other parts of the body.

The finding of a small elongate "hinge pearl" in a mussel affected by these parasites suggested that, under peculiar circumstances, the body of one of these creatures may form the nucleus of such a pearl, since the shape of the two is quite similar. This supposition, however, needs further investigation. *Aspidogaster* reproduces within the pericardial cavity of the host without any marked metamorphosis, and they are found of all sizes, the minute ones having the same form as the adults.^a

3. *The marginal-cyst distomid*.—A distomid forming spherical cysts was fairly common, especially in *Lampsilis ligamentinus* and *L. ventricosus*, along the whole length of the river. A few of these parasites were also found in one *Quadrula undulata* and one *Symphynota costata*. It is probably the species discovered and briefly described by H. M. Kelly,^b who noticed it in four examples of *L. ligamentinus*.

The cysts are usually found along the edge of the mantle, generally in the muscular portion below the pallial line. They are also frequently embedded in other parts of the body, such as the adductor muscles, and especially in the keel of the foot, where they are occasionally found in great numbers. There are indications that they prefer muscular tissue.

Cysts of various ages were frequently present side by side in the same mussels. The youngest cysts are translucent and refractive, faintly yellowish in color, and resemble minute pearls embedded in the edge of the mantle. As they grow older they form conspicuous black dots. One of the smaller cysts measured was 0.3 millimeter in diameter, and a large blackish opaque one was 0.9 millimeter.

Examined with a microscope the younger cysts appear as brick-red spheres, crossed and recrossed by irregular cracks like those of a dried mud flat. Upon carefully breaking open this crust a minute distomid is released, which slowly crawls about on the slide. One of the distomids thus released was colorless, 0.365 millimeter long and 0.21 millimeter wide at its widest portion. Viewed from above, it was pear shaped in outline, the anterior end being acute, the body gradually broadening behind and the posterior end being rounded. It had

^a The development of this species is given by Huxley, *Anatomy of Invertebrate Animals*, p. 178.

^b *Bulletin Illinois State Laboratory of Natural History*, vol. v, p. 406.

two suckers, an anterior one at the small anterior end and a ventral one, about the same size, placed far back near the swollen posterior end. The posterior part of the distomid contained a mass of black material, probably food.

As the cyst increases in age it becomes black and forms a conspicuous dot about the size of a pinhead in the tissue. It is found on examination that the cyst itself, which is surrounded by the black material, has not increased in size, and the wall retains its brick-red color. The appearances indicate that the black material, which is probably a product of excretion of the parasite, has been passed through the cyst wall.

In our alcoholic material the cysts, which appear as small black spots to the naked eye, show under the simple lens as minute orange globes, surrounded by a semitranslucent halo, the alcohol having apparently dissolved out the black material around the cyst wall.

The marginal-cyst distomid reminds one in its general appearance of *Diplostomum*, which is frequently found encysted in the skin of fishes, especially minnows, forming small black spots. In the fishes, however, the black color surrounding the cyst appears to be due to a deposit of pigment by the fish.

The effect of this parasite (the marginal-cyst distomid) upon the mussel appears to be quite various, according to the location of the cyst. In many cases, probably where the cysts are near the inner surface of the mantle, no effect whatever appears to be produced upon the shell. Under other cysts the shell is stained brown, and where the cysts are near the outer surface of the mantle the whole edge of the shell is blistered irregularly and stained a steel-blue color. Moreover, as the cysts increase in size they form firm nodules in the mantle and cause the shell to be built out around them, so that they leave pits in the nacre similar to those left by pearls.

In studying the collection of shells of *L. ligamentinus* at the Bureau of Fisheries, which contains perhaps 2,000 specimens of this species and is represented by shells from widely separate parts of the country, peculiar malformations of the shell were observed, which were probably caused by the parasite under discussion. Among these markings are pits near the margin of the shell, such as we have frequently observed in the living mussel underneath the cyst, and sometimes these contain small attached pearls. One of the most marked features is a tendency of the antero-ventral portion of the shell to cease growing outwardly and either become thickened or gape away from the middle line so that the mussel can not tightly close its shell in front. It appears that the presence of the cysts keeps the affected portion of the mantle in a constant state of contraction, thus preventing it from building the shell outward in the

normal fashion. In some of our alcoholic material this contraction and thickening of the mantle is quite markedly shown. The effect of this peculiar form of growth on the shell as a whole is to give it a somewhat more inflated and elongate appearance than is characteristic of the species. Shells of *L. ligamentinus* thus affected approach the contour of *L. luteolus*; and while close approximation of these two species is not rare in normal shells, some of the puzzling cases are probably *L. ligamentinus* which has been modified by this distomid.

In *L. ventricosus*, which is very susceptible to the attacks of this parasite, we frequently have gaping shells, and others which are markedly thickened. Some of these thickened shells closely resemble those of *L. ligamentinus*. The marginal-cyst distomid is of especial interest on account of its connection with pearl formation.

Suspicion that this distomid had some connection with the formation of pearls was aroused when the objects were first encountered, as their form and position was especially suggestive. This suspicion was intesified by frequently finding small round pearls in the mantle of mussels, closely associated with the cysts. Finally, on decalcifying and clearing in paraffin and xylol, preparatory to embedding, a portion of the mantle containing a small round free pearl surrounded by the cysts, a cyst could be clearly distinguished in the center of the pearl. Our material, which was preserved by simply dropping the mussels into strong alcohol, was not in good condition for histological purposes, so that we were unable to demonstrate the nature of the tissues surrounding the pearls.

Our studies indicate that the marginal-cyst distomid is widely distributed. We have found the cysts in alcoholic material collected in the Mississippi River, in *L. ligamentinus* collected by Freeland and Williams in the Illinois River in 1907, in *L. ventricosus* collected in the Yellow River, Ind., by ourselves in 1908, and in *L. ligamentinus* collected in the Ohio by Boepple in 1909. From the appearance of shells examined, we judge it to be common in the Minnesota River.

4. *The distomid of Osborn*.—Quite frequently during our mussel investigations we have found *Anodonta* affected with small white sporocysts, which covered the outside surface of the mantle next the nacre. The nacre of these mussels was often raised into a number of sharp pearly blisters, and in some cases small white areas, conforming with the size and shape of the sporocysts, indicate that the sporocysts had been actually covered with nacre. Mussels thus affected were found in the Little River ditch near Aboite Station, Ind., and in White Bear Lake and Lake Minnetonka, near St. Paul, Minn., in 1908. Notes on alcoholic examples of *Anodonta* collected in Wild Cat Creek, Carroll County, Ind., in 1899 refer to "white distomids," which were probably this species.

In the reservoir of the feeder canal at Fort Wayne we found an *Anodonta* plentifully infected with these sporocysts, and were able to make out in detail some of the steps in the life history of the animal.

The sporocysts were small white objects, elliptical in outline, about 1.14 millimeters in length and 0.05 millimeter wide. The skin of the sporocysts was transparent enough to reveal, in the interior, the cercariæ, which were three in number in most cases examined, closely doubled up and snugly packed together, and performing an uneasy wiggling motion. The walls of the sporocyst easily rupture; in an example studied at St. Paul the previous year the covering was torn apart by a dissecting needle and the cercarian set free. In the example now under discussion the sporocysts were rupturing of their own accord, allowing the cercariæ to escape. The following is a description of the various stages observed:

Cercaria just escaped from the sporocyst:

Body elongate cylindrical with bluntly rounded ends and divided by a well-defined constriction into an anterior two-thirds, the body proper, and a posterior one-third, the "tail." Body portion elliptical in outline with the two ends similar. Anterior sucker terminal, about one-fourth the greatest body diameter, circular, with concentric ridges faintly marked.

Posterior sucker one-third body diameter, also circular, but with radiating ridges, situated almost in the exact center longitudinally as well as transversely; constriction only one-seventh the body diameter with a well-defined groove all the way around. Posterior portion (tail) almost perfectly elliptical, twice as long as wide, both ends alike and more bluntly rounded than the body proper. Tail covered with a thick epidermis, raised into longitudinal ridges close together, very narrow and zigzag in arrangement.

The internal structure is indistinct, but far enough developed to distinguish the pharynx and digestive canals. The former is relatively smaller than in the adult and is much nearer the posterior sucker than the anterior one. This means that in after development the posterior sucker travels backward, while the pharynx travels forward. At this stage the whole interior of the body is filled with large cells having numerous and interlacing intercellular spaces.

After remaining under the cover glass for a little time the tails break off at the constriction and the body moves about alone.

The following is a description after the tail is shed:

Body elongate, ovate, without any traces of segmentation or separation into parts; anterior end evenly rounded, posterior end drawn out into a point, bluntly rounded at the tip.

Anterior sucker terminal, circular, three-sevenths the diameter of the body, with circular ridges. Posterior sucker on the mid line

of the ventral surface, four-sevenths of the entire length from the anterior end, circular, with radiating ridges and four-sevenths the diameter of the body. Posterior end of body with traces of the zig-zag longitudinal ridges seen on the tail of the young. Mouth in the center of the anterior sucker, opening into a spherical or transversely elliptical pharynx close behind the sucker and one-third its diameter. From the pharynx two digestive tubes lead back to the posterior end of the body, one on each side, each a little narrower than the pharynx, of nearly uniform diameter throughout, and curved outward parallel to the lateral body margin. They reach nearly to the posterior end of the body, where each ends in a network of intercellular spaces and tubes, the excretory organ.

The newly escaped cercarium is about 1.05 millimeters in total length and 0.2 millimeter wide. The length and width are constantly changing, according as the organism is stretched out or contracted.

The tail is no longer an organ of locomotion; it is very large and unwieldy and easily detached; most of the cercaria shed it soon after emergence from the sporocyst, so that it is evidently a vestigial organ.

After shedding the tail the organism, which now has the typical form of a *Distomum*, moves up to the umbonal region of the mussel and acquires a pinkish color. From the umbones it spreads in diverging lines postero-ventrally and antero-ventrally and finally fills in the space between. Where it is located it profoundly affects the nacre, staining it a salmon color, and frequently giving it a diseased appearance. The presence of this distomid in *Anodonta* and its relation to the salmon-colored nacre was first pointed out by H. L. Osborn^a and further discussed by H. M. Kelly.^b

In its general appearance and in its life history this organism agrees very closely with *Distomum duplicatum* as described by von Baer, who gives a detailed description of the sporocyst and a history of the escape of the cercaria and its subsequent behavior.^c It differs from that species in the fact that the tail is not clavate, is longer than the body, straight, and not pediculate. It differs from the cercarian genus *Rhopalocerca* Diesing, formed to include *D. duplicatum*, only in the fact that the tail is not clavate. Von Baer describes what appeared to him a form of reproduction in this distomid, but from what is now known of related forms it appears probable that he misinterpreted appearances. *Distomum duplicatum* (known also as *Rhopalocerca tardigrada* Diesing) is of special interest as the organism first shown by De Filippi to be the cause of pearls in

^a Zoological Bulletin, vol. 1, no. 6, 1898.

^b Bulletin Illinois State Laboratory Natural History, vol. v, art. VIII.

^c Nova Acta Physico-Medica Academiae Cæsareæ Leopoldino-Carolinae, Natural Curiosorum, vol. XIII, pt. 2, 1827.

Anodonta cygnea of Europe; hence a few remarks concerning it may not be out of place.

So far *D. duplicatum* has not been reported from any mussels except *Anodonta*. Its discoverer found it usually in the kidneys of *Anodonta ventricosa* and more rarely in the same organs in *A. anatina*. One badly infected example of this latter species had the sporocysts in the kidneys, gills, pericardial cavity, and edge of the mantle, and in an example of *A. ventricosa* they were even present in the general circulation. Filippi found the sporocysts and free distomids in the mantle of *A. cygnea*, some of them surrounded by nacre; and Pagenstecher found them in the tissue of the genital glands, liver, and kidneys of the same species. In this country Leidy^a has reported "*Rhophalocerca tardigrada* attached to the mantle of *Anodonta fluviatilis*; specimens also obtained by Mr. Lea from *A. lacustris*."

The mature form of *Distomum duplicatum* is said to be *D. tereticolle* Rudolphi, a parasite of fresh-water fishes.

To return to the distomid of Osborn: In addition to its being found in *Anodonta grandis*, this parasite (in the distomid form) has also been reported from *Strophitus edentulus* by Osborn. We had very few living mussels of this species to examine; however, we found dead shells with the peculiar salmon-colored nacre, similar to that produced by this parasite in *Anodonta*.

In view of the fact that a *Distomum* quite similar in appearance to this is found in other species of mussels, while sporocysts are rare (we found them only in the liver tissue of one example of *Quadrula tuberculata* in Tippecanoe River), it becomes an interesting question whether this distomid migrates from the *Anodonta* to other mussels after issuing from the sporocyst. In the first place, such a migration is probably not an event closely connected with the life history of the species; for the tail, which functions as an organ of locomotion in those species which do migrate, has here been allowed to become functionless, or even a dead weight. Moreover, if the host of the mature form is a fish, as one might expect it to be from the life history of its near relative *D. duplicatum*, it would be to the advantage of the distomid to remain in the thin-shelled *Anodonta*, which is much more likely to fall a prey to fishes, or indeed any other predaceous animal, than the thicker-shelled species of mussels. It is very likely, however, that, just as in greatly infested mussels the cercariæ frequently overflow the organs which appear to be their favorite habitat, so a considerable number of distomids may be crowded out of the host mussel and be forced to seek protection and food elsewhere. According to von Baer^b the sporocysts of *Distomum*

^a Proceedings of the Academy Natural Sciences, Philadelphia, 1858, p. 110.

^b Loc. cit.

duplicatum and their contained cercariæ live for a considerable time in the water when removed from the host. Migration would therefore be possible.

It has so happened that the *Anodontas* in which we found sporocysts were all taken in early and middle summer, in July or August; we found free distomids, however, as early as work in the field began, in June. It would require the study of infected regions throughout the year to ascertain whether the various phases in the life cycle of this distomid bear any relation to the seasons. Von Baer found his *Anodontas* affected by the sporocysts of *D. duplicatum* in late autumn.

5. *The distomid of Kelly*.—In several of the thicker-shelled species of mussels, such as *Lampsilis ventricosus*, *L. ligamentinus*, *Obovaria circulus*, and especially in *Quadrula tuberculata* and *Unio gibbosus*, one frequently encounters pink distomids bearing a close similarity to the distomid of Osborn mentioned above. Kelley,^a who first described and discussed these distomids, was of the opinion that they are identical with those described by Osborn as affecting *Anodonta* and *Strophitus* and producing a discoloration of the nacre.

Indications pointing to the identity of these two distomids are, first, the fact that dorsal baroques are formed in *Anodonta* by the distomid of Osborn, and second, that the distomid of Kelly, in addition to forming baroques in *Obovaria circulus*, frequently causes the nacre to become rough and assume a yellowish color, approximating the salmon color of affected *Anodontas*.

In their typical form as they appear in the thick-shelled species of mussels, these distomids exhibit several minor points of difference from the distomid of Osborn. Practically they present so different a set of manifestations that in our field notes it was found necessary to separate them.

After considerable study and comparison we are inclined to think them the same, but in this discussion, since the point of view is ecological rather than taxonomic, it will conduce to clearness to refer to this manifestation of the species under a different name. Similarly, it is convenient and customary to speak of the cercaria of a distomid, the nauplius of a crustacean or the leptocephalus of an eel. The distomid of Kelly is usually found in much fewer numbers than that of Osborn, a fact which suggests that it may be erratic or a stray migrant, and so far we have not found it associated with sporocysts or cercariæ except in the single instance of *Quadrula tuberculata* referred to above. It is usually confined to the outer surface of the mantle near the cardinal or lateral teeth of the mussels affected, and it is frequently associated, as Kelly has pointed out, with irregular dorsal baroques or pearls. It does not produce a salmon-colored stain in the nacre of the mussel affected, and usually

^a Bulletin Illinois State Laboratory Natural History, vol. v, art. 8.

produces no stain at all. The discolorations frequently found in the umbones of mussel shells can not all be attributed to it, since in one pond where such stains are very frequent, no distomids could be found. In general, it is a baroque former rather than a stain producer. In some localities it especially attacks *Unio gibbosus* and *Quadrula tuberculata*, and the host mussels are peculiarly prolific in baroques. Most of the dorsal baroques which the clammers save and sell to dealers in jewelry are probably formed through the activities of this parasite. The baroques are known among the clammers as "chicken feed" and usually bring about \$2 per ounce on the ground. In many places this material is fairly common and is a source of revenue among the clammers.

It is probable that the distomids which stray into large heavy-shelled mollusks fall out of the normal course of their life history unless they again migrate to thinner-shelled species, for the thick-shelled mussels, after they have grown, are proof against fishes, muskrats, or any other predaceous animals, and live to die a natural death, or in these recent times to fall a prey to the clammer. This gives the parasitic distomid no opportunity to enter into another host in the usual manner. Crawfishes eat mussels that have died; but so far as known the host of the mature distomid is always a vertebrate.

Moreover, on the supposition that the distomids found in the heavy-shelled mollusks are migrants from *Anodonta*, *Strophitus*, or other thin-shelled species, these mussels, which are regarded as valueless by the clammer and destroyed by the wholesale, are of importance as an intermediary in the formation of baroques and perhaps all distomid-formed pearls. Similarly, though in a somewhat different manner, the cockle, *Cardium*, acting as an intermediate host between a species of mussel-eating duck and the salt-water mussel *Mytilus*, brings about pearl formation in the latter species, as shown in the investigations by Jameson^a of pearl formation in *Mytilus*.

6. *Bucephalus polymorphus* (von Baer).—During the Maumee investigations this species was encountered in only one instance, when an example of *Lampsilis luteolus*, obtained near the mouth of the St. Joseph River, was found to be affected. In investigations outside the Maumee Basin it was not infrequently met. According to Kelly, who has had considerable experience with mussel parasites, it is fairly common, though not so common as *Aspidogaster*, *Atax*, or *Conchopthirus*, and affects a large number of species of mussels.

Bucephalus polymorphus is of considerable economic significance, since it has been shown by von Baer and later by Kelly that this species (and, as Kelly has pointed out, some other distomids as well) frequently affects the generative tissue of the host mussel to such an

^a Proceedings Zoological Society London, vol. I, 1902, pt. 2, p. 140-166.

extent as to wholly obliterate it and render the mussel incapable of reproduction. In those mussels (*Lampsilis gracilis*, *L. luteolus*, etc.) in which there is a marked difference in the form of the shell of the two sexes, *Bucephalus*, by arresting sexual development at various periods of the mussel's life, stops also the development of the peculiar form of shell characteristic of the sex. Shells are thus left at various intermediate stages of sexual development, though they may attain full size, and this has doubtless led to considerable perplexity in identifying them, or even to the descriptions of new species. It may also be partly responsible for the large amount of synonymy found in the *Lampsilis ventricosus* group.

It can be readily inferred that the introduction of *Bucephalus*-infected mussels into places where breeding or breeding experiments are being carried on would be likely to produce disastrous results. In collecting mussels for propagating purposes, therefore, shells of indifferently different contour as regards sexual peculiarities should be viewed with suspicion. In addition, examples should be dissected to detect signs of the presence or absence of the trematode.

The mature form of *Bucephalus polymorphus* is *Gasterostomum fimbriatum* von Siebold, which is a parasite of the pike (*Esox*) and perch (*Perca*), and an intermediate host (eaten by the final host) is some species of minnow. (*Leuciscus* is one of the known hosts.) In ponds devoted to the breeding of mussels the ravages of *Bucephalus* might be held in check by avoiding the peculiar combination of mussel, minnow, and pike or perch, provided of course these were not the particular species of fishes required to carry the glochidia.

7. *Ascaris*-like worms were occasionally found in the alimentary canals of mussels, and are probably to be regarded as parasites.

8. Leeches were found quite frequently on the inside of the shells of *Anodonta*, in all probability genuine parasites. They appear to be quite fond of the mucus of mussels, as is shown by the following observation: On the inside of a number of valves cleaned by muskrats and left on the bottom in Lake Maxinkuckee, the leeches were found to have accumulated in considerable numbers. Leeches also frequently attack other species of mollusks, as *Planorbis*, in large numbers. It could not be ascertained whether they injured the mussels to any marked extent or not.

9. *Atax ypsilophorus* was a common parasite of mussels throughout the length of the river, and was particularly common on *Anodonta* in the reservoir of the feeder canal. An example of *Atax*, probably this species, found in a mussel at the riffles of the St. Marys River, was so heavily burdened with a growth of *Vorticella* on its body that it could hardly move about. We came across several other specimens similarly affected.

Atax intermedius and *Atax tumidus* were also common on the mussels in the reservoir. There were probably several other species of *Atax* present; a small species with a red spot posteriorly was quite common. *Lampsilis alatus* below the dam at Grand Rapids was particularly heavily infected; in three examples 290 mites were found, thus averaging about 97 per individual.

Many of the *Atax* were full of eggs, and eggs and larvæ in different stages of development were common but not markedly abundant on the inner side of the mantle and in the gills of the mussels. We did not observe this year what was so conspicuous a feature in 1907 of the mussels found in the lakes about St. Paul, Minn., at the same season of the year, viz, the young mites clustered thickly about the papillæ of the inhalent siphons. The mites were apparently not breeding as heavily in the Maumee, and the young were not so far advanced in development at the date examined. *Atax* probably produces considerable irritation in the mussel, but we have no evidence that it affects shell characters. Where they bury their eggs in the tissue of the mussel they leave small but conspicuous scars which are apparently permanent.

Although it has been suggested that the eggs of *Atax* may lead to the formation of pearls, we have been unable so far to find convincing evidence on this point. In our studies of mussels of the Wabash Basin we obtained a great number of calcosphæric structures, many of them in situations that suggest a close relation to *Atax* eggs. This subject is reserved for future investigation, as it does not pertain to Maumee studies and would lead too far afield.

Wherever we have examined mussels we have encountered the parasite *Conchophthirus*, a protozoan bearing considerable superficial resemblance to *Paramœcium*. This organism is of such universal occurrence that we have not taken trouble to specifically mention its presence. There are several species (*curtus*, *anodonta*, etc.) parasitic on fresh-water mussels.

GENERAL CONCLUSIONS.

The Maumee River, as it exists to-day, is not on the whole a stream where clamming operations could be carried on profitably, as it would very quickly become exhausted if such operations were undertaken on a large scale. The mussels were apparently once much more numerous than at present. There are two conditions which militate against the well-being of mussels in the upper part of the river: The large amount of sewage, especially refuse from the gas works, and the irregularity of flow of the river, which has been increased by the removal of much of the original forest along the river banks. The best mussel beds in the river are at Fort Wayne, Ind., and below the dam at Defiance, Ohio. By far the greater number

of marketable shells in the river are *Lampsilis ligamentinus*, and the most valuable native species is *L. rectus*.

The species of mussels to be recommended for propagation naturally varies with different rivers. In the Maumee, the species generally regarded as the best button shell, the niggerhead, *Quadrula ebena*, could not be recommended as it is doubtful whether it would thrive in the shallow water. On the other hand, the mucket, *Lampsilis ligamentinus*, in many waters a poor or indifferent shell, is here remarkably large and thick, with nacre of an excellent luster, and is the best button species found in the river. This should be planted extensively as the main crop. *Plagiola securis*, the butterfly, would probably thrive in the water below Defiance Dam, and *Symphynota costata* would be well worth trying, especially in canals with black muddy bottoms, as it would be nearly certain to attain to unusual size and thickness there, and might rank as a good button shell.

The status of *L. rectus* is peculiar. In many streams and rivers this species is valueless on account of small size or purple nacre or both; in the Maumee it has large size and white nacre and is the most valuable species per pound native to the river. With enough button shells in the river to bring this species to the market it would be desirable to plant rather heavily of it. It would make a good export shell and yield the clammer much more revenue for work done and material handled than the button species.

The most valuable of the fresh-water mussels, *Lampsilis anodontoïdes*, would be well worth a trial. It is not native to the river, but there is every reason to believe that, like its close relative *L. rectus*, it would grow and thrive considerably better even than in rivers where it is native. Good shells of this species bring an unusually high price on the market.

As regards mussel parasites, the river appears to have about the average number as compared with other streams examined. They are usually most abundant in thin-shelled species in quiet waters. As regards pearls and pearly growths, which are closely related to parasites, these are few. The distomid of Kelly and dorsal baroques are rare. Round pearls, all very small, were occasionally found, and all these appear to owe their origin to the marginal-cyst distomid, which is quite common.^a

^a Since this was written, we have found several minute pearls which were formed about eggs of *Atax*.

CARDED 1945

DEPARTMENT OF COMMERCE AND LABOR

BUREAU OF FISHERIES

GEORGE M. BOWERS, Commissioner

THE MUSSEL FAUNA OF THE KANKAKEE BASIN

Bureau of Fisheries Document No. 758

WASHINGTON
GOVERNMENT PRINTING OFFICE

1912

CARD NO. 1945

DEPARTMENT OF COMMERCE AND LABOR

BUREAU OF FISHERIES

GEORGE M. BOWERS, Commissioner

THE MUSSEL FAUNA OF THE KANKAKEE BASIN

Bureau of Fisheries Document No. 758

WASHINGTON
GOVERNMENT PRINTING OFFICE

1912

THE MUSSEL FAUNA OF THE KANKAKEE BASIN

By CHARLES B. WILSON and H. WALTON CLARK

Bureau of Fisheries Document No. 758

CONTENTS.

	Page.
Introduction.....	5
Physical features of the Kankakee Basin.....	6
Mussel survey	9
Localities examined.....	9
Summary of mussel distribution.....	39
Commercial value of shells obtained.....	41
Small fishes found on mussel beds.....	40
Discussion of mussel species.....	40
Economic considerations	51

FIG. 1.—AN UNDREDGED PORTION OF THE KANKAKEE RIVER, FILLED WITH VALUABLE SPECIES OF MUSSELS, SHOWING CONDITIONS UNDER WHICH THEY FLOURISH

FIG. 2.—A DREDGED PORTION OF THE KANKAKEE RIVER. ALL THE MUSSELS HERE WERE KILLED BY DREDGING, AND NOT ONE CAN LIVE UNDER THE ARTIFICIAL CONDITIONS HERE ESTABLISHED.

THE MUSSEL FAUNA OF THE KANKAKEE BASIN.

By CHARLES B. WILSON and H. WALTON CLARK.

INTRODUCTION.

The following paper gives the results of fresh-water mussel investigations made by the authors in the Kankakee Basin during the summer of 1909, under the auspices of the United States Bureau of Fisheries.

The mussel fauna of the various localities is recorded in the table on page 38, and forms an important result of the investigations. But careful attention was also given at each of the localities to the kind of bottom on which the mussels were found, the depth of water and rapidity of the current, the relative temperature of the water, the nature of the plankton present and suitable for food, the actual stomach contents of selected samples, the relative size and physical condition of the mussels, the small fish and crawfish found on or near the mussel beds, and the times of spawning of the various mussel species. In particular, most of the species secured alive were examined for parasites, for the color of the nacre and any staining or spotting produced by the parasites, and for pearls or baroques as a result of parasitic infection. The results of these studies are given under the various stations where they were made and constitute by far the most valuable portion of the work.

Samples of the shells were afterwards examined by Mr. J. F. Boepple and others who are experts in the manufacture of pearl buttons. The value per ton of the different marketable species was carefully estimated and is recorded in the table on page 39, giving some idea of the economic importance of the investigation.

The boat was put into the Yellow River at Burr Oak, Ind., and traversed the remainder of that river to its junction with the Kankakee, and the latter river from this junction to the city of Kankakee, Ill.

The river below this city, the upper portions of both the Yellow and Kankakee Rivers, the whole of the Iroquois River, and the various lakes and tributaries, were worked by means of short drives

from the nearest railroad towns. At each of the lakes a boat was secured and the whole of the lake shore and as much of the outlet as was deemed advisable were examined. The fact that quite a portion of the Yellow and Kankakee Rivers has been artificially dredged and the old winding channel converted into a straight cross-country ditch, presented changed conditions of extreme importance in their relation to mussel propagation. These conditions have been accurately recorded, and furnish an instructive contrast to the remainder of the area worked.

While the entire Kankakee Basin was thus more or less completely examined and satisfactory results were obtained, the authors would not regard the work as in any sense final. It is rather initiatory and suggestive, and its value lies in the data and comparisons it furnishes with reference to the natural conditions under which mussels live and thrive in a region which has been as yet scarcely touched by the progress of civilization.

PHYSICAL FEATURES OF THE KANKAKEE BASIN.

The Kankakee Basin embraces the whole of the northwest corner of the State of Indiana south of the narrow Great Lakes drainage, and adjacent portions of Illinois, and is drained by the Kankakee, Yellow, and Iroquois Rivers and their tributaries. These 3 rivers, the principal streams that flow into them, and 12 of the more important lakes lying within the basin were thoroughly examined.

This basin is radically different from that of the Maumee River, previously examined, in that the Indiana portion of it lies wholly within what geologists designate as a plain of accumulation. The origin of the valley can not be stated more concisely than in the words of W. S. Blatchley in the Twenty-second Report of the Geology of Indiana, page 59:

The valley doubtless owes its origin to the flow of waters which followed the melting of one of the later retreating ice sheets. This flow was at first sufficient in volume and velocity to erode the present valley to quite a depth through the underlying clay. Later, on account of a diminution of the supply of water, as well as the gentleness of the slope, the current became too sluggish to erode much deeper or to carry coarse material, and only the finer sediment was brought down. From a still further diminution of the water supply, as well as by the building up of a sedimentary dam near the western end of the valley, the water for a long period ceased to flow, and a lake of shallow depth resulted. Again by a new accession of water from the northwest, the barrier at the foot of the valley was washed away and the river of the present had its beginning. At first its waters flowed the full width of the valley, but in time their volume decreased, and a portion of the river's bed became bare in summer. Over this a vegetation sprang up and decayed. A soil was thus started above the sands and was added to each year by the decay of the summer's vegetation and the sediment brought down by the overflow in the spring. The main current of the stream was thus gradually narrowed until it reached its present size.

We thus have a basin surrounded by glacial moraines and everywhere covered with a heavy mantle of glacial drift or till, so thick that not a single outcrop of surface rocks is known to occur within its limits,^a even in the bed of the river or any of its tributaries. Consequently, there are no rocky bottoms with alternating riffles and quiet reaches, but everywhere a uniform current and labyrinthine windings. The river itself is noted for its low banks and the crookedness of its channel. It rises in a marsh about 3 miles southwest of South Bend in St. Joseph County, Ind., flows southwesterly through that county to the Laporte County line, from which point it forms the boundary between the counties of Laporte, Porter, and Lake on the north, and St. Joseph, Starke, Jasper, and Newton on the south. At about the center of the Starke County line it receives the Yellow River as a tributary from the east. Crossing the State line between Lake and Newton Counties, it flows south of west to the town of Waldron, Ill., where it is joined by the Iroquois River from the south. Thence it flows northwesterly to the northeastern corner of Grundy County, where it joins the Des Plaines, coming from the north, and the two form the Illinois River.

The Yellow River, its principal eastern tributary, rises in three forks, north, middle, and south, in the southeastern corner of St. Joseph County, Ind., the southwestern corner of Elkhart County, and the northwestern corner of Kosciuszko County, respectively.

The north and middle forks unite near Bremen in Marshall County, and flow directly south until opposite Plymouth, the county seat. Here they are joined by the south fork, and the river turns westward through Plymouth, then south for about 5 miles, and then westward again through the remainder of Marshall and the whole of Starke County, entering the Kankakee at about the center of what was formerly English Lake.

The Iroquois River, the only other tributary of any size, arises in several creeks in the southeastern portion of Jasper County, Ind., flows a little south of west across Jasper and Newton Counties, cutting the State line 6 miles north of the southern boundary of Newton County. It then flows west through Iroquois County, Ill., as far as Watseka, the county seat, where it receives Sugar Creek from the south. The two then flow northwest about 5 miles to a junction with Spring Creek, also from the south. There the river turns almost due north and crosses the remainder of Iroquois County and into Kankakee County, where it empties into the Kankakee River a mile west of the town of Waldron. The Yellow River is about 65 miles, the Iroquois 100 miles, and the Kankakee 300 miles in length. The banks of the Yellow and Iroquois Rivers, and those of the Kankakee River in Illinois, are high and solid and in many places well wooded, and the adjacent country is of the usual prairie type.

^a That is, in the State of Indiana.

In Indiana, however, the entire basin of the Kankakee River is marshland, the most extensive body of swamps within the State. On the immediate border of the river there is a strip, from a few rods to a mile or more in width, which is heavily timbered. Then come dense thickets of underbrush, and finally the open marsh, covered with a rank growth of grasses, sedges, reeds, and semi-aquatic vegetation.

There were formerly more than half a million acres of this marshland in the seven Indiana counties drained by the Kankakee, but its area has been recently somewhat reduced by extensive ditching. Enough still remains, however, of this old glacial lake bed to act in the manner of an immense sponge, overflowing and absorbing water during the wet season and slowly oozing it forth during the dry.

There is thus never any real lack of water in the river, the amount of discharge at the State line being considerably over a thousand cubic feet per second even at low water. In general the soil of the marshes is a dark sandy loam, very rich in organic matter, and hence the waters of the river contain an abundance of food material for the mussels they contain. In many places the wild rice, rushes, lily pads, and aquatic grasses fill all except the very channel of the river and contribute their quota of food material. Owing to the fact that the land can not be cultivated, there are few dwellings on or near the river, and repeatedly one may row 15 or 20 miles without seeing a human habitation. The presence of the rich marshes, combined with the absence of human environment, have made this region an ideal breeding ground for waterfowl and aquatic animals of every sort. Fish are also abundant in the river, together with plankton of great variety and richness. Each and all of these conditions have a very important bearing upon mussel life.

And withal the region is one of marvelous beauty and attractiveness, and as radically different in many respects from an ordinary swamp as could well be imagined. In the first place, the river itself, in spite of its intricate windings and rich vegetation, is not sluggish as one would expect, but has everywhere a good current, averaging 3 or 4 miles an hour. Then the river bed is nowhere of the proverbial quagmire type, but is hard sand or fine gravel, mixed with mud to just the right consistency for most mussels. Here, then, we have a region especially favorable in almost every particular for mussel growth, strictly secluded by its environment from all but the hunter, the trapper, and the fisherman, and still maintaining primitive conditions throughout most of its extent. Furthermore, its waters have always drained into the Mississippi Basin as they do now, and the mussel fauna, originally derived from that source, has never undergone any radical changes.

We may be reasonably certain, therefore, that the data here obtained are natural and authentic, and that they have not been to any degree artificially modified.

MUSSEL SURVEY.

LOCALITIES EXAMINED.

Station 1. The middle fork of the Yellow River.—The entire upper portion of this river, down to within 6 miles of Plymouth, has been recently dredged. The result has been a conversion of the winding forks of the river and their tributary streams into a series of straight cross-country ditches, in which the water flows at a uniform rate over an equally uniform and undifferentiated bottom of sandy gravel.

These ditches were examined at several places (the first four stations) in order to ascertain what effect the dredging had upon the mussels and other life in the headwaters of the river. The dredged material, thrown up along the sides of the ditches, everywhere presented abundant evidence that mussels were formerly present in considerable numbers. But the process of dredging, by throwing out the living mollusks upon the land where the ditch coincided with the old channel and by withdrawing the water from such portions of the old channel as did not thus coincide, *completely destroyed the entire mussel fauna*. There has been some restocking of the new channels by ordinary natural methods, but the conditions have been extremely unfavorable for such restoration. Our fresh-water Unionidæ are dependent upon small fish for their distribution and for transportation into new regions like those created by this dredging. At the last rebuilding of the dam at Plymouth no fishway was provided. Consequently, the only fish available, as well as the only supply of glochidia, had to come from the short undredged space of 6 miles above the Plymouth dam and from such specimens as may have escaped destruction during the dredging. Furthermore, the reduction of the water channels to an absolutely uniform grade and depth has proved very unfavorable to the spread of mussel life. The constant shifting of the sand and soil along the bottom of the channel effectually prevents the young mussels from obtaining a stable foothold anywhere. In the presence of such adverse conditions it was remarkable to find any evidence of a restoration of the mussel fauna.

This first station was near the town of Bremen, in the northeastern corner of Marshall County; the ditch representing the middle fork of Yellow River was 6 feet wide and the water was about 8 inches deep at the center. There was no vegetation of any sort present, and no fish or crawfish could be found for the distance of a mile above the town. The bottom of the ditch was gravel or sand, kept

in constant motion by the swift current. The only trace of mussels were the dead shells which had been dredged out of the old channel and left high and dry along the sides of the ditch.

Station 2. Half a mile below (west of) Bremen.—The ditch had been enlarged here to 10 feet in width, and the water was knee-deep (22 inches) at the center, with a current fully 8 miles an hour. The bottom was of sand over firm peat, and there was some vegetation in the form of scattered patches of *Ceratophyllum*. This served to prevent in places the constant motion of sediment along the bottom and gave an opportunity for mussels to establish themselves. The three specimens recorded were found alive and of fair size, and there were more of the dead shells in the piles of clay along the banks than at the previous station.

A number of *Campeloma*, *Sphærium*, *Planorbis*, and *Pisidium* shells were also found, which probably represented the inhabitants of a swale that had been drained by the ditch. No fish or crawfish were seen. The only mussels found were two "fat muckets" (*Lampsilis luteolus*) and one "floater" (*Anodonta grandis*).

Station 3. Junction of north and middle forks.—This junction is about 2 miles west of Bremen and a few rods north of the Baltimore & Ohio Railroad tracks. The north fork is much the larger and its waters were very muddy, in strong contrast to those of the middle fork.

No life at all, animal or vegetable, except a few young pike, *Lucius reticulatus*, was found at this station. This was probably due to the fact that the peat over a large area along both sides of the forks and the main stream had been recently burned to a considerable depth, changing the water, for the time being, into a sort of lye.

Station 4. Yellow River, 1 mile below station 3.—The ditch here is 12 to 15 feet in width, and the water is 2 to 3 feet deep at the center; the bottom is gravel and clay, firm and solid, with a slower current, about 6 miles an hour. The ditch has been cut through about 8 feet of blackish alluvial soil, and the water, in consequence, is turbid.

There was no vegetation in the water, but we found a large number of mature crawfishes, *Cambarus propinquus*, and a few small fishes which proved to be young pike. No mussels were found alive, but there was an abundance of dead shells along the sides of the ditch.

A short distance to the west of this station are two other dredged ditches, running approximately parallel with the river. These are known as the Bunch ditches and were dredged several years before the river itself. They run into Bunch Creek, the first outlet of the Lake of the Woods, and this creek empties into Yellow River 2 miles farther south. Both ditches and the creek were examined for con-

siderable distances, but although fishes and crawfish appeared to be abundant no live mussels could be found. The water in the eastern ditch was quite black and there was considerable "ditch moss" (*Philotria*) in scattered patches. A few small minnows, *Notropis whipplii*, were found here, and a number of sunfish, *Eupomotis gibbosus*, were nesting in the crannies of a pile of rocks that had been thrown into the edge of the ditch from the railroad. The western ditch is shallower and cleaner; the water is yellow instead of black, and quite clear. The bottom is a fine gravelly clay, well adapted for mussel life, and many *Cambarus propinquus* were seen.

These facts seem to indicate that even after the conditions become again favorable for mussels it still takes a long time to restore them under natural conditions. In all probability the introduction of small fish well infected with glochidia would materially hasten the restoration of the mussel fauna here.

Station A. The Lake of the Woods.—This lake is situated in the northeastern corner of Marshall County, 4 miles southwest of Bremen. It is $1\frac{1}{2}$ miles long and $1\frac{1}{4}$ miles in extreme breadth; it is oval in shape, with a fairly regular outline, except on the western shore, where a broad bay increases the width by half a mile. It formerly occupied a much larger area than at present, as is evidenced by the distance from the present water's edge of an old shore line, separated by a broad, sandy, level plain, once lake bottom. On the eastern side large peat deposits extend north into St. Joseph County and south to the line between North and Center Townships. This latter southeast corner was the original outlet of the lake into the Yellow River.

Through the drying up of the lake its area was diminished to one-tenth of the original size. This reduced lake was bordered by high and heavily wooded banks, except at the northeast and southeast corners, and must have been a beautiful sheet of water, plentifully supplied with all sorts of life, including mussels. But a ditch was dug 50 or 60 years ago from the northeast corner into the north fork of the Yellow River and the lake level was reduced 4 feet. The original shore, in places a high, picturesque, abrupt bank, covered with large oak and cottonwoods, can still be seen from 500 to 1,000 feet back from the present beach.

Even this outlet, however, did not satisfy the farmers in the vicinity and another ditch was dug 15 or 20 years ago from the southwest corner of the lake, running south for a mile or more, then turning east into the Yellow River. This lowered the lake again from $2\frac{1}{2}$ to 3 feet and the second lake shore is also visible in many places, covered with poplars and yellow birches.

By these two lowerings the lake has become little more than a mud hole, fringed with reeds and rushes which grow far out into the

water. In addition the bottom of the lake, wherever it can be seen, is entirely covered with plants, *Chara* and *Potamogeton*. In following around the entire lake margin only a single spot was found free from this vegetation. Finally the water itself is filled with a suspended plankton which is entirely vegetative, made up mostly of minute algæ (*Clathrocystis* and *Lyngbya*).

All the water plants are covered with a fuzzy growth of *Mesocarpus*, which also forms in floating masses, and with the *Clathrocystis* collected in large curdlike lumps. Such a lake does not afford good conditions for either fish or mussels and both were very scarce. A careful examination of the entire margin of the lake yielded only 7 specimens of the "fat mucket" (*Lampsilis luteolus*), of which 5 were dead, 16 specimens of *Anodonta grandis*, 14 of which were dead, and 1 dead *Anodontoides ferussacianus subcylindraceus*. As it was of interest to know the food and parasites of mussels living under such conditions, the four live specimens were examined, with the following results: In *A. grandis*, *Atax* was abundant, with an occasional *Cotylaspis*. The distomid of Osborn¹ was exceptionally abundant and made the nacre very rough, but gave a dark discoloration instead of the usual salmon tint. The stomachs yielded *Clathrocystis* and *Cælospherium* in abundance with some *Pediastrum*. In *L. luteolus* both marginal cysts and the distomid of Kelly were fairly abundant, with no other parasites. Small pearls were found in the margin of one mantle and a small dorsal baroque in the other specimen. The stomachs were filled with *Clathrocystis* and *Cosmariium* well fused into a dark gritty mass.

Station 5. Above the dam at Plymouth.—This dam was built 60 years ago, but has been washed out and rebuilt several times, the last time without any fishway. It backs the water up the river about 4 miles; this dead water and the river for 2 miles above were thoroughly examined, as well as the side lagoons, which are common along the dead water. The center of the dead water was too deep for wading and there were so many snags it was impossible to dredge it. Elsewhere the mussels were widely scattered and not many were found alive. In some places the banks were too soft and miry, in others too hard and solid for mussels, and it was only the infrequent spots between the two that yielded any returns.

On examining the mussels for parasites the following were found: In *L. luteolus* there were many cysts along the mantle margin and the distomid of Kelly was fairly abundant. In many of the specimens there were small pearls and in some of them dorsal baroques. In *A. grandis*, *Atax* was the most common parasite, with a few

¹ This name is applied to a distomid which was found by Prof. Osborn to be the cause of salmon discoloration in *Anodonta grandis*; investigations undertaken since the above was written lead to the belief that the distomid in question, which produces a chocolate instead of a salmon-colored stain, is of a different species.

Cotylaspis. The distomid of Osborn was abundant, producing a dark discoloration and rough nacre like that found at the Lake of the Woods.

Station 6. Below the dam at Plymouth.—This station offered a pleasing contrast to the preceding. The water was shallow, the maximum depth being 2 feet, the bottom was firm sand and gravel, and the current was about 3 or 4 miles an hour. From the dam to the mill race we found good collecting; below there the river became deeper and there were not as many mussels.

Of the specimens obtained one small *L. ventricosus* had a very thin shell with pink nacre; *A. imbecillis* was quite common and five were obtained that were gravid; one *L. parvus* was also found gravid; a few *L. iris* and large *A. calceola* were found along the shore.

In addition to the mussels collected by the authors here, Mr. Aaron Greenwaldt, who had collected shells from the river for the State Geological Survey, presented the Bureau of Fisheries a beautiful collection of 125 shells very perfectly cleaned and kept with the two valves tied together. For this valuable present the authors here return sincere thanks. The collection included the following species, the number of specimens being given after each: *Q. coccinea*, 16; *Q. rubiginosa*, 6; *Q. pustulosa*, 3; *Q. undulata* (from above the dam), 6; *S. costata*, 12; *S. compressa*, 7; *A. imbecillis*, 1; *S. edentulus*, 2; *A. grandis*, 10; *L. iris*, 6; *L. luteolus*, 20; *L. ventricosus*, 21; *U. gibbosus*, 15.

Of the small fishes obtained at this station the straw-colored minnow (*Notropis blennioides*), chub (*Semotilus atromaculatus*), and Johnny darter (*Boleosoma nigrum*) were particularly abundant and many of each species were put back into the river. A considerable number of the young straw bass (*Micropterus salmoides*) and grass pike (*Esox vermiculatus*) were also caught, but only one or two samples were kept. We were told there was a severe attack of the "pearl fever" here during the previous year and that the boys brought out and examined mussels by the barrel without material results. If so, they must have disposed of the shells, since none were found except a single pile, containing about a ton and a half, a short distance below the dam.

Station B. Pretty Lake.—Pretty Lake, situated 3 miles southwest of Plymouth, is a typical glacial kettle hole, nearly circular in outline and about half a mile in diameter. The water is remarkably clear and has a fine greenish tint, like that of Lake Maxinkuckee.

It is fed by springs, the entire northeastern shore being covered with them, and at present has no outlet. There is a single inlet at the northwest corner which is a dry run most of the time, but the presence of a large gravel delta testifies that at times it discharges

considerable water into the lake. There is an old outlet at the southeast corner of the lake, which formerly drained into the Yellow River. Although the mouth is closed by a sand bar, the water in the lake occasionally rises high enough to overflow this and run into the river. The bottom of the lake is firm sand and gravel, and the shores slope off rapidly into deep water, the depth being 40 feet at the center.

It is a very clean lake and in this respect presents a marked contrast to the Lake of the Woods. For vegetation pickerel weed (*Pontederia*) was common around the shores, the largest patch being along the northern margin. The broad-leaved pondweed (*Potamogeton amplifolius*) and Robbins's pondweed (*P. robbinsii*) were found in large patches, and *Chara*, probably *foetida*, was also common. There were plenty of white water lilies but no spatterdock (*Nymphaea*). Great patches of ditch moss (*Philotria*), considerable wild celery (*Vallisneria*) and hornwort (*Ceratophyllum*), and some *Najas*, *Cladophora*, bladder wort (*Utricularia*), and *Decodon*, and in one place some *Nostoc* were found in shallow water. The water temperature at the surface near the center of the lake was 79° F.; the plankton was very light, containing no vegetation and but a few water fleas (*Cladocera*).

A careful examination of the entire margin of the lake yielded eight specimens of *L. luteolus*, widely scattered, and a half dozen *A. grandis*. The mussels were too far apart to breed well and all were stunted in size and peculiarly fragile at the hinge.

For food the stomachs of the *A. grandis* contained one *Cosmarium*, two or three *Cælosphæriums*, a few *Clathrocystis*, and one *Ascaris*. In the *L. luteolus* were found one *Anuræa* and a little *Clathrocystis* mixed in a dark gritty mass. Here where the mussels are nearly starved they seem to digest well. (It is common where food is abundant to find undigested organisms at the posterior end of the mussel's intestine, but such was not the case here.)

Station 7. Yellow River at Hibbard.—The water of the river here was perfectly clear and had a maximum depth of 3 feet. The bottom was of fine sand, coarse gravel, and here and there a mud bar, particularly along the shore. The current was rather slow, not more than 2½ miles an hour, and the temperature was 78° F.

For vegetation there were lodged masses of algæ, some *Cladophora*, and patches of the river pondweed (*Potamogeton fluitans*) and aquatic moss. There were also many small sponges scattered over the rocky parts of the bottom. A large number of young black bass, some Johnny darters (*Boleosoma nigrum*), and a few black-sided darters (*Hadropterus aspro*) were found on the mussel beds. Only a few mussels were found in the muddy places, chiefly *U. gibbosus*,

A. grandis, and *L. ligamentinus*. None occurred in the shifting sand, but where the sand was firmly packed and among the rocks they were placed almost as thick as they could lie. *L. ventricosus* and *U. gibbosus* were most abundant and occurred in about equal numbers. The *ventricosus* were all upright, the tips pointed upstream, and the entire mussel buried with the exception of the large brown siphons. The *gibbosus* were more active, moving about in every direction, and often found lying flat on one side. *S. costata* was also very common and when buried, with only the crinkled edge showing, was easily mistaken for *undulata*. A single *L. rectus* was found lying upon its back and spawning. Nearly all the *costata* also were gravid, and most of them contained one or more dorsal baroques, yellowish in color. The *Q. coccinea* nearly all had pink nacre.

The shells obtained at this station were of large size, particularly the pocketbooks (*L. ventricosus*), and of excellent luster. And it is certain that a qualitative examination would show them to be as valuable as any obtained during the entire summer.

Station 8. Yellow River at Burr Oak.—This is the station where the boat and outfit were launched for the trip down the river. The conditions were identical with those at Hibbard, except that the current was a little swifter—4 miles an hour. *Potamageton natans*, *Cladophora*, and *Tetraspora* were found in patches on the mussel beds. As before, the mussels were found mostly in the gravel and hard sand and were completely buried, except the siphons. Many of the *ventricosus* and some of the *gibbosus* were spawning and it was noticeable that the small fishes, especially *Notropis blennius*, *Boleosoma*, and *Semotilus*, which were the ones most abundant, kept playing about near the spawning mussels.

Station 9. County Line Bridge, 4 miles west of Burr Oak.—This was a broad, pond-like stretch of river, with a sluggish current, plenty of spatterdock and white water lilies, a bottom of hard mud and fine gravel, and banks of seepy blue clay.

Not many mussels were collected here—just enough to show that they were still scattered plentifully along the river bottom.

Station 10. Zinc Bridge at Ober.—The water was shallower than at the preceding station, with a maximum depth of only 2 feet, and a current of 5 miles an hour; the other conditions were the same.

The mussels were thickly scattered everywhere, with especially dense beds along the shore. The small fish were again noticed playing about in the immediate vicinity of the spawning mussels.

L. ventricosus has a habit of moving its bright yellow siphon fringes, which are much enlarged during spawning, back and forth in the water. This undulatory motion seems to attract the small darters and minnows, particularly *Notropis blennius*, which could

be seen darting in toward the fringes repeatedly. It also probably assists in furnishing fresh water for the respiration of the young mussels.

At intervals during the undulations small numbers of glochidia are discharged from the brood chambers of the mussel and carried out of the excurrent aperture. These glochidia are of the hookless type, and must be taken into the mouth of the fish that is to carry them during their parasitic period. We can thus understand the advantage of attracting these fish and keeping them in the immediate vicinity during the discharge of the glochidia.

Since this is the last station before the dredged portion, which includes all the remainder of the Yellow River, we may summarize the results.

This stretch of river from Plymouth to Ober, a distance of 20 miles or more, forms an ideal breeding ground for mussels. The natural conditions are exactly suited to mussel life; there are the right kinds of river bottom, plenty of lime and food in the water, and a current of fairly uniform velocity; the water is kept reasonably cool by the springs and brooks which flow into the river, and there are plenty of small fish to distribute the glochidia.

The river is already well stocked with mussels whose shells are far above the average in size and quality, as can be readily seen by reference to the table of values given on page 39. Furthermore, these mussels are not irregularly distributed in small patches, but form a single bed which is practically continuous for the entire 20 miles. With such natural resources it would be a very easy matter to keep the river stocked with mussels that would yield the farmers a far better revenue than any of the swamp land found in the immediate vicinity. A judicious use of the supply already at hand, selecting the larger mussels and leaving the smaller ones unharmed for further development, and replenishing the stock regularly by introducing small fish richly infested with glochidia, would insure ample returns for a long series of years.

The new mussel hatchery just started at Fairport, Iowa, will be able to supply the fish carrying glochidia. Furthermore, the proved quality of the mussels, particularly *L. ventricosus* and *L. ligamentinus*, would make of this a profitable region from which to obtain glochidia for supplying that same hatchery. The railroad facilities at Plymouth, Hibbard, Ober, and Knox are all that could be desired, and there is no trouble in navigating the river between these points in an ordinary rowboat, as was proved beyond question by the present expedition.

Station 11. Old bed of Yellow River below Ober.—No greater contrast could well be imagined than that which was actually presented between the strip of river just described and that same river

bed from Ober to where it empties into the Kankakee, all of which has been artificially dredged. The dredged portion begins 1 mile west of Ober, and since the sole aim of the contractors was to cover the greatest possible distance at the least expense, irrespective of natural scenery, animal and vegetable life in the river, or in fact anything else, they did not follow the old winding channel, but cut across country in a straight line, which intersected the old bed at various places. This dredged part is of nearly uniform depth, from 1 to 3 feet, with a flat bottom of sand and gravel, which the swift current washes up into ripple marks, zigzagging across the entire width of the river. The current is uniform from $4\frac{1}{2}$ to 6 miles an hour and keeps the finer sediment in constant motion along the bottom, thus forming an effectual barrier against mussel life. Hence, although this stretch has been dredged eight years, and there was an abundant mussel fauna in the old channel, which was not killed off except in limited areas, and which might easily have established itself in a much shorter time in the new channel if the conditions had been favorable, practically no progress has been made in that direction.

An occasional *L. ventricosus* was found alive in the dredged channel, together with shells of *Q. rubiginosa*, *L. iris*, *L. ligamentinus*, *L. luteolus*, etc., which had recently died (probably washed in from the old channel).

No real restocking can be expected until the bottom gets thoroughly solidified, packed down so that it will not wash along continually, and until at least some breaks in the current are formed similar to those in the old channel.

All the mussels found in this long stretch of 20 miles were obtained from the old channel, and it was very interesting to see how completely they had accommodated themselves to the changed conditions. Instead of a good current running over a sandy or gravelly bottom and keeping everything clear and clean, we now find lagoons and bayous in which the water is practically motionless except during floods.

Consequently, they are rich in algæ and other water plants, and the firm bottom has been covered with soft mud and in many places with fine ooze, 2 feet or more in depth. And yet the mussels have remained, *Q. pustulosa* being the only one killed off to any extent. The others have succeeded in climbing up on top of the mud and ooze as fast as it was deposited. Even the large and heavy *rectus*, *ventricosus*, and *undulata* are found on the very top. How such an unwieldy bulk as a full grown *undulata* can move about and actually lift itself up through mud so soft that it will not hold up an empty shell is difficult to understand. But the undoubted fact remains that they actually accomplish it. A noticeable peculiarity of all these lagoon mussels was the presence of a large tuft of growing

algæ around the siphonal (upper) end of the shell. These would be a manifest aid in oxygenating the stagnant water in which the mussels live, and might also be of assistance in keeping them on top of the mud, just as webs of gossamer keep spiders suspended high in air and enable them to perform aerial journeys.

Of the mussels found *luteolus* was far the most common; then came *ventricosus*, *undulata*, and *rectus*, in the order named. Many of the *luteolus* and *ventricosus* and one *rubiginosa* were gravid. *Atax ypsilophorus* was found in nearly all the species and was especially common in *luteolus*, *ventricosus*, and *edentulus*, and many of the eggs and young were found in the mantle. All of the *rectus* shells had a deep pink nacre, as did also one *ventricosus* and one *ligamentinus*. Both of the *imbecillis* found were gravid and were imbedded perpendicularly in the mud, with the siphons pointing straight upward, a very unusual position for that species.

The minnows and darters were abundant on the mussel beds, as is shown by the list of those obtained. *Notropis blennius* and *Boleosoma nigrum* were most in evidence and could be found everywhere, while the others were more scattered.

Only a few mussels were collected below Knox, and they have been recorded with the others from the old river channel. With the account of the Twin Lakes which follows, this concludes the investigations on the Yellow River.

Station C. The Twin Lakes.—These “twins” are really four in number, grouped near the center of the western third of Marshall County in two pairs, separated by the Vandalia Railroad. The eastern pair are elongated in a northwest and southeast direction and lie in the same straight line. The eastern and smaller one is Lorance Lake, about 80 rods in length and width. It is separated from the larger lake by a stream 50 rods in length. The larger is called Meyer’s or East Lake and is a mile in length and about 40 rods wide. The western pair on the other side of the railroad are elongated at right angles to the others, or in a northeast and southwest direction, and they lie side by side with their long diameters parallel. The northern, larger one is Cook or Northwest Lake, and is the same size as Meyer’s. The southern one is Holem or Southwest Lake and is about three-quarters of a mile long and 30 rods wide. It is separated from Cook Lake by a narrow ridge of gravel, 15 to 20 feet high and 200 to 300 feet in width.

Lorance Lake empties into Meyer’s through the short brook mentioned. Meyer’s runs under the Vandalia Railroad track into Cook; Holem also drains into Cook from its southwestern end and Cook delivers the drainage of all four lakes into Eagle Creek, which empties into the Yellow River just above Knox. All the lakes are very shallow, the maximum depth being under 20 feet, and the area

drained into them is limited. In general, they are surrounded by high banks of clay with only a little sand and gravel. They are fed largely by springs, nearly the whole shore line being marshy, with only a few bits of sandy beach.

Three of the lakes, Lorance, Meyer's, and Cook, were carefully examined for mussels; nothing was found in the one first mentioned; the other two yielded returns as follows:

East Lake (Meyer's) is considerably the shallower and warmer of the two; the bottom is a firm sandy marl, with scattered patches of *Chara* and *Potamogeton*, while the shores were fringed with pickerel weed, water lilies, reeds, bulrushes, and similar vegetation. The mussels were rather widely scattered, but formed beds where they did occur. Only two species were found, *Anodonta grandis* and *Lampsilis subrostratus*, the former in far greater abundance than the latter. The *subrostratus* yielded no parasites at all, the *grandis* were fairly loaded with them, every specimen yielding large numbers. They included *Atax* of several species, prominent among which was a rather small, deep-red one, *Cotylaspis*, marginal cysts, and the distomid of Osborn. The cysts of the marginal distomid were especially abundant and number hundreds in many of the specimens, while one must have had fully a thousand. The distomid of Osborn formed great pink patches under the umbo and tinged nearly all the shells with a reddish salmon color.

Northwest Lake (Cook) is deeper and the water was clearer and colder. Like East Lake the bottom is a firm sandy marl, covered in many places with *Chara*. The shallow water along the shore was one solid mass of reeds, bulrushes, and lily pads. The mussels were widely scattered and the same two species were found as in East Lake, with the addition of *L. luteolus*. As before, *grandis* was much the more common; the older examples were found with their shells high out of the sand, just enough being buried to hold them in place. The younger examples were more deeply buried. Many small fishes were seen upon the mussel beds; they included *Notropis blennius*, *Fundulus dispar*, and the young of *Lepomis pallidus* and *Erimyzon sucetta*.

Samples of plankton were secured from the clear water in the center of the lake at a depth of 8 feet. There were found five species of copepods, most of them covered with *Vorticella*, small pink water mites, *Daphnia*, a few nauplii, *Lyngbya*, minute *Spirogyra*, *Anuræa cochlearis*, *Ceratium hirudinella*, *Fragillaria crotonensis*, and *Anabaena*. This was the richest plankton obtained during the summer, and yet the water appeared perfectly clear.

On examining the mussels they were found to be as badly infested with parasites as those of East Lake, but here the *Atax* and *Cotylaspis* were far more numerous, and there were not as many

cysts. Some specimens contained 30 or more of the adult parasites, besides innumerable young swarming over the gills or the mantle.

The bed of mussels along the center of the north shore gave a remarkably fine opportunity to study the activities of the mussels in the natural beds, as the perfectly clear, calm water enabled one plainly to see them carrying on their life processes. The species examined was the *Anodonta grandis* of the lake, a plump, inflated form which probably represents the subspecies *footiana*.

The inhalent aperture was very large, black exteriorly and for some distance in. It was possible to look in far enough to see the gills. Long papillæ in approximately a single row project directly across and nearly to the center of the siphonal opening; most are single, but a few may be forked. The incoming current of the mussel is not nearly as strong as the outgoing, since the latter has a much smaller cross-section for the same amount of water. Minute red water mites ventured to the very orifice of the inhalent aperture but were not swept in, while small objects coming near the exhalent opening would be driven away with some force.

The exhalent opening was black for some distance in, then faded out to white. It was possible to see the posterior opening of the alimentary canal and the water-tubes running down into the gills of the living mussel. These mussels were quite apathetic; they did not close up at near approach, which must have caused both shock of waves and shadow. One, taken from the bed, closed only for a moment, then opened and began feeding while held in the hand. River mussels in general are more sensitive, and sometimes close when simply a shadow passes.

Station 12. Potato Creek, Kankakee River.—Having finished the workable portion of Yellow River, our attention was next directed to the headwaters of the main Kankakee.

At its source this river forks like the Yellow River, the west fork rising in the Fish Lakes, the east fork in the swamp southwest of South Bend. We found conditions here similar to those at the headwaters of Yellow River, but with this difference: While the east fork and the main river have been dredged recently down to the entrance of the Yellow River and about 10 miles beyond, many of the tributary creeks have been left in their original conditions; and since the west fork has been dredged only here and there, the Fish Lakes, at its source, remain practically unchanged. We were thus able to combine in our examination natural with artificial conditions, and we found an even stronger contrast between the two.

This entire section was worked by short drives from Walkerton, in the extreme southwest corner of St. Joseph County, since it was

impracticable to row up against the swift current in the dredged Kankakee above its junction with Yellow River.

Naturally we examined first those portions in which the conditions had been least changed. Potato Creek is the southernmost of several large creeks which empty into the east fork of the Kankakee, and lies just north of Walkerton. The bed of the creek is hard sand or gravel, and, being undredged, it still preserves those alternations of swift and sluggish current, deep and shallow water, coarse and fine bottom, which are conducive to mussel life.

We found in it nine species of mussels, nowhere very thickly bedded, but as many, perhaps, as would be expected in a creek of the size, it being 8 or 10 feet wide, with the water nowhere more than a foot or a foot and a half in depth. On examining these mussels, the *Anodontoidea* and the *Anodonta* were found infested with *Atax* parasites and the distomid of Osborn; the other mussels were free.

Station 13. Pine and Yellowbanks Creeks.—These are two other creeks of about the same size as Potato Creek and lying to the north of Walkerton. But, although they presented conditions apparently as favorable as those of the last station and were examined for long distances on either side of the highway, not a single mussel could be found in them, nor any dead shells, with the exception of one valve of *Symphynota compressa* in Yellowbanks Creek.

Station D. The Fish Lakes.—These lakes really occupy a single lake basin which is divided by narrow channels into four bodies of water, known as the Upper Mud Lake, Upper Fish Lake, Lower Fish Lake, and Lower Mud Lake, respectively. The two Fish Lakes have each an area of about 100 acres and a maximum depth of 40 feet. The thoroughfare between them is 80 rods long and 15 or 20 feet wide, with a maximum depth of 2 feet, and has a good current. The water in both of the lakes and the thoroughfare was clear and quite warm. The bottom was marl, hard and firm in most places, but very soft in a few spots. The shallow belt along the shore is narrow, as a rule, though wider and more irregular in the Lower Lake than in the Upper. The banks are high about halfway around each of the lakes, but low and swampy for the other half, where in each case it borders on the respective Mud Lake. There was the usual lake vegetation around the shores—reeds, rushes, spatterdocks, and some algæ.

Mussels were found abundantly everywhere. *A. grandis* was the most common and was found everywhere mingled with the other species. Most of the specimens were exceptionally large. Their shells were also thick and strong; in fact, many of them possessed shells of sufficient thickness for the manufacture of buttons.

L. luteolus was fairly abundant, and, instead of the usual dwarfed specimens found in lakes, these were fully as large as any obtained in the Yellow or Kankakee Rivers.

L. subrostratus was sparingly distributed, only 20 specimens being found, but each of these had large shells for the species, with an exceptionally thick white nacre.

A few *Unio gibbosus* were found in shallow water close to the shore.

A large number of dead shells of *Q. undulata* were scattered about over the bottom, and at one spot in the Upper Lake a colony of living examples was found. This is the first instance in our experience of finding this species in a lake, although Call reports it as fairly common in the lakes of northern Indiana. The shells were all fully as large and of as fine quality as those found in the rivers. A single live specimen of *L. iris* was found near the shore, one of *L. glans*, and one of *A. imbecillis*. All these mussels were well incrustated with marl, but the size of the shells and the healthy appearance of most of the specimens indicate that the conditions are at least very favorable.

A. grandis was as plentifully distributed in the thoroughfare between the lakes as over the lake bottom, but the other species were not found there.

The two Mud Lakes, as their names indicate, had a bottom of soft black muck and contained no mussels.

On the way back to Walkerton another Mud Lake on the east fork of the river, and into which Potato Creek empties, was visited. But the lake has been practically all drained by the dredging of the river and what is left was so black and swampy that it was not deemed worth examining.

The mussels from the Fish Lakes yielded an abundance of *Atax* parasites, some *Cotylaspis*, and many of the distomid of Osborn. The exceptional size and thickness of the shells of all the species is worthy of notice.

Station 14. Kankakee River at Davis, Ind.—The old bed of the river was examined close to the bridge of the Pittsburgh Division of the Pennsylvania Railroad. The same conditions were repeated here as in the dredged portion of the Yellow River below Ober. There was too swift a current and too much moving sand for the mussels to obtain a foothold in the dredged channel, but the old bed of the river was full of them. In this latter locality the hard sandy bottom had been overlaid with 1 or 2 feet of soft black mud, brought down during the freshets and deposited in the quiet water of these lagoons.

The mussels were even more numerous than in the old bed of the Yellow River, three or four being often obtained in a single square

foot of the mud. These mussels also usually had a large mass of algæ attached to their upper ends and forming a sort of funnel in the water. Whatever may be the effect of the supporting power of the algæ in the mud, the two furnish a good example of symbiosis. The mussel supplies the alga with a place of attachment, otherwise lacking, and in return the alga helps to purify and oxygenate the water for the mussel.

Q. undulata was by far the most common species, there being two of them to every one of all the other kinds. No adult *Atax* parasites were found in this species, but the mantles of many of them contained clusters of the eggs.

Each of the *Q. pustulosa* (75 specimens in all) contained from several to a large number of adult *Atax*, besides clusters of eggs in the mantle, and young in various stages of development, swarming over the gills. *Q. coccinea* contained no parasites at all, and the nacre of all but two of them was white and would make excellent buttons. *L. ventricosus* had an abundance of young *Atax* in the mantle and on the gills, and many of them had dorsal baroques.

L. rectus showed anywhere from 10 to 20 adult *Atax* in each specimen, besides plenty of young and an occasional *Cotylaspis*. A marginal baroque was found in one, and the nacre of all was a deep purple. None of the other species contained parasites.

Station 15. Kankakee River at the crossing of the Nickel Plate Railroad.—Just above the railroad bridge is a large island with the old channel to the west of it and the newly dredged one to the east. The water runs through this old channel oftener than at the previous station, so that only a few inches of mud have been deposited. The mussels were very abundant here, forming the largest and most densely populated bed found anywhere in the old channel of either river. There was much driftwood buried in the mud along the west bank of this old channel, and the mussels were clustered around the twigs and branches as thickly as they could stand, seeming to get some support from these solid objects.

Farther up behind the island the water was shallower and there was a perceptible current and no mud. Here the mussels were actively moving about, and as the water was clear they could readily be found.

On examination, none but the *Q. pustulosa* contained any parasites, but these had enough to compensate for any lack in the others. Every specimen was infested, and it was not at all uncommon to find 50 or 60 adult *Atax*, besides the eggs and young, in a single mussel. Many of these mussels contained small pearls and some of them dorsal baroques.

The *Q. coccinea*, again, had white nacre, none of the rosy nacre being found, and being at the same time large and flat, furnished

excellent material for buttons. (See values, p. 39.) The *L. rectus*, on the contrary, were not merely pink, but nearly all of them were deep purple.

The small fishes seined on these mussel beds furnish a good sample of those to be found in the upper part of the Kankakee River. *Boleosoma nigrum* was by far the most common, with *Notropis blennioides* second in abundance. *Notropis heterodon* was common and easily recognized by its dark lateral stripe and black chin. We also obtained five examples of *Ericymba buccata*.

Station E. Koontz Lake.—This lake is situated in the extreme northeastern corner of Starke County, Ind. It is shaped like a three-leafed clover, the middle leaflet considerably the largest, and the whole lake covers 200 or more acres. The outlet is at the southwest end, where a stone dam has been built, 10 feet high and wide enough to accommodate a carriage road across its top. This outlet, called at first Cedar Creek, runs west into Robbins ditch, where it is joined by other ditches and becomes 40 or 50 feet wide, or nearly the size of the Kankakee itself, and empties into that river a couple of miles above the mouth of Yellow River and about the same distance below station 15. The outlet was examined for a mile west of the lake but yielded only a single *L. luteolus*.

The lake is in a large measure artificial, being formed by back-water from the dam. It has a hard sandy or gravel bottom and the shallow water around the shore is filled with rushes and lily pads, while the bottom itself is covered with *Chara* and *Potamogeton*, and so does not afford good localities for mussels. In a few places, however, the bottom is of clear sand and here *A. grandis* and *L. luteolus* were found in considerable abundance, and a few *Q. rubiginosa*.

These mussels were all of good size and quality for lake shells. No adult *Atax* were found in the *A. grandis*, but the eggs and young were abundant. Adult *Atax* species were found in all the *luteolus*, in addition to eggs and young. No parasites were present in *rubiginosa*.

Station 16. Kankakee at mouth of Yellow River.—Since being dredged this part of the Kankakee is called the Sisbro ditch. The old channel of the river crosses the ditch here and is available on both sides.

To the north we found a rather deep pool with a solid bottom and only a little mud and containing a large number of minnows and darters. Here we obtained only a few shells, chiefly *undulata* and *luteolus* with some *coccinea* and *pustulosa*. Farther down where the old channel crossed to the south there was running water, shallow in depth, with a firm sandy bottom in places and mud elsewhere. Here the mussels were exceedingly active, and nearly all were found

at the end of long tracks that looped and turned upon themselves. Some *Oscillatoria* was found growing on the quieter shells.

Three or four miles farther down the river the old channel crossed the ditch again. Here in the deeper parts of the pools the mussels fairly touched one another. A pearler had been working on these mussels and had left a couple of large piles of freshly killed shells on the bank.

Along this stretch of river we obtained the first good evidence that the mussels are reestablishing themselves in the dredged channels. Living specimens were fairly common near the shore.

This part of the river was once the bottom of English Lake, a marshy overflow from the Kankakee, 10 or 12 miles long, 2 or 3 in width, and of shallow depth. It was filled with algæ of all kinds, reeds, rushes, water lilies, and an abundance of wild rice, and formed a natural breeding ground for thousands of waterfowl. It must have fairly swarmed with mussels, to judge from the dead shells of those thrown out by the dredge and the large numbers still found alive in every portion of the old channel that contains water. The dredging has entirely drained the lake and it is now a straight cross-country ditch, with the mussels gradually repopulating it. The conditions here are much more favorable than in the Yellow River, and a little artificial restocking would restore the mussel fauna in a few years.

On cleaning the mussel shells we found them an interesting lot. The *L. luteolus* were all more or less blistered and steel-colored at the tips of the valves, and frequently the whole shell was curiously roughened. They yielded many small pearls, all located near the tip of the mantle in the region of the siphons. And they usually had a number of young *Atax* crowded around the exhalent orifice. So far as our experience goes this is a rather unusual position for young *Atax*. Their ordinary situation is along the lips of the inhalent aperture. *Q. pustulosa* also contained many *Atax*, but they were not as numerous as at station 15. Four of the *Q. coccinea* had white nacre and all the *L. rectus* were pink instead of the deep purple of those farther up the river. Parasites were also found occasionally in *L. ventricosus*, *L. ligamentinus*, and *Q. undulata*. A few of the *ventricosus* and *luteolus* were gravid or beginning to become so.

Station F. Bass Lake, Starke County, Ind.—This lake is fourth in size among the Indiana lakes and covers an area of $2\frac{1}{4}$ square miles. It lies in the southeastern part of the county, about 6 miles south of Knox. It is somewhat boot-shaped, the leg portion elongated northeast and southwest, the foot portion at right angles to this. It occupies a shallow basin on the top of a morainic ridge and more than half of its area is 5 feet or under in depth; the maximum

depth is 32 feet. The greater part of the shore line is low and marshy, and the water is filled with a dense growth of reeds and rushes. The bottom is sand or blue and sticky clay, interspersed with extensive muck beds, the latter giving rise to a luxuriant growth of aquatic vegetation. The sand and clay are also covered with algæ, among which is *Chara*. *Potamogeton* is also common. In fact the lake flora is richly developed at the expense of the fauna. At present the lake has no outlet or natural inlet, but is fed entirely by springs. The old outlet, however, now so filled that water runs through it only occasionally, was to the west, emptying into the Kankakee about 3 miles below station 16. Dwarfed *L. luteolus* were fairly common in the gravelly sand close to the shore, and there was a large bed of them around a point which juts out into the lake from the eastern shore, Cranberry Point. A few *A. grandis* were also found. Both species were infested with *Atax* parasites, but not in large numbers, and in addition *Cotylaspis* and the distomid of Osborn were present in *A. grandis*. This lake had been examined in 1906, and a number of *Anodontas* obtained near the ice houses and *Lampsilis luteolus* on the opposite shore.

Station 17. Kankakee River, Riverside, Ind.—On the way down from English Lake to Riverside small piles of mussel shells that had been left by pearlbers were frequently found. Here the mussels have fully reestablished themselves in the dredged portion of the river, and the steep banks just under the water were well lined with *L. luteolus*.

Just above Riverside the dredged ridge along the north bank of the river held back a small pond covered with *Euglena* in a portion of the old channel. This was nearly filled with soft mud and contained but few mussels, though there were plenty of dead shells along the bank. On this stretch of river there was a marked increase in the number of *ligamentinus* and *ventricosus*. All the shells found were large and of excellent quality.

Station 18. Burrow's Camp to Baum's Bridge.—The dredged portion of the river stopped at the last station and we now entered the genuine Kankakee swamps. The sides of the river were low and boggy but heavily wooded for a short distance back from shore. The bottom we found to be firmly packed sand, admirable for wading, and there was a current of 4 miles an hour.

Mussels were plentiful along the shore wherever the bottom could be seen, and we waded often enough to show that they continued into the deeper water. There were occasional piles on the banks, left by fishermen and pearlbers, and in one of the shells thus left a small pearl was found. But only one of the live *luteolus* yielded pearls, a much smaller percentage than farther up the river.

Every specimen of *pustulosa* was infested with *Atax* parasites and most of them contained dorsal baroques. The *ventricosus* specimens contained both *Atax* and *Cotylaspis*; two of them were gravid and one had two dorsal baroques. The single *A. grandis* was the first one found in the Kankakee River.

Station 19. Baum's Bridge.—Just below the bridge is a clubhouse belonging to the Crawfordsville Club. We stopped over night with Mr. George Wilcox, the keeper of the clubhouse, who, besides entertaining us hospitably, gave us much valuable information in regard to the river. He told us of a mussel fisherman who had gone down the river two years before and who had obtained several hundred shells from a bed in front of the clubhouse. We had also been informed that button manufacturers had sent out circulars along the river offering \$20 per ton for good shells, and that people along the river who had sent in samples had been offered from \$5 to \$8 and \$12. We tried our dredge in the same place, a sort of eddy in the current. The water was 8 to 10 feet deep and the bottom of hard sand and fine gravel with some lumpy blue clay. The mussels were abundant both in the sand and at the edge of the clay. Most of the specimens were *undulata*, but there were many *luteolus* near the shore and some fine *ligamentinus*, *rectus*, and *coccinea*. Several of the *ligamentinus* were gravid, and most of the *coccinea* had white nacre. Nearly all the *luteolus* contained *Atax* and *Cotylaspis* parasites and 5 out of the 32 had small pearls in the mantle edge.

Station 20. Hebron Bridge, Kankakee River.—The river widens out into a sort of lake about 3 miles above this bridge. The bottom was firm sand and nearly uniform, not more than 4 feet deep at the maximum, with large patches of water lilies and smartweed, and plenty of *Potamogeton fluitans* along the banks.

Mussels were found all over the bottom, but were most plentiful among the roots of the *Potamogeton* along the shore. Nearly all the *L. luteolus* were found there, while the *ventricosus* and *ligamentinus* were in midstream and proved exceptionally large and fine. *Q. undulata* was also common in the deeper water, but there were almost no *Q. pustulosa*. The three specimens of *S. complanata* were the first found in this river.

Most of the *luteolus* and *ventricosus* were either gravid or becoming so, and, together with the *undulata*, were each infested with a few adult *Atax*, and often with eggs and young parasites; and many contained also *Cotylaspis*. The *luteolus* averaged about one pearl apiece in the edge of the mantle, while the *ventricosus* contained dorsal baroques. The other species were free from parasites.

Station 21. Water Valley, Kankakee River.—The collection here was obtained from three different localities: (1) Hog Wallow Slough,

a marshy lagoon on the north bank of the river with water 2 or 3 feet deep and a hard bottom of sand; (2) the south bank of the river, which is in the town of Thayer and where some pearlers had left a pile of about 100 shells all freshly killed; and (3) the middle of the river between the two places, where we used the dredge in water about 6 feet deep, with a hard sandy bottom and very little current.

At the slough the mussels were scattering, but of excellent size and quality. In the pearlers' pile, which were all *luteolus*, we found many pearls of small size in the edges of the mantles. From the deep water of the midriver were obtained *coccinea* (in deep water only), *undulata*, and *pustulosa*. Shells are said to be easily obtained in large numbers here at low water. Many of the *ventricosus* were nearly gravid, and the *luteolus* were all infested with *Atax* and *Cotylaspis* parasites, though the other species were free.

During our stay in Water Valley we stopped with Mr. John Phelps, a fisherman who is thoroughly acquainted with the Kankakee River, and who gave us much valuable information in reference to the mussels as well as the fishes. Through his courtesy we had an opportunity to examine many of the fish caught in the river.

The redeye, *Ambloplites rupestris*, yielded a few specimens of *Ergasilus centrarchidarum* attached to the gill filaments. Another specimen had mussel glochidia on its gills, while a third one was covered with bloody spots over the outside surface of the body, most common near the anal fin. Attached to one of these spots was a *Lernæocera cruciata*, which Mr. Phelps told us were quite abundant on this fish in the early spring. These redeyes, together with the large and small mouthed black bass and the sunfish, all of which are plentiful in this portion of the Kankakee, have proved to be the most satisfactory species for carrying glochidia (Bulletin of the Bureau of Fisheries, vol. xxviii, p. 624.) Their presence, therefore, insures one of the most important conditions for the success of artificial mussel propagation.

Station G. Cedar Lake, Lake County.—This must have been a favorite name with the early settlers, judging from the fact that there are at least six "Cedar" lakes in the State of Indiana. This particular one is in the center of Lake County and covers 1.17 square miles, being a little over 2 miles in greatest length and about three-quarters of a mile in greatest breadth. It is shaped like a kidney or bean, and owes its origin to irregularities in the deposition of the drift material. It is surrounded on all sides except the south by heavily wooded ridges, which formerly were its shores. It is another case of artificial drainage, like the Lake of the Woods.

In order to reclaim 200 acres of comparatively worthless marsh land at the southern end of the lake, a ditch was cut on its eastern side which lowered the level of the lake 10 or 12 feet. This artificial

ditch is the present source of Cedar Creek, which flows south into the Kankakee River.

The present shores are hard and firm and the bottom is sandy along the north and east sides and muddy along the west and south sides. Both sand and mud are covered in many places with *Chara* and *Potamogeton pusillus*, mixed with some *Vallisneria*, *Philotria*, and *Cladophora*, the latter on the pebbles. Along the shores are reeds and rushes, forming a thick fringe.

The water of the lake was remarkably green, due to the presence of minute suspended algæ, mostly *Clathrocystis*, with some *Lyngbya* and *Anabæna*. A tow taken at the surface near the center of the lake yielded a wineglassful of Entomostraca, chiefly copepods and *Daphnia*, much the richest haul of any taken during the summer.

In front of the Siegler Hotel, on the west shore, is a broad sand bar used for bathing. Here, just outside the bathing rope, in 6 feet of water, was a thick bed of mussels, nearly all *A. grandis*, with a few dwarfed *L. luteolus*.

Mr. Siegler kindly furnished us with a boat and a long-handled rake with which to secure our specimens.

We were told at the hotel that formerly the people about the lake were accustomed to cook and eat the *Anodontas* with much relish, but had gotten out of the habit in late years. An examination of the eastern shore showed that the *A. grandis* was very plentiful there, but *L. luteolus* was scarce.

A seine haul just south of Cedar Point gave us the largest number of small fishes obtained during the season, mostly *Labidesthes sicculus* and *Boleosoma nigrum*. Evidently the abundance of Entomostraca produced its legitimate effect.

On examining the mussels, all the female *luteolus* were found to be gravid and infested with a small red *Atax*. Only one or two of the *grandis* were gravid, but they were all badly parasitized, containing from 5 or 6 to 30 *Atax*, chiefly *A. ypsilophorus*, and a few *Cotylaspis*. No pearls were found in any of our specimens, though we were told many had been obtained from the *Anodontas*.

Station 22. Burtons Landing, Kankakee River.—This station was on the south bank of the river just above where the dredged ditch empties in.

The bank was very steep, giving 4 or 5 feet of water close to the shore; the bottom was mixed sand and mud; the current was slow and there was no vegetation present. The mussels proved to be abundant, both along the shore and in the deeper water of the mid-river, *Q. undulata* being the most common species. It was noticeable that there were no mussels in the sand brought down by the ditch. A broad delta had been formed, reaching far out into the river, but the mussels carefully shunned its shifting sands. Furthermore, all

those on the down-river side, which had been caught by these same sands, were dead, another striking testimony of the effect of a shifting bottom on the mussel fauna.

All the *luteolus* and *pustulosa* were infested with *Atax*, one *pustulosa* yielding 61 of the adult parasites. The *luteolus* also contained a few *Cotylapsis*; the other species were free.

The two *A. grandis* and the single *S. complanata* are worthy of note in view of the rarity of the species in the river.

This is the last station in the swamp region of the Kankakee, and it may be well to give a brief summary of the conditions prevalent there.

This length of the undredged portion of the river from English Lake to the State line is variously estimated by different authorities. A conservative estimate would make it at least 100 miles, and it is practically one continuous mussel bed for the entire distance. There are places where the mussels are thicker than elsewhere, but there is hardly a spot where search will not reveal at least some species.

We have here again an ideal breeding ground for mussels, similar to the Yellow River from Plymouth to Ober, but at least five times as large. The natural conditions are even better here than they were in the Yellow River; there is the same kind of a bottom, lime and food enough in the water, a good current the whole distance, and plenty of small fish to distribute the glochidia.

Then there is in addition the great swamp reservoir to regulate the supply of water, the organic material derived from the swamp vegetation to serve as food, and the enforced seclusion of the region to obviate any disturbing influences. There are several valuable species of mussels, like *rectus*, *pustulosa*, and *coccinea*, which were not common in the Yellow River, but which would add greatly to the value of the mussel product; and finally we find the mussels here infested with the same pearl and baroque producing parasites.

Instead, therefore, of expending large sums of money in an artificial drainage system, thereby entirely destroying the natural resources of the region, making it of no possible use as a game or fishing resort, and annihilating its rich mussel fauna, all for the sake of reclaiming a few hundred acres of land that have not proved to be worth much, it would seem to be far more profitable to cultivate the resources already in existence.

Nature has herself clearly indicated the kind of products suited to the region. Now that man has learned how to handle one of the most valuable of those products, mussel shells, it would require very little effort or expense to convert the native mussel fauna into a rich source of revenue. The *L. rectus*, which has white nacre, called the "white sand shell" by the mussel fishermen, could be easily intro-

duced, and would produce shells that bring large sums of money in the market. The hunting and fishing would not be injured, but rather benefited by the increase of the mussels.

Here is an ideal chance for the breeding of mussels on a large scale; it only needs to be once started to prove its value. Furthermore, the mussels are infested with the same kinds of parasites as those of the Yellow River, while pearls and baroques are even more plentiful. Consequently, the prospects of a reasonable bonus from this source are exceptionally good.

Station 23. Kankakee River between the State line and Momence, Ill.—Just across the State line occurs the first limestone outcrop in the bed of the river. This is the ledge which has acted as a natural dam and prevented the wearing down of the river bed. Were it not for this ledge the river would have long since drained the immense swamp region. But just as it is responsible for the character of the channel above it in Indiana, so it marks the beginning of a very different kind of channel below it in Illinois. In the 50 miles of river from the State line to the head of the Illinois, the Kankakee falls 130 feet, or nearly 3 feet per mile. From a deep and smoothly moving river, without a break between its source and the State line, it is suddenly converted, on passing this ledge, into a succession of broad and shallow rapids difficult to navigate. The old bed of sand and fine gravel ceases and in its place we find shelving rocks, coarse gravel, and boulders.

Such radical changes in the surrounding conditions would suggest that the mussel fauna must change also, and such we find to be the case. Several additional species appear all at once and are common down to the mouth of the river. We no longer find a continuous bed of mussels, but they are scattered wherever they can find a foothold. For long distances the solid rocky bottom prohibits them from remaining; then come favorable localities where they are packed as closely together as they can lie. In general, the conditions are not as favorable in Illinois as in Indiana; it is certainly very much more difficult to gather the mussels. Our first collection within the State, however, was made rather easy by the fact that pearlers had been at work along the river and had left small piles of shells scattered here and there on the banks. We selected from these and supplemented them with living specimens of other species. Near the State line some *undulata* were found with a yellowish epidermis instead of black.

Station 24. Momence, Ill.—Just above the town was the camp of three mussel fishermen who had been collecting shells from the immediate vicinity for the market. They had secured about 15 tons, the only culls from which were a few *U. gibbosus*. They told us the shells from this locality were not as tough as those in the Wabash

River, and hence did not bring quite as much per ton. They showed us a good collection of pearls and baroques obtained from their mussels, and just as we landed they picked a large spherical pearl the size of a pea out of the mantle of an *L. ligamentinus*. We looked over their pile of shells and took samples of the different species; the great bulk of the pile was *ligamentinus* and *ventricosus*.

We secured the following species which had not been found in the river above: *L. ellipsiformis*, common; *Q. tuberculata*, several; *Q. metanevra*, rather common; *A. truncata*, frequent; *S. edentulus*, two; *S. costata*, common and large; *O. ellipsis*, two. Some of the *L. rectus* had white nacre, but most were pink; the *U. gibbosus* showed purple, pink, and white nacre, with considerable difference in shape and size of shells.

Station 25. Waldron, Ill.—The river was shallow and rocky and very difficult to navigate below Momence, but the water was fairly clear, so the shells could be seen on the bottom. There was considerable *Potamogeton lonchites* and water willow along the water's edge. Beds of mussels could be seen in various places, especially near the riffles; but as the mussel fishermen at Momence had worked this part of the river thoroughly, no stop was made until we were close to Waldron. Here was found a pile of freshly cleaned shells, about one-quarter of a ton, which had been left by pearlers. Samples of the different species were selected and kept; the pile was nearly all *L. ligamentinus*, with some *L. ventricosus* and *U. gibbosus*; the other species listed occurred in small numbers. One of the *L. rectus* had white nacre, the first white-nacred one seen; the rest were pink. Both the *ligamentinus* and the *ventricosus* had been gravid in considerable numbers when captured.

At Waldron an 8-foot dam prevents all intercourse with the river farther down.

Station 26. Watseka, Iroquois River.—This river is the chief tributary of the Kankakee in Illinois as was the Yellow River in Indiana. Like the main river, the character of this tributary changes radically at Watseka. Nearly half the river basin, 800 square miles, lies in Indiana, and is of the same type as the Kankakee Basin in that State, marshy and sandy.

Just before reaching Watseka, Ill., it crosses the so-called Iroquois moraine and afterwards traverses an old lake bed. There is much more fall in the river, but it is never as rapid as the Kankakee. The great amount of dry prairie land it drains makes it a "flashy" river, subject to rapid rise and fall, and hence the upper portions of it are not very rich in mussels. Furthermore, in the vicinity of Watseka the banks of the main river and of Sugar Creek, a large tributary from the south, are so steep and slimy with clay that it was practically impossible to do any wading. The collection of

shells from this station, therefore, includes simply what could be picked up along the shore.

About a dozen years ago a Mr. Hill started a woolen factory in Watseka for the manufacture of woolen goods, and, as an adjunct to employ the surplus water power and to furnish the buttons for the goods he turned out, operated a button factory. The farmers along the Iroquois River and Sugar Creek kept him supplied with shells, which they gathered and carried to the factory. A flourishing business was done for six or eight years until hard times came and caused the shutting down of both factories. Enough was accomplished to prove that these two streams contain a plentiful supply of shells—enough to run such a factory for a long time.

Station 27. L'Erable, Iroquois River.—This is about 10 miles below Watseka, but the river widens in that distance from about 40 feet to fully 175 or 200. It was about 3 feet deep at the center, with a bottom of fine gravel along the channel bordered on each side by sand, while the banks were soft clay mud. The current was almost imperceptible and the water very muddy. The mussel fauna was rich and varied, as the list given amply proves, and the species were fairly well sorted according to the kind of bottom.

In the soft mud were found *luteolus* and the first *fallaciosus* we had seen, with an occasional *ventricosus*. In the sand were a few *lachrymosa*, also the first found in the Kankakee Basin, *pustulosa*, *undulata*, *complanata*, *costata*, and *rubiginosa*. In the gravel was the great majority of the *lachrymosa* and *undulata*, with an occasional *ventricosus* and *complanata*. *Q. lachrymosa* was more abundant than all the other species taken together, and in many places were so thick one could hardly get a foothold without standing on them. The shells were exceptionally large and of fine luster and quality.

On examining the mussels for parasites, nearly all the *complanata*, *luteolus*, *pustulosa*, *trigona*, and *lachrymosa* were found to be infested with *Atax*, the distomid of Kelly, and marginal cysts. A few of the shells contained pearls and dorsal baroques, but in much smaller numbers than were found in the mussels of the Kankakee River. A small number of each of the species just named were gravid, the others were free from parasites, and in none of them had the eggs passed down into the gills. While most of the *rubiginosa* had the characteristic reddish orange meat, a few were found almost white.

The Iroquois is a river of *Quadrulas*, with comparatively few *Lampsilis*, in marked contrast to the Yellow and Kankakee Rivers, which are nearly all *Lampsilis*, with comparatively few *Quadrulas*.

Station 28. Iroquois River 3 miles above its junction with the Kankakee.—The change in the bed of the river already noted was

even more apparent here; the river was shallow and full of riffles and the bottom was almost continuous rocks, with little sand or mud between them. But the shores still showed the obnoxious black clay mud.

Fortunately, the muskrats had been busily at work eating the smaller mussels with some of the large ones, and had collected large piles in many places. The mud on shore was nearly a solid network of muskrat tracks, with here and there the long groove where they had dragged a shell too large to lift and carry. They evidently had no trouble in finding plenty of mussels, although we could not locate the live ones among the rocks. The 15 species listed were all obtained from the muskrat piles, and, as will be seen, include *Q. metanevra*, which evidently prefers localities with a very rocky bottom.

Station 29. Mouth of the Iroquois River.—Where the Iroquois joins the Kankakee, there are two or three small islands, raised but little above the level of the water, but giving support to a mass of dense underbrush.

Here again the muskrats had nearly covered the mud around the roots of the bushes with nicely cleaned mussel shells of many species—probably all that can be found in the vicinity. Two *Q. lachrymosa* were found alive at the water's edge; all the others collected were the shells from the muskrat piles.

Station 30. Kankakee, Ill.—Several pearlers had been at work on this portion of the river and about 1 mile above the city of Kankakee were two large piles of shells close to the water's edge on the south bank. The first pearler, and evidently the more experienced one, had collected only *L. luteolus*, but his pile of shells did not show proof of having yielded many pearls. The other party had collected all species indiscriminately, and 14 different kinds were found in the pile. None of these shells gave evidence of having been much parasitized and probably did not yield very large returns. They gave us a fine collection from the locality, however, without the trouble of wading and hunting for them.

The selection of *luteolus* as a pearl producer is worthy of notice, since it coincides exactly with our own experience in the whole Kankakee Basin. The pearl problem is quite possibly different in each river. In some rivers *Q. undulata* or *plicata* are regarded as the pearl-bearing shells; in others, *L. ligamentinus*, and so on. In the Kankakee *L. luteolus* was the most prolific, and indeed the only species that one could count on to yield them, but the pearls were all, though perfectly spherical and of good luster, of very small size, called by the pearlers "mustard-seed pearls."

Station 31. Custer Park, Ill.—Just below the city of Kankakee there are five large dams across the river within a few miles, while at Altorf and Wilmington there are rapids with a sudden descent of 20

feet in the river. These make this part of the river unnavigable. Accordingly, the boat and outfit were shipped from Kankakee, and the remaining portion of the river was worked from the railroad.

From Wilmington, the nearest station, we drove to the house of Mr. Jesse Fairchild, on the north bank of the river. He kindly lent us his boat and told us where to find a mussel bed, which he said was the only one for some distance up and down the river.

It lay along the edge of a riffle where the water was about 2 feet deep and the current 5 or 6 miles an hour. The bottom was entirely covered with stones of all sizes and shapes, mostly well rounded, and thrown together with small pockets between them. These pockets were filled with sand or fine gravel, and in them the mussels were found. The stones, the gravel or sand, and the mussels were all covered with a dense coating of dark green algæ.

All the mussel specimens obtained were small, for large ones can not crowd in among the rocks, and many of the females were gravid. *L. ligamentinus* was the most common species, and every specimen showed clearly the radiating rays on the external surface.

Marginal cysts were found in some of the *S. edentulus* and *L. ligamentinus*, and a few *Atax* in one *L. ventricosus*, but as a whole this lot of mussels was remarkably free from parasites. The number of species at this station was only equalled by those which were obtained from the 15 tons collected at Momence by the mussel fishermen.

Station 32. Wilmington, Ill.—This station was just below the road bridge across the Kankakee River, between the second and third dams. The river here has a rocky bottom and is practically one continuous riffle with a very swift current. There was a large outcrop of limestone on the shore and more appeared in the bed of the river.

The collecting was very difficult, but the few live mussels found were supplemented by a large pile of freshly cleaned shells on the shore, probably left by a pearler. All the shells were large and well developed, particularly the *L. ligamentinus* and *S. costata*. The *L. ventricosus* and *rectus* had an exceptionally good luster and were of excellent quality; the other species were about average.

Station 33. Forked Creek, Wilmington, Ill.—This is a rather small creek that runs into the Kankakee from the north, and is made up of alternating pools and riffles. In the riffles the bottom is rocky, with many gravel and sand bars; in the pools there is more or less mud. The main vegetation is water willows, with occasional yellow water lilies and *Philotria*, and everywhere an abundance of tough algæ. Most of the shells were dead and seemed to have been killed by muskrats. The live specimens of *A. calceola*, *S. edentulus*, and *L. ellipsiformis* were all gravid. The *L. ventricosus* and *ligamentinus* and the *Q. undulata* were all small in size, but otherwise normal.

Station 34, Mazon Creek, Gardner, Ill.—This is another tributary of the Kankakee from the north and in its general features closely resembles Forked Creek. It consists mainly of rather shallow pools connected by slender threads of water, with numerous sand and gravel bars. The bottom is practically all pebbles and sand, with almost no mud. Water willows are thickly distributed, with large patches of spatterdock, but there were not many algæ.

The mussels were found mostly along the edges of the sand bars and were usually small in size. Many of them were actively crawling about and lay at the ends of long furrows. Pearlers had been at work here also, and many recently killed shells were seen along the banks, mostly *Q. undulata*, with some *L. luteolus*. The muskrats were evidently abundant and had left many dead shells scattered along the water's edge, chiefly the small *L. ellipsiformis* and young specimens of *Q. undulata*, *S. complanata*, and *S. edentulus*.

The *L. ellipsiformis* was particularly abundant and an excellent lot was obtained. The young *S. edentulus* and *S. complanata* were all bright-rayed. One *edentulus* and most of the *ellipsiformis* were gravid, and in the former was a single large *Atax ingens*, the only parasite found. The dead shells of *luteolus*, however, looked as if they had been well parasitized and had contained many pearls. One pearl about the size of a small buckshot was obtained from a living specimen, which contained many marginal cysts. This pearl was perfectly spherical, and though fresh, was of rather poor luster.

Station 35. Mouth of the Kankakee River.—The Des Plaines River, which joins the Kankakee to form the Illinois River, is simply an immense sewer bringing down the Chicago drainage. Both rivers, but especially the Des Plaines, are full of the characteristic algæ and other vegetation which grow in such waters, and the combination of a copious vegetation with the sewage has effectually killed off all the mussels in the vicinity. Not a single living specimen could be found in either river, but there were hundreds of dead shells along the banks, most of them old and well bleached, but still capable of identification. The species listed from this station are all such dead shells.

Since this finishes the examination of the Kankakee Basin, it will be well to sum up the general results of the work in the form of brief statements:

SUMMARY OF MUSSEL DISTRIBUTION.

1. The Kankakee River and its two principal tributaries, the Yellow and Iroquois Rivers, present a very rich and varied mussel fauna throughout their entire lengths, except in those portions which have been artificially dredged.

2. The 32 mussel species obtained in the Kankakee Basin produce shells of exceptional size, luster, and quality, and many of them are of high commercial value. (See table, p. 39.)

3. The basin is divided at the State line into two regions, radically different in the conditions which they present, and harboring consequently different mussel faunas. These regions may be designated as the Indiana and Illinois portions of the basin.

4. The Indiana part of the basin is a region of swamps, smooth sandy bottoms, a uniform current, and abundant vegetation. It is the home of *Lampsilis* and *Anodonta*, with relatively few *Quadrula* species. It contains seven species not found in the Illinois part of the basin, viz, *S. compressa*, *A. f. subcylindraceus*, *A. imbecillis*, *L. glans*, *L. iris*, *L. subrostratus*, and *L. parvus*.

5. The Illinois part of the basin is a region of rolling prairie land, rough rocky bottoms, alternating riffles and dead water, with almost no vegetation. It abounds in *Quadrula*, *U. gibbosus*, and *Symphynota*, with comparatively few species of *Lampsilis*. It contains eight species not found in the Indiana part of the basin, viz, *Q. trigona*, *Q. lachrymosa*, *Q. metanevra*, *P. æsopa*, *S. complanata*, *O. ellipsis*, *L. ellipsiformis*, and *L. fallaciosus*.

6. There are seven species universally distributed throughout both regions, viz, *Q. coccinea*, *Q. undulata*, *U. gibbosus*, *A. grandis*, *L. ligamentinus*, *L. luteolus*, and *L. ventricosus*. Five of these possess shells which are in constant demand for the manufacture of buttons, and the table of values given on page 39 shows that they are of exceptionally good quality.

7. Most of the species are richly infested wherever they occur with an interesting variety of parasites, and some of these furnish the requisite incentive for the production of pearls and baroques. Both these products are common throughout the entire basin and would undoubtedly become a valuable revenue if the mussels were properly cultivated. Pearling might not pay here now, as the pearls are quite small. It is, however, the best place the authors have ever seen from which to attack the pearl problem.

8. The most valuable species are all good breeders throughout the basin. This, taken in connection with the excellent quality of the shells they produce and the good railroad facilities everywhere available, makes this basin one of the best yet examined for the supply of glochidia to be used in artificial mussel propagation.

9. The fishes which have proved to be the most satisfactory hosts of glochidia are abundant in all three of the principal rivers of this basin. Their presence insures one of the most essential conditions necessary for the success of mussel culture.

10. The undredged portions of the Yellow River, a distance of 20 miles from Plymouth to Ober, and of the Kankakee, a distance

of at least 100 miles from Riverside to the State line, furnish an ideal breeding ground for the artificial propagation of mussels on a large scale. The swamp reservoirs keep the supply of water uniform, there is just the requisite amount of current, a suitable variety of hard bottom, plenty of lime and natural food in the water, and the region is well protected by its environment from outside molestation and disturbance. For this, as well as many other reasons, it well deserves to be protected from future dredging syndicates.

11. Dredging entirely annihilates the mussel fauna of such a basin throughout the portions operated upon, no matter how prolific and varied that fauna may have been previously. And it establishes artificial conditions, every one of which is antagonistic to any re-establishing of the fauna. The most fatal condition is the constant movement of the fine sand and silt along the bottom of the dredged channels. Until that has ceased there can be no chance for mussels to live.

Portions of the basin which were dredged 15 or 20 years ago show no signs of restocking with mussels, though there are thousands of them close at hand in the old channels.

12. The mussel fauna of the lakes is almost entirely composed of *Anodonta* and *L. luteolus*. With the exception of those found in the Fish Lakes all the lacustrine mussels were practically worthless from a commercial standpoint. The shells were either too thin and brittle or they were dwarfed below a workable size. The excellent quality of those found in the Fish Lakes, however, suggests strongly that under favorable conditions lake mussels may become as valuable as those from a river. The presence in the lake of such a flourishing colony of *Q. undulata* shows that some, at least, of the thick-shelled species can thrive in a lake, a fact experimentally proved for other species by the authors. Why not stock some of the lakes, then, along with the rivers, selecting those species best suited for such conditions?

Station H. Tippecanoe Lake, Kosciusko County, Ind.—This lake does not properly belong to the Kankakee Basin, but drains into the Tippecanoe River and thence into the Wabash. For this reason it has been placed here at the end of the list after the finishing of the Kankakee Basin. The lake lies a little north of the center of the eastern boundary of the county and covers 1.6 square miles, being the fifth largest lake in the State. It is divided into three basins—the eastern, known as James Lake; the central; and the western, called Oswego Lake. Tippecanoe River enters the eastern end of James Basin and flows through the entire length of the lake, maintaining a good current throughout the year. Grassy Creek, the outlet of a chain of four small lakes (Maybe, Sawmill, and the two Barbees) to the south, enters the middle basin near its southwest corner.

The two upper basins are remarkably free from aquatic vegetation, while Oswego basin is packed with *Potamogeton*, *Utricularia*, *Philotria*, and many species of rushes, spatter-dock, water arum, pickerel weed, cat-tails, etc.

The entire lake is surrounded by high and steep banks except in one or two places, and promontories run out into it from both sides. At the southernmost of these promontories on the east side the lake has the remarkable depth of 178 feet, making it probably the deepest fresh-water lake of its size in America. And this is true of the whole lake, the only shallow-water areas of any size being the delta brought in by the Tippecanoe River and a small area along the north side of the east shore. Furthermore, the lake is to-day more nearly in its natural state than any of the others examined. It was a genuine relief to find such a body of water unaffected by damming or draining.

Owing to its great depth, the water is always cool, even in the hottest weather, and is very clear and free from vegetable débris. The bottom is hard and marly in most places except the Oswego Basin, where it is soft black muck. The entire margin of the lake and Tippecanoe River for a mile and a half below the outlet were examined, and mussels were everywhere abundant. At Government Point, over the shallow-water area on the eastern margin already mentioned, they were especially plentiful. Here the marly bottom was softer and the mussels had dug circular cavities 2 or 3 inches deep into the marl. In the bottom of the excavation were sometimes one mussel, sometimes a whole nest of them of varying sizes. *Anodonta*, *Strophitus*, and *Lampsilis* were thus found.

This and other portions of the eastern shore were the only places where *L. glans* and *M. fabale* were found during the entire summer, with one exception for each species.

In the Tippecanoe River the sand and gravel of the swifter current and the marl of the quieter water were found thickly covered everywhere with living mussels and dead shells. *Q. undulata* was the most common species and most of the specimens were exceptionally large and plump. In several of them there was a decided breaking up of the ridges on the outside surface into pustules similar to those on *pustulosa*, making a sort of nondescript shell that was difficult to classify at first.

As would be expected, there were a few species in this fauna not found in the Kankakee Basin. These include *Micromya fabale*, *L. multiradiatus*, *T. sulcata*, and *P. phaseolus*.

The *Quadrulas* have been searched strenuously for pearls and several good ones are reported to have been found, but none of the other species contain either pearls or baroques.

DISTRIBUTION OF MUSSEL SPECIES.

Mussel species.	Stations.
Quadrula tuberculata (purple warty-back).....	1
Quadrula coccinæa.....	2
Quadrula trigona (pig-toe).....	3
Quadrula rubiginosa.....	4
Quadrula pustulosa (warty-back).....	5
Quadrula lachrymosa (maple-leaf).....	6
Quadrula metanевра (monkey-face).....	7
Quadrula undulata (three-ridge).....	8
Quadrula ebena (niggerhead).....	9
Pleurobema esopa (bullhead).....	10
Pleurobema clavata.....	11
Unio gibbosus (lady-finger, spike).....	12
Alasmidonta truncata (elk-toe).....	13
Alasmidonta calceola.....	14
Symphynota complanata (heel-splitter, hatchet-back).....	15
Symphynota costata (squaw-foot).....	16
Symphynota compressa.....	17
Anodontoides ferrussacianus subcylindraceus.....	18
Anodonta grandis.....	19
Anodonta imbecilis.....	20
Sirophitus edentulus.....	21
Obovaria ellipsis (Missouri niggerhead).....	22
Lampsilis alatus (pancake).....	23
Lampsilis glans.....	24
Lampsilis ellipsiformis.....	25
Lampsilis iris.....	26
Lampsilis subrotatus.....	27
Lampsilis rectus (black sand-shell).....	28
Lampsilis fallaciosus (slough sand-shell).....	29
Lampsilis ligamentinus (mucket).....	30
Lampsilis luteolus (fat mucket).....	31
Lampsilis ventricosus (pocketbook).....	32
Lampsilis multiradiatus.....	33
Micromya fabale.....	34
Truncella sulcata.....	35
Ptychobranchius phaseolus.....	H

COMMERCIAL VALUE OF THE SHELLS OBTAINED.

The relative values of the mussel shells from the Kankakee Basin were determined by Mr. J. F. Boepple, lately deceased, a mussel expert of wide experience and high authority, then stationed at Fairport, Iowa.

Average lots of the different species were weighed, blanks of various diameters were stamped upon the inside of the shells and counted, the number of similar blanks which could be obtained from a ton of shells was computed, and from these data, together with the quality of the pearl, the value per ton was calculated. In many instances the results of these computations were verified by sending the stamped shells to a button factory, where the blanks were actually sawed out, and their value given.

These values are expressed in the following table, each value quoted being an average from several lots of the same species. The diameter of the blanks is measured in "lines" ($=\frac{1}{40}$ of an inch), 16, 18, etc. "F." and "M." denote first and medium quality. "T." indicates that more than half of the blanks are "tips," that is, uneven in thickness and of poor quality; "t." indicates that considerably less than half are tips. The numerals "1," "2," and "3" indicate different grades of shells, including size, color, luster, etc. Thus, reading the second line, 1 ton of second quality *L. ligamentinus* shells would yield 1,119 gross of 20-line blanks, more than half of which would be "tips." The value of blanks and tips together would be \$33.57.

TABLE OF SHELL VALUES.

Locality and species.	Gross of blanks per ton of shells.							Value per ton.
	16 line.	18 line.	20 line.	24 line.	30 line.	35 line.	40 line.	
YELLOW RIVER.								
L. ligamentinus, 1.....			F. 1,009					\$60.54
L. ligamentinus, 2.....			T. 1,119					33.57
L. ventricosus, 1.....			M. 833			F. 173		50.94
L. ventricosus, 2.....				M. 588				23.52
L. luteolus.....			t. 607					12.14
Q. undulata.....			T. 573			M. 78		15.09
KANKAKEE IN INDIANA.								
L. ligamentinus, 1.....			M. 673			F. 104		38.91
L. ligamentinus, 2.....			t. 1,285					32.15
L. ventricosus, 1.....			F. 578		F. 347			64.76
L. ventricosus, 2.....			t. 1,166					29.15
Q. pustulosa, 1.....		M. 1,297						38.91
Q. pustulosa, 2.....			t. 803					32.36
Q. pustulosa, 3.....		t. 1,011						30.33
Q. coccinea, 1.....		t. 1,255						37.65
Q. coccinea, 2.....			t. 839					29.45
Q. coccinea, 3.....		T. 1,404						28.08
IROQUOIS RIVER.								
Q. rubiginosa.....		t. 1,198						35.70
Q. lachrymosa.....	t. 1,098					F. 32	F. 34	35.20
KANKAKEE IN ILLINOIS.								
L. ligamentinus, 1.....			T. 771			F. 111		39.78
L. ligamentinus, 2.....	T. 1,219	F. 406						24.37
L. ventricosus, 1.....			T. 1,190					35.70
L. ventricosus, 2.....			T. 711		F. 278			32.13
L. luteolus.....	T. 1,994							19.94
Q. pustulosa.....		t. 1,142						45.68
Q. undulata.....					F. 119			11.90

SMALL FISHES FOUND ON THE MUSSEL BEDS.

KEY TO TABLE.—I, the undredged portion of the Yellow River from Plymouth to Ober; II, the undredged portion of the Kankakee River from Riverside to the State line; III, the Iroquois River; IV, the Kankakee River in Illinois; V, the lakes.

Species.	I.	II.	III.	IV.	V.
<i>Catostomus commersonii</i>	x	x	.....	x	.....
<i>Catostomus nigricans</i>.....	.....	x	.....	.....	x
<i>Schilbeodes gyrinus</i>	x	x	.....	.....	.....
<i>Cottus icталops</i>	x	.....	.....	.....	.....
<i>Lucius lucius</i>.....	.....	x	.....	x	.....
<i>Lucius reticulatus</i>	x	x	.....	.....	.....
<i>Pimephales notatus</i>.....	.....	x	x	x	x
<i>Semotilus atromaculatus</i>	x	x	x	.....	x
<i>Abramis chrysoleucas</i>	x	.....	x	.....	.....
<i>Cirola vigilax</i>.....	.....	.....	x	.....	.....
<i>Fundulus dispar</i>.....	.....	.....	.....	.....	x
<i>Fundulus diaphanus</i>.....	.....	.....	.....	.....	x
<i>Percina caprodes</i>.....	.....	x	.....	x	.....
<i>Notropis blennioides</i>	x	x	x	x	x
<i>Notropis whiplii</i>	x	.....	x	x	x
<i>Notropis cornutus</i>.....	.....	x	x	x	x
<i>Notropis umbratilis atripes</i>.....	.....	.....	x	x	.....
<i>Notropis heterodon</i>	x	x	.....	.....	x
<i>Ericymba buccata</i>.....	.....	.....	x	.....	.....
<i>Phenacobius mirabilis</i>.....	.....	.....	x	.....	.....
<i>Hybopsis amblopius</i>.....	.....	.....	x	.....	.....
<i>Hybopsis kentuckiensis</i>.....	.....	x	.....	x	.....
<i>Labidesthes sicculus</i>	x	x	x	x	x
<i>Pomoxis annularis</i>.....	.....	.....	x	.....	.....
<i>Perca flavescens</i>	x	.....	.....	.....	x
<i>Microperca punctulata</i>	x	.....	.....	.....	.....
<i>Micropterus dolomieu</i>.....	.....	x	x	x	.....
<i>Micropterus salmoides</i>.....	.....	x	x	.....	x
<i>Chaenobryttus gulosus</i>	x	.....	.....	.....	x
<i>Ambloplites rupestris</i>	x	.....	.....	x	x
<i>Lepomis pallidus</i>.....	.....	x	.....	.....	x
<i>Eupomotis gibbosus</i>.....	.....	x	.....	.....	x
<i>Hadropterus phoxocephalus</i>.....	.....	.....	x	x	.....
<i>Hadropterus aspro</i>	x	x	x	x	.....
<i>Boleosoma nigrum</i>	x	x	x	x	x
<i>Etheostoma cœruleum</i>.....	.....	.....	x	x	.....
<i>Etheostoma iowæ</i>	x	x	.....	.....	x
<i>Maxostoma aureolum</i>.....	.....	x	.....	.....	.....

DISCUSSION OF MUSSEL SPECIES.

1. *Quadrula tuberculata* (*Rafinesque*). *Purple warty-back*.—This mussel, although it attains considerable size and weight, rivaling or exceeding the common warty-back (*Q. pustulosa*) in this respect, is of no value whatever to the button industry on account of the dull purple nacre. It nowhere forms large beds and wherever found usually constitutes a small per cent of the mussel fauna.

Of all the heavy-shelled species examined anywhere, however, this is the most liable to infection by distomids, perhaps on account of its immense inhalent aperture, which allows a larger and greater variety of objects to enter than is the case of other strong-shelled mussels. This makes it among the greatest producers of dorsal baroques and, generally speaking, it is the species most likely to produce genuine pearls. The baroques may be either purple or pale, almost white, and generally are rather lusterless and of low value. The pearls are always purple, sometimes almost black, and, when formed near the iridescent tip of the mussel, may have a very good luster. The clammer cleans all shells he obtains, whether valuable for buttons or not, in the hope of finding pearls.

Viewed in this light, *Q. tuberculata* is not altogether unimportant as a commercial species. Its shell is the package that may contain a prize—usually a worthless trinket, but always arousing expectancy. *Q. tuberculata* adds more markedly than any other species to the size, but hardly to the value, of the clammer's pile of slugs or "chicken feed" which furnishes, in some cases a small, in others a considerable addition to the revenue derived from the sale of his shells, and it is indeed one of the strongest incentives to persistence in the clammer's trade, as it furnishes not so much in actual cash as the element of luck or chance, and keeps him in constant expectancy of a possible great discovery.

Accordingly, it is not improbable that clamming operations the country over depend in no inconsiderable degree on the presence of this and similar species, not directly useful of themselves, but appealing to the instincts of the treasure seeker, the nomad, and adventurer, who can not endure the monotony of a steady, uneventful trade and who require some special incentive or stimulus to persistency.

This species is of value as furnishing in almost any part of the country readily available material for the study of the natural causes and phenomena of pearl production and will probably prove in the end one of the gateways through which our knowledge in that direction, and its practical applications, will come.

We did not find this species in the headwaters of the Kankakee or Yellow Rivers, though it is common in the Tippecanoe, not far distant. The first found in the Kankakee was at Momence, Ill., and in the lower stretches of the river. It was also found in the Iroquois.

The systematic position of this species is doubtful. We have never found it gravid, and it is, apparently, but rarely found in that condition. It is reported to bear glochidia in only the outer gills. When ground and polished for ornament, this is one of the most attractive of shells.

2. *Quadrula ebena* (Lea). *Niggerhead*.—This, the most valuable of button shells, does not occur within the Kankakee Basin, though it is fairly common in parts of the Illinois River, below. We found one specimen of what appeared to be this shell at Tippecanoe Lake, where its occurrence is difficult to account for.

3. *Quadrula coccinea* (Conrad).—*Q. coccinea* is, at its best, a very good, if not excellent, button shell. The assemblage of forms that pass under this name exhibit so much variation, however, that no general statement can be made concerning it. It has no trade name, probably because it has not been found in great quantities in regions exploited by the button industry and partly because of its lack of distinctive characters. But it is found throughout the length of the Kankakee and Yellow River systems wherever shells thrive at all, being represented by specimens in 22 of the 35 river stations

investigated. It occurs occasionally in lakes, but is essentially a river shell. A few were found in Tippecanoe Lake.

In the upper parts of the Yellow River, from Plymouth down to Ober, and in places in the upper Kankakee this species reaches great perfection and is represented by a well-defined type not easily confused with any other species—a large flat shell of pretty uniform thickness and very good luster. The majority of the shells of the upper part of the river are of a delicate pink color, very pleasing to the ordinary eye, but not to the maker of buttons. Farther down stream the majority are white-nacred and serviceable in the commercial sense. We were unable to obtain any gravid specimens of this flat, highly characteristic form. *Q. coccinea* was fairly common in the clammer's pile at Momence.

In some of the lower parts of the Kankakee system, and especially in the Iroquois River, what appears to be this species loses its distinctive character and is represented by a much more inflated form, closely approaching *Quadrula solida* or some other member of the perplexing *obliqua-trigona-plena-solida* group. A gravid specimen of this inflated form was obtained in the Iroquois River. Only the outer gills contained the glochidia. These filled the entire gill, which was padlike and white in color. According to Simpson's classification this would place it in the genus *Pleurobema*, but more examples are desired and the whole subject requires investigation. Dr. A. E. Ortmann is of the opinion that *Q. coccinea* is identical with *Q. obliqua*, which usually bears its glochidia in only two gills and which he considers a *Pleurobema*. All the examples of *Q. coccinea* we have ever seen, however, even the inflated ones, have lacked the peculiar sulcus that is to be found in *Q. obliqua*.

4. *Quadrula trigona* (Lea). *Pig-toe*.—This species is one of the staple button shells. Its size is usually rather small, and a furrow on the valve makes it difficult to cut to advantage, but its excellent luster and whiteness compensate to some extent for its deficiencies and it is excellent for small buttons. Its occurrence in the Kankakee area is exceptional; one was found in the Iroquois at L'Erable and one in that stream 3 miles above its mouth. Another was found in the Kankakee at Wilmington. These are not exactly typical shells. It is somewhat surprising that it is not more common, as it could easily come up from the Illinois River.

In the upper Mississippi, where the species is abundant, it is very constant in form, and well marked from any other species, but outside of this range it is quite variable in form. It is very frequently infested by a distomid which forms cysts in the mantle, and it occasionally produces beautiful pearls.

5. *Quadrula rubiginosa* (Lea).—This shell is quite similar to *Q. coccinea*, from which it is somewhat difficult to separate it. It

is usually a smaller shell and has a more distinct posterior ridge, which is the chief distinguishing characteristic. The nacre is never pink, but may in rare instances have a yellowish cast. The species has about the same value for buttons as *Q. coccinea*. In the button makers' category it would be classed with the pig-toe group, but it has received no regular trade name.

Q. rubiginosa was found almost the entire length of the Yellow and Kankakee Basins, but was more common in the lower river. It was common in the clammer's shell pile at Momence and in the Iroquois. It is one of the few *Quadrulas* found fairly common in the lakes. We found it in both Tippecanoe and Koontz Lakes. In lakes it is represented by a peculiar dwarfed form with a satiny epidermis. It was difficult to distinguish between the peculiar inflated form found at L'Ereble and *trigona*. Some of these were gravid, all four gills being filled, and of a reddish color. The flesh of some of the examples was white, of others reddish. Distomid cysts were very abundant in the margins of the mantle.

6. *Quadrula pustulosa* (Lea). *Warty-back*.—This is a well-known shell among the clammers and button cutters. It is exceedingly variable, sometimes being small and much inflated, and at other places flattish. In some localities it is exceedingly rough and warty and in other places almost smooth. It therefore varies considerably in value, the flatter shells being of more value than the inflated and the smooth better than the rough. In the Kankakee Basin this species has about the same distribution as *Q. rubiginosa*, but is never found in lakes, and is more common in the lower stretches of the river. The examples obtained at Nickelplate were unusually flattish; those about Momence had some of the tubercles developed into long ribs elongate along the lines of growth. It was common in the clammer's pile at Momence and at the pearler's camp below Momence. It was also found in the Iroquois at Watseka and L'Ereble.

7. *Quadrula lachrymosa* (Lea). *Maple-leaf*.—This is a well-known shell among button manufacturers, hardly so much on account of its excellence as of the fact that it occurs in considerable abundance in regions where clamming is carried on and the shells can be made good use of. In quality they are about the same as *Q. pustulosa*, the warty-back, but the sulcus or groove along the middle of the shell prevents it from being used to so good an advantage.

In the Kankakee Basin this species is found only in the lower stretches of the Kankakee River and in the Iroquois, and then only in small numbers. At L'Ereble on the Iroquois (Aug. 21) they were beginning to become gravid.

8. *Quadrula metanevra* (Rafinesque). *Monkey-face*.—This species, which has about the same commercial value as the preceding, was

found only in the lower stretches of the Kankakee. The first we saw were in the clammer's pile at Momence, where it was fairly common. A few were found in the mouth of the Kankakee.

9. *Quadrula undulata* (Barnes). *Three-ridge*.—Two closely related shells, *Q. undulata* and *Q. plicata*, are known to the shell trade as "three-ridge" and "blue-point," both names being applied indiscriminately to either species. The extreme forms of these two species are well marked and easily recognizable, and where this is the case it is better to apply the term "three-ridge" to *Q. undulata* and "blue-point" to the other shell. Generally, one does not find well-marked examples of both species in the same stream; where the well-marked flatter form (*Q. undulata*) is common, the fuller form (*Q. plicata*) is usually, if not always, absent. All the shells in the Feeder Canal, at Fort Wayne, Ind., seem to be *Q. undulata*, and all noted from the Illinois River seem to be *Q. plicata*. The shells of White River, Ind., seem to be intermediate.

Q. plicata is a fairly valuable button shell and is usually regarded among pearl hunters as a fruitful source of pearls. *Q. undulata*, on account of its thinness, is not quite so valuable as *plicata*. It is a variable shell and differs considerably in value, according to which of its many forms is encountered. The *Q. undulata* of the Kankakee is of low value on account of its roughness and the great depth of its furrows, which interfere with cutting and polishing. It was found abundantly and quite large in Fish Lake, as well as throughout the course of the Yellow and Kankakee Rivers, where it was one of the most widely distributed shells. It was fairly common in the Iroquois as well as in the Yellow and Kankakee and was found in Mazon Creek near Gardiner, Ill. In the old Kankakee Channel at the Nickel Plate Railroad bridge, also at Davis, Ind., and at Kouts and Burton's camp it was the most abundant shell. At Peterson's camp we found some with a yellow epidermis, and at Tippecanoe Lake (July 28) we obtained three gravid examples.

10. *Pleurobema asopa* (Green). *Bullhead*.—The bullhead is a well-known shell among button manufacturers. Its quality and value differ considerably in different rivers, but it is always a rather inferior shell on account of its brittleness, and in some of the southern rivers it is so hard and flinty that it breaks the teeth out of the saws and the button cutters do not attempt to cut it at all. Among the clammers of the Cumberland it is known as the "clear profit," as the clammer is the only one who gets anything out of it.

In the Kankakee this is a very rare shell. The only ones we saw during the entire trip were three in the clammer's pile at Momence and one at Water Valley.

11. *Pleurobema clava* (Lamarck).—This is a handsome shell, too small to be of any use in the manufacture of buttons. It does not

occur at all in the Kankakee Basin, but is common in the Tippecanoe River. We found a few in Tippecanoe Lake.

12. *Unio gibbosus* (Barnes). *Lady-finger, spike*.—*Unio gibbosus* is a common, widely distributed shell, found in all sorts of situations; being one of the common shells of lakes, as well as rivers. The nacre is usually a rather dull purple, which unfits it for the button industry. A white-nacred form is not altogether uncommon. It has a soft satiny luster and can be used commercially. The shells vary in form as well as in color, some being short and humped, more or less closely resembling *P. phaseolus*, and others long and sharp, and at times difficult to separate from *L. rectus*.

U. gibbosus was one of the most widely distributed shells within the Kankakee Basin, being found at nearly all the stations in the Yellow and Kankakee as well as in the Iroquois and in Fish Lake. It was also found in Tippecanoe Lake. It formed most of the culls in the pearler's pile at Momence.

Marginal cysts caused by distomids, dorsal baroques, and small round pearls are common in this species.

One white-nacred shell was found at Plymouth, but as a rule all the shells of the upper parts of the river were deep purple. At Momence these shells exhibited peculiar and interesting phenomena. They seemed to be passing here from the purple-nacred form to the white, and one had all intermediate stages; many were of a beautiful rosy hue throughout, others shaded from blue about the margin through rosy to pale rose. Investigations on other streams have shown similar peculiarities of the color distribution in this shell.

It is worthy of note that both *U. gibbosus* and *L. rectus* become more nearly, or a greater per cent, white-nacred as we go down the Kankakee system, and a careful study here may throw light on the cause of the color in these shells. It may be that the softer waters and amount of humic acid in the upper waters may favor the purplish deposit, while the colorless forms which occur shortly after the limestone river bed is reached may be favored by an excess or abundance of lime.

13. *Alasmidonta truncata* (B.H. Wright). *Elk-toe*.—*Alasmidonta truncata* is a handsome, beautifully rayed shell, attractive to the collector, but too thin to be of any service in the manufacture of buttons. It is not common in the Kankakee Basin. There was a fair number of shells in the clammer's shell pile at Momence and a few were collected at the mouth of the Iroquois River.

14. *Alasmidonta calceola* (Lea).—This shell is too small to have any commercial value. It is a shell of small streams, and is occasionally found in lakes. It was quite common in the Yellow River at Plymouth and some examples there reached a very large size for the species. It was found at Forked Creek, near Wilmington, and was there noted as becoming gravid (Aug. 27).

15. *Symphynota complanata* (Barnes). *Heel-splitter, hatchet-back*.—At its very best, this species, offering a broad, flat expanse of satiny white nacre, is an excellent button shell, furnishing more blanks per shell than any other species. In many cases, however, it is too thin for use. This species is found only in the lower half of the river; the first seen were at Hebron Bridge, where we found three. In the clammer's shell pile at Momence it was common and large. It was also found at the mouth of the Iroquois, some fine ones were seen at Kankakee, Ill., and a few at Wilmington. Small ones, cleaned out by muskrats, were found in Mazon Creek.

16. *Symphynota costata* (Rafinesque). *Squaw-foot*.—This species is rarely used for buttons, the nacre being too yellow, and frequently too thin. It is well distributed throughout both the Yellow and Kankakee Rivers, and is fairly common at Plymouth below the dam; 26 were obtained there in a shell pile left by pearlers. In the clammer's pile at Momence it was common and large, although not so immense and thick as found in some rivers. It was also found in the Iroquois River at L'Erable. This species in some rivers is especially subject to distomid infection and occasionally bears pearls.

17. *Symphynota compressa* (Lea).—Compared with the *Symphynotas* just mentioned, this is a small shell. It is always too thin to have any commercial value. It was found in the Yellow River from Plymouth just below the dam to the Zinc Bridge at Ober, in Potato Creek at Walkerton, in Yellowbanks Creek, and the Kankakee at Davis. It is a species belonging to small streams. It was beginning to be gravid at Plymouth September 20, with the embryos orange red, in the outer gills of the parent.

18. *Anodontoides ferussacianus* (Lea).—This is a small thin shell of no economic importance. Like *Symphynota compressa* it is usually confined to small streams, and occasionally lakes. It was rather common at Plymouth; one was found dead in Lake of the Woods, and a few in Yellowbanks Creek. The form found in this area appears to be the subspecies *subcylindraceus*.

19. *Anodonta grandis* (Say).—This species, although it reaches large size, is usually thin-shelled, and only exceptionally attains sufficient thickness to have any commercial value. It was found at the majority of stations throughout the Yellow and Kankakee Rivers, and in the Iroquois. In the lakes (except Fish Lakes, where the river form occurred) this species was represented by a dwarfed somewhat inflated form, the variety *footiana*. Particular attention was paid to the shells above the dam at Plymouth, where the water had been pond-like or lake-like for many years, to observe whether the shells were beginning to approximate in appearance the dwarfed form of the neighboring lakes; but they were all the large, elongate river form.

Anodontas are always more subject to attacks of parasites than any other of our fresh-water mussels, and those of the Kankakee Basin were no exceptions to this rule. Common among the parasites is a distomid which usually is found on the surface of the mantle in the dorsal region of the mussel next to the hinge and causing the nacre to become brick red in color. As this distomid has never received a scientific name, the adult form being up to the present unknown, in our reference to it we have spoken of this form as the distomid of Osborn, after its discoverer. Others of the infected shells were of a dark chocolate color and the distomids, which were plentiful, were smaller in size and probably belonged to a different species.

Other parasites frequently found were *Aspidogaster conchicola* in the pericardial cavity, *Cotylaspis insignis* in the axils of the gills, and numerous species of *Atax* inhabiting the branchial cavity. All the *Anodontas* found in the streams corresponded pretty closely to one type, in no case departing so far as to raise any doubts as to identity; in the lakes, however, it was different; each lake seemed to have a more or less pronounced type of its own. The *Anodontas* of Twin Lakes resemble those of Bass Lake and Cedar Lake pretty closely, but those of Lake of the Woods differ considerably, being larger and thinner. At Tippecanoe Lake, where the dead *Anodonta* shells were so abundant that in places we would frequently find them nested sometimes three in a nest, they presented a different, more inflated type. They very closely, indeed, approached the form known as *Anodonta corpulenta*, generally considered a distinct species from *grandis*. We also found two broken dead shells at Tippecanoe Lake which very closely resembled *A. suborbiculata*, and may, indeed, have been that species; more material would be desirable before deciding.

The *Anodontas* from one of the Twin Lakes, as has already been remarked, were infected in great numbers by a distomid forming clear spherical cysts in the margin of the mantle. Sporocysts and peculiar large white areas like blisters were common on the *Anodontas* of Tippecanoe Lake.

20. *Anodonta imbecillis* (Say).—This dainty, fragile *Anodonta* is of no commercial value. It is a shell of ponds and small streams. The only shell found in Millpond Lake of the Twin Lakes was one example of this species. In the Yellow River at Plymouth below the dam it was fairly common. On July 14 several were obtained here, all gravid, the entire outer gills being thick and padlike, and, when the gills were fully ripe, dark brown. The glochidia have a brown shell, shield-shaped in profile, and have long, coiled threads. One found in Tippecanoe Lake was unusually elongate. A large one was found in the Yellow River at Zinc Bridge, another was found in the outlet of Fish Lakes, and a gravid example was found in the Kankakee bed at Davis (Aug. 9).

21. *Strophitus edentulus* (Say).—This is an exceedingly variable shell, considerably resembling an *Anodonta*, and in none of its forms of any commercial importance. It is found in a great variety of situations, in lakes and ponds and both in rather small creeks and large rivers. It is never found in great abundance anywhere. In the Kankakee Basin we found only a few, but these were widely distributed. A dead shell was found at the first station made, on the banks of the Yellow River at Bremen. Some were found at the pearler's pile below the dam at Plymouth, some in Tippecanoe Lake, dwarfed and mostly dead, one valve in the old bed of the Kankakee at Davis, Ind., two at Momence, one at Custer Park with distomid cysts, some at Wilmington, and a gravid example in Forked Creek (Aug. 27). In Mazon Creek at Gardiner, Ill., occurred a brightly rayed form, *pavonia*.

The question of rays appears to be closely related to clearness of water; in turbid streams mussels are usually dull colored, while in clear streams they are usually more brightly rayed.

22. *Ptychobranhus phaseolus* (Hildreth). *Kidney-shell*.—This species, which at its best is a very good button shell, having a white nacre of soft satiny luster, was found only in Tippecanoe Lake. It is also fairly common in the Tippecanoe River, but was not found in the Kankakee River or any of its tributaries.

23. *Obovaria ellipsis* (Lea). *Missouri niggerhead*.—This is a first-class button shell and well known among clammers and button manufacturers. It is of rare occurrence in the Kankakee. We saw it only at the clammer's shell pile at Momence.

24. *Lampsilis alatus* (Say). *Pancake*.—This shell, on account of its thinness and purple color, is of no value to the button trade. It is rare in the Kankakee. We found only one decayed dead shell above Nickel Plate crossing and another dead shell at Custer Park.

25. *Lampsilis glans* (Lea).—This is a shell of lakes and small streams. Its small size and purple color prevent its being of any commercial value. *L. glans* was found only at Plymouth below the dam and in Tippecanoe Lake. At Plymouth it was found gravid (July 27). The glochidia were in a kidney-shaped mass in the posterior part of the outer gill, and are apron-shaped in outline, as is usual in *Lampsilis*. The edge of the gravid portion of the gill has a deposition of black pigment, as in *L. ventricosus* and related forms.

26. *Lampsilis ellipsiformis* (Conrad).—This small shell (too small to be of any value commercially) was found only in the lower part of the river and in the tributary streams. The first we saw were in the clammer's pile at Momence, where it was fairly common. We got 20 there. It was also common in Forked Creek near Wilmington, where all but one were gravid (Aug. 27). Shells opened by muskrats were quite common in Mazon Creek near Gardiner, Ill.

27. *Lampsilis iris* (Lea).—This very pretty shell is of no commercial importance on account of its small size. It was fairly common and reached an unusual size in the stretch of Yellow River from Plymouth to below Burr Oak. Two were obtained in Tippecanoe Lake, one of them gravid (July 28). A gravid one was obtained above Zinc Bridge (Aug. 3). One was found dead in the Kankakee at Davis, Ind.

28. *Lampsilis subrostratus* (Say).—This shell, like *L. iris*, which it in some respects resembles, is too small to have any commercial value. Although occasionally occurring in rivers, it is essentially a lake or slough shell. All we obtained within the Kankakee Basin were found in lakes. Four were obtained in Twin Lakes (July 2), of which one was gravid, the young being contained in a kidney or bean shaped mass in the posterior part of the outer gill, the mass being deeply ribbed, dusky near the margin, and white along the very margin. Some were obtained in Tippecanoe Lake and some in Fish Lake, where it was fairly common. Fragments were found at Round Lake, a small lake near Knox, Ind.

29. *Lampsilis rectus* (Lamarck). *Black sand-shell*.—This species, when it has white nacre, as it sometimes does, is an excellent shell for both buttons and knife handles, approaching in value the yellow sand shell. In some rivers the majority of shells are white, in others colored. This shell is rare in Yellow River. Some were found at the pearler's pile below the dam at Plymouth, Ind., and in 1906 a few were found at Knox. A few were found also in the Kankakee above Nickel Plate crossing, some at Davis, and near Kouts and Hebron Bridge. It was not common in the clammer's pile at Momence, and some young shells were found at Wilmington. It was also in the Iroquois at L'Erable and at the mouth.

The shells of the upper portion of the Kankakee were all colored, some of them a deep purple. Lower down this color faded to a pink. In a pearler's pile at Momence we found the first white-nacred one. The color of this shell seems to be about the same as that of *U. gibbosus* and seems to respond to the same conditions. It is not, however, distributed the same in the shell, but seems to be most marked in the umbonal cavity or teeth. Shells of *L. rectus* which are perfectly white otherwise often are pink or amethystine purple on the teeth or umbonal cavity. The rosy hue of *Q. coccinea* seems to be of a somewhat different nature and notably differs as one proceeds down the river.

30. *Lampsilis fallaciosus* (Smith). *Slough sand-shell*.—This species, valuable for small buttons, is rare in the Kankakee Basin. The only ones found were in the Iroquois River at L'Erable. Most of these contained distomid cysts in the margin of the mantle.

31. *Lampsilis ligamentinus* (Lamarck). *Mucket*.—The mucket is one of the best known of the button shells, and probably more tons of

this species are used in the button-making industry than any other single species. It is not so good a shell as the niggerhead and a few others, but is one of the commonest and most widely distributed and the material is very good.

This species is not found in lakes and is not common in the smaller streams. It occurs throughout the length of the Yellow and Kankakee Rivers, but is rather scattered in the Yellow and upper Kankakee. In the lower Kankakee it is found at every station, and began markedly increasing in numbers about Sheldon, Ind. It formed the main mass of shells in the pearler's pile at Momence, Ill., and fine examples were seen in a pile of shells left by a pearler below Momence. It was also found in considerable numbers at Custer Park, Wilmington, and at the mouth of the Kankakee. In the Iroquois River it was found at L'Erable and near the mouth. A large number were gravid at Momence, August 23.

32. *Lampsilis luteolus* (Lamarck). *Fat mucket*.—*Lampsilis luteolus* is a quite variable shell. It is inferior to the mucket on account of being smaller and more cylindrical, and the greater curvature of the valves makes it harder to work up satisfactorily. Such large fine specimens as occur in some rivers, e. g., the St. Joseph River at Fort Wayne, Ind., would make excellent buttons, but these are not common.

It is one of the most abundant and widely distributed shells and is usually found in lakes and in small rivers. In the Kankakee Basin it occurred at almost every station, in lakes, rivers, and streams alike.

In parts of the Kankakee Basin this species is of especial interest, as many of the examples found are infested with a parasite which leads to the formation of perfect spherical pearls. The pearls are all of small size and on this account not of enough value to justify working them. They are, however, of great scientific interest, as they offer unusual opportunities for the study of pearl formation. In places a single mussel will contain as many as a half dozen or more pearls, and the average will run more than a pearl per mussel. A lot of material was collected which furnished fine sections showing the epithelial sac in which pearls are formed. It also indicated the cause of pearl formation to be probably a small distomid which formed cysts in the mantle of the mussels. It was greatly hoped that opportunities would be given to follow up this subject further, but this hope has not been realized. This field offers excellent opportunities to the investigator.

33. *Lampsilis multiradiatus* (Lea).—This very pretty, much-rayed shell resembles *Lampsilis ventricosus* in general form, but is too small and thin to be of any service in the manufacture of buttons. It was not found in the Kankakee Basin at all, but was not rare in Tippecanoe Lake and River.

34. *Lampsilis ventricosus* (Barnes). *Pocketbook*.—*Lampsilis ventricosus* is a widely distributed and exceedingly variable shell, occurring in both lakes and streams. Its commercial value varies greatly in different situations. In some locations it is too thin to be of any value whatever. The nacre is usually white and of good luster, though pink or reddish ones are occasionally found.

In the Yellow and Kankakee Rivers this species reaches unusual size and thickness; indeed, in 1906 was obtained, in the Yellow River near Plymouth, what at that time was the record shell for this species, exceeding in size any in the National Museum collection. In the active collecting that has been going on since, it is possible, of course, that larger shells have been found. It was fairly abundant in the Yellow River below Plymouth and became more common in the Kankakee, until below Burton's camp it was present at every station. We did not find it in the Iroquois or in any of the lakes within the Kankakee Basin, though it is fairly common in Lake Maxinkuckee. The form found in the Yellow and Kankakee is the large oval form, either plain or, in some cases, beautifully rayed (*occidens*); near the city of Kankakee, Ill., however, we obtained some specimens with a pretty well-marked posterior ridge (*subovatus*). It was represented by numerous large shells in the clammer's camp at Momence. They were found becoming gravid at Plymouth July 15, spawning in the Tippecanoe River July 28, gravid at Zinc Bridge August 4, and at Custer Park August 27. In Yellow River this species bears numerous small dorsal baroques.

35. *Micromya fabale* (Lea).—This dainty little shell was found at Tippecanoe Lake and is fairly common in the Tippecanoe River, but was not found in the Kankakee Basin. It has no commercial value.

36. *Truncilla sulcata* (Lea).—This little shell was found at Tippecanoe Lake, but was absent from the Kankakee Basin. It is interesting as the representative of the most highly differentiated genus of mussels, a genus mostly southern in distribution. It has no commercial value.

ECONOMIC CONSIDERATIONS.

Although the upper portion of the Yellow River is fairly well populated with mussels, it is a small stream and the distance is short, so that commercial operations would soon deplete it. It is, however, a region of especially large and fine *L. ventricosus*. Many of the finest shells of this part of the river have been killed by pearl-ers, and to gather up and market the cleaned shells might be worth while to some resident of the vicinity. It would hardly be profitable for a professional clammer to construct gear and work this region. Whether it would be a good plan to procure spawn of the remarkably fine *ventricosus* found here for planting elsewhere can not be deter-

mined until it is known that their excellence was hereditary rather than produced by exceptionally favorable conditions.

The dredged portion of the Yellow River, extending from Ober to its mouth, and the dredged part of the Kankakee, so far as the bottom is still unsettled, extending from its source to below the Hebron Bridge, would be hardly workable, for though there is a fair number of mussels, these are all in the old bed, which lies now on this, now on that, side of the main navigable channel in the form of crescent-shaped bayous, in many cases extending miles back from the present (artificial) channel. Even in this new channel clamming operations would be neither wise nor profitable until the mussel fauna becomes more firmly established. The clammers at Momence worked upstream as far as they found it profitable, and were getting ready to leave for more promising regions at the time of our visit.

The most profitable region commercially is the stretch of river between Momence and Wilmington, Ill., and this is now (1911) being exploited. A shell dealer of Muscatine (Mr. W. S. Berry) furnished the information (October, 1911) that between Waldron and the Kankakee Dam ($5\frac{1}{2}$ miles by water) he had obtained nine carloads of shells, and three below Kankakee, 90 per cent of which were muckets, with a few razorbacks, three-ridges, and big pink pocket-books. The three-ridges were of little value on account of the deep furrows between the ridges. Below the Kankakee Bridge 200 tons were obtained within 1,000 yards by means of the fork.

II

A N A

RIVER BASIN AND ILLINOIS INVESTIGATION

09

OF FISHERIES

is shown thus: ○

le

ILLINOIS

LAKE MICHIGAN

INDIANA

KANKAKEE RIVER BASIN

INDIANA AND ILLINOIS

PEARL MUSSEL INVESTIGATION

1909

U. S. BUREAU OF FISHERIES

Collecting stations shown thus: ○

Scale

0 4 8 12 16 MILES

THE NORTH

1945
CAB 100
DEPARTMENT OF COMMERCE

BUREAU OF FISHERIES

HUGH M. SMITH, Commissioner

THE MUSSELS OF THE CUMBERLAND RIVER AND ITS TRIBUTARIES

By CHARLES B. WILSON and H. WALTON CLARK

Bureau of Fisheries Document No. 781

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

DEPARTMENT OF COMMERCE

BUREAU OF FISHERIES

HUGH M. SMITH, Commissioner

THE MUSSELS OF THE CUMBERLAND RIVER
AND ITS TRIBUTARIES

By CHARLES B. WILSON and H. WALTON CLARK

Bureau of Fisheries Document No. 781

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

THE MUSSELS OF THE CUMBERLAND RIVER AND ITS TRIBUTARIES

By CHARLES B. WILSON and H. WALTON CLARK

Bureau of Fisheries Document No. 781

CONTENTS.

	Page.
Introductory.....	3
The Cumberland River.....	4
General description.....	4
Physiography.....	5
Comparison with the Maumee and Kankakee Rivers.....	6
Characteristics of the mussel fauna.....	6
Geographical distribution.....	7
Contrast between the river above and below the falls.....	7
Faunistic divisions below the falls.....	8
First section—Cumberland Falls to Celina, Tenn.....	8
Second section—Celina to Nashville, Tenn.....	9
Third section—Nashville to Dover, Tenn.....	11
Fourth section—Dover, Tenn., to Smithland, Ky.....	12
Tabular statement of distribution of species.....	13
Relative abundance of different species.....	20
Summary of distribution.....	21
Notes on various stations.....	23
Upper river and its tributaries.....	23
River below the falls and its tributaries.....	24
Character of water of the Cumberland River.....	38
Commercial value of Cumberland shells.....	39
Breeding season of Cumberland mussels.....	41
Pearls and pearling.....	42
Discussion of mussel species.....	45

FIG. 1.—TRUNCILLA WALKERI, NEW SPECIES.

Upper figures, females; lower figures, males.

FIG. 2.—THE GREAT FALLS OF THE CUMBERLAND, 85 FEET HIGH, A BARRIER TO THE ASCENT OF FISH AND MUSSELS.

THE MUSSELS OF THE CUMBERLAND RIVER AND ITS TRIBUTARIES.

By CHARLES B. WILSON and H. WALTON CLARK.

INTRODUCTORY.

The purpose of this investigation was to ascertain the distribution, relative abundance, and habits of the various mussel species living in the river and its tributaries, and to make an intelligent appraisal of the mussel resources of the river from a commercial standpoint.

The party was under the supervision of Dr. Robert E. Coker, director of the United States Biological Station at Fairport, Iowa, who furnished general instructions to be used by all field parties engaged in mussel investigations. In addition to the authors, the party included the late Mr. J. F. Boepple, the shell expert of the Fairport station, and Mr. Ernest Danglade, now scientific assistant in the Bureau of Fisheries, each of whom contributed fully as much as either of the authors to the success of the investigations.

The work was begun about May 10 near the mouth of the Cumberland River, and conducted thence upstream through the State of Kentucky and into Tennessee as far as Clarksville. During the previous year it had been carried from Pineville, Ky., to Celina, Tenn. Accordingly, it was now resumed at Celina, where the Obey River, a tributary of the Cumberland from the south, was investigated. Thence the work continued slowly down the Cumberland itself.

From Jellico, Tenn., and Williamsburg, Savoy, Corbin, Livingston, and Barbourville, Ky., as centers, the upper portions of the Cumberland River, the Clear Fork, Big South Fork, Laurel and Rock Castle Rivers were examined. Neither the main river nor any of these tributaries is navigable for a boat, so that the investigations had to be conducted by team, driving along the banks or visiting convenient fords and shallows.

The party then drove by team from Williamsburg to the Cumberland Falls, proceeded again by team from the falls to Parkers Lake station, and thence by rail to Burnside, Ky. This is the head of steamboat navigation on the river, and here a small boat was constructed in which to proceed down the main river, thus completing the survey of the entire river.

During all these investigations the methods followed by the two divisions of the party were made as different as possible in order to cover the field more thoroughly. Mr. Boepple used the crowfoot dredge, tongs, and mussel rake, and worked the deeper portions of the river. The rest of the party covered the shallower water, riffles, sand bars, and smaller tributaries, and, of course, obtained the mussels by wading.

A careful record was kept of the temperature of the water at the various stations, and as often as seemed advisable samples were taken for subsequent analysis.

In addition to making original observations the party secured as much information as could be obtained from local fishermen and clammers with reference to the location of the mussel beds, past and present operations upon them, and the finding of pearls and baroques.

For such information we are particularly indebted to the following persons: Mr. Walter, of Dover, Tenn., an extensive dealer in shells; Mr. Samuel Dabbs, a clammer of Dover; Mr. M. K. Clark, proprietor of the blank factory at Clarksville, Tenn.; and Mr. Cicero Harris, a boatman who had floated down from the upper part of the river fishing and clamming, and who knew the river more intimately than anyone else it was our fortune to meet. To these gentlemen as well as to many others who extended favors and assistance whenever opportunity offered, our sincere thanks are tendered.

As fast as they were obtained, the samples of water and specimens were shipped to the biological station at Fairport. The shells were subsequently identified and studied by the principal author with the results herein set forth.

THE CUMBERLAND RIVER.

GENERAL DESCRIPTION.

The main branch of the Cumberland River rises among the foothills of the Pine Mountains, in the southeastern corner of Kentucky. It flows southwest along the eastern side of the mountains, receiving many tributaries. Near Pineville it turns at a right angle and flows northwest through a wide gap in the mountains, and then swings to the south, its general course being that of a half circle, convex toward the north. At State Line, in Monroe County, it crosses into Tennessee, its general course in the latter State being also that of a half circle but convex toward the south.

At Tobaccoport, in Stewart County, it crosses the State line back into Kentucky, flows northwest and enters the Ohio at Smithland, only 12 miles above the mouth of the Tennessee River at Paducah. The distance from the source to the mouth in a straight line is about 325 miles, but the river is so extremely crooked that its total length

is nearly 750 miles. Its principal tributaries are the Laurel and Rockcastle Rivers from the north, which join it within a few miles of each other at the southwestern corner of Laurel County, Ky.; the Big South Fork, whose mouth is at Burnside, Ky.; the Obey River from the south at Celina, Tenn.; Roaring River, from the south, at Gainesboro Landing, Tenn.; Caney Fork, from the south, at Carthage, Tenn.; Stones River, from the south, 15 miles above Nashville, Tenn.; Harpeth River, from the south, at Pardue, Tenn.; and the Red River, from the north, at Clarksville, Tenn.

The Cumberland is navigable during high water from its mouth to Burnside, Ky., a distance of 525 miles, and a system of locks is in process of construction which will make navigation possible during the entire year.

PHYSIOGRAPHY.

The area drained by the river and its tributaries is about 25,000 square miles, and embraces mountain ranges, a continental plateau (the Cumberland Plateau), and lowlands. Along the upper reaches of the river among the Cumberland and Pine Mountains in the eastern portion of the plateau the rocks are largely Cambrian sandstone; through the remainder of the plateau and the long stretch of lowlands they are almost universally limestone. The dividing line is at Cumberland Falls in the western part of Whitley County, Ky., where the river plunges over a wall 85 feet in height. From the source to the falls the river has nowhere cut its channel very deep; below the falls, and especially through the plateau, the banks are lined almost continuously with high limestone cliffs, filled with caves and roughly weathered. The faces of these cliffs furnish abundant evidence of past upheavals in numerous faults and contortions of the strata, as well as in repeated anticlinal and synclinal folds, differing considerably in intensity at different localities.

Above the falls the river valley is comparatively narrow, but below the falls it widens somewhat, and the river winds back and forth in broad and then in shorter curves, with cliffs now on one side and now on the other.

So evenly has the channel been worn down through the soft limestone that there are no rapids of any importance below the falls, and steamboats can run from the mouth up to Burnside in Pulaski County, Ky., within comparatively few miles of the falls, as already stated. This makes the river easy to navigate for two-thirds of its entire length, and since it runs through a great region remarkable for its mineral and agricultural resources and its large forests, but with a physical contour which makes the building of railroads exceedingly expensive, the Cumberland is destined to be one of the most important commercial highways of the United States.

COMPARISON WITH MAUMEE AND KANKAKEE RIVERS.

Both the Maumee and Kankakee Rivers, which were examined by the present authors, are situated in regions profoundly modified by the great glacier. In their basins the ice mass first removed the entire fauna and flora, and when it melted established new channels by which the river was restocked.

The Cumberland Valley presents an entirely different history. It is situated in a region which is geologically very old and which has not been much disturbed since its first upheaval, except by the ordinary forces of weathering and erosion and the subsequent formation of mountains. The Cumberland and Pine Mountains, as well as the great Cumberland Plateau, are portions of the Appalachian system, and the wrinkling which formed them took place toward the close of the Upper Silurian period. Originally very much higher than at the present day, they have gradually yielded to weathering and erosion, but are otherwise unchanged. The great glacier reached only a little below the Ohio River, which is far to the north of the Cumberland Valley.

CHARACTERISTICS OF THE MUSSEL FAUNA.

Consequently a primitive fauna and flora are to be looked for in this valley, one that began with the very origin of the valley itself, and has been gradually developing ever since without any serious disturbance; and in fact the best American authorities regard the Mississippi Valley as the original home of fresh-water mussels upon this continent, the rest of the rivers, ponds, and streams having been populated from this source. Some authorities even say that there is evidence to show that this fauna developed first in the New World and then spread to the Old World. However that may be, it is certain that the Mississippi area has the greatest diversity of species and the most magnificent shells to be found anywhere in the world.

The Cumberland and Tennessee Valleys are among the very oldest portions of the Mississippi region, and are commonly looked upon as the center of this wonderful mussel fauna. Accordingly we should expect to find in them a great diversity of species, some of which would be found nowhere else, and that such is the case has been well shown by many conchologists. Over 80 different forms of mussels have been reported from the Cumberland River, and the present examination has added 3 others. This is considerably more than twice the number found in the Maumee or the Kankakee River systems, and is a remarkably large representation compared with any river of equal size. A few of these species have never been reported from any other locality, but the great majority are common to the southern portion of the Mississippi system. Such of these as were found during the present examination are enumerated on pages 14 to 19.

GEOGRAPHIC DISTRIBUTION OF THE MUSSELS.

CONTRAST BETWEEN THE RIVER ABOVE AND BELOW THE FALLS.

The Cumberland Falls establish a natural barrier, dividing the river into an upper one-third and a lower two-thirds, between which there can be practically no interchange of animal life, and very radical differences appear in the mussel fauna. Above the falls only a very few species of mussels are found, and these are considerably dwarfed. *Unio gibbosus* is the only species in any abundance, and rarely one may find examples of *Lampsilis ovata*, *Alasmidonta minor*, and *Anodontoides ferussaciana*. This scarcity of species is as much due to the fact that all the conditions are unfavorable (see p. 23) as it is to the lack of intercourse past the falls, and in all probability there would be very little profit in stocking the river above the falls with mussels. Indeed we were told that some *Lampsilis ovata* were taken from below the falls and transplanted to the river above about seven years ago, with visible results, possibly, in the few dwarfed specimens of this mussel now present in the upper river.

In the river below the falls conditions are totally different. In the very pool at the base of the falls were obtained 19 species of mussels, all of them of normal size and perfectly healthy. And from this point down to the Ohio every portion of the river bed that is at all suitable for mussels is fairly covered with them.

Much of this part of the river has been thoroughly worked over by agents of the button factories, and the location, extent, and possibilities of the various beds are well known. Some clammers even have a memorandum list of the beds, giving the percentages of usable and useless shells in each. Many of these beds have been worked for some time, a few of them as long as 10 years, and an immense number of shells have been taken, as many as 200 to 300 tons from some of them. But in spite of the great number of mussels taken out, the river as a whole, according to general accounts, does not show any marked depletion except in one or two restricted localities. On the contrary, a comparison of many beds in the vicinity of Celina, Tenn., examined by Mr. Boepple in 1910 and again in 1911, showed a considerable increase. This was especially true of beds situated above the silt in the back water from the various lock dams. Such places seem peculiarly suited to rapid mussel growth, and furnish thereby a valuable suggestion as to the best localities for artificial propagation.

Of course the mussels that were too close to the dams, or that were in the mouth of tributaries filled with back water from the dams, would be killed by the increased deposit of silt, and the rise of water from behind the dams makes it harder to secure the mussels.

On the whole, however, the benefits seem greater than the disadvantages.

Incidentally it is worthy of note that the water privileges at Cumberland Falls have been leased to a company which has already begun operations toward establishing a power plant for furnishing electricity to Louisville and other cities.

FAUNISTIC DIVISIONS OF THE RIVER BELOW THE FALLS.

For our present purpose we may divide the river below the falls into four sections, fairly well separated by natural conditions, and by differences in the relative numbers of the various mussels. These sections will be discussed in order, beginning at the falls and proceeding toward the mouth of the river.

First section, from Cumberland Falls to Celina, Tenn., 175 miles.—While there are numerous and rich mussel beds along this portion of the river, there is no commercial clamming. This is chiefly due to the high percentage of culls, small species, and pinks, the latter mostly elephant-ear (*Unio crassidens*). The most important commercial mussel is the southern mucket (*Iampsis ligamentina gibba*).

The elephant-ear is not killed in any great numbers by pearlers because it is not looked upon as a pearl-bearing species, while other mussels, supposed to contain pearls, are often nearly exterminated. Up to the present time, moreover, this mussel has been refused by the buyers for button factories. Consequently it has been neglected or culled out by the fishermen in the lower sections of the river and left comparatively free to breed, the glochidia to be picked up by fish and carried up toward the falls. Natural conditions have in some way also given the purple spike (*Unio gibbosus*) an advantage over other species above the falls. Similar conditions may have been equally favorable to the closely related elephant-ear below the falls. Perhaps these considerations will help to explain their preponderance in these two localities.

There are 19 mussel beds in this section of the river and the proportion of commercial shells and culls, together with the size of the bed and the kind of bottom, are shown in the following table:

FIRST SECTION, CUMBERLAND FALLS TO CELINA, TENN.

Mussel beds.	Percentage of commercial shells.						Percentage of culls.			Conditions.			
	Mucketts.	Pigtoes.	Niggerheads.	Sand-shells.	Pocketbooks.	Warty-backs.	Spikes.	Elephant-ears.	Small or thin shells.	Size of bed.	Kind of bottom.	Temperature of air.	Temperature of water.
Just below falls.....	24	.....	.....	1	6	10	15	7	25	Large.....	Rocks.....	81	84
Big South Fork opposite Parkers Lake.....	5	.....	.....	4	3	10	26	15	37	do.....	do.....	92	86
Big South Fork above Burnside.....	7	.....	.....	3	.....	10	29	5	40	Medium...	Gravel....	86	82
Railroad bridge, Burnside.....	30	.....	.....	.....	.....	2	16	28	20	Small.....	do.....	.....	.....
Fishing Creek Bar.....	35	.....	.....	5	.....	.....	16	28	10	do.....	do.....	86	85
Fords Island.....	.....	.....	.....	.....	.....	.....	20	60	20	Large.....	Sand.....	86	85
Mill Springs Bar.....	5	2	.....	1	9	32	1	14	40	Medium...	Gravel....	86	82
Robertsport, Ky.....	22	.....	.....	.....	9	15	2	20	25	Large.....	do.....	.....	.....
One mile below Lock 21.....	10	.....	.....	2	.....	.....	20	50	10	do.....	Mud.....	86	85
Horseshoe Bottom.....	12	.....	.....	3	.....	.....	20	45	10	do.....	Sand.....	.....	.....
Beaver Creek.....	4	.....	.....	.....	5	10	6	.....	70	do.....	do.....	80	81
Indian Creek Shoals.....	40	1	.....	2	5	2	6	40	4	do.....	Gravel....	87	81
Snow Island.....	5	9	14	1	.....	5	1	39	20	Small.....	do.....	.....	.....
Wells Island.....	40	1	.....	.....	1	.....	.....	50	8	Medium...	do.....	.....	.....
Selfs Shoals.....	40	.....	.....	.....	3	.....	.....	50	6	Large.....	do.....	.....	.....
Greens Bar.....	30	2	2	2	6	8	2	40	8	Medium...	Sand.....	.....	.....
Champs Shoals.....	35	1	1	.....	.....	.....	1	60	.....	do.....	Gravel....	.....	.....
Biggerstaff Bar.....	10	10	.....	.....	33	2	18	15	.....	Large.....	do.....	80	82
Celina, Tenn.....	10	10	2	.....	6	6	4	20	30	do.....	do.....	.....	.....

The table shows at a glance that the proportion of culls is so large in nearly every one of the beds that they yield but a poor profit to the clammer.

The conditions, however, are everywhere favorable to mussel growth, as is evidenced by the number and variety of the shells. These mussel beds each contain a fair proportion of commercial shells, three of which, the southern mucket, the butterfly, and the Ohio River pigtoe, might well be propagated artificially. In this way the preponderance of culls could be greatly reduced in a few years, if not wholly overcome.

Although there is no clamming, there is considerable pearling in this section of the river and large piles of shells were found in a number of places where the pearlers had left them. This was especially true at Fords Island, Mill Springs Bar, below Lock 21, Wells Island, Selfs Shoals, and Champs Shoals. It will be noticed that in coming down the river the first pigtoes were found at Mill Springs Bar and the second lot at Indian Creek Shoals.

Second section, from Celina to Nashville, Tenn., 190 miles.—The mussel beds increase a little in number and considerably in size along this section of the river, and in consequence there is more commercial shelling. The percentage of pinks and spikes steadily decreases, especially that of the former, and there is a corresponding increase in the commercial species. The Ohio River pigtoe becomes the most common button shell; while the elephant-ear not only decreases in numbers, but partially changes its color, and with

white nacre it answers fairly well for button making. The conditions are even better suited for mussel propagation than in the preceding section.

The following table gives the percentages of the various mussel species and other useful data:

SECOND SECTION, CELINA TO NASHVILLE, TENN.

Mussel beds.	Percentage of commercial shells.					Percentage of culls.			Conditions.				
	Muckets.	Pigtoes.	Niggerheads.	Sand-shells.	Pocketbooks.	Warty-backs.	Spikes.	Pinks.	Small or thin shells.	Size of bed.	Kind of bottom.	Temperature of air.	Temperature of water.
Larrys Shoals.....	25	30	15	....	5	5	2	17	....	Small.....	Gravel.....	° F.	° F.
Roses Bar.....	20	25	10	....	10	10	5	20	....	do.....	do.....	....	....
Gainesboro Landing.....	5	....	....	....	....	....	....	....	85	do.....	do.....	....	....
Simpsons Island.....	20	30	10	1	....	5	10	20	5	Large.....	Sand and mud.	....	....
Saltlick Island.....	6	20	15	....	3	20	....	17	10	Medium.....	Gravel.....	80	79
Phillips Branch.....	20	15	15	1	5	10	6	20	....	do.....	do.....	....	....
Goodalls Island.....	20	15	15	2	6	15	2	20	4	Large.....	do.....	80	83
Johnsons Eddy.....	20	25	10	1	5	12	....	25	....	Small.....	do.....	....	....
Beasleys Bar.....	10	5	5	....	....	5	....	70	....	Large.....	do.....	....	....
Cotton Bar.....	10	40	10	2	10	4	6	20	....	do.....	do.....	....	....
Puryears Bar.....	3	37	10	2	....	18	2	4	10	do.....	do.....	....	82
Cairo Island.....	20	35	10	....	2	15	2	15	....	do.....	do.....	82	85
Coles Ferry.....	30	25	10	....	....	10	1	6	10	do.....	do.....	....	....
Lindsleys Island.....	20	15	10	1	8	12	5	12	10	do.....	do.....	91	85
Hills Island.....	20	40	10	2	5	10	5	5	....	do.....	do.....	84	85

In addition to the beds above enumerated, small and not very profitable ones were reported by local clammers at Bullards Gap, 8 miles below Simpsons Island; at Wartrace Creek Bar, 4 miles further down the river; at Pinks Bar, 2 miles below; at Lower Holliman Island, a mile below Phillips Branch; at the head of Sullivan's Island, 5 miles lower; at the foot of the sand shoals near Haney's Landing; at Turkey Creek Shoals, just above Carthage; at Hunters Point, a mile below Lock No. 5; at the mouth of Spring Creek, 5 miles above Cairo; at the foot of Cunningham Island, 2 miles nearer Cairo; at Mauskers Island, just above Edgefield Junction; and at Priestly Shoals, 5 miles above Nashville.

At Gainesboro Landing the mussels were all obtained from Roaring River, a tributary of the Cumberland from the south (see p. 29).

At Cotton Bar 12 tons of shells were cribbed along the bank, of which 60 per cent were pigtoes; washboards, monkey-faces, and butterflies were also common. Simpsons Island was the highest point on the river where clammers were found actually at work.

Muskrats were making heavy inroads into the mussel beds at several places, notably at Puryears Bar, at Mauskers Island, and Hills Island. All the piles of shells left by these animals showed that they have a decided preference for pigtoes.

Third section, from Nashville to Dover, Tenn., 105 miles.—This portion of the river has been more thoroughly worked by the clammers than has any other. It contains the largest and most valuable mussel beds of the entire river, and the location of all the beds, together with their size and relative value, are well known. The proportion of merchantable shells, moreover, has increased until there is no longer any locality in this part of the river where the pinks and spikes preponderate. The Ohio River pigtoe still continues to be the most common and valuable commercial shell, but the niggerhead becomes a close second and from Clarksville to Dover outranks the pigtoe.

So much does the commercial clamming increase and so great is the influence of the ready local market for shells that pearling as a distinctive vocation practically disappears. Every clammer is on the watch for such pearls as may be found in the shells which he cleans for the market, but there is very little hunting for pearls with no other object in view. This increase in the commercial clamming is due almost entirely to the activity of the button-blank factory at Clarksville, near the center of this third portion of the river, which furnishes a convenient market for all the shells taken in the vicinity.

The proprietor of this factory, Mr. M. K. Clark, is much interested in everything that pertains to clamming, and with his assistance several thousand glochidia of the yellow sand-shell were taken from ripe female mussels and placed in tubs of water with small fish caught in adjacent ponds. After the young mussels had fastened themselves to the fish the latter were turned loose in the river. This was the first time that mussels had ever been artificially planted in the Cumberland. Mr. Clark also gave us most of the data for the following table of mussels beds:

THIRD SECTION, NASHVILLE TO DOVER, TENN.

Mussel beds.	Percentage of commercial shells.					Percentage of culls.			Conditions.			
	Mucklets.	Pigtoes.	Niggerheads.	Sand-shells.	Pocketbooks.	Warty-backs.	Spikes.	Pinks.	Small or thin shells.	Size of bed.	Kind of bottom.	Temperature of air.	Temperature of water.
Penitentiary Bar.....	20	10	15	....	10	5	15	15	Large.....	Gravel.....	80°	82°
Robertsons Island.....	40	10	5	....	10	5	15	10	do.....	do.....	....	....
Gowers Island.....	2 50	5	5	2	5	....	25	5	Very large.	do.....	....	....
Harpeth Island.....	5 45	5	5	2	10	5	15	5	do.....	Mud.....	....	....
Half Pone Bar.....	5 10	15	....	5	20	1	2	30	do.....	Gravel.....	81	78
Burtens Creek.....	5 10	10	5	2	15	5	10	15	Medium.....	Rocks.....	....	....
Cotton Gin Bar.....	5 15	10	5	5	10	5	30	10	do.....	do.....	....	....
Seven Mile Ferry.....	3 24	20	7	5	15	14	5	5	Large.....	Mud.....	....	....
Guisers Bar.....	3 55	10	5	1	15	1	8	....	do.....	Gravel.....	....	....
Clarksville.....	5 30	20	10	5	10	5	10	....	do.....	do.....	....	....
Trices Landing.....	53	28	....	....	8	4	7	....	do.....	do.....	86	82
Meeks Spring.....	74	7	10	....	8	....	1	....	do.....	do.....	....	....
Martins Shoals.....	38	15	8	....	15	....	2	10	do.....	do.....	....	....
Hematite Bed.....	5 20	35	5	....	15	3	5	....	Small.....	do.....	....	....
Carbondale Bed.....	25	20	8	5	20	2	1	10	Large.....	do.....	....	....
Yellow Creek Towhead.....	5 30	20	10	5	15	....	5	5	do.....	do.....	....	....
Sailors Rest.....	30	25	10	....	15	....	4	7	do.....	do.....	....	....
Wild Cat Creek.....	25	20	6	....	12	....	5	10	do.....	do.....	....	....

There are also small beds containing a limited number of marketable species at the following localities: Just below Lock No. 1, along the north bank of the river, badly depopulated by sand dredges; near the Tennessee Central Railroad bridge, also along the north bank; at Whites Creek Bar, considerably dug up by sand dredging; along the mouth of Indian Creek, 20 miles below Nashville; below Lock A on the south bank of the river; at Betsytown on a very rough and rocky bottom; at Davis Riffle extending diagonally across the river; opposite the pumping station of the Clarksville waterworks; at Kentucky Landing and Red Rock Landing, the latter bed nearly worked out; at Palmyra Island along the west bank of the river; at Cumberland City just below the steamboat landing; and at Wells Island, 2 miles farther down the river.

Thus the third section of the river contains a larger number of mussel beds than any of the other sections, and the beds are richer both in numbers and species of mussels. It is the section of the pigtoe and niggerhead mussels, and those species are the most abundant button shells. There has also been a marked increase in the yellow sand-shell and the monkey-face.

This portion of the river, however, is also the nearest to the center of demand, and consequently its beds have been worked longer and harder than any of the others. The most of them do not show any signs of depletion but remain as rich as when the work first began. The most important beds are, for the conchologist, the one at Half Pone Bar, where the smaller and rarer species are specially abundant, and for the button man the one at Guisers Bar, which has yielded rich returns through a long series of years; in fact, from the very beginning of work here on the river.

Fourth section, Dover to Smithland, Ky., 85 miles.—While this section is not as well known as the preceding, and has not been worked as much, it probably contains as many and as valuable mussels.

The center of demand was still the blank factory at Clarksville, to which all the shells have to be transported up the river. But a sort of secondary center has been established at Dover, Tenn., where Mr. Walter, one of the leading merchants of the town, purchased most of the local shells and hired most of the clambers. Furthermore, the business in this part of the river was conducted in the most approved and up-to-date manner. The boats were towed to and from the mussel beds by small launches, the mussels themselves were conveyed from the boats up the steep river bank by steam power, and were finally cleaned by steam conveyed to the pans in a pipe from the engine.

FOURTH SECTION, DOVER TO THE OHIO RIVER.

Mussel beds.	Percentage of commercial shells.						Percentage of culls.			Conditions.			
	Muckets.	Pigtoes.	Niggerheads.	Sand-shells.	Washboards.	Warty-backs.	Spikes.	Pinks.	Small or thin shells.	Size of bed.	Kind of bottom.	Temperature of air.	Temperature of water.
Elk Creek Shoals.....		77	11		1	3		4	3	Large.....	Gravel.....	° F.	° F.
Walters Camp.....	5	10	25	10	5	15		6	5	do.....	do.....		
Ball Island.....		70	9		8	2	3	3	5	do.....	do.....		
Glasgow Landing.....		66	12			6		14		do.....	do.....		
Dover Island.....		70	14		8	4				do.....	do.....	95	79
Jones Landing.....		70	6	8	6	5	1	2		do.....	do.....	84	78
Linton, Ky.....		76	10	6		5		2		do.....	do.....	85	75
Donelsons Landing.....		56	15	4	8	7	2	4		do.....	do.....	92	76
Canton, Ky.....	4	54	25	5	5	5		2		do.....	do.....	84	74
Eddyville Bar.....		26	26		34	6		6		do.....	Rocks.....	86	73
Kuttawa, Ky.....	2	21	45		17	4		4	5	do.....	Gravel.....		
Money Cliff.....		9	51		37			2		do.....	do.....		
Mussel Shoals.....		20	62		6	5		3	3	do.....	do.....		

Mussel Shoals was the lowest point visited on the river, but from reports given by the clammers the niggerhead continues to be the prominent shell down to the mouth of the river.

The number of beds in this section of the river is fully equal to that of the preceding section, but they have not been worked as much because they are farther away from the center of demand and require transportation up the river to Clarksville. The niggerhead gains steadily in its percentage and at Canton passes the pigtoe, and then continues to increase down to the mouth of the river. There is also a steady decrease in the amount of culls, until at and below Canton nearly all the shells obtained were marketable. Of course, this means much to the clammer, as it does away with the necessity of sorting the shells and handling over the culls.

TABULAR STATEMENT OF DISTRIBUTION OF SPECIES.

In the table herewith given is expressed the distribution of every species of mussels obtained by the party in the Cumberland River and its tributaries. Where the mere presence of a species is all that is desired, it is indicated by an X. The percentages of the more important commercial species are indicated by numbers. The totals represent the actual number of specimens obtained. In order to catch the eye readily, all the side stations not on the main river are printed in italics. All commercial species are marked with an asterisk (*).

[illegible]

Total number specimens obtained.

[illegible]

Total number specimens obtained.

[illegible]

Total number specimens obtained.

RELATIVE ABUNDANCE OF DIFFERENT SPECIES.

In forming an estimate of the relative abundance of the different mussels in the various beds many things have to be taken into consideration.

For the clammer's purpose, a count of his entire catch would give the most reliable data, but this is usually impossible. It is almost as satisfactory to take the successive hauls as they come and count the various species in each; the greater the number of hauls counted the more accurate the results obtained.

From the viewpoint of the conchologist, however, such an estimate is in reality only a measure of the extent to which the species in question is capturable by the clammer's gear, and for the following reasons:

There are a number of species which never "bite" the hooks on a crowfoot dredge, or which do so very rarely. Such species may be plentiful in a mussel bed and yet never appear in the clammer's hauls.

Again, some mussels are found only in small numbers and around the edges of a bed. The clammer makes his hauls where the shells are most crowded, through the center of the bed, and may miss these altogether.

The clammer throws away the mussels that are too small to use as well as those whose shells are too thin or too highly colored. Such shells ought to enter into the percentages as much as the more valuable species, but they do not appear in the clammer's hauls.

Different methods of clamming produce very different results in the proportion of shells obtained. The crowfoot dredge, the rake, the tongs, and wading each secure an unduly large number of some species and an unduly small number of other species.

To enumerate all the shells obtained by all the methods would give the most accurate results, but that is obviously impracticable. When the water is low the clammer gets quite a different proportion of species, and may even get different kinds of mussels from those obtained when the water is high.

Each of these considerations has been kept in mind while making out the percentages; the clammer's hauls were counted; all the piles of culls were carefully examined; all the specimens possible were secured by wading along the edges of the beds; account was taken of the various shells found in muskrat piles; the relative stage of water was noted, and, so far as could be done, allowance was made for it. Then, too, there has been a careful consideration of numerous circumstances which can not be shown to the reader, but which result from the authors' experiences at the different stations. Notwithstanding all these efforts, the numbers must still be regarded as

approximate rather than absolute. But, even so, they will be of service to the mussel fishermen, for whom they are primarily intended. Only a very small percentage of the shells seen and handled could be kept for the final collection.

An endeavor was made to retain typical specimens of each species encountered, and also all puzzling and aberrant forms, since the latter add much to the actual knowledge of a species, though they may render positive identification more difficult.

SUMMARY OF MUSSEL DISTRIBUTION.

The practice of the Bureau of Fisheries in examining a river and its tributaries from source to mouth, in regular order, throws unexpected light on the distribution of species which could be obtained in no other way. The fauna of a river has a coherence never found and not to be expected in an artificial division of the country, such as a township, county, or State, whose boundaries are purely arbitrary. The larger the river and the more thoroughly the main stream and its tributaries are examined the more illuminating become the results. The study of the entire fauna of the Cumberland River and its tributaries leads to the following general conclusions, which are amply confirmed in all the river faunas that have been examined:

1. When two closely related forms differ essentially in their degree of inflation, the flatter and less inflated one will be found in the upper portions of the river and in the tributaries, while the rounder and more inflated one is confined to the lower portions of the main river, where there is a weaker current and more mud. To this there are, however, some noteworthy exceptions, such as *Symphynota complanata*.

2. The swiftness of the current, the size of the stream, and the kind of bottom affect other shell characters besides that of inflation. Consequently, where there is a mixture of conditions there is also a mixture of characters, and two species which in other localities may be well defined and easily separated will be found to merge imperceptibly into each other. In a miscellaneous collection of shells it is easy to find the blue-point (*Quadrula undulata*) from one stream and the three-ridge (*Q. plicata*) from another, the southern mucket (*Lampsilis ligamentina gibba*) from one locality in a State and the pocketbook (*L. ventricosa*) from another. But when specimens of the entire fauna of a river are spread out on a table in order from the source to the mouth there is found such a mingling of characters that it is often a mere matter of individual judgment to determine some of the species. This is essentially true of *Q. undulata* and *Q. perplicata* in the upper portions of the Cumberland.

3. There is sometimes a peculiar similarity in the faunas of widely separated tributaries, where the conditions at first would seem to be

very different. Such a similarity is found in Roaring and Rock Castle Rivers, although the localities are widely separated and the surrounding country quite different.

4. Some species demand peculiar conditions, and their presence or abundance in any locality depends on the presence and extent of the favorable conditions.

The washboard (*Q. heros*) lives in holes or depressions in the bottom, full of soft mud. Any mussel bed in the Cumberland that has such holes will be likely to contain washboards, whether that bed is high up the river or low down toward the mouth, and the percentage of the washboards will depend on the area covered with such holes.

5. The Cumberland is very different from the Maumee and Kankakee Rivers in that it shows a marked differentiation between small and large stream species, between the main river and its tributaries, but there is very little evidence of migration along the main river itself.

Such species as are confined to the upper, middle, or lower portions of the river owe their habitat chiefly to the fact that here, as elsewhere, they frequent smaller or larger streams, as the case may be.

Accordingly, we may distinguish the following classes:

(a) Small-stream species restricted to the upper portions of the river and its tributaries. Here belong seven species. *Anodontoides ferussacianus* was found only in the tributaries and not at all in the main river. The other six species, *Lampsilis perdis*, *multiradiata*, *orbiculata*, and *punctata*, and *Alasmidonta minor* and *truncata* are distributed in various tributaries and in the main river both above and below the falls. None of these are commercial species.

(b) Large-stream species, restricted to the lower portions of the main river. There are nine of these species, seven of which are not found in any of the tributaries, viz: *Lampsilis ventricosa* and *fallaciosa*, *Obovaria retusa* and *ellipsis*, and *Quadrula heros*, *ebena*, and *fragosa*. The other two species, *Lampsilis anodontoides* and *Quadrula undata*, were found in Harpeth River and the former also in Red River as well as in the main Cumberland. The most of these large-stream species are good button shells, as would be expected. Indeed, the only exception is *Obovaria retusa*, which is the smallest of them all and for that reason the least valuable.

(c) Species of universal distribution, which are well scattered throughout the entire length of the main river. There are seven of these species, three of which, the Ohio River pigtoe (*Quadrula obliqua*), the pink warty-back (*Q. tuberculata*), and the butterfly (*Plagiola securis*), are not found in any tributary. The other four are the southern mucket (*Lampsilis ligamentina gibba*), the pocket-book (*L. ovata*), the spike (*Unio gibbosus*), and the elephant-ear

(*U. crassidens*). The last two, of course, are culls, but all the others are valuable commercial shells.

(d) Species confined to restricted areas, including all of the rare forms that are of interest chiefly to the conchologist. These include all of the Truncillas, which were found in places widely separated from one another, and one of which was new to science; nine species of *Lampsilis*—*tæniata*, *picta*, *lienosa*, *vanuxemensis*, *trabalis*, *parva*, *glans*, *lævissima*, and *leptodon*—all of which are too small or too thin-shelled to be of any value. *Dromus caperatus* and *Symphynota complanata*; two *Anodontas*, *imbecillis* and *grandis*; two *Pleurobemas*, *clava* and *crudum*; and four *Quadrulas*, *undulata*, *tuberosa*, *rubiginosa*, and *granifera*. These last four have some commercial value but not very much.

6. The great bulk of the mussel fauna of the river is thus made up of the seven universally distributed species, and two of the large stream mussels—*Quadrula heros* and *Q. ebena*. All the others are confined to such restricted areas or occur in such small numbers as to possess only an incidental or accessory value.

NOTES ON THE VARIOUS STATIONS.

THE UPPER RIVER AND ITS TRIBUTARIES.

This portion of the river was examined by Mr. Boepple in 1910 as well as by the present party in 1911. Both the river and its tributaries are rather swift mountain streams which are much used as a source of power to run small gristmills, and hence they are frequently interrupted by dams. The bottom is mostly bedrock sandstone, with occasional fissures and sand and gravel pockets and bars, the latter furnishing the only localities where mussels can live. Consequently the shells are very few in number and widely scattered. The Clear Fork has more sand bars and pockets than the main river, and hence considerably more mussels.

Mr. Boepple in his notes called attention to the apparent presence of acids in the water above the great falls, which quickly dissolved the nacre of dead shells, and the present party observed the same thing. Moreover, in the small beds above the falls the muskrats had made considerable inroads into the mussel fauna. Against so many unfavorable conditions the mussels find it very hard to hold their own, and the few species able to survive are not of any importance either to the pearl-ers or the button manufacturers. These mussels above the falls are not only thin-shelled but are much dwarfed, and *Unio gibbosus*, the most common species, has a very pale nacre, which frequently becomes white or yellowish and approaches closely a dwarfed form found in Green River, Ky.

THE RIVER BELOW THE FALLS AND ITS TRIBUTARIES.

Not only were there a great number of additional species below the falls, but there was also a change in the character of the shells. This was especially noticeable in *Unio gibbosus*, which was no longer a pale-nacred dwarf, but was of normal size and color. The mussels are usually found crowded about the base of the large rocks along the bottom of the river just below the falls. They are easily accessible to their enemies, especially during low water, and many of them are killed by muskrats, raccoons, mink, and occasional otter. But the relative number lost in this way is very small when compared with the corresponding loss above the falls. Hinge pearls (baroques) are common in this portion of the river, especially in the pocketbook (*Lampsilis ovata*), nearly every specimen of which contains a few. The river from Anvil Shoals, 1 mile below the falls, to Burnside was not investigated either by Mr. Boepple in 1910 or by the present party in 1911, but it was reported by a mussel fisherman to be full of excellent button shells. The bottom is much too stony for any kind of gear, however, and it would be necessary to collect the mussels entirely by hand. Pearling has been conducted actively along this portion of the river, and piles of shells left by the pearlers were frequent along the shore. Indeed it was reported that pearling had practically cleaned out the river for the first 10 miles above Burnside. There are two tributaries, both from the north, which enter the Cumberland in this space between the falls and Burnside.

Rock Castle River is the larger of the two and is nearer Burnside. It was examined below the ford at Livingston, Ky., July 1. The shores here were high and rocky and were forested with a mixture of deciduous trees and hemlock. The water was clear, temperature 81°, with a maximum depth of a foot and a half. The current was slow (2 miles per hour) and the bottom was very rocky and rough, with only a few bars and patches between the rocks filled with clay. The flora was remarkable and wholly unlike any that we saw elsewhere. Nuphar grew along the water's edge, *Myriophyllum verticillatum*, a broad-leaved *Potamogeton*, and a small patch of *Scirpus americanus* grew in the shallow water, and there was plenty of water willow, the whole reminding one of a bit of creek in northern Indiana or Illinois. The mussels were excessively abundant in the sand and clay patches here, and in favored localities the little *Medionidus conradicus* covered the entire bottom with the elongate slits, which is all of the mussel that can be seen.

Nineteen kinds of mussels were found here, but only a very few of them possessed commercial value, and a few miles farther down the river all the species were widely scattered. This shell bed was markedly unlike any of those in the main river, containing some

species that were not found in the Cumberland at all, and others that were quite rare. In these respects they resemble those found in Roaring River in Tennessee.

Laurel Creek, a tributary of Laurel River, was examined below the dam at Corbin, Ky., July 3. The shores were rocky and were heavily wooded with a deciduous forest, mixed with hemlock and pine, and still supported a remarkably rich and varied flora. The dam cuts off the upper portion of the river, and no mussels were found above it. There was a city dumping ground near at hand and the water was milky in color and covered with a greasy scum. Below the dam the bottom was very irregular and mostly solid rock, full of potholes and patches of sand and destitute of vegetation.

We had expected to find a rich and varied fauna, something like that of the Rock Castle River, but could discover only five species, and three of these were represented by a single shell each. This river thus has almost identically the same species as the Clear Fork and the Cumberland above the falls. The poverty of species is doubtless due to the smallness of the stream and the general unsuitable conditions.

There was no dwarfing of the species, but there were several peculiar modifications in the color of the nacre which were not found in the main river. These suggest that while there is some intercourse with the Cumberland there is very little interbreeding.

The Big South Fork flows into the Cumberland at Burnside, Ky. Our party examined it first opposite Parkers Lake, where there is a fish trap and a low dam. The shores there were high limestone cliffs, the water was very clear, and the bottom was coarse gravel covered with bowlders and great angular fragments of rock, with some sand between them. Dead shells, recently killed by muskrats, were abundant on the rocks and on the dam at the fish trap. Twenty-eight species were obtained here, but although seven or eight of them were good button shells, they were not sufficiently abundant to make the gathering of them profitable. At Sloans Shoals, 6 miles from Burnside, during the autumn of 1910, Mr. Boepple found about 20 species, securing them all with a rake. At the riffles, 2 miles above Burnside, the present party found large but rather scattered beds of mussels, by far the greater number of which were noncommercial. There were 32 species in all, and evidently some of them had yielded good returns in pearls, for there were many piles of shells, along the river bank and the bed had been thoroughly worked over.

Minute marginal cysts were abundant in the edge of the mantle of *Unio gibbosus*, often leaving small pits along the margin of the shell. Baroques and the distomid of Kelly were found in *Quadrula tuberculata*, and a few large *Atax* in *Symphynota costata*. Several of the *U. gibbosus* and two of the *Pleurobema* were gravid. The latter

had fine red eggs in all four gills and the body was orange; the former had coarse white glochidia in only one pair of gills.

On proceeding down the main river from Burnside the first mussel bed of note is on the bar below the mouth of Fishing Creek. Very few living mussels were seen here, but the entire river bed was covered with shells which had been killed by pearlers. A large number of beautifully marked univalves were present among the dead mussel shells.

At Fords Island the bottom of the left chute, which we examined most carefully, is a shingly gravel, in which it was difficult to find the mussels. Mr. Boepple, who examined this bed in 1910 with a mussel rake, reported an "almost unbelievable quantity" of *Unio crassidens*. The present party would probably have obtained many more mussels if the bed could have been examined during low water.

Four miles farther downstream, at Mill Springs, is another long and straggling mussel bed, which covers several miles of the river bottom. The latter is here composed of shingly gravel, with some sand bars, and is largely covered with water-willows.

The pearlers' piles along the banks opposite this bed were chiefly the shells of *Unio crassidens* (elephant-ear) with some *Dromus* and *Quadrula obliqua* (Ohio River pigtoe). Although this was not an important shell bed it was noteworthy for the increase in the number of species. The pocketbooks (*L. ovata*) found here were the first typical ones seen.

At the pearling camp $1\frac{1}{2}$ miles below Eadsville or Lock 21 we found the water about 2 feet above normal and rising rapidly, with a swift current over a gravel bottom. The pearlers were farmers from near by, who carried on pearling at odd times. They had thrown their opened shells back into the river, and there were about a ton and a half of them lying in the shallow water along shore. The pocketbooks (*L. ovata*), muckets, and elephant-ears were the most numerous species. Mr. Boepple investigated Gands Island, in this vicinity, and found the mussels, especially *Unio crassidens*, abundant on both sides of the island, an unusual circumstance.

Beaver Creek is a small tributary of the Cumberland from the south, opposite Rowena, Ky. This creek was investigated for a mile, up to a series of long riffles. The bottom was rocky with considerable mud and sand, in which were obtained a surprising variety of shells for so small a stream, as is shown in the table.

In the mouth of Goose Creek, a little way down the river, a man was seen actively pearling with a fork. He said that he was getting mostly elephant-ears and that there were plenty of muckets on the other side of the river but the water was too high to work them. Mr. Boepple saw a fine lot of about 50 pearls in Rowena during his stop there in 1910.

Indian Creek Shoals, 53 miles below Burnside, is one of the most interesting mussel beds of the upper river. We found the water clear with a swift current over a gravelly bottom. Near the water's edge was a pile of about 300 pounds of shells left by a pearler. These were mostly pocketbooks and muckets, but contained a good sprinkling of sand-shells, *Dromus*, and monkey-faces. Mr. Boepple obtained a good collection of shells from this bed in 1910 and also from Copper Island a little farther down the river.

Snows Island is a large island covered with coarse pebbles, upon which many dead shells had drifted, while others along the shore had been freshly killed by muskrats. At the head of Weeds Island, a little way below, there was about a ton and a half of shells left by pearlbers, chiefly the southern mucket and elephant-ear.

At Tear-coat Bar on July 20 the water was muddy and high from a heavy rain the night before. The bottom here is black gravel mixed with yellow sand. Out of a ton and a half of shells left here by pearlbers about 90 per cent were southern muckets and elephant-ears and the remaining 10 per cent an admixture of other species.

Selfs Bar contained a large and populous mussel bed which had been the center of active pearling operations. The 3 tons of shells left by them contained about the same percentage of shells as at Tear-coat Bar.

Marrowbone Creek, a small tributary from the north, was examined up to the first riffles, a mile or more, but contained no mussels. In general the northern tributaries of the Cumberland were rather barren, while those from the south were well populated. On the top of a hill near the mouth of this creek was an old shell pile left by the Indians, and from this point these shells became quite frequent, especially near the sites of old camping grounds.

At Champs Shoals pearling was being actively carried on, and there was a large pile of discarded shells, two-thirds of which were elephant-ears, while nearly all of the other third were southern muckets. The river here widens out considerably, and there is more clay and sand on the bottom. The shell bed continues with some interruptions from this bar down to Burkesville. At Tobins Landing, below Burkesville, Mr. Boepple obtained a fine collection of shells, representing at least 14 species.

At Cloyds Island, below Tobins, there is an unusually good mussel bed which has been much worked by pearlbers. The banks along both sides were fairly covered with the shells left by them, principally southern muckets and elephant-ears. In this bed the mussels were thickest where the current was strongest.

Biggerstaff Bar and Island were examined July 24; at the head of the island were a few shells among which were found specimens of *Lastena lata*, a rare species.

A few rods below the bar there were several good-sized shell piles left by muskrats, from which we obtained an exceptionally fine lot of butterfly-shells (*P. securis*). From Martinsburg to Celina there were a few pearlers' piles which increased in size and number of shells as we approached the latter place.

The Obey River, a tributary from the south which enters the Cumberland at Celina, Tenn., and the Cumberland itself in the vicinity of Celina, were examined by Mr. Boepple in 1910 and again in 1911. He covered the lower 26 miles of the Obey River, beginning at Grass Lot Shoals, where no mussels were found. At Martins Bar a large collection was obtained representing 22 species, of which the southern mucket and the pocketbook were the most abundant. The bottom here was firm coarse gravel. At Holmes Bar 24 species were secured, the southern mucket being still the most abundant. The current was swift and the coarse gravel bottom was covered with a rich vegetation, in which the mussels were especially abundant. The southern mucket is the only shell in this river worthy of commercial consideration, the others being too scarce. Mr. Boepple estimated that when niggerheads are worth \$30 per ton these muckets would be worth \$50.

From 12 to 15 years ago there was considerable pearl fishing on the Obey River, and a local firm said that then one could easily get a wagonload of mussels a day. But now the larger mussels are gone and the small ones have only small pearls. Fourteen of these pearls which were examined weighed from 2 to 4 grains each, but were of extra quality.

In the Cumberland, 1 mile below Celina, there is a fair-sized mussel bed which has been worked for 10 years, entirely for pearls. The most valuable commercial species is still the southern mucket, and this is also regarded as the best pearl bearer.

Mr. Boepple examined a large bed near Butlers Landing and secured 13 species, but the specimens were all too badly eroded and spotted to have any commercial value. A storekeeper here had a number of pearls which he had taken in trade, and he showed us an assortment of 4 purple, 5 yellow, and 8 white ones, of the rosebud type, all of which had an exceptionally good luster.

About 3 miles below Butlers Landing we found the first pile of commercial shells we had seen, but they were all old shells, since no active clamming had been carried on for two years. There were 6 or 7 tons in the pile, most of them of second quality, the Ohio River pigtoe being the most common, with the southern mucket and the Cumberland pigtoe (*Q. cooperiana*) close seconds. There were fully 2 tons of culls, 98 per cent of which were elephant-ears and the purple warty-back. Mr. Boepple secured a fine collection of shells from this bed with the crowfoot dredge, and among them were 3 specimens of

Lampsilis fallaciosa, the slough sand-shell, which were the first obtained during our survey of the river.

At Brimstone Island there is a large mussel bed in water from 2 to 8 feet deep, with a bottom of coarse gravel, sand, and clay. Commercial clamming had been in operation here only a few days before our arrival, but must have been carried on during previous years, as evidenced by a pile of button shells on the bank containing fully 20 tons.

At Carsons Bar there is another large mussel bed in water from 3 to 6 feet deep, with a moderate current and a hard gravel bottom. This bed is worked only occasionally by local fishermen chiefly for fish bait and pearls.

Roaring River, a tributary from the south which enters the Cumberland just above Gainesboro Landing, was examined several miles above its mouth on July 28. Only one small mussel bed was found along the shore under the shade of the overhanging trees, in 3 to 6 inches of water on a gravelly bottom. The presence of a large amount of *Potomogeton* and the abundance of *Medionidus conradicus* was a strong reminder of the Rock Castle River at Livingston, Ky. The abundance of *Lampsilis glans* was also noteworthy, since this species was not found anywhere in the main river.

At Gainesboro Bar there is a small mussel bed which can not be worked with a crowfoot dredge, since the bottom is composed of flat rocks with gravel pockets in the cracks. At the lower end of the bed, where the rocks were well covered with a blue clay, the mussels were of especially fine quality, but the bed has never been fished commercially.

We reached Salt Lick Island when the water was low and the mussels were moving about actively. Similar conditions were found at Half Pone Bar (see p. 33), and the extremely interesting collections obtained at each of these stations show what a remarkable difference a low stage of water makes in the results of collecting. There is no reason for supposing these two beds to be exceptionally good, and probably most of the beds in the Cumberland would have nearly if not quite equaled them if the conditions under which they were examined had been equally favorable. This Salt Lick Island bed was especially noteworthy for the large numbers of *Truncilla* that were obtained. No parasites were found on any of the mussels. *Lampsilis gracilis* was gravid (July 31), while *L. ligamentina gibba* and *L. orbiculata* approached each other so closely in all their shell characters as to be indistinguishable except by the color of the nacre and epidermis.

At Fort Blount Bar there is a large mussel bed in water from 4 to 6 feet deep, with a swift current over a bottom of firm gravel mixed with yellow clay and sand. Two men from the Ohio River had been

working here for a week before our visit, and two more began on the day of our arrival. The Ohio River pigtoe is the most common button shell.

At Granville our party was caught in a very heavy rain, almost a cloudburst, and went from there down to Carthage on high and turbid water which rendered any satisfactory mussel survey impossible.

Sullivans Island was investigated by Mr. Boepple when the conditions were more favorable. He found a large mussel bed in a strong current on a bottom of rough gravel and yellow clay. Although he secured 22 species, and among them a large number of Ohio River pigtoes and southern muckets, the bed is worked only for fish bait and pearls. Two small beds at Buffalo Bar and Sand Shoals are not of commercial value.

Caney Fork, one of the most important tributaries of the Cumberland, joins the latter river just above Carthage. In Buffalo Valley, near Flat Pond, July 27, Mr. Boepple found a mussel bed covering the entire width of the fork and $1\frac{1}{2}$ miles long. He used a crowfoot dredge and scissors fork in water 5 to 10 feet deep on a bottom of coarse gravel mixed with sand and yellow clay. This bed has been fished for pearls and baroques during the last 15 years, and according to accounts it has yielded well. None of the shells have ever been sold, and fully a carload of merchantable species was seen scattered along the banks.

At Rock Springs there is a much smaller bed in a swift current, with water $2\frac{1}{2}$ to 8 feet deep, the bottom being flat rocks on one side and much fine sand and gravel on the other. This bed has also been fished for 15 years for pearls and baroques, and while the shells are exceptionally good for button purposes they have never been utilized. The spectacle-case (*M. monodonta*) was once common here, but has been nearly exterminated by being used for fish bait. Another bed at Lancaster Island shows similar conditions; the button shells are of first quality, but have never been utilized.

At the lower end of Goodall Island in the main river below Carthage there are two small beds separated by a short interval. The current is slow but steady, while the bottom is of firm gravel mixed with yellow clay. There was a pile of about half a ton of shells here. Down nearer to Lock 7 there is a third bed in water from 14 to 16 feet deep, which was fished for pearls up to 1908, two years before the lock was finished. The Ohio River pigtoe is the principal commercial species here, with a good sprinkling of second-grade button shells. The effect on this bed of the dam at the lock seemed to be to kill off the mussels at the lower end, but to allow the upper end to broaden out considerably. The clammer here opened all his shells with a knife instead of steaming them, since he was working principally for pearls.

He was reported to have found three during the preceding week, one of which sold for \$100.

At Beasleys Shoals there is a large and important shell bed with several good-sized piles of shells along the banks. These piles aggregated about 10 tons, and the Ohio River pigtoe furnished 80 per cent of the merchantable shells in them. They represented chiefly the residue of a great amount of clamming done here in the past. An Ohio River clammer had taken out 200 tons of good shells and left about 8 tons of culls, of which the elephant-ear formed 90 per cent. The bottom was gravel mixed with yellow clay and covered with 12 to 16 feet of water. Of 5 pigtoes examined 4 were gravid, 2 had young in the outer gills only, while the other 2 had a number of young in the inner gills also. The *Quadrula subrotunda* had orange flesh while part of the gills contained carmine eggs, most of which had been aborted.

Below Cedar Bluffs we found a pile of 12 tons of shells which had been collected a year or more before, and cribbed. The mussel bed here was large with a very slow current over a bottom of gravel covered in some places with clay. The bed has been extensively fished for pearls; during the previous year (1910) 8 boats had been employed and they collected over 100 tons of shells, more than half of which were saved and sold. But there was fully a carload of good button shells scattered along the banks.

Goose Creek, a tributary of the Cumberland from the north, was examined August 10, but although the conditions seemed in every way favorable no mussels could be found.

At Daniels Landing the mussel bed is half a mile long and 150 feet wide in water 12 to 16 feet deep, with a bottom of yellow clay and sand changing to rocks at the lower end. The fishing here has been chiefly commercial since pearls are scarce. Eight men fished this bed in the summer of 1910 and obtained 100 tons of shells, the principal commercial mussel being the Ohio River pigtoe, which is of extra-large size and of the best quality. A few very large niggerheads were also found. In spite of the large amount of shells taken from this bed it still remains one of the richest in the river.

At the mouth of Spring Creek, below Hunters Point, there is a large mussel bed 1 mile long and 125 feet wide, in a very slow current over a bottom of gravel and yellow clay covered in places with mud. This was first fished in 1910, when 50 tons were taken; at the time of our visit in 1911 the clammers had obtained about 14 tons, nearly all of Ohio River pigtoe, with a few washboards and niggerheads. Another large mussel bed was reported at the foot of Wings Eddy Bar, and still another at Armstrongs Island. At Cairo we saw a pile of 12 tons of shells, mostly Ohio River pigtoes.

At Grallatin Landing the mussel bed is $1\frac{1}{2}$ miles long and from 40 to 60 feet wide, on a bottom of gravel and yellow clay covered with mud. The river widens considerably, there is much dead water, and the shores are low, making the conditions almost lake-like. This is all the result of excessive backwater from the lock dam just below. The first *Quadrula fragosa* was found here.

At the head of Lindsleys Island we found a very large number of small shells killed by muskrats; 95 per cent of these shells were pigtoes. There is no commercial fishing here nor even any pearling. We found in this bed our first yellow sand-shell, and also a spectacle-case, specimens of which we had not seen for some time. Farther down the river, at the end of Lindsleys Bar, there was a clammer's camp. About 600 pounds of shells had been collected, of which the pigtoe formed 50 per cent, the washboard 25 per cent, and the remainder mixed species, including a few yellow sand-shells. There was a good mussel bed at Hills Island above Nashville on a muddy bottom in a fairly rapid current. Many mussels had been killed by muskrats who seemed to have a particular liking for small pigtoes.

Stones River, an important tributary from the South, was examined along its East Fork at Walterhill, Tenn. The water was shallow and turbid with numerous riffles; the bottom was composed of loose rocks with intervening gravel bars, covered with plenty of water willow.

Below the ford was found a large number (70) of a beautiful new species of *Truncilla* (see p. 46), many individuals of which had been killed by muskrats. The *Symphynota costata* found here were remarkably large, and contained many lusterless pearls.

The West Fork of this river was visited at Murfreesboro, Tenn. It is somewhat larger than the East Fork and is broken up by divers islands covered with water willows. There were many *Anodonta grandis* and *Symphynota costata* of large size on the bank, recently killed by pearlers.

The mussel fauna here is remarkable in containing several species not found at all in the Cumberland, and in a peculiar interchange of species. *L. ovata* of the Cumberland is replaced here by the genuine *L. ventricosa* and *Q. perplicata* is replaced by *Q. undulata*. The presence of *Q. rubiginosa* is unexpected, and that of the genus *Anodonta* is interesting, since this is the only place in the Cumberland or its tributaries where representatives of this genus were found.

At the foot of Gowers Island, 25 miles below Nashville on the main river, there is one of the most important mussel beds in the entire Cumberland. And we found here the largest pile of mussel shells yet seen, about 80 tons with 8 tons of culls. The bed is 3 miles long and from 60 to 175 feet wide in a strong current on a bottom of gravel mixed with sand and clay. The young pigtoes here were all so

brightly rayed that for a time they were regarded by the clammers as possibly a new species. Harpeth River, a tributary from the south which enters the Cumberland a little way above Lock A, was examined 5 miles above its mouth. The bottom here was of shingly gravel, changing to solid rock and farther up to beds of soft mud. There was formerly a large mussel bed here, but the backwater from the lock dam has killed the mussels in the lower portion of the bed. Another large bed was reported $1\frac{1}{2}$ miles farther up the river.

The unusual size and thickness of the shells obtained here suggest that this river would yield exceptionally good button material. The margins of the shells were much pitted, indicating parasites in unusual abundance. The presence of fine large *L. ventricosa* and *S. costata* so near the mouth of the river is remarkable, since both of these species are absent from the Cumberland.

Below Lock A we saw numerous sites of old shell piles where clamming operations had been carried on in the past. At Half Pone Bar the current was swift, the water shallow and somewhat turbid, and the bottom firm gravel and sand. The large number of specimens and species is at least partly due to the peculiar configuration of the bottom and the low stage of the water, the conditions being similar to those at Salt Lick Island (see p. 29). The great majority of the shells obtained were young, but many of them were eroded at the umbones. *P. donaciformis* was exceptional in being very thin and having a pink nacre. The large number of *Plagiola* is noteworthy, together with the only specimen of *Truncilla florentina* found below Nashville.

At the Seven Mile Ferry above Clarksville the current was rather feeble, the water clear, and from 5 to 8 feet deep, and the bottom composed of fine gravel. From this point on down the river a crow-foot bar was employed, similar to that used by commercial clammers but shorter and smaller, and furnished with 50 hooks. The latter were of two kinds, the ordinary form used by clammers and an improved form invented by Mr. Boepple, having a knob at the tips to prevent small mussels from taking hold or larger ones from dropping off. Hauls were made 200 feet long, the first as near the shore as possible, and each succeeding one 10 feet farther out. The detailed record of the different hauls made at a few stations is given in full, in order to convey a more accurate idea of the number and distribution of the mussels, and the ease or difficulty with which they could be caught. Such a record was kept for all the stations in this portion of the river, and forms an important factor in determining the relative abundance of the mussels.

At Owl Hollow Bar, $2\frac{1}{2}$ miles above Clarksville, we found a swift current with clear water over a clay bottom, more or less mixed with gravel. This bed had been worked for eight years and showed signs

of depletion. The detailed record of the 14 hauls made here is given in the following table:

HAULS MADE AT OWL HOLLOW BAR.

Number of haul.....	1	2	3	4	5	6	7	8	9	10	11	12	13	14	To- tal.
Duration in minutes.....	4	4	4	3	3	5	4	3	3	6	4	9	4	6	
<i>Lampsilis ligamentina gibba</i>									1						1
<i>Obovaria reflexa</i> <i>ellipsis</i>								1							1
<i>Plagiola securis</i>						3				1	1				2
<i>Unio crassidens</i>	1	3		1			1	1				1	1		12
<i>gibbosus</i>						1			1			1	1		4
<i>Quadrula heros</i>	2		1			1		2							6
<i>obliqua</i>	13	9	14	6	4	7	4		2	3	3	16	5	4	90
<i>ebena</i>	2	1	1	1			3	1		2	1	3	1	1	17
<i>tuberculata</i>			1			1							1	1	4
<i>cooperiana</i>						1			1						2
<i>fragosa</i>							1								1
<i>metanevra</i>								1	2	5	5	1	1	1	16
<i>pustulosa</i>										1	1				2
Total.....	18	13	17	8	4	14	10	6	7	12	11	22	10	7	159

This was one of the most important mussel beds visited, since clamming was going on actively at the time of our visit, the shells being used at the Clarksville blank factory. The bed has been worked for 10 years with from three to six boats every summer, but it shows very little sign of depletion. In sorting the shells the wash-board (*Q. heros*) is piled by itself, because it is badly stained, and sold at one-half or one-third the regular price. It forms about one-fifth of the entire catch.

Of the first-grade shells the pigtoes are much the most abundant, followed by the niggerhead and the monkey-face. Mussel enemies are scarce, most of the mink and muskrats having been trapped. Pearls and baroques are rare, slugs run about three-quarters of an ounce to the ton. A large number of the pigtoes obtained were gravid and several had young in all four of the gills.

At Clarksville June 12 the river was very low and a large sand bar was being uncovered. The bottom was fine gravel and the water rather shallow, with a slow current. The yellow sand-shells were traveling rapidly into deeper water. *Plagiola donaciformis* was gravid.

At Red Rock Bar, below Clarksville, on June 6 the water was unusually clear, about 8 feet deep, and there was practically no current, the bottom firm gravel. Fourteen hauls were made here under the same conditions as at Owl Hollow Bar, save that each was 300 feet long. The mussels found gravid here were 1 *O. reflexa*, 2 *U. gibbosus*, 3 *Q. perplicata*, 1 *Q. pustulosa*, 77 *Q. obliqua*, and 10 *Q. ebena*. This is the only place in the main Cumberland that we found *S. complanata*. This bed has been worked eight years and begins to show the effects of it. The shells obtained are of better quality than when the work first began, but there are fewer slugs,

the shells being younger. *Quadrula perplicata*, called locally the "round-lake," is the pearl bearer here.

HAULS MADE AT RED ROCK BAR.

Number of haul.....	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total.
Duration in minutes.....	7	6	2	6	8	2	9	12	5	9	12	14	11	4	
<i>Lampsilis ligamentina gibba</i>												1			1
<i>anodontoides</i>		1					1		1						3
<i>gracilis</i>		1													1
<i>alata</i>								1							1
<i>Obovaria ellipsis</i>							1	1			1				3
<i>reflexa</i>							1		2	1					4
<i>Plagiola securis</i>				1					1	2		2		2	8
<i>Unio crassidens</i>	3	3			1	2		1	3					2	15
<i>gibbosus</i>			1	2			1	2		1		1			8
<i>Symphynota complanata</i>	1	1													2
<i>Quadrula heros</i>	3	1					2		2	1		1	2		12
<i>obliqua</i>	21	2	6	17	20	12	25	12	3	13	8	18	10	20	187
<i>ebena</i>	3	2			1		2				1			3	18
<i>cooperiana</i>					1			1			1		1		4
<i>fragosa</i>	1			1											2
<i>pustulosa</i>	3														3
<i>perplicata</i>	1	1			1	2	5		2	1					13
Total.....	36	12	7	22	24	16	37	18	15	19	11	23	16	29	285

Trices Landing is $1\frac{1}{2}$ miles below Clarksville and the conditions are almost exactly the same as at Red Rock bar, except that the bed is full of "hang-ups," and therefore not fished commercially.

At Meeks Spring bar, about 8 miles below Clarksville, some fine springs enter the river, one of which has its outlet richly incrustured with diatomaceous scum. The current was very slow and the water unusually clear over a bottom of coarse gravel. This bed has been fished for 10 years and 500 or 600 tons of shells have been taken from it. Most of the *O. reflexa* and *Q. fragosa* were found cleaned at muskrat holes and were practically the only shells there. The yellow sand-shell and the rabbit's foot had been going shoreward during a previous rise in the river, but turned and went back when the water fell. Many of these sand-shells were gravid June 10 and were used in making a plant of mussels in the river at Clarksville.

The Red River is the only tributary of any size that enters the lower Cumberland from the north. No mussels could be found for several miles above its mouth, probably because the bottom was found to be covered with soft mud which shifted considerably during high water.

At Ringgold, on the west fork of the river, there is a high milldam, which backs the water up for several miles. No mussels were found above this dam, and below it they were rather scarce and all of small species. Several *L. multiradiata* were found which showed no rays, a few *L. vanuxemensis*, and one live *L. glans*. This proved to be the only place where *vanuxemensis* occurred.

Mr. Boepple visited Port Royal, at the junction of the two forks of Red River, on June 14. The river here is not large and is shallow

except a few deep holes; the bottom is gravel and mud. The mussels were collected with a rake and by wading, and were mostly near the bank in the mud, only a few being found in the gravel. Sixteen species were obtained in all, two of which, *S. costata* and *S. complanata*, were rare in the main river. The mussels were said to have been formerly abundant, but they had been nearly cleared out by pearlers, and not enough marketable species were left to make fishing profitable.

Haynes Lake lies several miles below Clarksville, on the north side of the river, and is apparently a part of the old river channel. It is about a mile long and surrounded by woods; the bottom is soft mud and the water is about 3 feet deep, with a temperature of 89°. Very large specimens of *Anodonta grandis gigantea* were obtained, 2 of which contained sporocysts of some distomid, while 2 others were gravid (Sept. 4). The nacre of 8 was purplish, that of the remaining 17 a beautiful creamy white. Of the 2 specimens of *A. imbecillis* 1 was gravid.

Elk Creek Shoals, 13 miles above Dover, had a current of 3 miles an hour in water 10 feet deep over a bottom of gravel mixed with some sand. Nine of the pigtoes obtained here were gravid (May 30), and on the land bar above the shoals was found one dead *Truncilla sulcata*, a species which is exceedingly rare in the Cumberland.

Walter's shelling camp was about a mile below these shoals, and Mr. Walter very kindly conveyed us up and down the river in his launch, giving much valuable information. He had a pile of shells containing about 150 tons, of which the most important button shells, in the order of their abundance, were the Ohio River pigtoe, the Cumberland pigtoe, the monkey-face, the yellow sand-shell, the butterfly, the niggerhead, and the southern mucket.

At Glasgow Landing, 2 miles above Dover, on May 29 the current was about 4 miles an hour, the water high and muddy but rapidly falling, and the bottom gravel mixed with clay. About one-third of the pigtoes were gravid, the glochidia being usually in the lower half of the outer gills. The niggerheads were also in the early stages of gravidity, all four gills being red and padlike; one elephant-ear was gravid. At the foot of Dover Island the conditions are the same as just recorded except that the water was 20 feet in depth. A small species of *Atax*, with broad white marks on the back, was found on several of the mussels obtained here. Marginal distomid cysts were fairly common, especially in *P. securis* (the butterfly). This same butterfly was frequently gravid, the pigtoe was less often gravid, and a single specimen of *Q. fragosa* had glochidia in all four gills.

A noteworthy feature of the lower river, somewhat marked at Clarksville, but decidedly more so at Dover and below, is the land-

slips that occur along the banks, when great masses of earth slide into the water, sometimes carrying trees with them.

At Jones Landing there was another clammers' camp, operated by a Mr. Scarborough, who rendered us considerable assistance. The water here was 15 feet deep and the current about 3 miles an hour over a bottom of mud and gravel. Sixteen hauls were made here, with the following results:

HAULS MADE AT JONES LANDING.

Number of hauls.....	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16 ^a	Total.
Duration in minutes...	15	8	6	5	4	2	2	4	8	6	6	8	5	8	4	4	
<i>Lampsilis anodontoides</i>							1	2									3
<i>gracilis</i>													1				1
<i>alata</i>						1											1
<i>Plagiola securis</i>	1	1	1		1								1	2			7
<i>Unio crassidens</i>		1			2							1	1				5
<i>gibbosus</i>													1				1
<i>Obovaria ellipsis</i>											1						1
<i>reflexa</i>									1	1							3
<i>Quadrula heros</i>	2	2	5	1	2			3	1	3		6		1			26
<i>obliqua</i>	13	15	12	12	31	14		20	18	24	4	32	21	27	25		268
<i>ebena</i>	1		1	1	4			3		2		4	5		2		23
<i>tuberculata</i>	1				1				1			1	1				5
<i>fragosa</i>										1							1
<i>metanevra</i>						1								1			4
<i>pustulosa</i>	1	1			1				2			1			2		8
<i>perplicata</i>		2		2	1	1						1					7
<i>plena</i>						1											1
<i>tritogonia</i>										1							1
Total.....	19	22	19	16	44	18	1	28	23	32	5	46	31	31	31	0	366

^a No mussels taken.

At Three Sisters Springs, near Linton, Ky., some remarkably large springs flow out of a cave into the river. There was a current of 4 miles an hour in water 20 feet deep over a bottom of soft gravel. No parasites were found except distomid cysts along the margin of the mantle of a few shells. Stained and rough tips, which in some places indicate pearl formation, were common in the shells here. Six of the pigtoes had the lower half of the outer gills filled with glochidia (May 24). All the mussels examined had their intestines filled with greenish mud and appeared well fed.

The main bed is a little below the springs and had been worked for four seasons. Our helper, who had been a professional clammer, had on one occasion dug in this bed 13 boxes of shells of 100 pounds per box in one day. This was in competition with another man who dug 12 boxes in the same time—a ton and a quarter by the two men in a single day.

Below Linton shell beds are common but none were being worked above the mouth of Donelsons Creek. The largest of these beds is at Dead Mans Bar, where there was a large pile of culls near the mouth of Terrapin Creek.

At Donelsons Creek a clammer had just begun working and had only a few shells, chiefly pigtoes, washboards, niggerheads, and

monkey-faces. A mile below Canton, Ky., there is another bed in 12 to 15 feet of water which had been worked previously as was evidenced by an old shell pile, in which a single valve of *L. fallaciosa* was found. In the hauls here taken by our party were obtained, May 23, four gravid niggerheads and five pigtoes.

The bed at Eddyville, Ky., examined May 18, was on a gravel bottom covered with 15 feet of water, with a current of about 2 miles an hour. This bed had been worked more or less for four years, but was difficult and unsatisfactory on account of numerous "hang-ups."

Just above the Ferry at Kuttawa, Ky., there was a large mussel bed on a bottom of sand and gravel, covered with 8 or 10 feet of water, with a swift current. Eighteen hauls were made with the following results:

HAULS AT KUTTAWA, KY.

Number of hauls.....	1	2	3	4	5	6	7	8	9	10	11 ^a	12 ^b	13 ^a	14 ^c	15	16	17	18	Total.
Duration, minutes....	3	3	6	4	4	4	4	3	4	6	5	2	4	5	5	2	5	5	
Length in feet	100	200	100	100	100	30	100	50	50	100	100	30	60	40	100	30	100	100	
<i>Lampsilis fallaciosa</i>			2							1									2
<i>orbiculata</i>					1														2
<i>ovata</i>							1												1
<i>recta</i>										1									1
<i>alata</i>																	1		1
<i>gracilis</i>							1												1
<i>Quadrula heros</i>		6	5	3	6	1		7				1				4		1	34
<i>ebena</i>	1	8	4	3	18			1		26					6		9	12	88
<i>obliqua</i>		2		7	11		8	3		2							7	8	48
<i>fragosa</i>				1						1							1	1	4
<i>metanevra</i>				1	2	1	3	1		2									10
<i>pustulosa</i>				1													1		2
<i>perplicata</i>						1			4								8		13
<i>trigona</i>								1											1
<i>tritogonia</i>							1												1
<i>Unio crassidens</i>			1	4	1		3	1		1							2	3	16
<i>Plagiola securis</i>		1																	1
Total.....	1	17	12	20	39	3	17	14	4	34	0	1	0	0	6	4	29	25	226

^a No mussels, due to shifting sand.^b Water 50 feet deep.^c No mussels.

Of the gravid mussels obtained in these hauls the elephant-ear (*U. crassidens*) had the entire outer gills padlike, striate, and white. *Lampsilis orbiculata* has a marsupium that is black-edged, while the mantle is striated brown and black like that of *L. ventricosa*. The pigtoes (*Q. obliqua*) were just beginning to become gravid (May 13), with minute white spawn along the crenate edge of the outer gills. In *Lampsilis gracilis* the posterior half of the outer gills had much the appearance of a lima bean, in which the conglutinates were somewhat separated, with no black edge and no furrows.

CHARACTER OF WATER OF THE CUMBERLAND RIVER.

In the coal regions of the upper Cumberland River the water is generally clear and of an acid nature. The acidity is well shown by the limy parts of the dead shells being greatly dissolved away and in

many cases the epidermis alone left. That the mussels do not thrive well in this portion of the river is probably due to the fact that the bottom is rocky, food scanty, and the water deficient in lime.

Below the Cumberland Falls in the limestone formations the water contains a considerable percentage of lime. Here the shells are much larger and thicker than those above the falls.

The table given below is taken from the United States Geological Survey "Water-Supply Paper 236," by R. B. Dole, and shows the mineral conditions of the Cumberland River, at Nashville, Tenn., and Kuttawa, Ky., two widely separated localities of the lower river. A sample of water was taken daily, these mixed, and a sample from the mixture was taken for analysis. There were about 3 analyses made per month, or 36 per year. This method gives a much better general knowledge of the conditions than a single sample would do. From Nashville the samples were collected from October 24, 1906, to November 3, 1907, and 35 analyses made; from Kuttawa, from January 11, 1907, to January 11, 1908, 34 analyses were made.

The following table gives the general average of the analysis, in parts per million, and also the per cent of the anhydrous residue:

MINERAL ANALYSES OF WATER FROM CUMBERLAND RIVER.

[Parts per million, unless otherwise stated.]

	Near Nashville, Tenn.		Near Kuttawa, Ky.	
	Mean.	Anhy- drous residue.	Mean.	Anhy- drous residue.
		<i>Per cent.</i>		<i>Per cent.</i>
Turbidity.....	126	.....	176	.....
Suspended matter.....	94	.....	165	.....
Coefficient of fineness.....	.74	.....	.92	.....
Silica (SiO ₂).....	20	16.4	18	14.6
Iron (Fe) ^a	.42	1.5	.30	1.4
Calcium (Ca).....	26	21.3	28	22.8
Magnesium (Mg).....	3.6	2.9	4.3	3.5
Sodium and potassium (Na + K).....	9.6	7.8	7.8	6.3
Carbonate radicle (CO ₃).....	0	37	.9	40.6
Bicarbonate radicle (HCO ₃).....	92	.....	100	.....
Sulphate radicle (SO ₄).....	14	11.4	9.7	7.9
Nitrate radicle (NO ₃).....	1.2	1.0	1.8	1.5
Chlorine (Cl).....	2.1	1.7	3.0	2.4
Total dissolved solids.....	119	.....	124	.....

^a Fe₂O₃.

COMMERCIAL VALUE OF THE MUSSELS.

Taking into consideration both the relative abundance of the species and the intrinsic value of the shell, the southern mucket (*L. ligamentina gibba*) is the most important commercial mussel of the upper river; that is, from Burnside down nearly to Nashville.

From Nashville to Clarksville the mucket is not relatively as abundant, and is consequently surpassed in value by the Ohio River pigtoe (*Q. obliqua*).

From Clarksville to the mouth of the river the honors are divided between the pigtoe and the niggerhead (*Q. ebena*). There are other shells all along the river which possess a high intrinsic value but are not found in sufficient quantities to equal the ones just mentioned. The most important of these are the yellow sand-shell (*L. anodon-toides*), the most valuable of all our fresh-water species, the butterfly (*P. securis*), *Lampsilis orbiculata*, a shell of very high value and desirable for propagation, and the Missouri niggerhead (*O. ellipsis*). The Cumberland pigtoe (*Q. cooperiana*) and the long niggerhead (*Q. subrotunda*) are also much esteemed by the button manufacturers. Samples of shells from the upper portions of the river were carefully weighed, measured, and appraised by Mr. Boepple, with the results indicated in the following table:

COMMERCIAL VALUE OF MUSSEL SHELLS TAKEN FROM THE CUMBERLAND RIVER IN OCTOBER AND NOVEMBER, 1910.

Species.	Locality.	Weight.	Number shells.	Number blanks.	Lines.	Number gross per ton.	Value per gross.	Value per ton.
		Pounds.					Cents.	
<i>Lampsilis ligamentina gibba</i> .	Martinsburg, Ky.....	5	16	237	-----	685	5	\$34.25
Do.....	Coes Landing, Ky.....	2½	12	180	20	916	6	54.96
Do.....	Martinsburg, Ky.....	5	17	222	20	522	3	15.66
Do.....	do.....	5	17	222	20	723	5	36.15
Do.....	Burnside to Burksville.	5	32	390	-----	928	5	46.40
Do.....	Obey River, Celina, Tenn. }	5	12	57	36	135	20	27.00
	do.....			129	20	307	7	21.49
<i>Quadrula obliqua</i> ..	Coes Landing, Ky.....	5	37	76	30	180	10	18.00
<i>Dromus dromas</i> ..	Martinsburg, Ky.....	2½	11½	23	35	109	15	16.35
<i>Lampsilis ovata</i> a.	do.....	2½	11½	T 67	-----	319	2	6.38
<i>Dromus dromas</i> and small <i>Quadrulas</i> mixed. b	do.....	2	34	125	-----	744	2	14.88
<i>Unio crassidens</i> ...	do.....	2½	13½	137	20	652	-----	-----

a Tips.

b Pearly tips.

A good idea of the extent of clamming operations on the river below Nashville may be obtained from the following data, contributed by various shell buyers at Paducah, Ky.: On some of the beds mussel fishing has been conducted for at least 10 years. One mussel firm, with headquarters at Paducah, had 300 boats operating from Paducah to Nashville. In 1907 this company obtained 1,783 tons of shells from this part of the Cumberland River; in 1908, 1,400 tons; in 1909, 1,100 tons; in 1910, 1,125 tons. In consequence of a sudden drop in the price of shells this company was not working the river during 1911.

Another buyer reported 500 tons obtained from the same region of the Cumberland by his company during each of the years 1907, 1908, and 1909, but only 100 tons in 1910.

In addition to these companies there were Ohio River parties and private fishermen operating in the river, which must have increased the annual output to considerably over 2,000 tons per year.

Because of the drop in prices mentioned above, none of the larger companies were operating the river during 1911 with the exception of Mr. Walter, at Dover, Tenn., and the blank factory at Clarksville, Tenn.

BREEDING SEASON OF THE CUMBERLAND MUSSELS.

Throughout the progress of the survey the various species of mussels were examined as to breeding condition and the date at which the various species were found gravid is shown in the table following. In addition to the table, which gives only the bare facts, the following additional notes will prove of interest and value.

The only *Lampsilis ovata* found gravid was on May 13. Mr. Boepple sent in some gravid examples during the late autumn of 1910. Without doubt this species is usually gravid from autumn until the next spring. *L. multiradiata* was found becoming gravid July 28. In other streams we have found it fully gravid in September and October. *Lampsilis anodontoides* was found fully ripe in abundance from June 10 to 21. The breeding season of this species is well known; it usually becomes gravid in autumn and remains so during the winter. *Quadrula perplicata* was noticed becoming gravid May 24, and gravid samples were still found July 27. Although *Quadrula cooperiana* remained gravid for a considerable length of time, we saw only a few samples; the citations refer to single individuals, so that, while we have it recorded from June 3 to August 11, only 11 gravid examples altogether were seen. The characteristics of the gravid mussel are described under the discussion of the species. It is a desirable species to propagate. *Quadrula obliqua* is the most prolific mussel in the river, and we saw many more gravid examples of this than of any other species. From June 3 to 10 is the height of its breeding season, and at that time about half the catch obtained would be gravid. When the life history of the species is known and the fish which serves as host, it will be easy to procure material for propagation during a considerable part of the summer.

Quadrula ebena was observed in early stages of gravidity about the beginning of the work, and gravid examples were obtained as late as July 16. The other species noted are not of special economic importance and gravid examples were found only in small numbers. Sufficient information about them can be obtained by a glance at the table.

TABLE OF GRAVID SPECIMENS OF MUSSELS FOUND IN THE CUMBERLAND, 1911.

Dates.	<i>L. ovata.</i>	<i>L. multiradiata.</i>	<i>L. anodontoides.</i>	<i>L. vanuxemensis.</i>	<i>L. gracilis.</i>	<i>M. conradicus.</i>	<i>O. circulus.</i>	<i>O. ellipsis.</i>	<i>O. reflexa.</i>	<i>A. imbecillis.</i>	<i>A. grandis.</i>	<i>U. gibbosus.</i>	<i>U. crassidens.</i>	<i>P. elava.</i>	<i>Q. perplicata.</i>	<i>Q. cylindrica.</i>	<i>Q. metanavra.</i>	<i>Q. pustulosa.</i>	<i>Q. fragosa.</i>	<i>Q. cooperiana.</i>	<i>Q. obliqua.</i>	<i>Q. coccinea.</i>	<i>Q. subrotunda.</i>	<i>Q. ebena.</i>	<i>Q. tuberculata.</i>
May 13.	×				×								×												
15.																					×				
17.																								×	
18.																									
23.								×									×								
24.									×															×	
29.																			×						
June 3.													×												
5.									×								×								
6.												×												×	
7.																									
10.			×																						
16.									×																
17.			×													×									
21.				×								×													
28.												×													
29.												×													
July 1.						×						×		×											
8.																									
9.							×																		
10.																									
11.																									
13.												×												×	
14.																									
15.																									
16.																									
27.															×	×								×	
28.		×																							
31.					×																				
Aug. 9.																									
10.																									
11.																									
17.																									
18.																									
21.																									
Sept. 2.																									
3.																									
4.											×	×													
9.																									

PEARLS AND PEARLING IN THE CUMBERLAND.

Just when pearling began on the Cumberland there is no definite record. It has been in operation quite steadily on the upper river for at least 20 years. It is not generally carried on actively the year round, but chiefly in August and September, when the water is low. There are few professional pearlmen, however; that is, men who devote their entire time to the gathering of pearls. Most of the pearling is carried on by farmers at odd times, and by men who in the winter devote their energies to lumbering, chopping, or trapping.

Hunting for pearls is confined mostly to the upper river and the tributaries. It seems that the conditions suitable for pearl formation are more abundantly fulfilled in small streams.

The first sign of active pearling operations seen by the present survey was encountered about Burnside. The search for pearls extended above the town as far as Seven Mile Shoals and downstream as far as Celina, and less actively to Carthage and beyond. A short

distance below Burnside pearling has been recently in active operation, at Pittman and Fishing Creek. From Burnside down to Burkesville Mr. Boepple had noted in 1910 that the river bed was well filled with shells killed by pearlers, and in 1911 the same work was being continued farther on downstream. At Patty Shoals below Mill Springs in 1910 "yellow mussels" (*L. ligamentina gibba*) had been pretty well fished out, since the pearlers opened only this species.

In order that due allowance may be made for the inevitable degree of unfounded rumor on such subjects, we will give at first the reports of the rivermen and supplement them later by our own observations.

At Burnside we heard that a pearl had been found at the mouth of Pittman Creek which was worth \$250 or \$300 and another that had been sold for \$40, and we were told of a man living down the river, back some distance in the country, who had a fad for pearling and buying pearls, and who had accumulated in this way about \$20,000 worth of pearls, baroques, and slugs at the time our informant visited him. Many pearls had been found in the vicinity of Eadsville, the highest price any single pearl from that locality brought being \$800.

In August and September 100 men were often pearling at once on a shoal near Rowena, and the highest price paid for any single pearl was \$500. There had also been much pearling on a mussel bed below Tear-coat Bar and on another at Clouds Island during the past five years, sometimes as many as 50 men working at the same time. At Goodall Island, for 20 years previous to the time of closing the lock, pearling had been in active operation. At one time 150 men were at work together on the bed, and in one week \$30,000 worth of pearls were found. Pearling had also been carried on near the mouth of Goose Creek above Hartsville in former years, but it stopped after the building of the lock below, which flooded the beds with lock water and rendered it difficult to obtain the mussels.

Not only the upper river but its tributaries also were famous for pearls. At Carthage it was said that better pearls were found in the Caney Fork than in the Cumberland, and that they commanded a much better price. Mr. Boepple, who investigated the lower 26 miles of the Obey River at Celina, remarks: "Twelve to fifteen years ago there was much pearl fishing here, and it seems to have paid until, indeed, the mussels had been fished out by pearlers." Stones River was in good repute as a pearling stream, and a merchant at Clarksville stated that his father used to buy many pearls from there. There had been active pearling on this river only a short time before our visit, and some shells left by the pearlers and examined by our party showed indications of pearl formation. Red River, which enters at Clarksville, is said to be a good pearl-bearing stream in its upper

portion, and we saw a number of very good pearls from there. Little River, across from Canton, Ky., is also said to yield numerous pearls, which, however, are rather small.

Our own observations, as well as the records of people engaged in the pearl trade, indicate that pearling was once an important occupation in the upper river. We saw in many places large piles of shells left by pearlers along the river banks, and came across one party actively engaged in pearling. Mr. Boepple saw a collection of pearls in Rowena valued at \$1,000, and this represented only a portion of those found in the vicinity, since the largest and finest pearls were sent directly to New York. At Butlers Landing a store-keeper showed us a very pretty collection of "rosebud" pearls, all with a good luster, four of which were purple, five yellowish, and eight white.

At Clarksville, as mentioned above, we saw some very pretty pearls from Red River. One of the principal merchants at Carthage buys about \$15,000 worth of pearls every year. The highest price he had paid for a single pearl was \$2,500. They generally range from \$20 to \$300. A shell buyer at Paducah, Ky., bought \$2,000 worth of pearls during the season of 1910. While genuine round pearls are not common in the lower river, rough pearls and baroques are usually present to the amount of three-fourths ounce per ton of shells. The baroques vary from \$2.50 to \$3.50 an ounce.

On account of the ground to be covered and the time at our disposal, together with unfavorable weather while on the upper Cumberland, we did not have opportunity to devote very much attention here to pearl formation, though this region would prove an exceptionally good location from which to attack the problem. In looking over the flesh of some mussels recently killed by pearlers a number of black distomid cysts, similar to those found in the Maumee River (Indiana and Ohio), were observed, and these probably figured in part at least as an exciting cause.

A study leading to the discovery and the consequent conservation of the peculiar conditions which favor pearl formation in the upper Cumberland and its tributaries, accompanied with active propagation of the southern mucket in that region, would be highly desirable. The mussels are not yet so nearly exterminated that gravid material can not be readily procured, though it is feared that they soon will be, in view of the active depredations of the pearlers. It is believed that mussel planting could be kept well ahead of any onslaught likely to occur and that the resulting harvest would yield not only an abundance of the very best button material but also a plentitude of pearls, and thus prove a source of much greater benefit than where mussels are reared for the shells alone.

DISCUSSION OF MUSSEL SPECIES.

In the list of species here presented we have followed in most respects the classification and sequence given in Simpson's well-known Synopsis of the Naiades. In the spelling of the names, however, we have followed the suggestions of Lindahl^a and have made also a few minor changes, such as the substitution of the older name *Quadrula undata* for *Quadrula trigona*, as suggested by Mr. Bryant Walker, and the transference of the *Medionidus subtentus* (Say) to the genus *Ptychobranchus*, and of *Tritogonia tuberculata* (Barnes) to *Quadrula* under the name *Quadrula tritogonia*, as suggested by Dr. Ortmann. Many other changes have been proposed which will probably in the end prove justifiable. We have avoided making any shifts between *Pleurobema* and *Quadrula*, although several have been advocated which may be desirable. The fact that both *Pleurobema æsopus*, *Quadrula obliqua*, and another perplexing form which we have found may have glochidia in two, three, or all four gills indicates that these two genera should really be united.

We are very favorably inclined toward the new classification proposed by Ortmann,^b but its present state of incompleteness and the uncertain position of many species, as well as our own conclusions regarding *Quadrula* and *Pleurobema*, make it seem best at present to use the older and better known system with the few exceptions noted above.

1. *Truncilla triquetra* Rafinesque. Snuffbox.

This attractive little shell occurs only in the upper part of the river. In all we procured 21 specimens, 19 of which were obtained at Salt Lick Bar. In the autumn of 1910 Mr. Boepple found it at Indian Creek, Cloyds Landing, Albany Landing, and in the Obey River at Celina, Tenn.

It is in all probability considerably more common and widely distributed in the river than our collections would indicate. But it does not seem to occur as far down the river as Half Pone Bar or at Clarksville; if it did a few examples would certainly have been taken among the great number of small mussels collected in that region in June.

Truncilla triquetra is a small species, dwelling in the shallower water. On account of its small size it is rarely or never taken on the mussel dredge or rake, but must be gathered by hand. It has a handsome, strong and thick shell, but is too small to have any commercial value. All our examples are pretty well eroded at the umbones.

2. *Truncilla brevidens* (Lea).

This species was not found in the main river at all and only at three stations altogether. It was most abundant in the Big South Fork opposite Parkers Lake Station. Three examples were procured in the same fork 2 miles above Burnside and one in Beaver Creek. It is too small to have any commercial value.

All the specimens found were dead, but some had been recently killed by muskrats, therefore nothing was learned concerning its habits. It appears to be a species

^a Lindahl, J.: Orthography of names of the Naiades, The Journal of the Cincinnati Society of Natural History, vol. xx, no. 5, art. viii.

^b A monograph of the Naiades of Pennsylvania, reprinted from the Memoirs of the Carnegie Museum, vol. 14, no. 6, Feb. 15, 1911.

occurring in moderate-sized, clear streams with a rocky bottom, avoiding the smaller tributaries.

3. *Truncilla arcæformis* (Lea).

Rare; only one example obtained. This was procured in the Big South Fork 2 miles above Burnside, Ky., and is rather peculiar in shape.

4. *Truncilla sulcata* (Lea). Pewee, cat's-claw.

Although this species seems to be pretty well distributed along a considerable stretch of the river, we obtained only occasional examples here and there along shore. Mr. Boepple found one in Caney Fork. It can probably be procured in larger numbers during low water. It is common enough to be pretty well known to the clammers, who call it "pewee" on account of its small size, or "cat's-claw" because of the peculiar clawlike structures on the marsupial expansion of the shell of the female.

5. *Truncilla haysiana* Lea.

Our collection of this species is rather small, but it is probably more common than the collection would indicate, as it is too small to bite on the crowfoot hook and is easily overlooked. Most of the examples collected had been killed and cleaned by muskrats. It is one of the handsomest of the *Truncillas* on account of its beautifully polished epidermis, and it has an unusually thick and solid shell for the genus. It is, however, too small for manufacturing purposes.

6. *Truncilla capsæformis* (Lea).

Fairly abundant in the Big South Fork, where nearly all the specimens had been killed by muskrats; in the main river we found it sparingly. Our shells are pretty badly eroded, very thin and brittle, with the marsupial expansion colored a dark green. The species is of no value for manufacturing purposes, being too small and thin.

7. *Truncilla florentina* (Lea).

Rare; the only specimen obtained was the dead shell of an old and very inflated female at Half Pone bar. In the autumn of 1910 Mr. Boepple found a specimen at Indian Creek bar. During low water probably many more could be obtained.

8. *Truncilla walkeri*, new species. (See fig. 1, frontispiece.)

A fine, large *Truncilla* with a honey-yellow epidermis and numerous capillary rays. Shell rather thin, elliptical in outline, much inflated in the females, only moderately in the males. Anterior margin projecting and evenly rounded, ventral margin strongly convex in the larger males, much less so in the females and smaller males; posterior margin oblique, but usually well rounded in both sexes; dorsal margin comparatively long, straight, or slightly curved. Umbones narrow and flattened. Anterior, lateral, and posterior slopes all well rounded; umboidal ridge flattened and indistinct, especially in the females. In front of this ridge the males have a broad and shallow sulcus; in the females the marsupial expansion is very pronounced, and is usually limited anteriorly and posteriorly by a deep and narrow sulcus. It is somewhat like that of *capsæformis*, but is considerably swollen, especially in the larger females, instead of being flattened, and does not project as strongly. Lines of growth smooth, distinct, and close together. Ligament long, thin, and light brown.

Interior: Pseudo cardinals large and thick, rather blunt and only slightly serrate or smooth; laterals long, high, thick, and slightly curved; anterior adductor scar slightly longer than wide, squarely truncated posteriorly; posterior scar large, deeply impressed, and squarely truncated anteriorly much as in *brevidens*; pallial impression fairly distinct, nacre milky white, thinner and quite iridescent posteriorly.

This species was quite abundant just below the ford of the East Fork of Stones River near Walterville, Tenn. We found here 140 shells, most of them on shore and recently killed by muskrats, and 1 or 2 living mussels. The smallest specimen (male)

measures 23.2 mm. long, 15.3 mm. high, and 8.8 mm. in diameter, the smallest female 31 mm. long, 19.9 mm. high, and 12.9 mm. in diameter. The largest male measures 57.7 mm. long, 42.7 mm. high, and 26.4 mm. in diameter, and the largest female 52.8 mm. long, 39 mm. high, and 23.9 mm. in diameter. There are 49 females, the others being males.

Walkeri, to Mr. Bryant Walker, one of our most eminent conchologists.

9. *Lampsilis ventricosa* (Barnes). Pocketbook.

Typical specimens of this species were obtained in two tributaries of the Cumberland, Harpeth River near its mouth, and Stones River, in the east fork at Walterhill and the west fork at Murfreesboro, Tenn. Just how common or widely distributed it is in the streams above mentioned is not known. The examples found were exceptionally fine and would make very good button shells.

In the main Cumberland *L. ventricosa* seems to be quite rare, its place being usually taken by the closely related *L. ovata*. Indeed, the distribution and relationships of *ovata* and *ventricosa* as found in the Cumberland and its tributaries are exceedingly perplexing. A few examples found near Clarksville, and a dwarf shell found at Elk Creek shoals above Dover, however, offered exceptional difficulties in classification, fitting in neither with *ventricosa* nor *ovata*; the male shell would perhaps fall on the *ovata* side of the dividing line; the females on the *ventricosa* side, if indeed not rather beyond the limits of the typical shell; these shells, both male and female, were rather too thick and solid for *ovata*. A marked feature of those at hand is a deep pink tinge of the nacre posteriorly, this tinge being pretty sharply limited to the postero-dorsal area, a feature not common with either *ventricosa* or *ovata*.

The female shells are considerably more inflated than the males and have a peculiar flattening of the lower part of the posterior margin. One of the female shells was sent to Mr. Bryant Walker, who remarks concerning it as follows: "No. 5456 is a most remarkable shell. I have never seen a female *ovata* with such an enormous expansion. *Ventricosa* not uncommonly tends that way, but not to such an extent. * * * This shell is comparable only with *satur*. [A variety of *ventricosa*, according to Simpson; *satur* is *L. excavata*, according to Frierson.] This shell is either an extraordinary abnormality of *ovata* or is *ventricosa*. In view of the occurrence of *ventricosa* both in the Harpeth and Stones, I am inclined to refer it to the latter."

10. *Lampsilis ovata* (Say). Southern pocketbook; "grandma."

A fairly common species throughout the entire length of the Cumberland, more numerous in the upper portions and upper tributaries.

This species is one of the very few found in the Cumberland above the falls. Mr. Boepple obtained it at Pineville and Williamsburg and we found a few in the vicinity of the latter place and several examples just above the falls. Just below the falls it was abundant and common at the stations farther down. Associated with the typical form, which is relatively uncommon, is an aberrant form, more closely resembling *ventricosa*.

The specimens of this aberrant form were at first identified as *L. subovatus* Say, described and figured by Call.^a On examination of the literature, however, there is no "*Unio subovatus* Say," and the name in Call's report is plainly a misprint for *ovatus*, the *Unio subovatus* Lea being an entirely different thing.

Say's original description of "*Unio ovatus*" is brief and the figure poor, but recognizable; it is probably better known from Conrad's description and excellent figure.^b

The greater number of our specimens, however, differ considerably from the typical form. Beginning with the shapely, high-ridged clear yellow shell, which represents

^a Mollusca of Indiana, Twenty-fourth Annual Report of Geology and Natural Resources of Indiana, p. 481, pl. 39.

^b Conrad, Monography, p. 4, pl. 2.

the species in its perfection, we have stained horn-colored examples, then deep-brown specimens and specimens with broad distinct rays. Inflated females are likely to have the ridge characteristic of *ovata* less markedly developed than males; in both sexes, however, there is a tendency for it to appear in all degrees of imperfect development until in some examples it is barely discernible. Indeed in one of our examples it is almost wholly absent, and we have a shell that, with the exception of purely individual features, can not be distinguished from a specimen of *L. ventricosa* from the upper Mississippi River.

Judging from the soft parts of a single gravid female examined, the bodies of *ventricosa* and *ovata* are quite unlike, the mantle flap of *ovata* showing a peculiar mottling quite different from the markings observed in the other species.

The variously modified forms of *ovata* are not only more abundant, but also more widely distributed than the type form. Just below Cumberland Falls most of the shells of this species are of medium size or smaller, nearly all are smoky brown, and several are well-rayed. At Indian Creek Bar brown and few-rayed individuals occur along with the typical form. At Goodall Island we found one with numerous distinct rays.

The shells of the Rock Castle River are different from the others and can be told almost at a glance. They are dark brown, longer and heavier than those of the other streams and have the posterior ridge rather low; *ovata* takes nearly the same place in the Cumberland that *ventricosa* does in the upper Mississippi.

We have always found *ovata* considerably inferior to *ventricosa* as a button shell, being thinner, smaller, and more brittle. The Rock Castle River *ovata* could possibly be used for buttons, but would furnish rather poor material. In the Cumberland the *ovata* is a rather valueless shell.

Call's experience with *ovata* is different. He says it is "one of the largest that are found in American waters; * * * it also attains a much greater size than Barnes's form (*ventricosa*)." This may be perfectly true for some rivers, as shells vary greatly in size and thickness in different streams.

11. *Lampsilis multiradiata* (Lea).

Rather rare in the main river and found almost entirely in its upper portion. Occurs typically in small, clear streams and often in lakes. It is more common in the tributaries than in the main river. The specimens from both forks of Stones River are beautiful shells, typical in form, not much eroded, and with a clear, white nacre. The specimens from Rock Castle River, Big South Fork, and the main stream depart more or less from the typical form, being unusually elongate and sharp-pointed posteriorly, rather thin, considerably eroded, and more or less stained or diseased in the nacre or in the teeth. On comparing the Red and Stones River shells with the others, a marked difference was noted in the cardinal teeth. In these typical specimens the large posterior cusp of the right valve pointed more or less anteriorly, while in the Rock Castle River specimens and most of the others it pointed more or less posteriorly. A few shells with intermediate characters in this respect were found, however.

12. *Lampsilis ligamentina* (Lamarck). Mucket.

This species is represented in the Cumberland chiefly by the southern mucket, *Lampsilis ligamentina gibba* Simpson, which differs from the typical form in being shorter and more compressed. The two forms grade into each other so imperceptibly that it is impossible to find the point of separation between them. In the lower part of the river it approaches more nearly the typical form.

The shell of the subspecies often has the epidermis more highly polished than in the type form, the nacre has more luster, and the valves are flatter and more uniform in thickness. The shells are therefore superior to those of the common mucket for manufacturing purposes and are sought after by shell buyers. Like the other forms of this genus this mucket carries its young in the gills through the winter. The

glochidia fasten readily to our common spiny-rayed fishes. Some gravid examples of this form were collected by Mr. Boepple in the autumn of 1910 from the upper Cumberland and sent to the biological station at Fairport, and though the mussels were dead the glochidia were still alive and attached themselves readily to fishes.

This is the most desirable form with which to stock the river and extensive plantings from the falls to the mouth would greatly increase its value as a mussel stream.

13. *Lampsilis orbiculata* (Hildreth).

Fairly common in the middle portion of the river, usually from 1 to 3 examples being found on each bed.

We were struck with the remarkable similarity between this species and the southern mucket, *Lampsilis ligamentina gibba*. About the only way to distinguish between them was by the bright orange shade of the epidermis, and usually orange tint of the nacre of *orbiculata*, and it is easy to understand Call's^a remark that Dr. Hildreth and the earlier naturalists seem to have considered this shell as a variety of *Unio crassus* Say (= *Unio ligamentinus* Lamarck, short and thick variety found in the Ohio), but Call adds: "It certainly would seem to be a good species." Our own studies and comparisons showed them more distinct than appeared at first glance. The difference is most plainly seen in the female shells, which differ considerably from the males, being truncate posteriorly and short and well swollen postbasally. They are well represented by Say's^b figure of *Unio abruptus*, and look somewhat like a compromise between the southern mucket and *L. ventricosa*. Ortmann^c says that this species "is not at all related to *L. ligamentina* as Simpson thinks; but it belongs to the *ventricosa* group of *Lampsilis*, for it has a well-developed flap on the mantle edge."

L. orbiculata also very closely resembles *L. higginsii* which is more generally northern in its distribution, but the males of *higginsii* are shorter, more closely approaching *Obovaria ellipsis*. *Orbiculata* and *higginsii* are probably closely related.

This is a very good button species, but so uncommon that it is not much of an item in the trade.

14. *Lampsilis tæniata* (Conrad).

Rare; none at all were found in the Cumberland or in any of the tributaries except Stones River. It appears to be a species of small clear streams, and was found in the fine gravel at the edge of the water among the water-willows.

15. *Lampsilis picta* (Lea). Painted mussel.

Rather rare, and not taken by us in the main river. We found three in the Rock Castle River a few miles back from the Cumberland. Mr. Boepple, in the autumn of 1910, obtained it in the Big South Fork at Sloans Shoals, near Burnside. It is too small and thin to have any commercial value. Our largest example measures 61 mm. long, 33 mm. high, and 17.5 mm. in diameter.

16. *Lampsilis punctata* (Lea). Spotted mussel.

It is very like *L. picta* in color and outline, but differs in being more inflated and in carrying its thickness to the edge, so that its ventral margin is rather rounded and blunt, while that of *picta* is sharp. Both species are new to our collection. Mr. Bryant Walker, who identified them for us, called attention to the differences. The shell is thick anteriorly, but thins out rapidly behind the center. It has no commercial value on account of its small size, and most of our specimens are also badly eroded.

17. *Lampsilis perdix* (Lea).

Abundant in the Cumberland just below the falls. Mr. Boepple in 1910 found it as far down as Rowena and in the Obey River at Celina. It is common in Rock Castle and frequent in the Big South Fork.

^a Mollusca of Indiana, Indiana Geological Report, p. 493.

^b American Conchology, pl. 17.

^c Nautilus, vol. XXIII, no. 9, p. 119.

This species bears a general resemblance to an elongate flattish *L. ligamentina*. Unstained shells are easily recognized by the character of the rays, which are broken up and more strongly marked in places, making a series of heavy green blotches. Another peculiarity is the short lateral teeth, 1 in the right valve and 2 in the left; these are low and blunt, and separated from the cardinals by a wide interspace. Our older shells are badly eroded and so stained and discolored that the characteristic rays and blotches are absent. Such specimens can be recognized by the narrow border of latest formed nacre, which is yellowish or reddish and semitranslucent. Our shells usually have the nacre badly stained. Even if obtained free from stains they would make rather poor button shells, as they are somewhat brittle. In thickness they are about equal to a thin mucket. A few of the examples have brick-red pimply patches on the interior which probably indicate the presence of parasitic trematodes. No parasites, however, were noted.

18. *Lampsilis anodontooides* (Lea). Yellow sand-shell.

Rather uncommon, distributed chiefly through the central portion of the river, and never forming a large percentage of any of the beds. This species thrives best on sand bars in rather shallow water. It is generally confined to large streams. It is one of the most active of the mussels, responding quickly to changes in environment by moving about. This is by far the most valuable of the fresh-water mussels, the shells being generally used for export and in the manufacture of knife handles.

This species is easily propagated, the glochidia fastening readily to most of the common spiny-rayed fishes, such as sunfishes, bass, etc. On June 13 we found a number of gravid shells at Meeks Bar. Some sunfishes were caught, a tub was procured, and an infection made. The infected fishes were then liberated into the Cumberland in front of the blank factory at Clarksville.

19. *Lampsilis fallaciosa* (Smith). Slough sand-shell.

Rare in the Cumberland and not found in any of the tributaries. This species thrives best along shore in shallow water with a rather lively current and muddy bottom. Such conditions exist only in the very lowest portion of the Cumberland. From Kuttawa to the Ohio side sloughs are more common and the species is probably more abundant. The nacre of most specimens secured is stained. This is a first-class species for the manufacture of buttons, but it would be unprofitable to plant in the Cumberland because of the absence of favorable locations for its best development.

20. *Lampsilis recta* (Lamarck). Black sand-shell.

Rather common throughout the entire length of the river, but nowhere abundant. Many of the shells are badly eroded and stained; none are deep pink throughout, but are pale pink about the cardinal teeth and in the umbonal cavity.

Good white-nacred shells of this species are exceptionally excellent button shells, and where select stock could be obtained would be one of the most desirable species to propagate.

21. *Lampsilis lienosa* (Conrad).

The specimens we have are hardly typical and were with some doubt identified as this species. It is a small species of no commercial importance.

22. *Lampsilis vanuxamensis* (Lea).

The females of this species were gravid June 6. They are peculiar in having the marsupial expansion of the shell rather limited in area, not extending to the posterior end, but followed by a pointed extremity. In this localization of the shell they remind one somewhat of the *Truncillas*. The shells are small, red nacre, and of no value.

23. *Lampsilis trabalis* (Conrad).

Found only in the upper part of the river and its tributaries. The females are not markedly swollen posteriorly, but differ from the males in being shorter and broader.

Nearly all we found were dead shells, usually badly eroded at the umbones. Mr. Boepple found the species as far down as Cloyds Landing and in the Obey River at Celina. As found, the epidermis is generally jet black, usually due to the shells being stained. On being cleaned with acids they exhibit beautiful rays. This is a small species of no commercial importance.

24. *Lampsilis parva* (Barnes).

Rare; none at all in the Cumberland; indeed it has not been reported from that river. But we obtained one specimen in the East Fork of Stones River at Waterville. This was a slender shell; length 27 mm., height 15 mm., width 11 mm. Nacre beautifully white and iridescent.

25. *Lampsilis glans* (Lea).

Rare; none at all in the Cumberland; 10 specimens from the tributaries. Those found were in gravel in shallow and rather swift water. In general it prefers quiet streams with muddy banks and burrows in the firm mud. It is also frequently found in lakes.

One of the smallest of our species; too small for commercial use, and with a rich purple nacre. In one specimen, a female found in Roaring River, the peculiar glands of the mantle, small white cylindrical objects on each side, were protruded and were undergoing spasmodic movements.

26. *Lampsilis alata* (Say). Pancake; pink hatchet-back.

While not a rare species in the Cumberland, this is not especially common. In a few of the beds it is entirely absent, and in many only one or two shells were found. It never exceeded 4 per cent of the catch of any of the beds, and is usually less than one. It is well distributed throughout the entire river. It prefers rather deep water and a soft, muddy bottom. The shell, on account of its thinness and red nacre, is of no value whatever.

27. *Lampsilis gracilis* (Barnes). Paper-shell.

Frequent enough to be a rather familiar species among clammers, but not so abundant as to be a nuisance. It has much the same distribution as *alata*, but is less common. We usually obtained only 1 or 2 from a bed. Our shells are rather badly worn at the umbones. As this thin-shelled species is of no value whatever, but readily catches the mussel hooks, it proves to be a nuisance when present in large numbers where clamming operations are being carried on.

28. *Lampsilis lævissima* (Lea). Paper-shell.

Rare; only one specimen found in the Cumberland; this was at Meeks Spring Bar. It seemed to be more common in the Harpeth. This species closely resembles *L. gracilis* in general appearance, but has, among other distinguishing features, a beautifully polished epidermis. Our examples have a number of peculiar rays, consisting not of a different pigmentation of the epidermis but of a series of short, finely wrinkled lines.

29. *Lampsilis leptodon* Rafinesque.

This fragile, thin-shelled species is rare in the Cumberland. The only examples obtained were collected by Mr. Boepple at Albany and Cloyds Landing in the autumn of 1910.

30. *Medionidus conradicus* (Lea).

This species is confined chiefly to small streams. It is exceedingly abundant in the Rock Castle River at Livingston, Ky., the sandy bottom being almost covered with these animals, which showed up as narrow black lines, the mantle and exhalent and inhalent apertures being thin and black. It is also abundant in Roaring River.

In the Cumberland we found it just below the falls and at Salt Lick Island. All the shells were badly stained and eroded, and for this reason, as well as on account of its small size, it has no commercial value.

31. *Obovaria retusa* (Lamarck). Golf-stick.

Although we obtained only a few specimens of this species, scattered valves were frequently found along shore, and there is reason to believe that it is considerably more common than our small collection would indicate, although by no means abundant anywhere. In the Cumberland it attains a rather large size, our largest shell measuring 68.5 mm. long, 74.5 mm. high, and 46.9 mm. in diameter. It is a heavy and solid shell, but the deep purple of that portion of the nacre within the pallial line makes it valueless for buttons. All our shells are somewhat eroded at the umbones. Two of them are considerably less retuse than the others, somewhat approaching *O. circulus* in this respect. All have the epidermis somewhat paler posteriorly, but not so markedly so as is usually the case with *O. circulus*.

32. *Obovaria circulus* (Lea).

Rather common in the main river from Burnside to Half Pone Bar. This species produces too small a shell to be of much importance to the button trade. The larger shells would furnish two or four blanks apiece, and are excellent both as to material and thickness. The nacre seems to be unusually durable and retains its firmness and luster long after others have become chalky.

33. *Obovaria ellipsis* (Lea). Missouri niggerhead.

This species is chiefly northern in its distribution and does not attain large size in the Cumberland. Although in its shell characters it bears considerable resemblance to some of the *Quadrulas*, especially the niggerhead, *Q. ebena*, it is really more closely related to the sand-shells. Where it attains large size it is an excellent button shell and would be a fine species to propagate, but the reduced size of the shell in the Cumberland indicates that the conditions there are not favorable. We found gravid examples above Clarksville early in June.

34. *Plagiola securis* (Lea). Butterfly.

This species is fairly common throughout the entire length of the river below the falls, and, while not abundant enough to make a large percentage of the shells taken for commercial purposes, it makes a fair sprinkling in most of the clammers' piles. It seems to thrive exceptionally well in the Cumberland and is more common here than in most rivers. The shell, especially of young to medium-sized, well preserved males, is one of the most attractive among the *Unionidæ*. In the Cumberland there is a marked difference between the shells of the males and females, that of the former being flat and compressed and of rather uniform thickness, while those of the females are much more tumid and swollen. The measurements of a fairly typical male (F5086) of medium size are 54 mm. long, 44 mm. high, and 21.1 mm. in diameter, while those of a tumid female of about the same length (F2660) are 55.3 mm. long, 45 mm. high, and 33.7 mm. in diameter. In the lower part of the river the nacre is somewhat spotted, but upstream the shells are free from stain. On account of its excellent luster, flatness, and uniform thickness, this is an excellent button shell, the males being much superior to the females.

Females were found gravid May 29, and were in the height of the breeding season from about June 3 to 16. This would be a very valuable species with which to stock the river.

35. *Plagiola elegans* (Lea). Deer-toe.

This species is not as common nor as widely distributed as the preceding. Large shells can be used in the manufacture of buttons, but the great majority are too small. The largest example found was a single valve 59 mm. long, picked up at the foot of Gowers Island. The beautifully tessellated green markings on the epidermis make it an attractive shell when perfect.

36. *Plagiola donaciformis* (Lea).

This dainty little species is more limited in its distribution in the Cumberland than either of its two relatives. A peculiarity of the species at Half Pone Bar was the frequent unfolding of the anterior ventral portion of the shell, the inner layer being folded back against the rest, as if by some injury. The specimens found here were unusually thin-shelled and frequently had the nacre well tinged with pink. Perfect specimens of this shell are among the most attractive to be found in the Unionidæ, but the Cumberland examples, especially those from Half Pone Bar, are badly worn at the umbones, so that even small specimens have the appearance of age. This is one of the smallest of the mussels—too small to be of any use for manufacturing purposes.

37. *Cyprogenia irrorata* (Lea).

This species is of rather infrequent occurrence in the Cumberland. We found none at all in any of the tributaries, and usually found only one or two on each bed examined. The species seems to inhabit rather deep water, since we never saw any crawling around on the shallow bars. Most of the examples are rather small, and some have a shallow sulcus running over the middle of the disk from the umbonal region to the postventral margin.

A very solid shell, but of little commercial value, as it is rather brittle and has pink tips. The few shells that get into the clammers' piles are generally worked up, however.

38. *Obliquaria reflexa* (Rafinesque). Three-horned warty-back.

One of the most common shells of the river, and found throughout its entire extent. Although a rather small shell, this is so thick and solid that it is used to a considerable extent in the manufacture of buttons, each valve furnishing one or two small blanks. The species has a long breeding season, spawning through almost the entire summer, the young being extruded in white cylindrical masses. Some of these spawn masses were seen lying on the gravel at Half Pone Bar June 16. Shells of females are somewhat fuller anteriorly than the males and can usually be distinguished after some practice. The Cumberland specimens are not so beautifully rayed as those from the upper Mississippi.

39. *Ptychobranchus phaseolus* Hildreth. Kidney-shell.

Scattered in the upper Cumberland from the falls down to Half Pone Bar. Although this is a species of rather wide distribution, especially southward, and is by no means a rare shell, it is never found in great numbers or making a large per cent in any bed. The clammer rarely gets over a half dozen or dozen to the ton; the nacre is white, with a soft satiny luster; the shape is nearly that of *Unio gibbosus*, and the species would probably make a fair button shell.

40. *Ptychobranchus subtantus* (Say). Fluted kidney-shell.

This species in Simpson's Synopsis is placed in the genus *Medionidus*. Dr. Ortmann, however, has removed it to *Ptychobranchus*, and, although we have seen no gravid examples, we are inclined to follow him in this regard on account of the close resemblance of the shell to that of *P. phaseolus*, differing from that species chiefly in its thinner shell, greater inflation, and the presence of costæ on its posterior slope. On account of its small size and its thinness it has no commercial value.

41. *Dromus dromas* (Lea). Dromedary mussel.

In the main river this shell is of occasional occurrence from Mill Springs Bar, in the upper river, down to Red Rock Bar, below Clarksville, Tenn. We usually obtained one or two specimens at a station. The shells are rather heavy and inflated, though the hump on the disk, which is characteristic of the species, is not nearly as prominent as in some specimens from the Washington collection obtained by Mr. Boepple in the Clinch and Holston Rivers. Some of the shells are beautifully rayed, especially

anteriorly, but the greater number are too deeply stained for the rays to show. In the living animal the mantle is prettily rayed.

The shape, size, and solidity of the shell of this species make it suitable for the manufacture of buttons, but unfortunately it is too brittle and hard, resembling *Pleurobema xosopus* in this respect. About one-third of the shell, moreover (the tip part), is of a pink tinge, which runs entirely through the shell, making it of no value.

42. *Dromus caperatus* (Lea). Fan mussel.

The examples of *Dromus* obtained in the Big South Fork of the Cumberland differ from those found in the main river by being considerably flatter, with the hump on the disk less pronounced or nearly absent. These flattened shells represent the species *caperatus* (Lea). Our series indicate that the two forms run together. In young specimens, before the step-off is formed, it is doubtful if *dromas* and *caperatus* could be distinguished.

From what has been said concerning the relationship between this and the preceding species it may be readily inferred that this species also, from a commercial standpoint, is valueless.

43. *Strophitus edentulus* (Lea). Squaw-foot.

We found only a few examples of this species. It has a fragile shell, which disintegrates quickly and is probably more common than our small collection would indicate. Mr. Boepple found it at Pineville, the highest point at which the river was examined. It is a species which occurs in all sorts of situations—in both small and large streams and in lakes. Two of our specimens have a pink-purple nacre; in the others it is of a yellowish cast. The species is of no value on account of its thin, brittle shell. It is exceedingly variable, and presents many puzzling forms. According to Mr. Bryant Walker our specimens represent the form *shaefferiana* Lea.

44. *Anodonta imbecillis* (Say).

The distribution of this fragile, beautiful species is almost identical with that of *A. grandis*. Of the two found in Haynes Lake one was gravid (Sept. 3). The glochidia are rather large, chestnut-shaped in outline, brown, and fill the entire outer gills. The species remains gravid through the winter. The Haynes Lake shells contained several *Atax* apiece.

45. *Anodonta grandis* (Say).

This species was not found in the main river. In general, conditions throughout the whole Cumberland system are not favorable to its development. The small tributaries are too swift and rocky, and the Cumberland itself is lacking in the quiet, muddy sloughs in which *A. grandis* can thrive. The only river examples we found were in the Stones River, a few in the East Fork near Walterhill, Tenn., and several in the West Fork near Murfreesboro. At the last-mentioned place it had apparently once been abundant in the vicinity of the railroad bridge, where it had thriven in the mud of the deep, quiet pools among the water-willows. A number of shells, recently killed by pearls, were lying on the bank. These were large, heavy shells, unusually thick for the species, and varied considerably in shape, some of them being markedly elongate.

In Haynes Lake, a shallow, muddy pond below Clarksville, *Anodonta grandis* was fairly abundant, and about 30 examples were secured. These were more shapely, of a larger size than those from Stones River, and much thinner. They are indeed the largest and finest examples of the species we have ever seen and represent the form *gigantea* Lea. The largest example measured 201.3 mm. long, 112.5 mm. high., and 82.3 mm. in diameter. These shells are peculiar in having two distinct colors of nacre, about half of them being dark purple, while the other half are a beautiful, lustrous, creamy white. The reason for this difference is not apparent; parasites are almost entirely absent.

46. *Lastena lata* (Rafinesque).

Very few examples seen in addition to those enumerated in the table. Mr. Boepple obtained it at Burnside, Albany Landing, and Cloyds. Its apparent scarcity is due in part to its habits. It can not be caught on the crowfoot hook, but must be obtained by wading, and is best secured when the water is low and clear. The species appears to prefer gravel bars with a rather swift current. The shell is beautifully polished and rayed, and is very thin, cracking easily when exposed to the air. Our examples are rather badly eroded.

47. *Anodontoidea ferussacianus* (Lea).

Rare; only a few specimens found. A thin, fragile *Anodonta*-like shell of no commercial value.

48. *Pegias fabula* (Lea).

A rare species of which we found only two living and four dead specimens in the Rock Castle River near Livingston, Ky. They are quite small, the smallest measuring 22.7 mm. long, 15.5 mm. high, and 11 mm. in diameter, and the largest 31 mm. long, 20 mm. high, and 14 mm. in diameter. In their perfect condition these must be very attractive little shells, but our specimens are very badly eroded.

49. *Symphynota costata* (Rafinesque). Fluted shell.

Occasional in the upper Cumberland from the falls down to the foot of Gowers Island. Occurs typically in moderately small streams and appears to be entirely absent from the lower stretches of the Cumberland. It is rather common in the various tributaries. The Stones River shells were exceptionally thick and heavy, and bore a goodly number of dead or soft pearls.

On account of its yellow nacre and tendency to crack this species is of no use in the manufacture of buttons.

Several of our specimens have numerous deep wrinkles extending ventrally over the posterior half of the disk. One is unusually shortened, truncate posteriorly and produced forward, and has well-marked rays, while another medium-sized shell from a mile below the falls is unusually elongate.

50. *Symphynota complanata* (Barnes). White heel-splitter.

Rare; only two examples of this species were found in the entire Cumberland. The shells were small, thin, and badly stained. These were obtained on Red Rock bar below Clarksville. Fragments of large strong shells were found in the Harpeth River. This species thrives in a muddy bottom and is often found in sloughs. Under especially favorable conditions it produces a fairly thick large shell which furnishes usable button material, but the Cumberland shells of this species have no value.

51. *Alasmodonta minor* Lea.

Confined to the upper river and tributaries. So far as our experience goes, this species is found typically in small streams, living in the sand between rocks. It may live along the border of large streams, but on account of its small size would be easily overlooked. Most of the specimens found had been killed by muskrats. The shells were all badly eroded and so deeply stained that the characteristic rays were obscured and the nacre rather badly stained.

This species is always too small to have any commercial value. Our smallest example measures 17 mm. long, 11 mm. wide, and 6 mm. in diameter, and our largest 45 mm. long, 28 mm. wide, and 18 mm. in diameter.

This species closely resembles *A. calceola*, a better known and more widely distributed species, but has a heavier shell and teeth and darker epidermis, and is somewhat flatter and longer.

52. *Alasmodonta truncata* B. H. Wright. Elk-toe.

This is not a common mussel in the Cumberland and is, generally speaking, a species of rather small streams and the upper courses of larger rivers. All the shells found were dwarfed, very thin and eroded, and with the epidermis rather badly stained.

When well developed this is an attractive shell, but it is always too thin and fragile to have any commercial value.

According to Mr. Bryant Walker, there is no difference between this and *A. marginata* Say, and our thin dwarf specimens lend probability to this view. As we have seen but few *marginata* we have no means of comparing them. As Simpson has separated the two forms, however, and ours are within the geographic range of *truncata*, we retain for the present Simpson's name.

53. *Margaritana monodonta* (Say). Spectacle case.

Occasional from Snows Island, where we first encountered it, as far down as Dover and perhaps beyond. The shells are fragile and break and crack easily, and disappear soon after dying. The species has no commercial value.

54. *Unio gibbosus* Barnes. Lady-finger; spike.

Unlike *Unio crassidens* this species is not especially abundant in the Cumberland. Though distributed throughout the entire length of the river, at many stations only a half dozen specimens were found, and nowhere did it rise above 4 per cent of the entire catch. In the Cumberland above the falls it is about the only species found. In the Clear Fork at Jellico, Tenn., and Savoy, Ky., it was abundant, forming about 90 per cent or more of the entire mussel population, and numerous dead shells recently killed by muskrats were found along shore and at the base of the water-willows.

These Clear Fork examples were all small dwarf shells with a rather pale nacre. They approach a well-marked form found in Green River, Ky., and other southern streams. The Clear Fork flows through sandy and shaly country and the water may be too deficient in lime to promote good shell growth. Immediately below the falls we encountered the normal full-grown form which is the one of the main river.

Gravid examples of this species were found during the entire summer.

55. *Unio crassidens* Lamarck. Elephant-ear.

Exceedingly abundant, especially in the upper part of the river. It is a species of large streams, and we did not find it in any of the tributaries nor above the falls. In the upper part of the river this shell is a decided nuisance, forming a large part of the clammer's catch, taking much of his time and labor and yielding little in return. It is generally known as the "pink," and clammers, on their prospecting cruises, note down the percentage of "pinks" and "whites," from which to judge the value of a bed. It is the great abundance of this species that makes the section of river from Burnside to Celina unprofitable clamming, and the problem of making this stretch a valuable clamming ground consists as much in the reduction of this species as in the increase of valuable kinds.

U. crassidens exhibits considerable modification as one ascends the Cumberland. In the lower stretches of the river most of the shells are the rather elongate form, which seems to be most common the country over. As one advances upstream these elongate shells gradually give way to a short and chunky variety.

The shells from Half Pone bar and a few from Mill Springs and Salt Lick bar show rather well-marked rays; most of the others are rayless.

Occasionally shells with the nacre very pale or almost white are found. These are called "white-pinks" and are acceptable to the buyer. Even the more or less markedly pink ones are beginning to be used, but there is little demand for them and they always bring a rather low price. The shells work up exceptionally well, being soft and free from grit.

While at Clarksville we were informed that the superintendent of one of the smelting furnaces along the river had been trying cull shells as a flux and found them satisfactory. It is doubtful whether this utilization, however, will make an important market for them.

56. *Pleurobema clava* (Lamarck). Club-shell.

Generally rare, and not found at all below Burnside. The shells are all badly eroded and discolored; one of them is unusually elongate, and several show a rather well-marked, broad and shallow furrow in front of the posterior ridge. We have usually found this species most abundant in small streams, and this may explain its absence from the greater part of the Cumberland. It is a rather handsome shell but too small to have any commercial value.

57. *Pleurobema crudum* (Lea).

This species does not appear to be common or widely distributed. All our examples are rather small shells, somewhat resembling a much-flattened *Quadrula subrotunda*, but with the epidermis of a brighter yellow and the rays quite distinct, well defined, and broken up into blotches.

58. *Pleurobema æsopus* (Green). Bullhead.

We did not see many examples of this species in the Cumberland, but it is common enough to be well known among the clammers. In the upper Mississippi it is called "bullhead" or "sheepnose," and is used in button manufacture, although it is ranked as a rather low-grade shell on account of its brittleness. In the Cumberland it is so hard and flinty that no attempt at all is made to cut it as it breaks saws. The clammers call it "clear profit" because they are "the only ones who get anything out of it." A small example obtained at Half Pone bar was of a beautiful yellow color; the older ones are brown.

The systematic position of this species is in doubt. It seems to stand between *Quadrula* and *Pleurobema*. Simpson ^a was not certain as to where to place it, having seen only one example gravid, and it with the gills partly filled. At the biological station at Fairport one was found with only the inner gills filled with glochidia and another with all four. Sterki ^b has found glochidia in all four gills. Usually, however, only the outer gills are used as a marsupium.

59. *Quadrula tritogonia* (Barnes). Buckhorn; pistol grip.

This is the *Tritogonia tuberculata* of Simpson's Synopsis. At the time the Synopsis was written the gravid female was not known. The shell stood pretty much by itself, and Mr. Simpson, who was struck by certain peculiar features, especially the noteworthy difference between the male and female shells, formed a separate genus for it. Since the discovery by various students that it bears young in all four gills, there is a general tendency to place it in the genus *Quadrula*, and Dr. Ortmann, who was the first to propose the shift, suggested the name given above. The species is quite aberrant; none of the other *Quadrulas* resemble it very closely, the nearest approach being some of the elongate *Quadrulas* such as *cylindrica*, especially the rough subspecies *strigillata* or *Quadrula trapezoides* from the south. The marked difference between the males and females is unique among any related forms and entitles it at least to subgeneric rank.

This species is not rare in the Cumberland and was obtained in small numbers at most of the stations from the falls down to Dover. Our specimens are mostly of medium size and a number have the nacre rather badly stained. They exhibit but little variation among themselves or from the form as generally known. The nacre of all but two is white; in these two, obtained near Clarksville, it is pink.

^a Synopsis of the Naiades, Proceedings of United States National Museum, vol. xxii. p. 745 and 764.

^b According to Ortmann, Nautilus, vol. xxii, no. 10, Feb., 1909, p. 100.

Where it attains its best development, the buckhorn is an excellent button shell, indeed one of the best. It does not find the most favorable conditions for growth and development in the Cumberland, however. It is not as yet amenable to propagation on a large scale, as it is but rarely that one finds gravid examples.

60. *Quadrula perplicata* (Conrad).

The plicate *Quadrulas* of the Cumberland, especially the middle portion of the river, are rather peculiar shells, lying somewhere between typical '*plicata* and *undulata*. The beaks are too low and flattened for *plicata* and the shells are too heavy and a trifle too inflated for *undulata*. A marked feature about them, in addition to their general rotundity of outline, is the fact that they usually taper to a point posteriorly. The clammers call them the "round-lake," and say that in proper conditions they are good pearl bearers. The folds are few and gently rounded. Mr. Bryant Walker, who examined them, is of the opinion that they are *perplicata*. We obtained some good specimens at Meeks Spring bar. Our largest measures 119 mm. long, 86 mm. high, and 56 mm. in diameter. At Half Pone bar a particularly interesting and instructive lot of young shells were obtained. These are inflated and rotund, approaching a spherical form with a greenish epidermis. Though quite small, they are so worn at the umbones that they look like old shells and no beak sculpture is shown. The smallest measures 17 mm. long, 15 mm. high, and 10 mm. in diameter. Farther up the river, at Cloyds Landing, this shell approaches *undulata*, while in Stones River, near Murfreesboro, the real *undulata* is found.

The shells are thick, solid, and heavy, but the nacre is spotted and they form rather poor button material. If they could be obtained free from spots, they would have a good market value.

61. *Quadrula undulata* (Barnes). Three-ridge or blue-point.

Beautiful examples of this species are common in the West Fork of Stones River near Murfreesboro, Tenn. It is also found in the East Fork near Walterhill. The young examples are yellowish brown, well compressed, and entirely free from erosion, so that the umbones show the sculpture very plainly. This consists of four or five high, coarse ridges, the first-formed ones crescentic, the older ones gradually vanishing backward until the last one is a short, low tubercle. The undulations are deep and crossed by numerous small furrows. A noteworthy feature of these shells is the great distance of the pallial line from the margin. The shells are somewhat spotted, but the spots are small and they would yield a fair amount of good button material.

62. *Quadrula heros* (Say). Washboard.

This is a species of large rivers. It is not found in the upper part of the Cumberland, but is abundant in the lower river. The first we saw was at the Mill Springs bar.

This species bears the largest and heaviest shell of the North American Unionidæ. It becomes rather large in the Cumberland, but not as immense as in the Wabash and some parts of the upper Mississippi. Our largest shell measures 162.8 by 115 by 62.4 mm. Our collection exhibits little variation. From the unusually large number of small examples seen it appears that the species is exceptionally prolific in the Cumberland, especially about Half Pone bar and Owl Hollow bar above Clarksville. All our examples are somewhat eroded at the umbones, but only two or three badly. The young examples are noteworthy for having the finely waved broken sculptures, characteristic of the umbones of the older specimens, over the entire disk and the plications rudimentary or only faintly developed, so that they do not closely resemble the old.

We found no gravid examples. They are indeed very rarely found, and nothing is known at present about its spawning habits or as to what fish acts as host to the embryos.⁴

⁴ Since the above was written investigators at the Biological Laboratory at Fairport have thrown considerable light on the breeding habits, hosts, etc., of this species.

In some rivers, as parts of the Illinois, this shell does not become stained early, and the younger shells furnish excellent button material. For the common run of buttons this shell is becoming one of the most important species, as its large size and expanse allows it to be worked up readily into buttons of various sizes, and the stains can be bleached out or the buttons "smoked" or artificially dyed. In the Cumberland the nacre becomes badly stained, even when the shell is quite small, and the washboards are always sorted out and sold separately as low-grade shells, bringing but \$2 to \$5 per ton when first-grade shells are bringing \$6 to \$8.

But few parasites were found, and we have as yet no clue to the cause of the discolored spots on the nacre. These spots are usually circular in outline and frequently have what appears to be a foreign body in a small raised pustule at the center. The fresher stains, or those near the surface, do not really permeate the nacre, but are composed of a flat hornlike skin overlying it and can be softened by acids and scraped away from the unstained shell beneath. The older, duller stains are doubtless the same thing covered by layers of nacre.

Many of our specimens are interesting as showing with unusual clearness the path, during growth, of the posterior adductor muscle scar, the anterior border of which is dimly defined, while straight converging lines from the dorsal and ventral borders of the scar lead up into the umbonal cavity. One of our specimens has a pinkish nacre.

63. *Quadrula cylindrica* (Say). Rabbit's-foot.

Occasional to abundant in the upper part of the river. On account of its narrow cylindrical shape it is of little value for buttons; the nacre, moreover, is frequently diseased and stained. The flesh is usually orange yellow and the gills, when filled with glochidia, markedly so. Some of our examples are well covered with small tubercles over the anterior portion of the disk, approaching the subspecies *strigillata*.

This is a rather active species, the most active of the *Quadrulas*. Its elongate form, in which it differs markedly from its nearest relative, *metanevra*, and indeed from all *Quadrulas* in general, may be an adaptation to an active life.

64. *Quadrula metanevra* (Rafinesque). Monkey-face.

This well-known button species is fairly common. A few were to be found at nearly every station, clam pile, or mussel bed. It was not abundant enough, however, to form more than a sprinkling among the shell piles, and it cuts a rather small figure in the button industry of the Cumberland. On account of its luster and solidity it is very acceptable to the manufacturers. It would not be worth propagating, however, as there are plenty of better species. We found one example of this species gravid on the last of May.

65. *Quadrula tuberosa* (Lea).

Rare and collected only in the upper river. In the autumn of 1910 Mr. Boepple obtained it at Sloans Shoals in the South Fork near Burnside, at Selfs Bar, and at Cloyds Landing.

66. *Quadrula fragosa* Conrad.

This species is occasional, and in some places abundant, in the lower Cumberland. It does not appear to "bite" readily on the crowfoot hook and the few examples taken by clammers are apparently no indication of its abundance. Small mussels of this species are a favorite food of the muskrat. Of a large pile of shells cleaned out by these rodents near Meeks Spring Bar, nearly all were this species and *Obliquaria reflexa*, although other mussels appeared to be common in the vicinity.

This species is very similar to *Quadrula lachrymosa* (Lea) and the differences between the two are difficult to express either by description or figure. It is somewhat more square-cornered, more inflated, and the tubercles on the posterior slope are more markedly arranged in rows, forming costæ. This species does not become as large as

Q. lachrymosa and is of little commercial value. We found gravid examples below Kuttawa May 17 and at the foot of Dover Island May 29. All four gills serve as marsupia and are thick and pad-like.

67. *Quadrula pustulosa* (Lea). Warty-back.

Common throughout the entire length of the river. Our shells exhibit a marked uniformity in general appearance, being rather inflated with only a moderate number of low tubercles. A few shells found a mile below Cumberland Falls are almost entirely smooth. With the exception of the Half Pone Bar specimens most of the shells have a cloth-like epidermis.

The warty-backs of the Cumberland are as a rule rather undersized, and their inflated form is something of a disadvantage, so that they are not as valuable as in some other streams.

68. *Quadrula cooperiana* (Lea). Cumberland pigtoe.

Not rare in the Cumberland. The proportions of the shell vary considerably, some being higher than long and others longer than high. The older examples are generally more elongate than the younger. The shells also vary somewhat as regards degree of inflation. One of the young shells has the epidermis faintly rayed, the others are eradiate. Three of the shells have the epidermis polished and shining; in the others it is dull. The nacre is sometimes a pale suffused pink within the pallial line, but in the majority of cases it is pure white. This is regarded as a very fair button shell. In appearance it lies intermediate between *pustulosa* and *granifera*. From *granifera* it can always be distinguished by the color of its nacre. It is usually longer and flatter than *pustulosa*, and there are peculiarities of epidermis, disposition of pustules, and shape of teeth that taken together help to separate them. They can always be separated if in the flesh, as *cooperiana* always has an orange-yellow flesh. The ova which fill the gills are bright yellow.

We found only two examples gravid, early in June. The developing ova were borne in the outer gills and gave it a sulphur-yellow color.

Dr. Ortmann removes this species from the genus *Quadrula* and places it in *Pleurobema*; he remarks that it is closely related to *P. æsopus*. We are rather favorably inclined to this view, but in view of the fact that these two genera need a thorough revision and may possibly run into each other we prefer at present to leave it where Simpson placed it, among shells that it strongly resembles.

69. *Quadrula rubiginosa* (Lea). Wabash pigtoe.

This species was found nowhere except in the East Fork of Stones River at Walterhill, Tenn. The shells show very little difference in general appearance, except that in the smallest the posterior ridge is poorly defined, and one of the medium-sized examples is somewhat more rounded, and has a lower posterior ridge. Large examples of this species make a moderately good button shell.

70. *Quadrula undata* (Barnes). Pigtoe.

This, as Bryant Walker has shown,^a is the proper name for the *Quadrula trigona* (Lea) of Simpson's Synopsis. Ortmann^b regards it as a subspecies of *Q. rubiginosa*. Though we have observed great variation in this shell, we have never seen any transition forms between the two species. It is rare in the Cumberland and the shells are rather small, measuring about 45 mm. long, 43 mm. high, and 25.7 mm. in diameter. The epidermis is clothlike and finely striate. The flesh is orange, in which respect it approaches *rubiginosa*.

An example procured at Linton, Ky., had a dorsal baroque, and the mantle contained 4 marginal distomid cysts, a parasite which is especially frequent in this species.

^a Nautilus.

^b Nautilus, vol. XXIII, no. 9, Feb., 1910, p. 116.

Where the pigtoe is found in abundance, as in some parts of the upper Mississippi, it is used quite extensively in the manufacture of buttons. It yields only a few blanks per shell, however, and would not be a desirable species to propagate.

71. *Quadrula obliqua* (Lemarck). Ohio River pigtoe.

This is the most abundant, and, on this account, the most important, commercial species in the river, especially in the central portion, where it greatly exceeds any other species in number.

The Ohio River pigtoe is a very good button shell. It is inferior to the niggerhead, both in luster and form, the sulcus on the side and the thinning out at the tip making it of unequal thickness; but, with the exception of the niggerhead, it is one of the best species.

It is a rather prolific breeder. We found more gravid specimens of this than of any other species. The height of the spawning season is during the latter half of May and the earlier half of June. Occasional examples, however, may be found during the entire summer. Of five examined at Beasleys Shoals August 9, four were gravid. The portion of the gills used as marsupia varies greatly in different examples; it may depend upon the amount of ova fertilized and upon the age of the mussel. In some of the mussels the lower half of the outer gills are filled; in other cases the entire outer gills and quite frequently all four gills. Occasionally three gills, the two outer and one of the inner, contain eggs or young. There are no well-marked sulci between the conglutinates, which are rather thin and flat, resembling the seed of the green cucumber in general appearance. They are peculiar in that, when viewed from the side, they present a wavy appearance. This, so far as we know, is found only in the present species and enables one to distinguish the conglutinates even when found free from the animal. The wavy appearance is due to little pits in the anterior and posterior faces. A conglutinate of this species was found lying on the gravel bar in shallow water at Half Pone Bar June 16; the species was therefore spawning at that date.

Dr. Ortmann has removed this species from the genus *Quadrula* and placed it in *Pleurobema*. All the examples he had examined up to that time had glochidia in the outer gills only. According to the data given above, its transfer to *Pleurobema* seems hardly advisable until the whole group is more thoroughly revised.

72. *Quadrula coccinea* (Conrad).

What appears to be an oblique form of *Quadrula coccinea* occurs rather frequently in the Big South Fork opposite Parkers Lake Station. Similar forms occur in the upper Cumberland down as far as Tear-coat Bar. In the main river these forms run into others in inextricable confusion, and nothing definite can be said about this species from the material at hand.

Dr. Ortmann is of the opinion that *Quadrula coccinea* is a variety of *Q. obliqua*. In some of the northern rivers it seems to be a fairly constant and well-defined form.

73. *Quadrula solida* (Lea).

Only occasional. We obtained a few, principally at Indian Creek Bar. The shells were not typical and differed considerably from those found in the upper Mississippi. The sulcus is very faint, and the nacre is not white but varies from pale rosy to purplish red.

74. *Quadrula plena* (Lea).

This appears to be a rare species in the Cumberland, and we obtained only a few scattered shells. They are all small and resemble very closely a much-shortened *Q. obliqua*, the compressed posterior portion being very short and the height of the shell being very great, considerably exceeding the length. The nacre is pale rosy.

Mr. Boepple obtained this species in 1910 from Fords Island down to Martinsburg in the upper part of the river.

75. *Quadrula pyramidata* (Lea).

Rare; we obtained a few examples in the vicinity of Mill Springs Bar. Our specimens have a broad furrow on the posterior half of the shell and differ from *Q. obliqua*, which they otherwise much resemble, by the umbones projecting far forward. They agree quite closely with Conrad's figure and description^a of *Unio mytiloides* which Simpson regards as a synonym, except that the epidermis of our shells is black rather than brown and umbones are badly eroded.

This is a very perplexing species. The extreme form, which, if it were only constant, would represent a very well marked and easily recognizable species, resembles an immensely overgrown *Pleurobema clava* in general appearance. Such specimens are rare; we have a few in the Washington collection. Our shells represent a sort of intermediate form between that and *Quadrula obliqua*.

Mr. Boepple obtained examples from several stations in the upper river, to which portion it is apparently pretty well confined.

76. *Quadrula subrotunda* (Lea).

The young of this species have a general resemblance to *Quadrula ebena*, the niggerhead, but can be distinguished by their polished epidermis and broken rays near the umbones. We obtained only a few examples of these easily recognized shells.

What is probably the adult of this species is occasional through the length of the river. We have not been able satisfactorily to connect the small shells with the large ones through a perfectly unbroken series, but up to the present can think of no better disposition to make of them. They have a black epidermis, with the umbones generally more or less eroded, and very much resemble an elongated *ebena*. These large shells are fairly common in the upper stretches of the river. A peculiarity of the old mussel is the rich orange color of the soft parts. At the blank factory at Clarksville they are known as the "long solid" and are regarded as one of the best button species of the river. None were found gravid. If they were to prove amenable to propagation, they might be profitable to plant in the upper part of the river and in similar situations where *ebena* would not thrive.

77. *Quadrula ebena* (Lea). Niggerhead.

This important commercial species, which is generally regarded as the producer of the most valuable shell for the manufacture of buttons, is absent in the upper Cumberland, and is abundant enough to be of considerable commercial importance only in the lower stretches of the river.

The niggerhead is a deep-water shell and is rarely found in small rivers, or in such mussel beds as are found in shallow water. It seems in general to prefer mud to sand and gravel, and the percentage collected depends much upon the methods of collecting. Work in deep water will bring to light a larger percentage than wading or gathering by hand or a rake.

The breeding season in the Cumberland begins in May and extends through the greater part of June, perhaps longer. In this species the condition of the development of the young can be roughly estimated by the appearance of the gill. When the ova pass down into the gill they are at first red, or carmine, probably because of an abundance of food material; as the glochidia develop they gradually fade out until the gills of a fully ripe niggerhead are of a dirty white color.

There is not much variation in shape among the shells, some being elongate and others more rounded than the average. The shells show very little erosion, and the young exhibit the peculiar white patch near the umbone, as has been fully described by Lea. The nacre is rather frequently stained brown, and nearly all lack uniformity in thickness, the shell thinning out somewhat abruptly a little behind the middle of

^a Conrad, Monograph, p. 41, pl. xx.

the ventral margin, leaving thin tips. The shell is easily distinguished from any other species in the river except from old examples of *Q. subrotunda*, which are always more elongate and always have yellow flesh.

Q. ebena would probably thrive only in the lower parts of the river, although when the propagation of this species becomes feasible it may be worth trying in the upper river.

78. *Quadrula tuberculata* Rafinesque. Purple warty-back.

A careful study of our material, as well as of the evidence at hand from the literature, convinces us that *Q. granifera* and *Q. tuberculata*, though quite markedly distinct in typical cases, are really connected by intermediate forms. In some rivers, like the Tippecanoe at Delong, Ind., only strongly marked *tuberculata* are found. In others, like the Mississippi about Fairport, Iowa, only well-marked *granifera* are found. In such streams or portions of streams as contain both species they are indistinguishable, or so connected by intergrades that no clear line of demarcation can be drawn between them. In the Cumberland, the first shells seen, in the lower part of the river, were identified provisionally as *granifera*; as we ascended the river some doubts as to the species began to appear, while in the upper tributaries the shells were pretty clearly identified as *tuberculata*. This naturally introduces the question as to influence of environment on shell form, which may be touched upon briefly here.

The most striking and essential difference between *tuberculata* and *granifera* is one of degree of inflation, *tuberculata* being a flat form and *granifera* much inflated. We have a number of cases among the Unionidæ where two otherwise similar shells are distinguished by this feature; among these are: *Q. plicata*, inflated, *Q. undulata*, compressed; *D. dromas*, inflated, *D. caperatus*, compressed. From our experience we are inclined to believe that one usually finds the compressed species in small streams, while the more inflated forms are found in large rivers. Often when a main stream has *plicata*, the little tributaries will have *undulata*, especially if they are rather shallow and swift streams with gravel bottoms. The more compressed form is better adapted to plow into the gravel or crawl under rocks and hold its position in a swift current, where the inflated form would present too much surface to the force of the water. In the softer mud and weaker current of larger streams an inflated form would be advantageous, helping to buoy up the animal.

To state the situation precisely as we have found it, if one takes one of the larger rivers from source to mouth, and finds both *tuberculata* and *granifera* or *plicata* and *undulata* in the stream, the compressed form is likely to be in the upper stretches of the river while it is a small swift stream, and the more inflated form farther down in the main body of the river where the bottom contains more mud and the current is slower. Extreme forms of either species, so far as we know, are never found in the same bed, but where both are represented the forms run together.

The literature relating to *granifera* and *tuberculata* is exceedingly interesting, but too long to give in detail. To understand the present status of the group, however, it is necessary to state that Simpson in his Synopsis removed these two species from the *Quadrula pustulosa* group, where they had been previously placed, making of them the subgenus *Rotundaria* on the basis of a "well-developed sulcus on the posterior slope and remarkable beak sculpture." The beak sculpture is well marked on *tuberculata* but not so well, or almost absent, on *granifera*. Ortmann, finding only the outer gills used as marsupia in *tuberculata*, raised *Rotundaria* to generic rank. We have usually found only the outer gills of *granifera* at Fairport marsupial, although we have a record of one example with marsupia in all four gills.

The species does not reach a very large size in the Cumberland. On account of its purple nacre it is of no value for buttons.

1945
CARD

DEPARTMENT OF COMMERCE

BUREAU OF FISHERIES

HUGH M. SMITH, Commissioner

THE MUSSEL FAUNA OF CENTRAL AND
NORTHERN MINNESOTA

By CHARLES B. WILSON and ERNEST DANGLADE

APPENDIX V TO THE REPORT OF THE U. S. COMMISSIONER
OF FISHERIES FOR 1913

Bureau of Fisheries Document No. 803

WASHINGTON
GOVERNMENT PRINTING OFFICE

1914

DEPARTMENT OF COMMERCE

BUREAU OF FISHERIES

HUGH M. SMITH, Commissioner

THE MUSSEL FAUNA OF CENTRAL AND
NORTHERN MINNESOTA

By CHARLES B. WILSON and ERNEST DANGLADE

APPENDIX V TO THE REPORT OF THE U. S. COMMISSIONER
OF FISHERIES FOR 1913

Bureau of Fisheries Document No. 803

WASHINGTON
GOVERNMENT PRINTING OFFICE

1914

THE MUSSEL FAUNA OF CENTRAL AND NORTHERN MINNESOTA

By CHARLES B. WILSON and ERNEST DANGLADE

Appendix V to the Report of the U. S. Commissioner
of Fisheries for 1913

CONTENTS.

	Page.
Introduction.....	5
Glacial origin of lakes and rivers.....	6
Mussels of the St. Croix group.....	8
Mussels of the Minnesota River group.....	11
Mussels of the Red River group.....	11
Mussels of the Crow Wing group.....	14
Mussels of the Mississippi group.....	17
Mussels of the isolated lakes.....	20
Summary.....	25

THE MUSSEL FAUNA OF CENTRAL AND NORTHERN MINNESOTA.

By CHARLES B. WILSON and ERNEST DANGLADE.

INTRODUCTION.

As a part of the fresh-water mussel investigations conducted by the Bureau of Fisheries, the central and northern portions of Minnesota were examined during the summer of 1912 with regard to the kinds and numbers of mussels to be found in the lakes and rivers. The mussel fauna of the Mississippi River in Minnesota below St. Paul and of the Minnesota River have been thoroughly investigated by representatives of the various pearl-button companies, and the quality and amount of shells which they produce have become fairly well known. The central and northern portions of the State had never been examined except by mussel fishermen. The shells obtained by some of these fishermen, however, and shipped to the button factories were of such exceptional quality as to attract the attention not only of the manufacturers but also of the Government experts at the biological laboratory at Fairport, Iowa. Since some of these shells were obtained from lakes and others from rivers, it was determined to make a preliminary survey of both lakes and rivers through the central and northern portions of the State.

This survey had a threefold object: First, to determine the geographic distribution of the various mussels in those portions of the State. Incidentally, of course, this would answer the question whether the exceptionally fine shells were locally or generally distributed, and where they were to be found.

Second, to make as careful a survey as possible of the various conditions, conducive or adverse to mussel development, in the different localities visited. This would not only throw some light on the presence of exceptional mussels in certain localities, but would also serve as a basis for the final object of the survey.

Third, to ascertain whether it would be profitable to introduce artificial propagation in any of the lakes or rivers, and if so, what species would be best adapted to the locality.

The investigating party consisted of the two authors, and in consequence of the large territory to be covered and the isolation of many of the localities visited it was necessary to travel entirely by rail-

road, stopping at convenient centers and driving to the lake or river. During this trip 45 lakes and 15 rivers were examined, with the results as herein given.

Samples of the shells obtained by the authors at the different localities herein mentioned have been identified by Mr. H. Walton Clark, of the biological station at Fairport, Iowa. Similar samples have been tested as to their mercantile value by Mr. John Southall, of the same station.

In order to understand the geographic distribution of the mussels, it is necessary to review so much of the glacial geology as will explain the present location of the lakes and rivers as well as their former relations.

GLACIAL ORIGIN OF LAKES AND RIVERS.

Minnesota was formerly covered by a great glacier or ice sheet, which came down from the northeast and flowed across the State into Iowa. When the glacier melted, the gravel, sand, and clay which it carried was spread out over the surface of the underlying rocks and has remained there ever since. The only exception is a narrow strip bordering the Mississippi River from Lake Pepin southward, and thus outside of the present survey. North of Lake Superior this drift, as it is called, is thin in places, but elsewhere it averages from 100 to 150 feet in thickness and effectually conceals the bedrock.

Both glacier and drift have made the contour of the State more level and uniform than it was before. The glacier accomplished this by grinding off the ridges and elevations, while the drift assisted by filling in such hollows as were left by the glacier. In some places the material of the drift has been subsequently worked over and arranged in layers by the streams and rivers that flowed from beneath the glacier, but in most places it is still unstratified. During the melting of this great glacier there were successive periods of advancing, halting, and retreating, and at such times the drift accumulated in long hills or ridges called moraines, parallel with the edge of the glacier. Twelve of these moraines may be traced across the State in various directions, and while they are only from 25 to 75 feet in height, they are still sufficient to determine the general drainage of the State. They have the further effect of rendering any free drainage impossible, and thus they give rise to the remarkable number of lakes that are found in Douglas, Ottertail, Itasca, and other counties. Furthermore, the streams and rivers are very winding, and have a uniform current, and there are plenty of sand and gravel beds in the bottom of the lakes and rivers, and not very much mud. All these conditions are favorable for mussel growth and propagation and profoundly influence the mussel fauna.

When the melting ice sheet had receded beyond the moraine or watershed which separated the basin of the Minnesota River from

that of the Red River of the North, a large lake, called Lake Agassiz, was formed along the edge of the ice. As the ice withdrew, this lake extended northward along the Red River Valley as far as what is now Lake Winnipeg. Lake Agassiz was 700 miles long and covered 110,000 square miles, and its duration is estimated to have been about a thousand years. Its outlet, known as the glacial river Warren, was along the valley now occupied by Lakes Traverse and Big Stone and the Minnesota River, into the Mississippi. At that period, therefore, the Mississippi River may be said to have had its origin in Lake Agassiz. And during the thousand years of its existence, this lake had abundant opportunity to become populated with fresh-water mussels ascending from the Mississippi. The lake disappeared, however, and the valley of the Minnesota River separated from that of the Red River. But the mussel faunas of the two rivers were derived from identically the same source, and the only differences would be the few minor changes that have crept in since then.

Many other glacial lakes were formed during the melting of the ice sheet, only to be subsequently obliterated. But while they existed they served as temporary channels for the migration of fish and mussels from the south. Two of these are of especial interest, in view of the results of our present investigation. Lake Upham once covered the region south of the Mesabi Iron Range, and drained southeast along the valley now occupied by the St. Louis and Cloquet Rivers. This lake was very shallow and temporary and, as far as can be determined, was not connected with the Mississippi River in any way. This fact accounts for the paucity of mussels in that portion of the State, as well as in all the Lake Superior drainage.

Lake Nicollet was formed around the headwaters of the Mississippi River and covered an area of 1,500 square miles. It drained southwest into the valley now occupied by the Crow Wing River and thence into the Mississippi. The Crow Wing River thus becomes the modern representative of the old headwaters of the Mississippi, and is older than that portion of the latter river which now extends from the mouth of the Crow Wing up to Lake Itasca. These facts explain the richness of the mussel fauna in the Crow Wing and its tributaries. At two places in the area covered by the present survey the bed rocks appear above the drift with sufficient prominence to materially affect the mussel distribution. At Carlton the St. Louis River plunges over a rocky ledge and through a gorge, which prevents the passage of either fish or mussels. Consequently that portion of the Lake Superior drainage which is tributary to the St. Louis River above Carlton is devoid of mussels.

The Falls of St. Anthony at Minneapolis have formed a similar barrier in the Mississippi River, but with this difference: Some fish have evidently been able to ascend these falls while others could not accomplish it. Accordingly, we find in the Mississippi above the falls, and in its tributaries an abundance of mussels belonging to the *Lampsilis* or mucket group, plenty of *Anodonta*, *Symphynota*, *Strophitus*, and the like, but not a solitary specimen was seen of the great *Quadrula* or pig-toe group. The falls have manifestly furnished in some way an effective barrier to the distribution of these mussels. On the other hand, the Minnesota River enters the Mississippi some distance below the falls, and it contains as many pig-toes as muckets.

The pig-toes also ascended the glacial river Warren into Lake Agassiz, and we find them to-day in the Red River of the North. They also ascended the St. Croix River, and in the St. Croix drainage they are even more numerous in species than the muckets.

For convenience we may divide the lakes and rivers which were examined into five groups, and designate them, respectively, the St. Croix group, the Minnesota River group, the Red River group, the Crow Wing group, the Mississippi River group, and the isolated lakes.

MUSSELS OF THE ST. CROIX GROUP.

The lakes and rivers in this eastern central portion of Minnesota have been populated with mussels by way of the St. Croix River. This connection was established after the melting of the glacier and has not been materially changed since that period.

Joining the Mississippi some distance below St. Paul, and having no falls or other natural obstruction in its own course, the St. Croix River has afforded a constant and easy passage for all the Mississippi species of fish and mussels. Hence we find a goodly variety of both in the lakes and rivers belonging to the St. Croix drainage. The following table gives the geographic distribution of the various mussels found here during the present survey:

DISTRIBUTION OF MUSSELS IN ST. CROIX DRAINAGE.

Species.	Pokegama Lake.	Snake River.	Cross Lake.	Rush Lake.	Bald Eagle Lake.	White Bear Lake.	Forest Lake.
<i>Lampsilis luteola</i> (fat mucket).....	×	×	×	-----	-----	-----	×
<i>Lampsilis ventricosa</i> (pocketbook).....	×	×	×	-----	-----	-----	-----
<i>Lampsilis recta</i> (black sand-shell).....	-----	×	×	-----	-----	-----	-----
<i>Lampsilis alata</i> (pink heel-splitter).....	-----	×	×	-----	-----	-----	-----
<i>Symphynota complanata</i> (white heel-splitter).....	-----	-----	×	-----	-----	-----	-----
<i>Strophitus edentulus</i> (squaw-foot).....	×	-----	-----	-----	-----	-----	-----
<i>Anodonta corpulenta</i> (floater).....	-----	-----	×	×	×	×	×
<i>Quadrula undulata</i> (blue-point).....	×	×	-----	-----	-----	-----	-----
<i>Quadrula plicata</i> (three-ridge).....	-----	×	×	-----	-----	-----	-----
<i>Quadrula undata</i> (pig-toe).....	×	-----	×	-----	-----	-----	-----
<i>Quadrula lachrymosa</i> (maple-leaf, stranger)....	×	×	×	-----	-----	-----	-----
<i>Quadrula pustulosa</i> (warty-back).....	×	×	-----	-----	-----	-----	-----

No comment upon the fauna of the last four lakes is needed save the single statement that the muckets in Forest Lake are all dwarfed and thin-shelled. The other two lakes and Snake River are parts of the same system, for the river flows through the entire length of Pokegama Lake and across Cross Lake nearly at its center. Both of the lakes and the river are shallow, and consequently the mussels are gathered with a rake or by wading. No crowfoot dredges were seen.

QUALITY OF SHELLS.

The principal mussel here is the fat mucket, which is not dwarfed, as is usual in a lake, but retains its full size. Furthermore, the shell is exceptionally thick and heavy, and maintains this thickness to the extreme tips, making every portion of it available for buttons. The shells have a fine luster, show no discoloration, and will cut from 700 to 720 gross of blanks (20-line) to the ton. In Pokegama Lake these muckets form 75 to 85 per cent of the entire catch; in the Snake River between the two lakes, 60 per cent, and in Cross Lake from 40 to 50 per cent.

Of the other shells, the maple-leaves and blue-points are also exceptionally thick, of large size, unspotted, and in every way first-grade button shells. The three-ridges, on the contrary, are badly spotted, have a poor luster and are only second or third quality. The culls are nearly all heel-splitters and *Anodontas*. In Cross Lake the bottom is sandy next to the shore, and then becomes covered with mud, while in Pokegama Lake it is hard sand throughout. Hence there are more three-ridges, black sand-shells, blue-points, and floaters in Cross Lake, and the shells are not quite as thick as those in Pokegama Lake.

At the time these lakes were examined (July) there were fully two carloads of shells scattered along the shores of Cross Lake on the west side, and as many more at the upper end of Pokegama Lake, gathered within a space of 400 or 500 feet. The fishermen said they had been offered \$23.50 per ton for these Pokegama shells.

PEARLS.

The best pearl found in this vicinity was obtained from a fat mucket in Cross Lake several years ago, and was held for some time at \$4,000. The price then gradually dropped to \$3,000, and it was finally sold for \$2,300. Of those found in 1912 one brought \$1,800, another \$1,200, a third \$900, two were sold for \$500 each, and six or eight reached \$100 or over. In consequence of these exceptional finds everyone in the neighborhood caught the pearl fever, and they were all—men, women, and children—fishing for pearls at the time of our visit, the mucket being the favorite shell for them. But they

showed far more wisdom than is common under such circumstances, for even the children had sense enough to save the valuable shells and turn them over to a local blank factory situated on the shore of Cross Lake in Pine City. At that time this factory was running entirely on such small job lots, which could be obtained at a considerable reduction in price.

PROPAGATION.

Some of the mussel fishermen claimed that this locality was practically worked out, and in consequence they had left and gone to Rice Lake. But all of those who remained told us that they had no difficulty in gathering 500 or 600 pounds a day. The supply, however, is not inexhaustible, and unless measures are taken to replenish the more valuable species they will soon be gone.

Everything combines to make this an ideal location for such artificial propagation. Pine City, the county seat of Pine County, is conveniently reached by the Northern Pacific Railroad, 60 miles from St. Paul. It is located on the shores of Cross Lake and along the banks of Snake River, and the waterway is unobstructed up the river into Pokegama Lake. Hence propagation at a single point would supply both of the lakes and the river. And there is an abundance of the right kind of fish to serve as hosts for the glochidia.

RECOMMENDATIONS.

1. The muckets and the maple-leaves that are found here are exceptionally fine shells, and in some way the local conditions are peculiarly suited to their development. They should be locally propagated, therefore, in sufficient numbers to keep up the supply. In all probability they will yield better returns than any other species that could be introduced.

2. A careful study of these mussels and of the local conditions should be undertaken in order to determine, if possible, what it is in the way of lime, food, or other things that renders these shells so exceptionally fine.

3. With a good local supply of these remarkable shells and a working knowledge of the conditions under which they flourish, it would be a simple matter to introduce them into other localities having a similar happy combination of river and lake. Among such possible localities may be mentioned Rice and Koronis Lakes near Paynesville in Stearns County, Clearwater Lake near Annandale in Wright County, Lost and West Lost Lakes near Fergus Falls, and Pine and Little Pine Lakes near Perham in Ottertail County.

4. A small local factory may often render efficient service by saving the odd lots of shells that are just as good in quality as any of

the others and perhaps even better, but are not sufficient in quantity to warrant shipping them for any distance. Such factories deserve the encouragement of both fishermen and manufacturers.

MUSSELS OF THE MINNESOTA RIVER GROUP.

As has been already stated, the Minnesota River and its tributaries have been pretty thoroughly worked up by representatives of the button factories. Like the St. Croix, this river empties into the Mississippi below the Falls of St. Anthony, and so affords a free passage for all kinds of fish and mussels. Furthermore, it formed a part of the glacial River Warren, which was the outlet of Lake Agassiz, and thus there has been no break in its connection with the Mississippi.

The present investigation did not include the river itself, but only some of the lakes in Douglas County that eventually drain into it by way of the Chippewa River.

Within a radius of 6 miles from Alexandria, the county seat of Douglas County, there are 20 small lakes, several of which have become quite noted summer resorts.

Lakes Agnes, Henry, and Winona are close to the railroad station, small, shallow, and filled with water plants. The only mussels found in them were dwarfed and thin-shelled muckets (*L. luteola*), whose epidermis was highly polished and somewhat marly and whose nacre was a beautiful smoky brown.

Four miles north of the city there is a group of three larger and much deeper lakes, called, respectively, Darling, Carlos, and L'Homme Dieu. These lakes are comparatively free from water weeds, have sand and gravel bottoms, are very deep, and contain plenty of fish, but the only mussels that could be found in them were *Anodontooides freussacianus modestus* and *Anodonta pepiniana*.

A similar fauna was reported for the other 14 lakes, so that it does not appear as if any of the lakes in Douglas County contained commercial shells. Nor do any of them present conditions that would recommend the introduction of merchantable species by means of artificial propagation.

Some of the isolated lakes in this drainage, however, present entirely different conditions.

MUSSELS OF THE RED RIVER GROUP.

The lakes and rivers belonging to this group were populated with mussels from the Mississippi River by way of the glacial river Warren and Lake Agassiz. Since the disappearance of this glacial river and lake the Minnesota River drainage and the Red River drainage have been separated, and each has acquired peculiarities of its own. The Red River turns northward along the western border of the

State and carries its mussel fauna across the line into Canada. It therefore becomes of great interest to the conchologist, as well as the mussel fisherman, since in it the mussels of the Mississippi Valley reach the point farthest north in their migrations. In consequence of the long continued glacial connection with the Mississippi, we are not surprised to find the rich mussel fauna indicated in the following table:

DISTRIBUTION OF MUSSELS IN RED RIVER GROUP.

Species.	Little Pine Lake outlet.	Red River at Per- ham.	Otter- tail Lake outlet.	West Lost Lake outlet.	Red River below Fergus Falls.
<i>Anodonta pepiniana</i> (paper-shell, floater)	×	×	×	×	
<i>Anodontoidea ferussacianus subcylindraceus</i>			×		
<i>Strophitus edentulus</i> (squaw-foot)		×	×	×	
<i>Symphynota costata</i> (fluted-shell)	×	×	×		
<i>Symphynota complanata katharinae</i>	×	×		×	
<i>Lampsilis luteola</i> (fat mucket)	×	×	×	×	×
<i>Lampsilis ventricosa</i> (pocketbook)	×	×	×		×
<i>Lampsilis recta</i> (black sand-shell)	×	×	×	×	×
<i>Quadrula coccinea</i> (round pig toe)			×		
<i>Quadrula rubiginosa</i> (Wabash pig toe)					×

The only place in this entire drainage that has ever been worked is just north of Fergus Falls, where some of the country boys gathered and shipped a carload of shells to the button factories in Iowa in 1910. All of the lakes and the river are shallow and the shells must be gathered with rakes or forks, or picked up by hand; there is no chance for crowfoot dredges.

QUALITY OF SHELLS.

The mucket, the pocketbook, and the fluted shell are the principal commercial mussels in the Red River. The black sand-shell is abundant and the best shell of them all in quality, but as it always has a dark purple nacre it can be used only for novelties. In many of these northern sand-shells, the hinge line, instead of being straight (*recta*), is strongly curved. But as it conforms in other particulars to a normal *recta*, it seems best to regard this merely as a local variation. The pocketbooks also are peculiar in being much flattened, somewhat elongated, and with short and stumpy teeth, very much like the variety designated by Lea as *Unio canadensis*. Many of the muckets have shells as thick and heavy as those of the St. Croix drainage, but there are others whose shells are thin and sometimes dwarfed like lake specimens.

The shells of nearly all the mussels which have a white nacre are badly stained. These stains vary from a light-gray or drab to a dark rusty brown in color. Sometimes there is but a small discoloration

on each valve, at other times the whole interior of the shell is discolored. The stain usually affects only the interior layer or coat of nacre and when this is removed the rest of the shell is perfectly clean and uninjured. Such spotting of the shell, of course, injures their commercial value and reduces the material to the second or third grade. In other respects the shells have a fine luster and good texture, and would make excellent button material.

PEARLS.

A few pearls and about the usual number of slugs were obtained from the carload of shells sent from Fergus Falls. At Little Pine Lake we also received reliable information that pearlers had worked the Red River above Mud Lake two years before, and that they obtained an abundance of mussels, with a fair amount of pearls. Further than this there has been no search for them in the Red River. If the discoloration noted above is due to some sort of parasite, it would very likely affect the pearls and slugs as well as the shells, but no data could be obtained. There is no reason other than this why the Red River should not be as prolific of pearls as the Mississippi.

PROPAGATION.

The conditions at Ottetail Lake are very favorable for the propagation of certain species of mussels. The lake is 10 miles long by 4 miles wide, and is remarkably clean and free from weeds. It is surrounded also with fine sand and gravel beaches and contains many large sand bars. The Red River enters at the northeastern corner and flows the entire length of the lake. Similar conditions exist at Lost, West Lost, Pine, and Little Pine Lakes, but the lakes themselves are much smaller. At little Pine Lake the bottom was nearly covered with *Chara* and algæ, but wherever there was a bare spot the mussels were present in large numbers. As these lakes are full of just the kind of fish to serve as hosts the conditions are ideal for mussel propagation. On the river itself the conditions are less favorable. There are several dams in Fergus Falls, and a large power dam, 36 feet in height, 4 miles below the city. None of these dams are provided with suitable fishways, so that they form an effective barrier to the ascent of all fish.

RECOMMENDATIONS.

1. Evidently the first thing to be done is to determine the cause of the stains which are so abundant. A satisfactory solution of this question would be of immense practical value, not merely here in the Red River drainage but wherever mussels are found. Different

regions show different degrees of discoloration but stain is present in some degree practically everywhere. How to check it, control it, and eventually eliminate it become exceedingly important questions. This Red River offers ideal opportunities for solving these questions.

2. Practical and efficient fishways should be provided for every dam across a river of the size and importance of the Red River. The blocking of the passage of the fish not only hurts the fishing in the waters above the dam but seriously affects every industry that is at all dependent upon fish. A dam or a natural fall, impassable for fish, may mean the entire absence of mussels in the river above.

3. Until there has been a solution of the cause of the numerous stains on the Red River shells and suitable means have been provided for the passage of the fish around the dams, there is little to be gained either by propagating the mussels already in evidence or by introducing new species.

4. Since the staining is the only character in which these shells are not first quality, since quite a percentage of the shells are free from stains, and since a goodly proportion (unstained part) of most of the stained shells can be utilized for buttons, it follows that a local blank factory, using the shells where they were found would obtain an abundance of material. The loss occasioned by the stained portions of the shell would be more than offset by the saving in freight.

MUSSELS OF THE CROW WING GROUP.

The lakes connected with this group were once part of the great glacial lake Nicollet, which covered 1,500 square miles and drained southwest through the Crow Wing River into the Mississippi. This drainage, therefore, represents the original headwaters of the Mississippi River and was populated with mussels from that source. The center of the Crow Wing drainage is in Wadena County, from whence it extends north through the Fishhook River into Hubbard County and nearly up to the present headwaters of the Mississippi; west through Straight and Shell Rivers into Becker County; west also through Red Eye, Leaf, and Wing Rivers into Ottertail County, and south through Wing and Turtle Rivers into Todd County.

There are very few lakes in this drainage and they are close to the headwaters of the various tributary rivers. Both the lakes and the rivers are shallow, with sand or gravel bottoms; the mussels thus far secured have been obtained with forks and rakes; there was no opportunity to use a crowfoot dredge. The following table gives the distribution of the mussels in this group:

DISTRIBUTION OF MUSSELS IN CROW WING GROUP.

Species.	Stations.			
	Shell River, Menahga.	Leaf River, Wadena.	Fish-Hook River, Park Rapids.	Crow Wing River, Motley.
<i>Lampsilis ligamentina</i> (mucket).....	×	-----	-----	×
<i>Lampsilis luteola</i> (fat mucket).....	×	×	×	×
<i>Lampsilis ventricosa</i> (pocketbook).....	×	×	×	×
<i>Lampsilis recta</i> (black sand-shell).....	×	-----	-----	×
<i>Anodonta pepiniana</i>	-----	×	-----	-----
<i>Anodonta grandis</i> (floater).....	×	×	×	-----
<i>Anodontoides ferussacianus subcylindraceus</i>	-----	×	×	×
<i>Strophitus edentulus</i> (squaw-foot).....	-----	×	×	-----
<i>Strophitus edentulus pavonius</i> (squaw-foot).....	-----	×	×	-----

As can be seen from this table, the mussels are quite evenly as well as universally distributed, and it may be said that they were also fairly abundant at every place examined. Hitherto the mussel fishermen have worked at only one locality in this drainage, the Shell River at Menahga, but the shells obtained here were so exceptional in size and quality that they brought a high price, and many of them were exported to England and Germany.

QUALITY OF SHELLS.

The principal mussel of this drainage is the pocketbook, which attains a large size and has an exceptionally thick shell. It also shows a good luster, has a fine texture, and is free from stains. Consequently it ranks as a first-grade shell and will cut 100 gross of 20-line and 1,000 gross of 16-line buttons to the ton.

The bottom of the river where these shells are obtained is covered with algæ and water weeds to the depth of 12 to 18 inches, and the thicker the vegetation the more plentiful the mussels beneath it. Two men were actively working the Shell River at Twin Lakes near Menahga at the time of our visit, and we watched them rake off the algæ and weeds and then dig into the underlying gravel and sand for the mussels. The latter are often buried to the depth of a foot or more. This is, at the least, a novel condition and one which, so far as is known, has not been reported from any other locality.

The *Anodontas* were also very thick shelled, so thick as to be easily mistaken for fat muckets, and to cut a poor quality of buttons. Quite a large percentage of the black sand-shells had white nacre, and of course these made first-quality button shells.

PEARLS.

The slugs and small pearls from these shells run about $1\frac{1}{2}$ ounces to the ton of shells, which equals that of the Illinois River, is twice the average for the Cumberland River, and three times that for the Ohio.

An ounce of these pearls and slugs was purchased and they have been carefully examined and compared with those from other localities. In luster and general character they are considerably better than those from the Illinois and Ohio Rivers, but are not equal to the Wabash River output.

One of the musselmen at Menahga showed us a large rosebud cluster of yellowish tint and the size of a small hickory nut, which was attached to the valve of a mucket near the posterior end. They also had several fine pearls, rather more than would be expected from the quantity of shells they had obtained.

While conditions in the Crow Wing and its tributaries are exceptionally fine, as is evidenced by the superior quality of the shells, and while there is an abundance of the right kinds of fish to serve as hosts, these advantages are more than offset by the very poor facilities for transportation.

The rivers run through those portions of Wadena County which are the farthest removed from railroads, and not until we reach Motley in Morrison County do we find good railroad facilities. Even at Menahga the shells must be carted 5 miles over a very sandy road in order to reach a shipping point. The Shell River, however, will furnish gravid pocketbooks of exceptional size and quality to stock other rivers that happen to be more conveniently located.

RECOMMENDATIONS.

1. One of the musselmen at Menahga suggested a way to overcome the lack of transportation facilities. A "wannigan" as he called it—that is, a sort of house boat—could be built and equipped with machinery for sawing blanks at an expense not greatly, if at all, exceeding what it now costs (\$300) to transport a single carload of shells from Menahga to the button factories. With this equipment it would be an easy thing to float down the Shell River into the Crow Wing, and down the latter into the Mississippi, using up the shells where they were found. The Crow Wing and its tributaries would supply enough material to keep such an outfit busy for several years. There would be no freight or transportation charges on the shells. Spotted shells, those with thin tips, and the white-nacred sand shells could be utilized along with the others, and when the work was finished the boat and its outfit would bring a very respectable portion of the original cost.

2. While the shipping facilities do not warrant artificial propagation in this drainage, such exceptional shells should not be allowed entirely to disappear before an earnest effort is made to introduce them in other localities. Here is a peculiarly fine parent stock which richly deserves protection and cultivation as a source from whence to derive propagation material.

MUSSELS OF THE MISSISSIPPI GROUP.

As would be expected, this is much the largest of the groups here considered, and includes all of the Mississippi River above the mouth of the Crow Wing River, together with the lakes and tributaries connected with it. This portion of the Mississippi is entirely post-glacial and has been formed since the disappearance of the glacial lake Nicollet.

It drains Crow Wing County, the northern portions of Aitkin, Cass, and Hubbard Counties, and the southern portions of Itasca, Beltrami, and Clearwater Counties. All of these regions, but especially Itasca County, contain a large number of lakes, some of which, like Leech, Winnibigoshish, and Cass Lakes, are among the largest in the State. This region, of course, has been in constant communication with the Mississippi since the very beginning and hence has been stocked with samples of all the mussels found in that river above the Falls of St. Anthony. The following table gives the geographic distribution of these mussels:

DISTRIBUTION OF MUSSELS IN THE MISSISSIPPI GROUP.

Species.	Mississippi River, Brainerd.	Prairie River, Grand Rapids.	Prairie Lake, Grand Rapids.	Mississippi River, Wolf Lake.	Mississippi River, below Bemidji.	Mississippi River, Bemidji Lake.	Mississippi River, above Bemidji.
<i>Lampsilis ligamentina</i> (mucket).				×	×	×	
<i>Lampsilla luteola</i> (fat mucket).	×	×	×	×	×		×
<i>Lampsilis ventricosa</i> (pocket-book).				×	×	×	×
<i>Lampsilis recta</i> (black sand shell).		×		×	×	×	×
<i>Anodonta grandis</i> (floater).		×	×	×		×	×
<i>Anodonta corpulenta</i> (floater).		×	×			×	×
<i>Anodontoides ferussacianus subcylindracus</i> .			×	×		×	×
<i>Symphynota compressa</i> .						×	
<i>Strophitus edentulus</i> (squaw-foot).						×	
<i>Strophitus edentulus pavonius</i> (squaw-foot).				×			×

The poverty of specimens at Brainerd is explained by the fact that we could only examine the river for a short distance above and below the city, and in this interval we did not find any mussel bed. Doubtless there are as many mussels in this portion of the Mississippi as elsewhere.

QUALITY OF SHELLS.

The *Lampsilis* or mucket group are the only mussels in this drainage that possess any commercial value. While the pocketbook does not attain the size or the quality of those found in the Shell River, and the fat mucket is not as thick as those found in Snake River and Pokegama Lake, yet on the whole the shells are of medium size and good quality. They are very plentiful in many places; at the outlet of Lake Bemidji 3 tons were obtained in one week from a space only a few rods in length. These mussels are like those in the Shell River, in that they are buried deep. The man who collected them told us that he dug down into the sandy bottom 2 and 3 feet for them and found them nearly as thick as they could lie.

The shells were remarkable for the small size of the cardinal teeth, indeed a few valves were found entirely destitute of teeth.

Another excellent locality is up the Mississippi above Lake Irving. The conditions here are excellent and several carloads of shells could easily be obtained. The Schoolcraft River comes into the Mississippi here from Lakes Marquette and Plantagenet and both the river and the lakes are reported to be full of good mussels.

The black sand-shells throughout this portion of the Mississippi have the hinge margin very strongly curved like those already described from the Red River and the Crow Wing drainage.

The fat muckets here are not thickened like the shells from Pokegama Lake, Pine County, and many of them are dwarfed after the manner of ordinary lake shells. In addition, those from Wolf Lake proved to be chalky and brittle when tested for button making, but those above Lake Bemidji were of medium size and furnished good button material.

The *Anodontas* form but a very small percentage of the mussel fauna, nearly all the shells seen being some form of *Lampsilis*. The mussels in this region would all be obtained with a fork or a rake; there is no locality where the water is deep enough to use a crowfoot dredge.

PEARLS.

Quite a number of pearls and slugs have been obtained by professional pearlers, especially in the region about Bemidji. One beautifully colored pearl as large as a hazelnut had been purchased by a firm of jewelers in Bemidji just before our arrival there and was valued at \$200. It weighed 21 grains, but had a slight blemish on one side. Some pearling has also been done in the Mississippi below the power dam, which is situated 11 miles down the river from Lake Bemidji. One pearl found here in July, 1912, was valued at \$300. There was also a display of pearls and slugs and manufactured

articles in the window of this jewelry store, all of which were stated to have been found in the vicinity. We saw several piles of shells that had been recently made by pearlers along the stretch of river above Bemidji, but did not find them anywhere else in this drainage. Evidently there has been very little search for pearls anywhere within this entire drainage.

PROPAGATION.

The conditions in most of the lakes and rivers of this group are excellent for propagation purposes. The water everywhere is clear and contains an abundance of lime; the bottom is almost universally composed of hard sand and gravel; there is nowhere any surfeit of algæ or aquatic vegetation, and there is apparently an abundance of food.

At Leech Lake, which, next to Red Lake, is the largest body of fresh water in the State, the outlet is muddy and full of weeds, and is reported to contain nothing but very thin-shelled floaters or paper shells. But the lake itself presents ideal conditions, and a small river which runs into it on the south shore out of Lake Linda is reported by a mussel fisherman to be full of thick shells for the mile of its course. The same fisherman said that Little Bay River, which enters the lake on the west shore, contains no commercial mussels from Leech Lake up to Laura Lake, but from there up to Little Bay Lake is full of them.

Lake Winnibigoshish was formerly a shallow mud lake, but its surface was raised 14 feet by a dam across the outlet. It would furnish a favorable locality for the introduction of the three-ridge, blue-point, washboard, and similar mud-loving species.

Cass Lake, Long Lake, and Wolf Lake are also very favorably situated, and all three, as well as the intervening portions of the Mississippi River which connects them, contain good bottom material. The conditions here are similar to those on the Snake River in the St. Croix drainage, and would be particularly well suited to the thick-shelled fat muckets.

The Mississippi flows through Lake Bemidji and Irving Lake to Beltrami County, and here again the conditions appear very propitious for the propagation of the fat muckets.

At Pokegama Lake in Itasca County there are long stretches of sandy beaches and numerous sand bars, which, combined with something of a current flowing through the lake, would favor the introduction of the yellow or slough sand-shells. This lake is 14 miles in length, but is quite narrow, and is made up of a succession of long arms and bays surrounded by fairly high land. A dam was placed across the outlet about 8 years ago, which raised the water in the lake 10 feet, and which effectually prevents any fish from entering the lake out of the Mississippi River.

At Prairie Lake, 6 miles north of Grand Rapids, the water is considerably discolored with iron brought down by the Prairie River from the Mesabi Iron Range. This iron does not appear to affect the mussel fauna at all, since they are neither stunted nor discolored. But thousands of logs are run down the Prairie River, and the bottom of both the river and much of the lake is covered so thickly with fragments of bark that no mussel can live in it.

It is hardly necessary to add that all these lakes, the Mississippi itself, and its tributaries are full of just the right kind of fish to serve as hosts. Furthermore, Walker, Cass Lake, Bemidji, and Grand Rapids are very conveniently situated for propagation work, and are in easy railroad communication with all other parts of the State.

RECOMMENDATIONS.

1. As noted under the Red River group, suitable passage should be provided for fish around the dams at the outlet of Lakes Pokegama and Winnibigoshish, and the large power dam 11 miles below Lake Bemidji. These last two are across the Mississippi, and surely that river ought never to be closed to the passage of fish, to say nothing about the mussels.

2. The farther the source of supply is removed from the button factory the greater is the cost of transporting the shells. Therefore, in a city like Bemidji, forming a convenient center, the establishment of a local factory for sawing blanks can not be too strongly recommended.

3. This is not the best locality for trying the experiment of introducing commercial species of mussels into some of the Minnesota lakes. But after such an experiment has been made a thorough success, there are large and well adapted lakes here in which artificial propagation would undoubtedly yield profitable returns.

MUSSELS OF THE ISOLATED LAKES.

LAKE PEPIN.

This so-called lake is really a simple widening of the Mississippi River just below Red Wing. The bottom is of fairly coarse gravel mixed with some mud, there is very little current, and the water varies from 6 or 8 to 12 or 15 feet in depth. This locality has not been fished for mussels until within a few years, but at the time of our visit there were 100 clamming outfits along the east shore of the lake, and they were averaging more than 200 pounds apiece per day.

An examination of the piles of shells collected by these fishermen yielded examples of the following species: *Lampsilis luteola*, *recta*, *fallaciosa*, and *alata*, *Unio gibbosus*, *Strophitus edentulus*, *Obovaria reflexa*, and *Quadrula plicata*, *undulata*, and *pustulosa*.

The culls were mostly razorbacks, spikes, such of the black sand shells as have a pink nacre, and a few floaters. By count about half of the commercial shells obtained are fat muckets (*luteola*), while by weight they form only 40 per cent of the entire catch.

A large number of fine pearls have been found here, nearly all of which come from the *luteolas*. One of these found just before our visit sold for \$300, and another for \$150. The fishermen reported the pearls not as numerous as during the previous year. They also reported another curious fact, that shells with pearls run along certain ridges on the lake bottom and are not found in the hollows along either side of the ridge.

In view of these facts it would seem advisable to propagate artificially the local commercial species, especially these thick-shelled *luteolas*, and to use this locality as a source from which to introduce desirable species into other lakes and rivers.

Mr. Andy Noel, a shell buyer for the Wisconsin Button Co. at La Crosse, took us around the lake and showed us every courtesy in the way of obtaining samples and data. Our sincere thanks are hereby acknowledged for these kind attentions.

PLEASANT AND CLEARWATER LAKES.

These lakes are situated near Annandale, in Wright County, and are connected by the Clearwater River with the Mississippi. Pleasant Lake, right in the edge of the town, is $2\frac{1}{2}$ miles long and 1 mile wide, with a gravelly and sandy bottom, comparatively free from vegetation. Shells of the pocketbook (*ventricosa*) and *Anodonta pepiniana* were obtained here. The former proved to be excellent button material, but was very scarce. It was reported, however, to have been abundant during the previous year, but had been killed or driven into deeper water by the ice.

Clearwater Lake is 4 miles from town and is much larger than Pleasant Lake, being $7\frac{1}{2}$ miles long and $1\frac{1}{2}$ miles wide. The southeastern end of the lake is wider and deeper and has rocky shores; the northwestern half is narrower, shallower, and so lined with reeds and rushes that it is impossible to get anywhere near the shore in most places.

The fat mucket (*luteola*) was found here, in addition to the pocketbook and *A. pepiniana*. Both the mucket and the pocketbook are large and thick and make excellent button material.

The Clearwater River flows through the lake and was reported to be full of fine shells. This lake and river would yield a carload of first grade mussels, which could be readily floated down to the town of Clearwater, on the bank of the Mississippi, and shipped from there. Also the local species might well be propagated at the lower end of the lake and in the river, while in the muddier bottom at the

upper end of the lake it is probable that some of the pig-toes (*Quadrula*) would thrive well.

It is very doubtful whether any recommendations can be made for Pleasant Lake.

PULASKI, BUFFALO, RICE, AND KORONIS LAKES.

These four lakes are connected with the Crow River, but the outlets are very small streams, and those of the first two are open only during spring freshets.

Lake Pulaski is nearly circular in outline, about $1\frac{1}{2}$ miles in diameter, with a bottom composed of gravel and sand, covered with a heavy growth of *Chara*, *Potamogeton*, and algæ.

Buffalo Lake is $2\frac{1}{2}$ miles long and 1 mile wide, with a maximum depth of 50 to 60 feet. There are two shallow bars across the center of the lake which are covered with rushes, and the bottom is firm sand and gravel, with very little vegetation.

Rice Lake, 6 miles northeast of Paynesville in Stearns County, is 3 miles long by 2 miles wide. The bottom is composed of much coarser gravel than in Buffalo Lake, and there is a little more *Chara* and algæ. The north fork of the Crow River runs into the southwest corner of this lake and empties out again within a short distance.

Koronis Lake, 2 miles southeast of Paynesville, is $3\frac{1}{2}$ miles long and 2 miles wide, with a very irregular and precipitous shore. The bottom contains much more sand than gravel and the vegetation is very limited except at the inlet and outlet.

The fat mucket (*Luteola*) and *Anodonta pepiniana* were found in all four lakes, and in addition *Anodontoides ferussacianus modestus* was found in Buffalo and Koronis Lakes. Most of these muckets are dwarfed, as is usual in a lake, and thin-shelled, but those from Rice Lake are full size, of good thickness and have a fair luster, and were classed as first-grade shells.

The *Anodontas* were found in regular windrows 10 or 15 feet from shore, and outside of them were the *Luteolas*, in water shallow enough to obtain them by wading. The epidermis of these *Luteolas* was a dark straw-yellow, and was highly polished like that of the same species from Lake Henry (p. 11).

The comparative paucity of shells in these lakes is easily explained by the fact that fish can not run into them freely at the time of year when they are infested with glochidia. The conditions in Buffalo Lake are excellent for sand-shells and species which frequent shallow bars. The thick-shelled *Luteolas* from Pokegama Lake (Pine County), or Lake Pepin would undoubtedly thrive in Rice and Koronis Lakes. Lake Pulaski is not worth stocking with any kind of shells.

Each of these lakes contains an abundance of perch, bass, sunfish, crappies, and wall-eyed pike, which could be seined with little trouble

and would furnish sufficient hosts for the glochidia; therefore, in case the artificial stocking of lakes proves a success, three of these lakes present good opportunities for work on commercial species.

SAUK LAKE AND SAUK RIVER.

Sauk Lake, 3 miles above Sauk Center in Stearns County, is 7 miles long and $\frac{3}{4}$ mile wide, and is thus little more than a widening of the river. It is partly natural and partly artificial, produced by a dam across the river at Sauk Center. The bottom is composed of sand and coarse gravel, covered with a profuse growth of algæ, *Chara*, *Potamogeton*, and other aquatic vegetation. The only mussels found in the lake were the fat mucket (*luteola*), *Anodontoidea ferussacianus modestus* and *Anodonta pepiniana*. The muckets are thin-shelled, dwarfed, and covered with a large amount of marl posteriorly. The epidermis is honey-yellow in color, highly polished, and faintly rayed. The two floaters, of course, possess no commercial value, and were found only in limited numbers.

The river was examined below the mill dam at Sauk Center, and again 3 miles above St. Cloud. The fat mucket (*luteola*), the pocketbook (*ventricosa*), and the black sand-shell (*recta*) were found in abundance at both places, and in addition near St. Cloud there were some ordinary muckets (*ligamentina*) and *Anodontoidea*.

The fat muckets were of river size, and a small percentage were thick enough for buttons, the ordinary muckets were of large size and thick-shelled, but were somewhat spotted; the pocketbooks were exceptionally large, much flatter than usual, thick, and with a good luster, but they were also spotted, and on being tested proved to be brittle, thus rendering practically worthless material that to all appearance seemed to be as good as that from the Shell River at Menahga. The only thing worthy of comment here is the lack of a suitable fishway around the dam at Sauk Center. The effect of this is seen in the fact that although the pocketbook was common just below the dam, not one could be found in the 3 miles of river above the dam.

LAKE MINNEWASKA, LAKE OSAKIS, AND BATTLE LAKE.

Lake Minnewaska, situated at Glenwood, near the center of Pope County, is 8 miles long and 2 miles wide. The bottom is of sand and rather fine gravel, with numerous shallow sand bars along the southwestern shore. The average depth of the water is from 12 to 15 feet, and while there is an interrupted fringe of rushes along the shore line the lake itself is exceptionally clear and free from aquatic vegetation. There is no outlet except during very high water, when a small stream overflows into the Chippewa River, which is a tributary of the Minnesota River.

The lake is fed by numerous large springs in addition to several inlet streams, which drain the surrounding country. The lake contains an abundance of sunfish, perch, crappies, wall-eyes, and bass. On the northwest shore of the lake, within the city limits of Glenwood, there is a State fish hatchery under the supervision of Supt. J. A. Pinkerton. The water for the hatchery comes from one of the large springs that feed the lake, while a series of fishponds or aquaria are built in the lake along the shore. The lake was found to contain a great many mussels, which, however, possess no commercial value. These include the fat mucket (*luteola*), which is much dwarfed and thin-shelled, with an epidermis which erodes easily and turns dead white on exposure, three species of *Anodonta*, *imbecillis*, *pepiniana*, and *benedictensis*, and *Anodontooides*. The profusion of these mussels and the rapidity of their development show that there is an abundance of food in the lake.

We find, therefore, that the temperature and depth of the water, the kind of bottom, the presence of numerous shallow sand bars, the freedom from aquatic vegetation, and the abundance of suitable food combine to make this lake an ideal one for the artificial propagation of mussels, particularly the *Lampsilis* group. And, as if to complete the requisites, here is a fish hatchery, in whose interests hundreds of bass and wall-eyes are seined out of the lake every spring. Along with the game fish which are used by the hatchery there are always taken in the seine a large number of sunfish and yellow perch which are simply thrown back into the lake. What could be simpler than to supply the hatchery with gravid mussels of some valuable commercial species and impregnate these sunfish and perch with the glochidia before they are returned to the lake? Manifestly this is a rare opportunity for testing the possibilities of mussel propagation with almost no additional expense. The importance of such practical experimentation under the direction of skilled workmen can hardly be overestimated.

While in Glenwood we were rendered great assistance and were shown many courtesies by the officials at the hatchery. One of them, Mr. John Dahl, took us around the lake, gave us many data, and explained the local conditions, with which he was thoroughly conversant. Our sincere thanks are hereby returned to him and to the superintendent for these and many other favors.

Lake Osakis, situated close to Osakis, in the southwestern corner of Todd County, is 10 miles long and 3 miles wide. The bottom, the depth of the water, the presence of sand bars, and the freedom from aquatic vegetation correspond exactly to those at Lake Minnewaska. This lake also has no outlet except at very high water, and is a typical shallow lake, such as are common in glaciated regions.

There were found here the fat mucket (*luteola*), *Anodonta pepiniana* and *Anodontoidea*. Some of the muckets were dwarfed and thin-shelled, but a small percentage were full-size and had moderately thick shells.

Battle Lake is in the southern central portion of Ottertail County and empties into the Red River. It is 6 miles long by 3 miles wide. It has a bottom of sand and gravel sparsely covered with aquatic vegetation, and the water is very clear and cold. The fat muckets here were small and dwarfed and approached very closely the species known as *rosacea*. They were easily eroded, and the epidermis on exposed portions of the shell became absolutely snow-white.

In addition there were two species of *Anodonta*, viz, *pepiniana* and *kennicotti*, and *Anodontoidea*. All of these shells, including the muckets, were worthless from a commercial standpoint.

Neither Battle Lake nor Lake Osakis has a fish hatchery, but otherwise they possess as favorable conditions as those at Lake Minnewaska, and are as conveniently situated. Consequently, if the experiments at Lake Minnewaska proved successful, it would be an easy matter to repeat them in these two lakes.

SUMMARY.

1. Fat muckets (*Lampsilis luteola*) with exceptionally thick shells, and making first-grade button material, are plentiful in Pokegama and Cross Lakes, and in the Snake River, and also in Lake Pepin. They are not found in any of the other lakes or rivers which were examined.

2. Pocketbooks (*L. ventricosa*) of unusual size and luster are abundant in the Shell River and Twin Lakes near Menahga and elsewhere throughout the Crow Wing drainage and in the Sauk River. The Crow Wing shells are of superior quality and command a high price. Those from the Sauk River are so brittle as to render them worthless.

3. Muckets (*L. ligamentina*) are common in the Crow Wing and its tributaries and in the upper Mississippi. They are the ordinary good button material that is common in this species.

4. Black sand-shells (*L. recta*) are fairly abundant in all the rivers visited. Nearly all have purple nacre, are very thick, and make excellent material for novelties. The only exceptions are the white-nacred ones found at Menahga, which are excellent button shells.

5. Pig-toes (*Quadrula*) are found only in the St. Croix drainage and in the Red River. There are none in the Mississippi above the Falls of St. Anthony, nor in any of the other rivers and lakes visited. Some of the three-ridges were badly spotted, but all of the other pig-toes were of first quality and would make good button material.

6. Bemidji, in Beltrami County, is the best center from which to work the upper Mississippi. A blank factory situated there could

easily find material to keep it running for several years. Phelps, in Ottertail County, would make an equally good center for the Red River.

7. There are two of the recommendations which possess especial importance: First, to preserve by artificial propagation the types of shells shown in the muckets of Lake Pokegama and the pocketbooks of Menahga; second, to improve the opportunity so favorably offered at Lake Minnewaska and thoroughly try out by experiment the introduction of valuable commercial species into lakes that are specially suited to them.

E R R A T A

Bureau of Fisheries Document No. 882, "Dragonflies and Damselflies in Relation to Pondfish Culture, with a List of Those Found Near Fairport, Iowa."

Page 183.--Line 8: "198" should read "199".

Page 198.--Line 1 of legend: "maquilla" should read "maxilla", and "31," should be inserted before "mandible".

Page 207.--Line 9: "alga-l" should read "algal".

Page 221.--Line 7 from bottom: "(p. 205)" should read "(p. 225)".

Page I.--Line 8: "(Colopteryx)" should read "(Calopteryx)".

Line 10: "cnemies" should read "enemies".

DRAGONFLIES AND DAMSELFLIES IN RELATION
TO POND FISH CULTURE, WITH A LIST OF THOSE
FOUND NEAR FAIRPORT, IOWA : By Charles Branch Wilson

From BULLETIN OF THE BUREAU OF FISHERIES, Volume XXXVI, 1917-18

Document No. 882 : : : : : : : : : : : : : : : : Issued August 4, 1920

PRICE, 15 CENTS

Sold only by the Superintendent of Documents, Government Printing Office, Washington, D. C.

FOREWORD.

The accompanying paper by Prof. Charles Branch Wilson, concerning a group of common insects in relation to fish culture, merits a special comment. The author has not confined himself to a mere list of dragonflies and damselflies or to the recording of observations regarding their distribution, abundance, habits, and life history. He has supplied such necessary information, but, more important from the point of view of the Bureau of Fisheries, he has treated these insects fully and judiciously in their relations to fish, and thus in their relations to the food supply and welfare of man.

We know that some insects, through destruction of crops and property or through injurious effect upon public health, are to be classed as insidious enemies of humanity and to be combated in every possible way; but there are others which we have learned to class as allies in the struggle for existence, since they make it possible for us to have useful articles of food and clothing, or are destructive to enemy insects.

There are many insects of several orders, including the dragonflies and damselflies, which, before they begin to fly, spend a long period of existence in the water where they have direct or indirect relations to the useful fishes. The attitude assumed toward any of these must depend on whether they are found to be useful or harmful to fishes and to man. The relations of insects and fishes are complex. Voracious insect larvæ may destroy the fry of fishes or may consume food otherwise available to young fishes; they may destroy other and more dangerous enemies of fishes; or they may feed upon things that are not available to the desirable fishes and themselves become food for fishes. It is necessary to accumulate exact information and wisely to balance the good against the evil before we can determine whether the abundance of any particular aquatic insect should be opposed or promoted in the interests of an increased food supply from fishes.

After a thorough analysis of all that has been known regarding the dragonflies and damselflies and all that has been learned in the course of this investigation, the author concludes with evident justification that these insects are, on the whole, of great economic importance, and he recommends them to the favor of the fish-culturist.

Studies such as this, which can be applied not only to other insects but to various kinds of aquatic animals and plants, will necessarily have the effect of enabling us to apply more intelligence to the practices of fish culture and the production of food from private and public waters.

H. M. SMITH,
Commissioner of Fisheries.

CONTENTS.

	Page.
Foreword.....	182
Introduction.....	185
General description of the ponds and their environment.....	186
Abundance of dragonflies and damselflies.....	188
Relative abundance of different species.....	189
Life history of an odonate.....	192
Mouth parts of odonate nymphs.....	193
Mouth parts of odonate imagos.....	198
Economic relations between odonates and fishes.....	200
Food of odonate nymphs.....	201
Enemies of odonate nymphs.....	209
Food of odonate imagos.....	211
Enemies of odonate imagos.....	222
Odonate nymphs as fish food.....	225
Odonate imagos as fish food.....	231
Stocking the fishpond.....	232
Experiments in hatching odonate eggs.....	238
General conclusions.....	246
Annotated list of dragonflies and damselflies obtained near Fairport, Iowa.....	248
Bibliography.....	260
Index.....	I

FIG. 1.—Pond No. 4, Series D, showing fringe of *Carex stricta* around the margin.

FIG. 2.—The cinder road along the north sides of ponds Nos. 1, 2, 3, and 4. To the left is seen the upland grass field which served as a roosting place at night for the dragonflies.

DRAGONFLIES AND DAMSELFLIES IN RELATION TO POND FISH CULTURE, WITH A LIST OF THOSE FOUND NEAR FAIRPORT, IOWA.

By CHARLES BRANCH WILSON, Ph. D.

State Normal School, Department of Science, Westfield, Mass.

Contribution from the U. S. Fisheries Biological Station, Fairport, Iowa.

INTRODUCTION.

Among the various activities carried on by the Fairport Fisheries Biological Station is that of fish propagation, not the artificial rearing of fry and fingerlings for subsequent distribution, as usually carried on at a national or State fish hatchery, but rather the comprehensive and experimental breeding and rearing of adult food fishes in artificial ponds made for that purpose. Such intensive culture of food fishes bids fair to attract wide attention in the near future.

The Bureau of Fisheries has repeatedly called attention to the opportunities and possibilities of such culture, and recently the State colleges of agriculture have taken up the subject, led by the New York State College, at Cornell University. This latter institution published, August 15, 1915, a paper on "The Farm Fishpond," by George C. Embury (The Cornell Reading Courses, vol. 4, No. 94), in which are found the following statements: "Farm fish culture has been almost wholly neglected in America, even though a large part of the country possesses exceptional advantages for it. * * * During the past four years the New York State College of Agriculture at Cornell University has been giving instruction in the propagation of useful aquatic animals to a steadily increasing number of students. Letters are continually coming in from persons in different parts of this and other States seeking information concerning the propagation of frogs and fishes" (pp. 214 and 215). Much suitable instruction is then given, but very little is said with reference to environmental ecology.

In an article published in the Popular Science Monthly for July, 1915, Dr. R. E. Coker said: "The artificial propagation of fish, even under present conditions, is producing results of significant value, but it is no disparagement of such operations to venture the prediction that the future will show that the effective conservation of fishery resources depends upon the coupling of intelligent fish culture with comprehensive and well-advised conservation of the environment favorable both to the natural propagation of fish and to the multiplication of the essential elements of food supply" (p. 95).

The same author, in a later paper (1916, p. 402), while discussing the equipment, organization, and functions of the Fairport Fisheries Biological Station, said: "It is

held as a most important responsibility of the station to stimulate and to guide the development of fish farming as a more widespread industry. This function as a fish-cultural experiment station should rightly be regarded as second to none."

On page 398 of the same report he stated: "It is manifest that the assembly of fish-cultural ponds, supplied originally with water from the Mississippi, but permitted to develop essentially pond conditions, stocked with abundant aquatic vegetation and rich in entomostraca, insect adults, and larvæ, together with the customary variety of smaller animal forms that thrive on the bottom, amidst the vegetation or in free-swimming condition, offer favorable opportunities for biological and physiological studies bearing upon problems of fish food, as well as for investigations of more particular scientific interest."

One feature of the environment, especially well developed at Fairport, and which will always be present in the pond culture of food fishes, is the presence of a greater or less number of dragonflies and damselflies which pass their larval life in the waters of the ponds and their adult life in the immediate vicinity. It becomes, therefore, of considerable importance to know whether the presence of these larvæ and adults is beneficial or injurious to the fishes. The ecology of this problem forms the main theme of the present paper, to which is added a list of such species as have been obtained at or near the station during three years of collecting.

The observations here recorded were made during the months of July and August, together with the last week in June and the first week in September. Some species emerge earlier in the year, but they usually have a second period of emergence within the limits just mentioned, and hence it is believed that the present observations cover all species of real importance.

GENERAL DESCRIPTION OF THE PONDS AND THEIR ENVIRONMENT.

The position and arrangement of the ponds of the Fairport station are clearly shown in the accompanying map. For convenience of manipulation they have been divided into six series called, respectively, A, B, C, D, E, and F, the ponds in each series being numbered independently. Series A and C are small cement ponds or out-of-doors aquaria for the temporary keeping of fish and mussels under experimentation and do not concern the present discussion at all. Series E and F are dirt ponds filled for the first time in July, 1916, and used the remainder of that summer and ever since. But owing to their newness when the present investigation on dragonflies and damselflies was begun, they were given no attention. During the summer of 1917, however, some of the observations on the food of odonate imagos were made around the shores of these ponds. Some of the young fishes also, the food contents of whose stomachs were examined during 1917, came from these ponds. This leaves only series B and D, the former south of the railroad and within 200 feet of the river bank, the latter north of the railroad and much farther from the river. Series B is made up of six small dirt ponds, the largest only 0.19 of an acre in extent, all of them heavily filled with algæ and water vegetation of various kinds.

Series D, on the other hand, contains nine large ponds with a total area of nearly 6 acres and presents admirable conditions for an ecological study of their environment. This is the series upon which the present study is based; they are all dirt ponds of the usual construction, having wide embankments thickly covered with vegetation, and

HR CISTERN
Copy 4160 Gals

ROCK ISLAND

PONDS SERIES 'B'

Blacksmith Shop

Pump House

Meat

PLANT DISTRIBUTION IN PONDS OF SERIES D, FAIRPORT, IOWA, 1916.

[a=abundant, c=common, s=scarce.]

Species.	Pond numbers.								
	1	2	3	4	5	6	7	8	9
IN THE WATER.									
Potamogeton illinoensis: Illinois pond weed		a	a						
Potamogeton pusillus: Small pondweed		a			c				
Potamogeton pectinatus: Fennel-leaved pondweed						s		a	
Trypha latifolia: Cattail			a		s		s		s
Ceratophyllum demersum: Hornwort	s	c		s	s		c	s	c
Ranunculus aquatilis: Common water crowfoot			c				c	c	
Oedogonium, sp.: Filamentous alga	c		c						
Elodea canadensis: Water weed	a	a	a	s			a	c	
Vallisneria spiralis: Belgrass			c			s		s	
Najas flexilis: Slender naias	s	s	s	s	s	s	s	s	
Castalia odorata: White pond lily			c						
Blanket algæ	a	a	c	a	a	a	c	a	a
ALONG THE MARGINS.									
Carex stricta: Crex grass	a	a	a	a	a	a	a	a	a
Rumex crispus: Curled sorrel	c				c		s		c
Eleocharis palustris: Creeping spike rush	s			c	c	c			s
Sagittaria latifolia: Broad-leaved arrowhead		c	c	s					
Homalocenchrus oryzoides: Rice cut-grass							c		
Juncus effusus: Common rush				s			s		s
Echinochloa crusgalli: Cockspur grass		s			a		s		a
ON THE EMBANKMENTS.									
Convolvulus sepium: Bindweed	c		c	s		c			s
Lactuca scariola: Prickly lettuce	c		a	a	a	a			a
Equisetum fluviatile: Swamp horsetail		a	c	s					
Trifolium pratense: Red clover	c	c	c	a	c	c	c	s	s
Plantago rugelii: Common plantain	a	a	a	a	c	c	c	s	s

ABUNDANCE OF DRAGONFLIES AND DAMSELFLIES.

The actual number of both dragonflies and damselflies varies greatly from time to time, due to a variety of causes.

1. PERIODICITY.—The emergence of the imago is periodic in occurrence; most of the Libellulidæ have a one-year cycle, and the great majority of any given species emerge at or near the same time. Just after this period of maximum emergence their numbers reach the highest point for the season, and then gradually decrease. Some species of *Anax*, *Tramea*, and *Æschna* may have two broods during the year, in spring or early summer, and again in late summer or early fall, and consequently would have two periods of maximum abundance. Even the Gomphidæ, whose nymphs require more than a year in which to mature, show similar periods of maximum emergence, large numbers being transformed within a few days and then diminishing rapidly in abundance. On the other hand, the damselflies apparently have several broods during the season, and their numbers rise and fall accordingly.

2. MIGRATION.—The imagos of many species have the habit of scattering rapidly soon after their emergence, even while they are still teneral, and they may sometimes entirely disappear. This is true of *Epicordulia princeps*, whose fresh nymph skins were second in abundance during the last of June, and yet not a single imago could be seen about the ponds at that time. The Gomphidæ furnish numerous similar examples; the most abundant of their nymph skins was that of *Gomphus plagiatus*, over a thousand of which were secured along the bank of the Mississippi opposite the ponds, but not a single

imago was found anywhere in the vicinity until the last of July, and then only a few. On the other hand, the imagos of both *Gomphus externus* and *G. vastus* were common about the ponds, but neither nymphs nor nymph skins were secured from the ponds themselves.

The nymphs of *Anax junius* and *Æschna constricta* were abundant in all the ponds, but comparatively few imagos could be found at any one time. This migratory scattering profoundly affects the numbers of imagos found about the ponds.

3. THE WEATHER.—“All dragonflies are most active in hot, quiet, sunshiny weather” (Needham and Hart, 1901, p. 11), and consequently they appear more abundant at such times than on a dull, lowering day, when many remain in the shelter of the grass and weeds. Hence if we are to estimate the number of dragonflies correctly we must take into account the kind of weather during which the observation is made.

4. CONCEALMENT.—Large numbers of the smaller damselflies, especially such species as *Ischnura verticalis*, frequent the dense grass and are sure to escape observation. Hence the actual number of damselflies in any locality is almost certain to be underestimated, unless the grass and weeds are closely examined. A vigorous sweeping of the net over them always reveals far larger numbers than were first seen and often yields species that would otherwise escape detection.

Careful estimates, made by repeatedly walking around the ponds and counting such specimens as could be seen, making due allowance for repetitions and keeping in mind the considerations just presented, indicate that there is for each of the ponds a fairly constant average of 100 to 150 dragonflies, while the numbers of damselflies vary with their periods of emergence. Just after emergence there will be 300 to 500 for each pond, but between times the number may fall to 50 or even less. These numbers hold through the latter part of June, July, and the first of August, but become greatly reduced by the last of August.

RELATIVE ABUNDANCE OF DIFFERENT SPECIES.

Turning now to the relative abundance of the various species we can secure an exact numerical basis for our estimate. While it would be manifestly impossible to count the imagos of the different species and obtain any result worthy of record, good results can be obtained by gathering and counting the nymph skins. Such collections were made at intervals of two weeks during the summer of 1916 with the results shown in the following table. The successive counts were made along the north shores of ponds 4, 3, 2, and 1, respectively, the length of shore covered by each count being about the same. Over 2,000 nymph skins were obtained in the four counts, which indicates that the numbers given above under actual abundance are not too large.

NYMPH-SKIN COUNTS, PONDS 1 TO 4 D, FAIRPORT, IOWA, 1916.

Nymph skins obtained.	July 3.		July 16.		July 31.		Aug. 15.	
	No.	P. ct.	No.	P. ct.	No.	P. ct.	No.	P. ct.
<i>Æschna constricta</i>	1	.....	2	.....	30	5	20	4
<i>Anax junius</i>	2	.....	10	2	46	7	48	10
<i>Epicordulia princeps</i>	31	6	1	.....	12	2	15	3
<i>Pantala flavescens</i>	2	.....	3	.....	4	.....	10	2
<i>Tramea lacerata</i>	2	.....	1	.....	2	.....	40	8.5
<i>Perithemis domitia</i>	5	1	3	.....	16	2.5	8	2
<i>Celithemis eponia</i>	2	.....	1	.....	3	.....	25	5
<i>Leucorrhinia intacta</i>	5	1	3	.....	16	2.5	8	2
<i>Sympetrum rubicundulum</i>	2	.....	1	.....	3	.....	25	5
<i>Sympetrum corruptum</i>	3	.....	10	2	12	2	26	5.5
<i>Pachydiplax longipennis</i>	1	.....	2	.....	.....	.....	.....	.....
<i>Libellula luctuosa</i>	442	89	6	1	51	8	20	4
<i>Libellula pulchella</i>	1	.....	310	66	246	40	137	29.5
<i>Erythemis simplicicollis</i>	1	.....	6	1	20	3	4	.....
<i>Plathemis lydia</i>	2	.....	114	24	160	26	112	24
	5	1	.....	.....	8	1	.....	.....

Certain additional facts were noted during the gathering of the nymph skins.

1. CHOICE OF LOCALITY.—Upon reaching maturity the nymph does not crawl out of the water blindly wherever he may happen to be, but shows a definite preference for certain localities. Most of the nymphs here recorded transform in the early morning, at which time the west and north margins of the ponds receive the early sunshine, while the east and south margins are in the shade. It has been stated that the counts were made on the north shores; this was because those shores were found by actual trial to yield many more nymph skins than the east or south shores, and considerably more than the west shore. Another important reason is that the north shores border the shallower water of the ponds, and are thus naturally frequented by the nymphs when nearly ready for transformation.

A third factor which may influence the nymph in its choice of a locality for transformation is the kind of support obtainable. Some nymphs, such as those of *Libellula luctuosa*, *Anax*, and *Epicordulia* crawl up on anything that may be convenient, including wire screening, old boards, fence posts, and the like. Others show a decided preference for certain kinds of support and will even choose between different water plants. *Erythemis simplicicollis*, for example, selects the arrowleaf, *Sagittaria latifolia*, in preference to the cat-tail, *Trypha latifolia*, when the two are equally available. And this same species was the only one found in any abundance upon the stems of the crex grass, *Carex stricta*.

Erythemis transforms later in the day than many of the other species, and its exuviae were found in large numbers along the eastern shores of the ponds. In five of the ponds these shores contain both cat-tails and arrowleaf in addition to the crex grass, but almost without exception the *Erythemis* nymphs had chosen the latter.

On the other hand, *Anax* usually emerges during the night, and its exuviae were found upon the western and northern shores, and more of them upon the cat-tails than upon all other kinds of support combined. The large, sprawling nymphs of *Tramea lacerata* also take very kindly to the cat-tails, but shun the crex grass altogether.

Among the damselflies the *Enallagmas* are always found upon some convenient stem, a short distance above the water. Often there will be several exuviae upon the same stem, and in one instance the number reached 21, as recorded upon page 230.

On the other hand, the nymphs of *Ischnura* very frequently crawl out upon the top of the lily pads and perch for transformation on the margin of the leaf, where it has

curled up in the sun, half or three-fourths of an inch above the water. Twenty-five such teneral *Ischnuras* were seen close to their exuviae upon the pond-lily leaves of pond 3 on the afternoon of July 28, 1917, but not a single *Enallagma*. Nor have the exuviae of the latter ever been found in such places around the Fairport ponds.

The nymphs of *Argia mæsta putrida* often crawl long distances over the land and then up the trunk of a tree and are the only damselfly exuviae found in such positions. This leads naturally to the second consideration.

2. DISTANCE TRAVELED.—The distance to which the nymphs crawl before transforming varies greatly, not only for the different species, but also for different individuals of the same species. Some nymphs, like those of *Perithemis domitia* and the two *Sympetrum*s, were always found upon rush or grass stems standing in the water, often at quite a distance from the shore. Others, like *Anax*, *Æschna*, and *Erythemis*, were close to the shore, sometimes over the water, and sometimes over the land, but never very far from the water's edge. *Libellula luctuosa*, *Epicordulia*, and *Plathemis*, on the other hand, crawl much farther and sometimes go a long distance. In the first count, 1 *Plathemis*, 5 *Epicordulia*, and 47 *L. luctuosa* crawled up the bank of the pond, across the cinder road, up a dirt bank bordering the road, and into the grass field, the entire distance being 50 or 60 feet. The other individuals of these species were all found between the road and the water's edge.

3. LACK OF PROTECTIVE INSTINCT.—While instinct may guide the nymph to the shallow and sunny side of the pond, it apparently fails him in some other directions. There were two red-winged blackbirds' nests in the cat-tails and crex grass on the shore of pond 2, where the second count was made. Twenty-five nymph skins were taken within a radius of 6 inches of one of these nests, three of which were actually fastened to the sides of the nest itself, and seven were found within a similar radius of the other nest. The young birds had only just left the nests and were still in the immediate vicinity, so that some of the nymphs must have transformed while the nests were still occupied.

4. RELATIVE ABUNDANCE OF SPECIES.—From the counts above recorded it appears that *L. luctuosa* is the most abundant species, and also that it emerges before the others. Its time of greatest abundance is during the last of June and the first of July, when it constitutes over 90 per cent of the dragonfly fauna of the ponds. Although it keeps up a good percentage and remains throughout the season more numerous than any other single species, it quickly loses its relative predominance and steadily declines during the latter part of the season, until by the middle of August it is only a little more numerous than *E. simplicicollis*.

On the other hand the latter does not begin to appear until *luctuosa* has reached its maximum. It then rapidly increases, while *luctuosa* is decreasing, and its time of greatest abundance is the latter part of July, following which it declines through August.

Tramea, *Anax*, and *Æschna* did not really begin to appear until the middle of July and then steadily increased through the remainder of the season, until by the first of September, together with *Epicordulia*, they were about the only species left. In 1917 a very much larger number of *Anax* and *Æschna* exuviae were found early in the season, by the last of June or the first of July; but the imagoes were no more numerous than during the preceding year, because they scatter immediately after emergence. Both species must return to deposit their eggs either in the pond where they were hatched or

in some similar body of water. The *Anax* imagos are present in considerable numbers around the ponds by the first of August, and may be seen mating and ovipositing. The *Æschna* imagos delay much longer, and none have thus far been seen depositing eggs before the second week in September. In Massachusetts the same species, *constricta*, may be seen depositing its eggs as late as October.

Sympetrum corruptum appeared late in June and lasted for about three weeks and then entirely disappeared, its place being taken by *S. rubicundulum*, which remained the rest of the season.

Perithemis domitia was never present in sufficient numbers to really enter into the reckoning.

Platthemis lydia and *Libellula pulchella* were much more abundant in 1917 than in 1916, and both took an active part in the odonate life of the ponds. Previously they had remained quite constantly along the ditches beside the railroad tracks, but finally deserted them and assumed their appropriate places around the ponds.

LIFE HISTORY OF AN ODONATE.

In order to properly appreciate the relations between fish and dragonflies and damselflies it is well to consider briefly the life history of these insects.

EGGS.—The eggs are laid in the water and hatch into larvæ called nymphs. The period of incubation varies greatly in different species; perhaps the average for dragonflies is from 5 to 10 days, and for damselflies about 20 days. Eggs laid by a *Pachydiplax* female and kept in the laboratory hatched in 5 days; Warren (1915, p. 8) also found the period of incubation in *Pantala flavescens* to be 5 days for two females and one male and 7 days for another male. The dragonfly's egg is ellipsoidal, narrowed a little at either end, and surrounded by a gelatinous envelope (fig. 1). There is a small projection or knob at the anterior end of the egg, which is known as the pedicel. It is formed of a thickening of the egg shell or chorion and furnishes the means by which the egg is attached to the egg string inside the ovary of the female.

The eggs of damselflies and of *Anax*, *Æschna*, and their relatives among the dragonflies are considerably elongated and assume a cylindrical form (fig. 58). The anterior end is pointed, with a short and wide pedicel, while the posterior end is bluntly rounded.

NYMPH.—At the end of the third day the larval pronymph could be seen inside the *Pachydiplax* egg and appeared as shown in figures 2 and 3, the long concentric lines being the folded legs. On emerging from the shell the pronymph is closely covered by a chitin sheath which holds the legs tightly to the body. It quickly molted out of this sheath and took the form shown in figure 5, but one was pulled out of the sheath before it had time to molt, and this one looked like figure 4. The body was elongate and fully segmented and the legs were more or less twisted from their previous folding. The pronymphal stage lasts usually but a very short time, less than a minute, sometimes only two or three seconds. The nymph, on the other hand, continues until it is ready to be transformed into the imago or perfect insect. Most nymphs require a year in which to fully mature; a few, like *Gomphus*, require more than a year, while others, like the damselflies *Enallagma* and *Ischnura*, may produce more than one brood in a season.

IMAGO.—In these latitudes the winter is passed in the nymph stage, and toward the close of the following spring the nymph, having passed through successive molts, is ready for transformation. This is accomplished by crawling out of the water onto some convenient object near at hand, to which it fastens with its claws. In a short time the skin splits across the top of the head and then along the back and the imago or perfect insect emerges, leaving the old nymph skin, called an exuvia, fastened to its support.

TENERAL.—After emerging, the imago is of a uniform pale yellow or tinged with blue, brown, or white, and it takes from a few hours to several days for it to acquire the bright colors of the mature adult. During this time it is called a teneral, its body is soft and flabby, its wings shine as if varnished, and its powers of flight are quite limited.

FIGS. 1 TO 3.—The egg of *Pachydiplax longipennis*: 1, newly laid; 2, three days old, dorsal view; 3, three days old, side view, showing at the right the large ventral plate and in the center the folded legs. FIG. 4.—Pronymph of *Pachydiplax longipennis*; length, 0.90 mm. FIG. 5.—Nymph of *Pachydiplax longipennis* after the first molt; length, 1 mm.

PRUINOSE.—After becoming thoroughly hardened, some species, especially the males, are gradually covered with a bluish or whitish powder which may hide entirely the original bright colors; they are then said to be pruinose.

In *Plathemis lydia* the old males are almost white on the dorsal surface; in *Erythemis* and *Pachydiplax* they become blue; while in the damselfly, *Argia putrida*, the thorax and the last two segments of the abdomen appear to be blue, but this color disappears at once when they are put in alcohol.

MOUTH PARTS OF ODONATE NYMPHS.

DRAGONFLY NYMPHS.—In dealing with the food of nymphs and adults we need to know a little about the means which they possess for seizing, eating, and digesting their prey; let us begin with the mouth parts.

Mask.—The most noticeable thing about a nymph is the so-called mask, which is folded back beneath the head and which may or may not cover the lower part of the face (fig. 6). This mask is really the lower lip or labium, whose outer end terminates in three lobes, one median and two lateral; the latter may take the form of stout claws (*Æschnidæ*) or of spoon-shaped lamellæ (*Libellulidæ*). The mask is hinged near the center and when not in use is folded at the hinge; the lateral lobes are turned inward across the front end of the median lobe, and the whole apparatus is folded back beneath the head. Figure 7 is a side view of the head of *L. luctuosa*, showing the mask folded back, while the lateral lobes at its tip cover the lower half of the face. This is the condition found in the nymphs of all the *Libellulidæ*. Figure 9 is a side view of the head of *Anax junius*; here the lateral lobes do not cover the face at all, but extend straight forward as stout claws beneath the chin. This condition is found in the nymphs of the *Æschnidæ*, with the exception of the genus *Cordulegaster*, and as an accompanying character the head is depressed or flattened. The length of the labium varies considerably in different dragonflies, but is usually longer in the *Æschnidæ* than in the *Libellulidæ* and reaches back, when folded, between the bases of the second legs.

With the mask folded the nymph either conceals itself in the mud or trash on the bottom or steals up on its prey and when within striking distance shoots the mask forward in front of the head and grasps the victim between the lateral lobes. Figures 8 and 10 show the same two specimens of *luctuosa* and *junius* with the mask thus extended.

The distance which they can reach, of course, varies with the size of the nymph and the length of the mask; some of the large *Anax* nymphs can cover 15 to 25 mm. This, in addition to the lurching forward of the body, enables them to catch insects like *Corixa*, much more agile than

FIG. 6.—Face of nymph of *Erythemis simplicicollis*, showing the large mask-like labium covering the lower part of the face up to the antennæ and eyes.

themselves, and even to capture small fishes.

To assist in holding their prey, the lateral lobes of the mask are toothed along their inner margins in the *Æschnidæ* (fig. 11). In the *Libellulidæ* they are armed with a long, slender spine at the tip and a row or raptorial setæ behind this along the outer margin, varying in number in the different species. There is a crescent of similar setæ, also varying in number, along the body of the mask, called the mentum, on either side of the median line. And there are more or less regularly arranged spines and hairs along the remaining margins of all three lobes. Figures 12 to 14 illustrate some differences between the species.

Maxillæ.—Once grasped between the lobes of the mask, the prey is drawn quickly to the mouth, where there are two pairs of organs ready to dispose of it. The first of these, the outside pair, are the maxillæ, which are very much alike in all nymphs; each maxilla has two fingerlike branches or rami, the outer (ventral) of which is

FIG. 7.—Side view of head of nymph of *Libellula luctuosa*, mask folded. FIG. 8.—Same, mask extended. FIG. 9.—Side view of head of nymph of *Anax junius*, mask folded. FIG. 10.—Same, mask extended. FIG. 11.—Mask of *Anax junius*. FIG. 12.—Mask of *Libellula luctuosa*. FIG. 13.—Mask of *Erythemis simplicicollis*. FIG. 14.—Mask of *Pachydiplax longipennis*.

armed with stout, curved claws, while the inner is covered with stiff hairs; these maxillae are evidently used to help hold their prey securely (figs. 15 and 16).

Mandibles.—The second pair are the mandibles; they are much stouter, are hard and chitinous, and are armed with strong teeth (figs. 17 and 18). They can easily crush the shells of small pond snails like *Limnea*, *Physa*, and *Planorbis*, or they can bite through the hard chitin covering of beetles and water boatmen. The food contents of the stomachs of all the nymphs examined shows that the mandibles are used chiefly for crushing the food and not for chewing it. It is chewed only enough to get it down the gullet, and much of it is swallowed whole.

Gizzard teeth.—The real mastication takes place in the gizzard, and for this purpose the wall of the gizzard at the posterior end is armed with four longitudinal ridges of chitin—two dorsal and two ventral. Each ridge carries projecting teeth, whose number and arrangement varies a little in different species. The general character of these

FIG. 15.—Maxilla of *Anax junius* nymph. FIG. 16.—Maxilla of *Erythemis simplicicollis* nymph. FIG. 17.—Mandible of *Anax junius* nymph. FIG. 18.—Mandible of *Erythemis simplicicollis* nymph.

toothed ridges is well shown in figures 19 to 24. The churning of the gizzard grinds the food against the teeth and soon reduces it to finer fragments; it then passes on into the intestine.

DAMSELFLY NYMPHS.—The structure of the mouth of the damselfly nymph is in all respects similar to that of the dragonfly. The mask (fig. 25) is more like that of the Libellulidae, with raptorial setae on the lateral lobes and the mentum, but the lateral lobes only cover a very small portion of the lower face. The mandibles (fig. 26) and the maxillae (fig. 27) are so much like the larger ones of the dragonflies that they can be recognized at once by comparison. In the gizzard we find a somewhat different arrangement; instead of 4 chitin ridges there is some multiple of 4 up to as many as 32, 8 and 16 being the most common numbers. Each ridge has a row of small spinelike teeth along the anterior half of both lateral margins; there is a narrow space through the center which is unarmed, and the whole posterior surface is covered with short stout spines, curved forward (fig. 28). Such a mill ought to be able to grind the food into very small fragments, and we find that this is actually done. In other damselflies the gizzard varies greatly both in the number of ridges and in the size and number of the teeth. The differences in the various genera and species have been admirably worked out and figured by Miss Higgins (1901).

FIGS. 19 and 20.—Dorsal and ventral tooth from gizzard of *Anax junius* nymph. FIGS. 21 and 22.—Dorsal and ventral tooth from gizzard of *Libellula luctuosa* nymph. FIGS. 23 and 24.—Dorsal and ventral tooth from gizzard of *Epicordulia princeps* nymph. Posterior end of each tooth toward the right. FIGS. 25 to 28.—*Enallagma* nymph: 25, mask; 26, mandible; 27, maxilla; 28, gizzard teeth, the upper edge of figure anterior.

MOUTH PARTS OF ODONATE IMAGOS.

DRAGONFLY IMAGOS.—When the nymph transforms into an imago, the hinged mask disappears, and the labium or lower lip is now attached directly to the ventral surface of the head. In consequence there is a much greater similarity in the mouth parts of the imagos, though there are still some differences. In general, the labium of the imago consists of a basal portion, corresponding to the mentum of the nymphal mask, but destitute of raptorial setæ and very much shortened. From its anterior margin projects the median lobe, greatly enlarged in *Anax* and *Æschna* (fig. 29) and covered with hairs, but reduced to a small triangular piece in the *Libellulids* (fig. 32) and more or less free from hairs.

On either side of the mentum is a side piece known as the squame (ms) which supports the lateral lobe. These latter now fold together across the front of the face in all the imagos. In *Anax* and *Æschna* they are enlarged into concave lamellæ, strongly convex on their outer borders and covered with hairs. The inner border ends distally in a sharp end hook (e) which is immovable; just outside of this is a larger movable hook (mo), which is rounded and palplike and covered with hairs. When the lobes are folded

across the front of the face, these four hooks meet on the median line, but the margins of the lobes beyond them diverge rapidly. In *Erythemis* (fig. 32) and the other *Libellulids* the margins of the lateral lobes, when folded, meet each other in a long median line, both hooks have practically

FIGS. 35 to 37.—Imago of *Enallagma hageni*: 35, mask; 36, maxilla; 37, mandible. e, end hook; ml, median lobe of labium; mo, movable hook.

entirely disappeared, and the lobes are covered with hairs. The mandibles (figs. 31 and 34) and the maxillæ (figs. 30 and 33) have changed a little in detail, but are practically the same as before. The teeth of the mandibles are very strong and may be divided into two sets, the incisors (in) at the tip of the mandible, which are long, curved, and sharply pointed, and the molars (m) near the base, which are much shorter and armed with separate cusps or points. The maxillæ still retain the outer lobe or palp (p), which is curved and covered with hairs, and the inner lobe, which is armed with curved and sharply pointed teeth and a pad covered with long sensory hairs.

DAMSELFLY IMAGOS.—In the damselflies the general structure of the mouth parts is the same as in the dragon flies. Here the median lobe of the labium (ml, fig. 35) is fully as long as the lateral lobes, is divided by a deep median fissure, and is covered with long hairs. The lateral lobes retain the immovable end hook (e), which is very long and slender and curved to an acuminate point, and the movable hook (mo), which is also long and narrow, but is bluntly rounded and covered with hairs. These lobes are relatively much narrower than those of the dragonflies, and, when folded, only the terminal hooks meet on the median line. The mandibles (fig. 36) and maxillæ (fig. 37) are similar in all respects to those of the dragonflies, except that there is a sharper distinction between the incisors and the molar in the mandibles, while the maxillæ have long hairs on the outer margin near the base.

The gizzard in the imago is relatively much smaller and weaker in the nymph, and has very little functional use. The chitin ridges or folds along its walls are still retained,

but the teeth are either completely lost, as in the dragonflies and in *Lestes* among the damselflies, or they are reduced to a much simpler form. The imago evidently chews its food before swallowing it, as we may well believe after watching one munch its prey.

This brief description of the mouth parts of the nymphs and imagos will enable us to understand better both how they secure their prey and how they dispose of it afterwards.

ECONOMIC RELATIONS BETWEEN ODONATES AND FISHES.

The artificial propagation of fish falls very naturally into three great divisions: 1. Suitable methods of obtaining and hatching the eggs; 2. Care and protection of the young after they are hatched; 3. Provision of an abundance of the right kind of food.

Our national and State fish hatcheries are concerned very largely with the first two of these, and the progress they have achieved is marvelous, considering the difficulties surmounted. In a comparatively brief period of years they have accumulated a wealth of accurate information and statistics, which have attracted the attention and awakened the admiration of the entire world.

But the last factor, in so far as it concerns pond fishes, has thus far received almost no attention in this country. Europe has been studying the problems connected with fishponds for many years and has far outstripped us along these lines. In fact, we have made hardly a beginning as yet, and the few facts that have been ascertained still lack correlation and logical arrangement.

In speaking of the food relations of insects and fishes Needham (1901, p. 395) said: "And so little are the essential features of good foraging ground understood that each planting of fry in a new place is still largely an experiment. * * * Any new study of fish food should include the study of the feeding grounds, feeding habits, choice of food offered, and conditions that make for the continuance and possible increase of the food supply." In spite of the 15 years that have elapsed since then, the statement retains practically its full value to-day.

Prof. S. A. Forbes and his associates in Illinois were pioneers in this aspect of fish culture, and have put out much valuable information on the food of fresh-water fishes during the last 35 years; an admirable summary will be found in Forbes, 1888b. More recently papers have been published by L. L. Dyche, 1914; Wm. E. Meehan, 1913; A. S. Pearse, 1915; Geo. C. Embury, 1915, and Dr. Robert E. Coker, 1915.

These papers are all excellent in both their subject and its treatment, but of necessity they are general in character and do not treat any of the phases in detail. For this reason and for many others it is believed that a summary of the economic relations between odonates and fishes will prove of interest to all who are, and especially to those who may become, engaged in pondfish culture. At present the old idea prevails that the nymphs of the Odonata, especially those of *Anax*, *Æschna*, and other large species, are very destructive to small fishes.

So far as known, the other side of the question has never been presented, and we have not only drawn a one-sided and biased conclusion, but we have also been led into the common error of condemning the many for the sins of the few. A hawk steals a farmer's chicken, and immediately all hawks are condemned as pests and robbers, irrespective of species, and a loaded shotgun is kept for their reception. Similarly because *Anax* and *Æschna* nymphs have been known to kill small fish, all dragonfly nymphs have been condemned as nuisances and dangerous to have around a fishpond.

Such a conclusion is, of course, not warranted, and even with reference to *Æschna* itself it does not follow that it must be considered dangerous simply because it eats a few small fish. Needham (1903, p. 213), one of our most experienced observers, said with reference to *Æschna constricta*, which was common at Bone Pond, one of the three propagating ponds controlled by the Adirondack hatchery in New York, and artificially stocked with brook trout: "I have not been able to determine as yet whether in relation to trout culture *Æschna* is more disadvantageous than otherwise. It eats a few fry and it eats the food of the larger trout, but, on the other hand, it furnishes a moderate supply of food itself for the larger trout." In order to solve such a problem satisfactorily we must consider in detail all phases of the economic relations between odonates and fishes. An endeavor to do this has been made in the following pages by a careful consideration of the food and enemies of dragonfly and damselfly nymphs and imagoes, by a summary of all that is known of nymphs and imagoes as fish food, and by extensive observation and experimenting.

FOOD OF ODONATE NYMPHS.

The alimentary canals of 50 nymphs of each of the four dragonflies enumerated in the following table and 50 others of various damselfly species, making 250 in all, were examined to ascertain what food had been eaten. The presence in a nymph's digestive tract of any of the various kinds of food listed was represented by a single unit, whether found in large or small quantities. The figures in the table, therefore, tell us how many of the nymphs had eaten any specified food, but do not indicate how much they had consumed.

FOOD OF 250 ODONATE NYMPHS FROM FAIRPORT, IOWA.

[The figures indicate the number of nymphs in which each kind of food was found.]

Contents of alimentary canal.	<i>Anax junius</i> .	<i>Libellula luctuosa</i> .	<i>Erythemis simplicicollis</i> .	<i>Pachydiplax longipennis</i> .	Damselfly nymphs.	Contents of alimentary canal.	<i>Anax junius</i> .	<i>Libellula luctuosa</i> .	<i>Erythemis simplicicollis</i> .	<i>Pachydiplax longipennis</i> .	Damselfly nymphs.
Mollusca:						Crustacea—Continued.					
Physa shells, mostly fragments.....	16	6	16	4	8	<i>Simoecephalus</i> , sp.....	5	2	2	4	8
Planorbis shells, mostly fragments..	15	34	22	4	12	<i>Daphnia</i> , sp.....	2				17
Beetles:						<i>Pleuroxus</i> , sp.....			3	5	5
<i>Dytiscus</i> larvæ.....	10	8	2	2		Copepods, fragments unidentified...	2	2	4	14	15
Haliplid beetle, elytra of adults.....	8	3	8	12		<i>Diaptomus</i> , sp.....		1	1	4	6
<i>Peltodytes</i> larvæ, jointed hairs.....	7	6				<i>Hyalella</i> , sp.....		2	2	1	
Diptera:						<i>Crayfish</i> , sp.....	11		1	2	
<i>Ceratopogon</i> larvæ.....	2	3	6		2	Odonata:					
Chironomid larvæ.....			5	3	8	Damselfly nymphs, unidentified...	11	15	1	2	2
Mosquito larvæ.....		1		1	6	<i>Ischnura verticalis</i> nymphs.....	12	3	2	1	
Simuliid larvæ.....			8	4	9	<i>Enallagma</i> , sp., nymphs.....	3	2	5	1	
Hemiptera: <i>Corixa</i> , sp., elytra of adult..	14	4	3	1		<i>Lestes</i> , sp., nymphs.....	6	2	4	5	
Sialidae: Sialid larvæ.....	3		2			<i>Libellula luctuosa</i> , nymphs.....	5				
Perlidae: Stonefly larvæ.....	2	6	2			<i>Anax junius</i> , nymphs.....	2				
Ephemera: Mayfly larvæ.....	27	9	7	4	6	<i>Erythemis simplicicollis</i> , nymphs..	6	4	1		
Crustacea:						Algae:					
Entomostraca, fragments unidentified.	5	21	26	15	20	<i>Desmids</i>		9	4	2	13
Cladoceran eggs, with ephippium...	2	7	9	6	10	<i>Diatoms</i>			8	2	
<i>Bosmina</i> , sp.....	3	8	6	4	12	Sponge spicules, in masses.....		5			
<i>Cypris</i> , sp.....	6	35	2	20	15	<i>Oedogonium</i> , scattered filaments...			6	3	14
						Algae filaments.....	7	7	32	1	25

GENERAL CHARACTER OF THE DIET.—On the whole there is a remarkable similarity in the diet of the various species. Eleven of the food items appear in all five of the columns and nine more are found in four out of the five. There are only three foods confined to a single species and three others that are restricted to two columns.

Perhaps the most noticeable items are those which begin and end the list. Two species of snails are very common in all the ponds, and upon these every kind of nymph examined had been feeding freely. Not only had more than half of the nymphs partaken of these snails, but in several instances no other food was found in their digestive tract.

With reference to the algæ, it is of course understood that inasmuch as the nymphs catch their prey among the algæ, they would be expected to swallow some of the latter. Hence its presence was not noted unless in sufficient quantity to make it reasonably certain that it had been taken voluntarily. Like the snails, in a few instances it constituted the sole article of diet.

The other popular foods were the mayfly larvæ and the small crustacea, the latter being consumed in large quantities.

Cannibalistic tendencies are shown by the presence of odonate nymphs in all five columns; and in four out of the five, nymphs were found which had eaten others of their own species.

There is a good showing of beetle larvæ and adults, and of adult water boatmen, all of which are injurious to young fishes.

SPECIFIC DIFFERENCES IN THE DIET.—Notwithstanding the wonderful agreement just mentioned, a careful examination reveals also striking differences in diet. Every one of the *Anax* nymphs was fully grown, with well-developed wing cases, and was captured in pond 4, which contained only adult buffalofish. Of course the nymphs could not eat these fish, and hence the absence of fish in their diet is a matter of necessity rather than choice. (See p. 206.) Neither did the fish eat the nymphs, however, and this probably accounts for the exceptional abundance of the latter, as evidenced by the exuvæ obtained. The bulk of the food of these nymphs was made up of mayfly larvæ and snails, but it is worthy of note that they also ate large quantities of *Dytiscus* larvæ, the water boatman *Corixa*, and small crayfish. The proportion of odonate nymphs in their food was much greater than for any of the other species examined. One very large specimen had eaten nothing but crayfish, and its stomach was packed full of their shells and claws, which had turned red in color like a boiled lobster. The *Dytiscus* larvæ were identified by their heads and mandibles, *Corixa* by the peculiar color pattern of the elytra, and the Halipid beetles also by the color pattern of the elytra. All three of these foods were especially abundant in this pond.

The bulk of the food of the *Libellula* nymphs consisted of snails and various entomostraca, Cypris being a particularly toothsome tidbit; there were also quite a number of damselfly nymphs and a good representation of the beetle larvæ. A beetle larva belonging to the genus *Peltodyes* was found to be common on the algæ in the ponds, and its body was covered with long, jointed, bristlelike processes. The broken fragments of these processes were found in the gizzards of seven nymphs, in three of which the larvæ were the only food eaten.

In the gizzards of five of the nymphs were rounded masses of the spicules of a fresh-water sponge. Sponges are common in two of the ponds, and on them live a species of *Sigara*, which is a minute water boatman, and one of the caddisworms, *Leptocerus*.

Of course, the snails crawl about over these sponges, as well as over the algæ. The nymphs probably took in the spicules while feeding on these insects and snails, for they would hardly eat the sponge itself. The *Libellula* nymphs had eaten a much smaller number of mayfly larvæ than those of *Anax* and were content with the Amphipod *Hyaella*, in place of crayfish.

Twenty of these nymphs were taken from pond 7 D, June 23, 1916, while the others came from ponds 1, 2, and 3 D, at different dates in July and August. Pond 7 had been stocked in the spring with 75,000 small fry of the buffalofish; on July 1 these young fish had reached a length of 1 inch, and on July 15 specimens were taken an inch and a half long. Previous to June 23, on this basis of growth, the fish were small enough to be caught and eaten by the nymphs, if the latter had made the attempt. The entire absence of fish from the diet of these nymphs shows that they chose other food even when fish were present. The remains of odonate nymphs in so many of their gizzards is good evidence, on the other hand, that the *luctuosa* nymph is not inert and lethargic.

The food of the *Erythemis* nymphs consists also of snails and entomostraca, with a moderate amount of beetle and mayfly larvæ, and an almost complete absence of the larger crustacea and of damselfly nymphs. A large amount of algæ was present in 64 per cent of the gizzards, and in several individuals nothing else had been eaten; at least, there were no remains in either gizzard or intestines. Algæ, therefore, must constitute a respectable portion of the food of these nymphs.

It might seem strange to report Simuliid larvæ from a fishpond, but the screens at the outlets of all of the ponds were covered with the larvæ of *Simulium vittatum*, and some of the nymphs evidently picked them off the screens. The ephippium surrounding the Cladoceran egg is proof against the digestive juices of the nymphs, and eggs taken from the posterior end of the intestines were as plump and uninjured as those just swallowed. The Desmids and Diatoms, like those found in *luctuosa* nymphs, are not numerous enough to make it certain that they were really sought for and eaten. They might well have been taken in accidentally with some of the food. Ten of these nymphs were taken from pond 7 D on June 26, 1916, and 15 were taken from pond 9 D on July 7. As already stated, the former pond contained an abundance of small fish, while the channel cats in the latter pond had produced a brood of fry previous to the capture of the nymphs. None of them had eaten fish, however, and their small size makes it improbable that they could overpower any but the smallest fry.

Entomostraca and copepods are the chief articles of diet for the *Pachydiplax* nymphs, and there is a minimum amount of snails, beetle larvæ, and mayfly larvæ. The larger crustacea are practically absent, and damselfly nymphs are the only odonates represented. The food in the gizzards of these nymphs and that in the *Erythemis* nymphs was particularly well ground up, so that only small fragments were left. Even the shells of the small entomostraca were broken and resembled the débris obtained from the posterior intestine of *Anax* and *Libellula*.

The damselfly nymphs included species of *Enallagma*, *Ischnura*, *Argia*, and *Lestes*, and were obtained from the various ponds indiscriminately. No attempt was made to separate the different species, and they were treated as though all one kind. The food in the gizzards of these nymphs was broken up into smaller fragments than that of any of the dragonflies, and in much of it the identification of species or even genera was almost impossible. As will be seen the great bulk of the food consisted of ento-

mostraca of various kinds, with a good percentage of snails. Many of these nymphs also, like those of *Erythemis*, had eaten large quantities of algæ, and two of the larger nymphs, *Argia mæsta putrida*, had shown cannibalistic tendencies and had eaten smaller nymphs.

BENEFITS OF DIET TO FISH BREEDING.—A very respectable portion of the nymph food consists of the adults and larvæ of insects and crustacea that are known to be injurious to fish fry. Here belong the larvæ of the diving beetle *Dytiscus*, the adult water boatman *Corixa*, and the crayfish. The *Dytiscus* larvæ are known by all fish-culturists to prey upon small fish, and they have been repeatedly observed doing this in these ponds at Fairport, whenever the water is drawn out of them for any purpose. *Corixa* and the closely related genus *Notonecta* have proved to be serious pests in European fishponds, killing so many of the young fry that they have to be exterminated before the culture can go on successfully (Benecke, 1886, p. 340).

Crayfish not only prey upon young fish but are also a great nuisance in a fishpond because of their burrowing habits, and therefore anything which diminishes their numbers must be looked upon as beneficial.

Curiously enough the entomostracæan genus, *Cypris*, which is eaten in large numbers by the nymphs of *L. luctuosa* and the various damselflies, is sometimes less innocent than it may appear. In a report on fish-cultural operations at Beaune, France, M. Chabot-Karlen (1889, p. 310), said:

The rearing of *Daphnia pulex* and *Cypris fusca* was also tried [to serve as fish food]. * * * The *Cypris*, however, were found to prey upon the young fish. Having been put in with the embryos of the carp, they were often discovered to the number of two or three fixed upon the back of an alevin devouring it, notwithstanding the efforts of the poor animal to shake itself free.

CLAIMS OF INJURIES OF DIET TO FISH BREEDING.—Much of the food eaten by these nymphs is the same as that of small fish, and it is often claimed that they thus diminish the quantity of food available for the fish fry. But the young fish increase rapidly in size, and if they are to be reared successfully larger prey must be provided for them as they grow older. These odonate nymphs furnish such larger prey and are apparently quite acceptable to the fish. (See p. 225.)

Hence if the above argument against the nymphs is to prevail, it must be proved that their value as food for the larger fish plus their value as destroyers of certain enemies of the smaller fish does not recompense for the food they themselves consume plus the few fish fry that the largest species may destroy. This leads very naturally to a discussion of the last statement, which is worthy of separate consideration.

NYMPHS AS FISH EATERS.—There seems to be a prevailing opinion among fish-culturists that dragonfly nymphs are very destructive to young fish, but when we examine the testimony upon which this opinion is founded it does not prove to be very satisfactory.

Two insects were sent to Prof. C. V. Riley for identification in October, 1884, as recorded in *Insect Life*, volume 1, 1888, page 58. They came from W. L. Jones, of Atlanta, Ga., who stated that the larger one, identified as a nymph of *Anax junius*, was sent to him by a gentleman who stated that "it fastens on the carp fish and finally kills it." Accepting all this as true, we must acknowledge that the evidence is rather indirect and roundabout. No details are given; we are told nothing as to how or when or where; and it is not even stated whether the fish was eaten after being killed, or whether more than one fish was destroyed in this manner.

Another so-called proof has been widely copied by both entomologists and fish-culturists and appeared even in the Cambridge Natural History (Insects, 1901, pt. 1, p. 425). It was originally published in the Hungarian Rovartani Lapok for December, 1884, and consisted of a statement by L. Birò that in a pond belonging to the piscicultural establishment of M. le Comte Palffy at Szomolony, Hungary, only 54 small fish could be found in September, although 50,000 had been placed there the previous spring, but there were present an enormous number of Libellulid larvæ, species not determined. Hence the nymphs must have eaten the fish. The simple facts, however, that the fish were gone and the nymphs were present could hardly be accepted as scientific proof that the latter ate all of the former or any part of them. There are too many other causes which might have removed the fish. It was not even determined to what species the nymphs belonged, none of them were seen eating fish, and no stomachs were examined for fish remains. Then, too, the nymphs found in September, if they were Libellulids, were hatched from eggs laid during that summer and could not have been large enough to eat any fish.

James G. Needham has two records of nymphs eating fish: In Aquatic Insects in the Adirondacks (Needham and Betten, 1901, p. 474) he states that "nymphs of the species described below as *Cordulegaster maculatus* supposition" captured and ate young trout as long as themselves at Saranac Inn, when the trout were placed in their cage. In Aquatic Insects in New York State (1903, pt. 2, p. 213) he says that the nymphs of *Æschna constricta* eat a few trout fry, but he does not tell how this was proved unless his statement on page 212, "I demonstrated this at Saranac Inn by confining them together in a breeding cage" is understood to apply to *Æschna* as well as to *Cordulegaster*. That is no proof, however, that trout constitute any part of the regular diet of either nymph mentioned, or of any other nymph.

Warren (1915) found that the nymphs of *Pantala flavescens* would eat practically anything he gave them, even earth worms and chicken lice, but one would hardly care to draw any argument from this fact. When confined together in a besieged fortress or town human beings have been known to eat horses, dogs, or even one another. A nymph must be observed actually eating fish under natural conditions, or fish remains must be found in its stomach when captured, before anything can be really "demonstrated" with reference to its normal diet.

For this reason such pictures as figure 232 on page 389 of The Life of Inland Waters, by Needham and Lloyd (1916), are likely to be very misleading. The authors were there discussing the forage problem in connection with fish culture, and introduced this picture of the nymph of *Anax junius* devouring a small sunfish without a word of comment or explanation. It is evidently a photograph and must have been taken under either natural or artificial conditions. If the conditions were natural, we have a perfect right to know it, because it would add greatly to the value of the picture; but if the conditions were artificial, the picture never should have been published. In either event it is misleading unless fully explained, because it gives the prospective fish breeder the idea that all dragonfly nymphs eat small fish whenever they get a chance. The ordinary individual will comprehend the words "nymph" and "dragonfly," but the specific name, *Anax junius*, will mean nothing to him. He will keep the picture and its implied testimony constantly in mind during his subsequent fish breeding, and it will require long-continued and patient efforts to correct its influence. It is unfortunate that this was not recognized by the authors of a book so admirably designed and executed in its general features.

All the ponds of series D usually contain both *Anax* and *Æschna* nymphs, and several of them contain young fishes. When the ponds are drawn, as is done for each of them twice a year and sometimes oftener, the young fish and the nymphs, as well as all the other denizens of the pond, are brought into close contact. At such times crayfish, *Dytiscus* larvæ, and the like have been repeatedly observed catching and eating small fish, but no dragonfly nymph has been thus far seen attacking a fish. There is always an abundance of other food for them, and they evidently prefer it. In further proof of this 18 *Anax* and *Æschna* nymphs were taken from ponds 7 and 9 on July 6, 1916, when they had attained their maximum size. Both ponds at that time contained an abundance of small fish, but no fish remains could be found in the alimentary canal of the nymphs.

Hence when an *Anax* or *Æschna* nymph does prey upon fish it may well be because of a scarcity of other food. In evidence of this, Warren (1915, p. 35) has recorded a very interesting experiment. He placed 69 nymphs of *Pantala flavescens* and one of *Anax junius* in a small aquarium and gave them no food except one young fish. At the end of a week there were left 7 *Pantala* nymphs, the *Anax* nymph, and the little fish. As long as other food was present, therefore, the fish remained untouched.

Furthermore, Warren examined the contents of the alimentary canal of 253 *Anax* and *Pantala* nymphs and found fish in only one of them. (See p. 207.) Even there the remains were so doubtful that he placed a question mark after his identification of them. In a series of experiments made "with the view of finding out how far the food range of the nymphs extended among the aquatic forms of life," he placed various aquatic animals in the breeding jars and allowed the nymphs to eat them at their leisure. Among the forms thus eaten were several kinds of fish, which were common in the localities from whence the nymphs were obtained. Under natural conditions when other food was abundant the fish were not touched, but when brought into the laboratory and deprived of other food the nymphs ate the fish freely.

Garman (1917, p. 441) gave as one of the foods known to be eaten by damselfly nymphs very young fish. No authority was given for this statement, and inquiry has revealed that it was a mistake. We thus see that practically all the positive evidence shows that when an *Anax* or *Æschna* nymph does eat a young fish it is because of a scarcity of other food. Even if they do eat them occasionally they also eat enough *Dytiscus* larvæ, adult *Corixas*, *Cypris*, and crayfish to more than offset this. We must remember that it is only with reference to a very few of the largest species that any claims are made—2 dragonflies out of the 27 on the present list. The other 25 and all of the damselflies are admitted to be perfectly harmless so far as young fish are concerned.

AMOUNT OF FOOD CONSUMED.—The nymphs are not only predatory and omnivorous, but they may fairly be called voracious. They gorge themselves to the full extent of their capacity, and the distended gizzard with its dark contents is often visible through the skin and always stands out prominently when the thorax is opened. Usually also the intestine behind the gizzard is filled out into a plump cylinder for 4 or 5 mm. with finely ground indigestible material, such as the mandibles of insect larvæ, fragments of snail shells, broken elytra, etc.

There is a great difference in the amount of food consumed according to the condition of the nymph. Just after a molt the nymph is light in color, yellowish or greenish, and shows a characteristic color pattern very distinctly. As development progresses toward the next molt the color pattern gradually disappears, and the nymph becomes darker and darker until, in *L. luctuosa* and *E. simplicicollis*, it turns to a uniform dark brown.

The nymph eats voraciously as long as it remains light colored; while the color pattern is disappearing the amount eaten also diminishes, and after it has turned brown the nymph's gizzard contains little if any food. All the nymphs whose gizzards were empty were dark-colored, but the intestine usually contained indigestible debris from food previously eaten. One very dark nymph of *L. luctuosa* contained only a single tiny *Cypris inequivala*, another had but one *Ceratopogon* larva, while a third yielded two *Ischnura* nymphs with nothing in the intestine. Similarly two dark-colored nymphs of *Anax* had each eaten but one *Ischnura* nymph, and the intestines were empty. A dark nymph of *E. simplicicollis* contained only half a dozen short alga-l filaments with nothing in the intestine. This condition is particularly true of nymphs as they approach their final transformation, when they apparently fast for quite a long period before crawling out of the water. Hence we conclude that an empty digestive tube is one of the essential prerequisites for the great change which then takes place.

Warren (1915, p. 8) has given the lengths of the various instars, meaning by that the periods between molts, during the entire nymphal life of four specimens of *Pantala flavescens*. These periods are about the same length for the first 9 or 10 molts and then increase greatly the last two molts. The final period, corresponding to the pupal stage in insects which have a complete metamorphosis, lasted for a month, while the first nine molts were only five or six days each. He did not record the periods of fasting, but it is probable that these nymphs ate very little during the last week before transformation.

Balfour-Brown (1909, p. 270) similarly found that the periods between molts tend to lengthen as the nymph grows larger. In some of his damselflies there were nearly two months in the last period; in such cases the fast preceding transformation would also be lengthened.

Besides these fasts which accompany the various molts and the one which precedes the final emergence, the nymph is able to go without food for long intervals when necessary and apparently suffer no injury. It is doubtful, however, if a nymph could transform when the fast preceding emergence was considerably lengthened. It is quite possible that some of the failures to fully emerge from the nymph skin (p. 222) may be caused by an insufficiency of food.

FOOD OF HAWAIIAN NYMPHS.—Warren examined the contents of the alimentary canal of 253 *Anax* and *Pantala* nymphs captured in the vicinity of Honolulu, Hawaii, and it is interesting to compare his results with those recorded for Fairport. (See table, p. 201.)

FOOD FOUND IN ALIMENTARY CANAL OF 253 ODONATE NYMPHS FROM HONOLULU, HAWAII,
EXAMINED BY A. WARREN.

Mollusca: Spiral shells.	14	Ants and bees:	
Beetles: Dytiscidæ.	16	Pheidole megacephala (Myrmicidæ).	2
Flies:		Ants, undetermined species.	11
Chironomid larvæ.	168	Dragonflies: <i>Pantala flavescens</i> , nymphs.	6
Chironomid adults.	4	Crustacea:	
Mosquito larvæ and pupæ.	12	Cypris, sp.	108
Mosquito adult.	1	Shrimps, sp.	3
Dolichopodid fly.	1	Protozoa: <i>Euglena</i> , sp.	30
Adult fly, undetermined.	1	Worms: <i>Nereis</i> , sp.	1
Bugs:		Amphibians: Tadpoles.	8
<i>Merrigata hebroides</i> (Næogeidæ).	1	Fish: Top minnow (?).	1
<i>Microvelia vagans</i> (Veliidæ).	2		

The first thing to be noticed is the general similarity in the food. The Hawaiian nymphs ate mollusks, beetles, flies, bugs, crustacea, odonates, and protozoa, the same as the Fairport nymphs. Many of the food species were different, as would naturally be expected, but they belong to the same families and sometimes to the same genera. Unlike the nymphs at Fairport, those at Honolulu ate bees, ants, and adult Chironomids, mosquitoes, and flies. These land insects undoubtedly dropped into the water before they were captured, and Warren has suggested that since the Hawaiian streams and pools contain but few aquatic insects, while the dragonfly nymphs are numerous in many localities, the latter must obtain a part of their food from land insects that fall into the water. This idea induced him to try them with all kinds of land insects, and he found they would eat anything he offered. (See p. 206.)

Tadpoles also appear in their diet, probably due to the scarcity of insect food just mentioned and also to the fact that the frogs and dragonflies are compelled to breed in restricted bodies of water, so that they are brought into close contact. Another result of the scarcity of insect food is that the majority of the nymphs fed upon a single Chironomid species, *Chironomus hawaiiensis*, and upon the crustacean genus Cypris. If the food had been more plentiful there would have been a greater variety in the diet. Consequently the extreme variety in the food of the Fairport nymphs is a good indication of the richness of the food supply.

FOOD OF NYMPHS FROM ITHICA, N. Y.—A table has been made out by Miss Lyon (1915) showing the food of 36 nymphs, distributed among 3 *Æschnid* species, 2 Gomphids, 4 Libellulids, and 4 damselflies. Cascadilla Creek, from which the nymphs were obtained, flows along the southern border of the Cornell University campus at Ithaca. The nymphs were collected at intervals from November to July, thus covering nine months of the year.

For the sake of convenience, her figures have been reduced to the same method of treatment as used in the statement on page 201.

FOOD FOUND IN ALIMENTARY CANAL OF 36 ODONATE NYMPHS FROM CASCADILLA CREEK, ITHACA, N. Y., EXAMINED BY M. B. LYON.

Mollusca: Physa, partly digested.....	1	Crustacea—Continued.	
Beetles: Dytiscus, sp.....	2	Cyclops, sp.....	2
Diptera:		Cypris, sp.....	2
Chironomid larvæ.....	24	Undetermined.....	1
Mosquito larvæ, Anopheles, sp.....	1	Odonata:	
Undetermined larva.....	1	Libellulid, sp., nymph.....	1
Hemiptera:		Ophiogomphus, sp., nymph.....	1
Corixa nymphs.....	6	Damselfly nymphs.....	9
Corixa adults.....	2	Arachnid:	
Ephemeridæ:		Mite.....	2
Heptagenia, sp.....	4	Macrobiotus, sp.....	1
Hexagenia, sp.....	1	Algæ:	
Cænis, sp.....	1	Diatoms.....	5
Undetermined mayflies.....	2	Closterium, sp.....	3
Crustacea:		Ædogonium, sp.....	1
Hayalella, sp.....	5		
Diaptomus, sp.....	2		

Miss Lyon's investigations showed that while Chironomids, mayflies, and odonates were eaten voraciously throughout the year, the crustacea and Hemiptera were con-

fined to the warmer months, when they are present in greater numbers. The abundance of crustacea in the Fairport list will thus depend somewhat upon the fact that all the nymphs were examined during the months of July and August.

CONCLUSIONS.—Comparing the three food lists here presented from widely separated localities, it would seem that odonate nymphs eat very much the same food everywhere. They feed largely upon insects and are able to confine themselves practically to a single species that happens to be abundant, as in Hawaii, or they may extend their diet to include a rich variety of genera and species, as in the other two lists. In her text notes Miss Lyon enumerates 11 species that could be identified amongst the Chironomid larvæ, with the probability that still others were represented in the unidentified material.

Judging from the lists, odonate nymphs do not devour many mosquito larvæ or pupæ, although Warren (1915) was firmly convinced that the Hawaiian nymph was a great destroyer of mosquitoes, in spite of the unfavorable showing of his list. He even fed some of his nymphs with mosquito larvæ and adults. One *Pantala* nymph ate during a single night 40 imagos of *Stegomyia scutellaris* that had been stunned with cyanide fumes and placed in the aquarium with the nymph. Another *Pantala* nymph ate 75 full-grown mosquito larvæ within 12 hours. But here, as in the eating of the fish, no convincing argument can be drawn from what is fed to a nymph when no other food is available.

The food of the odonate nymphs is by no means confined to insects, however; they also eat quantities of crustacea and mollusks and may include protozoa, algæ, and even vertebrates in their diet. In fact, the nymph seems capable of accommodating itself wonderfully well to its environment and can seemingly thrive upon whatever form of food happens to be available. Consequently if the nymphs are introduced into a fishpond, no special food will need to be provided for them. If the pond is stocked with the usual insect larvæ, crustacea, etc., whatever the species may be, the nymphs will quickly adapt themselves to them.

ENEMIES OF ODONATE NYMPHS.

1. FISH.—A full discussion of nymphs as food for fishes is given on page 225.

2. LARGER NYMPHS.—The proportion in which the smaller nymphs are destroyed by the larger ones is well shown in the table and statements already given.

About 20 per cent of the food of *Anax* nymphs and 10 per cent of the food of the nymphs of *L. luctuosa* consist of other nymphs smaller than themselves. In general, the nymphs that are eaten belong to a different genus, but the large nymphs are cannibalistic as well as rapacious and sometimes eat others of their own species. This is not as likely to occur, because all the nymphs of a given species develop at about the same time and are consequently nearer the same size. But they always vary more or less in their rapidity of growth, so that some are larger than others, and even if two were of the same size it would not be safe to keep them together unless plenty of suitable food were provided for them. If they once became real hungry, they would fight it out and the stronger would devour the weaker. To protect themselves against one another, as well as against all their enemies, the Gomphid nymphs habitually burrow in the mud or débris of the bottom; *L. luctuosa* and the heavier Libellulids sprawl

amongst the rubbish, while *Erythemis*, *Celithemis*, *Tramea*, etc., and all the damselfly nymphs hide in the matted vegetation. Such lurking places also serve as admirable ambushes whence to secure their prey.

3. DIVING BEETLES, WATER SCORPIONS, AND AQUATIC HEMIPTERA.—These retaliate by eating the nymphs before they are large enough to defend themselves. An adult *Dytiscus* beetle was seen in pond 7 eating a small *Erythemis* nymph, which would partly compensate for the beetle larvæ of the same species that are found in the table on page 201. Dr. Muttkowski has observed both *Dytiscus* and *Zaitha* feeding upon nymphs and noted that after capturing the nymph they invariably stick their beak first into its head. Garman (1917, p. 441) has recorded that "among aquatic Hemiptera the genera *Ranatra*, *Belostoma*, and *Notonecta*, and probably others feed upon damselfly nymphs." The fact that the water boatman, *Notonecta*, attacks the nymphs of dragonflies was also recorded by W. J. Lucas (1908, p. 16).

4. FRESH-WATER HYDRA.—Another enemy of the nymph is found in the common hydra; the green species, *H. viridis*, does not probably reach a size sufficiently large to overcome even a newly hatched nymph, but the brown species, *H. fusca*, can and does eat small nymphs. Two leaves of *Potamogeton illinoiensis*, which contained a large number of *Enallagma* eggs that were just hatching, were brought into the laboratory August 11, 1917, and placed in a small aquarium. On going over them with a hand lens to remove the nymphs already hatched, a large brown hydra was found eating one of the tiny nymphs. It was attached to the under surface of the leaf, nearly in the center of a large cluster of the *Enallagma* eggs, and could reach many of the nymphs with its tentacles as they emerged. If this species of hydra became at all plentiful in a fishpond it might kill a large number of the young nymphs.

5. NEMATODES.—Good-sized specimens were found in the stomachs of several nymphs of both *Anax* and *L. luctuosa*, and Needham (1898, p. 86) found the intestine of a nymph parasitized by large Gregarines a millimeter in length. An *Enallagma* nymph examined July 27, 1917, contained a dozen large Gregarines, and several others contained one or two apiece. These intestinal parasites probably never become numerous enough to actually kill their host, but their presence may weaken the nymph and make it more susceptible to its other enemies.

6. PARASITIC MITES AND FLIES.—Some of the *Ischnura* and *Enallagma* nymphs were found infested with small mites between the wing pads and around the bases of the legs; 10 of these were taken from a single *Ischnura* nymph.

Mrs. Aaron (Lamborn, 1890, p. 50) mentioned another small red mite "which skims rapidly over the water in search of an Odonat egg, upon which it either deposits an egg or excavates it for immediate nourishment." She also saw one of the parasitic Diptera ovipositing on the egg of *Diplax*. In these two cases, of course, the larvæ of the mite and the fly when they hatch feed upon the dragonfly's egg.

Needham (1903) reported that many hymenopterous parasites prey upon the eggs of *Lestes*, which are inserted in plant tissues above the water line, where they are exposed to such attacks. He succeeded in rearing three species of the parasite, belonging to different genera.

Brandt (1869) similarly reported rearing another parasite, *Polynema ovulorum*, from the eggs of *Agrion* (*Calopteryx*), and added that half the eggs were sometimes destroyed in this way.

7. ALGÆ, FUNGI, AND VORTICELLIDS.—“The Confervoid alga, *Ædogonium*, is often found growing upon the larva of *Æschna brevistyla*. I found by means of sections that the *Ædogonium* does not penetrate the cuticle of the larva, but simply grows on it as it grows on everything else in such places. On one larva of *Æschna* there were no less than 3 species of *Ædogonium*, 15 species of Diatoms, and a large number of *Vorticella*.” (Tillyard, 1917, p. 332.) *Ædogonium* is very common in several of the ponds at Fairport and is found growing over many of the pond contents, including nymphs, but it appears to do them no injury further than to impede their movements slightly.

Miss Lyon (1915, p. 5) published a table giving the Diatoms, green and blue-green algæ, the protozoa, and the epizoa found growing upon the nymphs of Cascadilla Creek. She noted the similarity between these species and those of the mud and water plants in the immediate vicinity. She concluded that the relationship between the two was simply a natural one, resulting from the proximity of the various forms, and not one of symbiosis, as Kammerer and others would have us believe.

Similarly a Saprolegnious fungus frequently attacks damselfly nymphs, especially if they are enfeebled from any cause. This fungus is related to the one attacking young fishes and often causes the death of the nymph. (Garman, 1917, p. 442.)

8. BIRDS.—Needham has recorded dragonfly nymphs as found in considerable numbers in the stomachs of herons (1898, p. 85). McAtee (1912) also recorded nymphs as forming part of the food of the horned grebe, *Colymbus auritus*. But herons and grebes and their kin are deadly enemies of fish, and hence should always be kept away from fishponds. Under natural conditions, however, they might well consume a considerable quantity of nymphs.

9. REPTILES.—Martin (1886, p. 232) said with reference to the Odonata of the Département de l'Indre in France:

The eggs, larvæ, and nymphs are the prey of several fishes, snakes, newts, Coleoptera, aquatic Hemiptera, and of some diving birds. Sometimes the destruction is on a considerable scale, and one may notice the dragonflies of some piece of water diminish gradually in numbers, while the animals that prey on them increase, so that a species may for a time entirely disappear in a particular spot, owing to the attacks of some enemy that has been specially prosperous and also eager in their pursuit.

Baker (1906, pp. 231, 232) in his study of The Relation of Mollusks to Fish in Oneida Lake found numerous dragonfly nymphs in the stomachs of painted terrapins, *Chrysemys picta*.

None of the terrapin at Fairport were examined for the food they had eaten, but they may fairly be reckoned among the enemies of the nymphs.

Ordinarily the dragonfly nymph is able to hold its own in spite of its enemies, and it requires conditions exceptionally adverse to the nymph and exceptionally favorable to its foes before there is any danger of the extermination of the nymphs.

FOOD OF ODONATE IMAGOS.

There are several things which make it difficult to obtain specific lists of the food of the imagos similar to those presented for the nymphs.

A considerable portion of the animals eaten by the nymphs, such as snails, entomostraca, beetles, hemiptera, and the like, are inclosed in hard shells or elytra, which persist inside the digestive canal of the nymph and are easily recognized. The food

of the imagos, however, consists chiefly of soft-bodied insects, destitute of elytra, or of insects from which the harder parts, if present, are carefully rejected. Consequently the only things that can be recognized with any certainty in the contents of the imago's digestive canal are an occasional mandible or maxilla, portions of the wings of various insects, legs and antennæ, scales of butterflies and moths, hairs, and claws. The accurate identification of such minutæ is a painstaking and laborious task, and the frequency with which the species or even the genus must be left undetermined is not surprising.

Again, the nymph swallows much of its food whole or at least in large fragments, so that the relation of the various parts remains undisturbed. The imago, on the other hand, believes in thoroughly masticating its food, and every mouthful is chewed into fine fragments before being swallowed. At the same time such parts as the wings and legs, which would be of great value for identification, and even the harder tissues of the body, are carefully rejected. Occasionally fragments of a wing or elytron are sometimes included, but they are usually badly torn and often lack the very part that is wanted. The imago is particularly fond of teneral insects, whose chitin has not yet hardened, and whose pigment markings have not been developed. Such insects, after being chewed and swallowed, form an indistinguishable mass in which there is very little hope of finding anything that can be identified.

A third difficulty is found in the fact that, although the digestion of the nymph's food is comparatively slow and the large fragments are recognizable for some time after they have been swallowed, the food of the imago, on the other hand, is digested with exceptional rapidity and must be examined as soon as it is swallowed, if anything definite is to be hoped for. Even the short space of time between the insertion of the insect into a cyanide bottle and its subsequent death is sufficient to materially affect the contents of the alimentary canal, and the changes apparently continue a short time after the insect's death. To obviate this, good results were obtained by making an incision in the thorax and abdomen, and then plunging the imago into 95 per cent alcohol as soon as it was taken from the net. All the examinations of the alimentary canal here tabulated were made in this way.

In view of these difficulties the most feasible method of determining the food of the imago is to watch it while feeding and capture it with enough of its food still uneaten to render identification possible. That this method has proved very satisfactory is shown by the frequency with which it appears in the following statements. In addition, all the available American records have been included, with acknowledgment of their source.

FOOD OF GOMPHID IMAGOS, FAIRPORT, IOWA, 1916.

Gomphus fraternus:

Diptera—House fly, *Musca domestica*.....Captured while eating.

Trichoptera—Caddisfly, undeterminedIn alimentary canal.

Odonata—

Erythemis simplicicollis.....Needham and Hart, 1901, p. 64.

Libellula luctuosa.....Captured while eating.

Argia æsta putrida.....Do.

Teneral dragonflies.....In alimentary canal.

FOOD OF GOMPHID IMAGOS, FAIRPORT, IOWA, 1916—Continued.

Gomphus vastus:

Diptera—House fly, *Musca domestica*.....Seen picking from window screen.

Trichoptera—

Caddisfly, undetermined.....In alimentary canal.

Caddisfly, *Macronema zebratum*.....Walsh, 1862, p. 391.

Ephemeridæ—Mayfly, *Hexagenia*, sp.....Captured while eating.

Odonata—

Libellula luctuosa.....Do.

Leucorrhinia intacta.....Do.

Argia mæsta putrida.....Do.

Libellulidæ.....Needham and Hart, 1901, p. 21.

Dragonfly teneralis.....In alimentary canal.

Dromogomphus spoliatus:

Lepidoptera—*Pieris rapæ*.....Williamson, 1901, p. 119.

Odonata—

Heterina americana.....Do.

Argia mæsta putrida.....Do.

FOOD OF ÆSCHNID IMAGOS, FAIRPORT, IOWA, 1916.

Anax junius:

Diptera—

Mosquito, *Culex*, sp.....Taken from mouth.

Black fly, *Simulium*, sp.....In alimentary canal.

Midge, *Chironomus*, sp.....Captured while eating.

Midge, *Ceratopogon*, sp.....In alimentary canal.

Syrphid fly.....Captured while eating.

Undetermined flies.....In alimentary canal.

Ephemeridæ—

Mayfly, *Callibaetis*, sp.....Captured while eating.

Mayfly, *Hexagenia*, sp.....Do.

Trichoptera—Caddisfly, undetermined.....In alimentary canal.

Lepidoptera—

Butterfly, undetermined.....Scales in alimentary canal.

Moth, Tortricidæ.....Captured while eating.

Butterfly, *Ancyloxypha*, sp.....Do.

Odonata—

Leucorrhinia intacta ♂.....Do.

Erythemis simplicicollis ♀.....Do.

Argia mæsta putrida ♂.....Do.

Damselflies, undetermined.....In alimentary canal.

Æschna constricta:

Diptera—

House fly, *Musca domestica*.....Seen picking off screen door.

Mosquito, *Culex*, sp.....Taken from mouth.

Æschna brevistyla:

Diptera—

Mosquitoes.....Tillyard, 1917, p. 328.

Gnats.....Do.

FOOD OF LIBELLULID IMAGOS, FAIRPORT, IOWA, 1916.

Leucorrhinia intacta:

Diptera—

House fly, *Musca domestica*.....Seen picking off window screen.

Midge, *Chironomus*, sp.....In alimentary canal.

Muscid fly, *Sarcophaga*, sp.....Captured while eating.

FOOD OF LIBELLULID IMAGOS, FAIRPORT, IOWA, 1916—Continued.

Leucorrhinia intacta—Continued.

Lepidoptera—

Butterfly, undetermined. Scales in alimentary canal.

Butterfly, *Lycaena comyntas*. Captured while eating.Ephemera—Mayfly, *Callibaetis*, sp. Do.

Odonata—

Enallagma civile ♂. Do.*Enallagma hageni* ♂. Do.

Tenerals, undetermined. In alimentary canal.

Libellula luctuosa:

Diptera—

House fly, *Musca domestica*. Taken from mouth.

Muscid fly. In alimentary canal.

Midge, *Chironomus*, sp. Do.

Lepidoptera—

Lycaena comyntas. Captured while eating.

Butterfly, undetermined. Scales in alimentary canal.

Moth, Tortricidae. Captured while eating.

Odonata—

Ischnura verticalis. Do.*Leucorrhinia intacta*. Seen eating.*Sympetrum*, sp. In alimentary canal.

Tenerals, undetermined. Do.

Ephemera—Mayfly, undetermined. Do.

Erythemis simplicicollis:

Diptera:

House fly, *Musca domestica*. Seen picking off window screen.Midge, *Chironomus*, sp. In alimentary canal.*Sarcophaga sarracenia*. Captured while eating.Tabanid fly, *Chrysops*. Williamson, 1900, p. 326.

Lepidoptera—

Hematopsis gratia. Captured while eating.*Ancyloxypha numitor*. Do.*Pamphila*, sp. Williamson, 1900, p. 326.*Pieris rapa*. Captured while eating.

Ephemera—Mayfly, undetermined. In alimentary canal.

Odonata—

Erythemis simplicicollis. Captured while eating.*Argia mæsta putrida*. Do.*Enallagma hageni*. Do.*Lestes vigilax*. Williamson, 1900, p. 326.*Argia violacea*. Do.*Lestes unguiculatus*. Captured while eating.*Plathemis lydia*:Diptera—House fly, *Musca domestica*. Seen picking off window screen.Lepidoptera—*Ancyloxypha numitor*. Captured while eating.*Celithemis eponina*:

Diptera—Syrphid flies. Do.

FOOD OF DAMSELFLY IMAGOS, FAIRPORT, IOWA, 1916.

Enallagma hageni:

Diptera—

Midge, *Orthocladius*, sp. Captured while eating.Midge, *Corynoneura*, sp. Do.Midge, *Chironomus*, sp. In alimentary canal.

FOOD OF DAMSELFLY IMAGOS, FAIRPORT, IOWA, 1916—Continued.

Enallagma hageni—Continued.

Diptera—Continued.

Dolichopodid fly. Captured while eating.

Anthomyiid fly. Do.

Syrphid fly. Do.

Simulium vittatum. Taken from mouth.

Undetermined flies. In alimentary canal.

Palpomya, sp. Captured while eating.

Nematocera, sp. Garman, 1917, p. 445.

Lepidoptera—*Ancyloxypha numitor*. Captured while eating.

Odonata—

Ischnura verticalis. Do.

Enallagma, sp. (dead). Seen eating.

Ischnura verticalis:

Diptera—

Midge, *Orthocladus*, sp. Captured while eating.

Grass-stem fly, Geomyzidae. Do.

Midge, *Chironomus*, sp. Do.

Undetermined. Do.

Lepidoptera—Butterfly. Garman, 1917, p. 445.

Ischnura kellicotti: Diptera—Undetermined. Williamson, 1899, p. 280.

Lestes vigilax: Diptera, Nematocera. Garman, 1917, p. 445.

Argia mæsta putrida:

Coleoptera—Beetle, *Berosus striatus*. Captured while eating.

Ephemera—

Mayfly—*Callibaetis*, sp. Do.

Mayfly—*Hexagenia*, sp. Do.

Hemiptera—Plant louse, *Aphis*, sp. Do.

Diptera—Undetermined flies. In alimentary canal.

Argia apicalis: Diptera—Nematocera. Garman, 1917, p. 445.

Enallagma civile and *E. antennatum*: Diptera—Nematocera. Do.

GENERAL STATEMENT.—Williamson (1899, p. 235) has given one of the best general statements.

The food of the imagos consists almost entirely of other insects, though some are known to occasionally eat the flesh of dead animals. Of the insects eaten Diptera are more preferred than any other order, though all soft-bodied insects seem to fall a prey to their ravenous appetites. Larger species eat their smaller relations. Leaf hoppers and other Hemiptera and Lepidoptera are consumed.

The above statements very strongly substantiate Williamson's statement that the Diptera form a favorite food. Every odonate species included in them, with one exception, has eaten Diptera of some sort. And, curiously enough, all we know about the food of this one exception, *Dromogomphus spoliatus*, is derived from Williamson himself. Some of the species, such as *Anax junius* and *Enallagma hageni*, show a decided preference for flies and midges. The statement that the larger species eat the smaller ones is also well verified, even among the damselflies.

Williamson also recorded on the same page that he once captured a dragonfly holding a large wasp in its mandibles. There were two wasps in Poulton's list of the prey of the Odonata (1906, p. 399), and honeybees were included in Champion's list (1914, p. 499). The English paper Field for March 21, 1908 (p. 486), mentioned a bee keeper in Australia who complained that the dragonfly destroyed more of his bees than any of the birds. None of these records were American, but they serve to indicate that our

American species may possibly eat more Hymenoptera than we are aware. Termites, winged ants, and cicadas are also interesting victims of the odonata which have been recorded in other parts of the world. A dragonfly is reported to have dug a cricket out of the ground and eaten it (Habit of a Dragonfly, editorial notes, *Psyche*, vol. 5, p. 364), but this is the only instance, so far as known, where odonates have eaten any of the Orthoptera.

SIZE OF PREY.—Perhaps the food of the damselflies is usually made up of smaller insects than that of the dragonflies, but the size of the prey is not always in proportion to the size of the imago that eats it. *Æschna* and *Anax*, two of our largest dragonflies, are among the most persistent eaters of gnats, midges, and mosquitoes, while one of the favorite foods of the damselfly, *Argia mæsta putrida*, is a black mayfly almost as large as itself. Like that of the nymphs, the appetite of the imago seems well-nigh insatiable, and no sooner is one insect devoured than another is caught. Stories of the amount eaten by some imago are told by nearly every observer, and the present author would add one more to the list. A male *A. m. putrida* was given eight black mayflies, one after the other, and he ate every one of them, simply throwing away the legs and wings; yet any two of them exceeded in bulk the damselfly's whole body, minus its wings and legs.

SOURCE OF FOOD SUPPLY.—The food is usually captured in greater or less proximity to the water, sometimes being picked off the very surface of the latter. However, the female dragonfly habitually hunts at a greater distance from the water than the male. The females of *Plathemis lydia* and *Perithemis domitia* are only rarely seen around the ponds. The females of other species come to the water for the purpose only of laying their eggs, while the males are constantly patrolling the surface of the ponds, as well as the banks in the immediate vicinity.

Even the males, however, do not obtain all their food near the water. *Anax*, *Æschna*, *Libellula pulchella*, *Tramea*, and *Epicordulia* make long foraging trips out into the surrounding country and are often found a considerable distance from any body of water. In this way they help to rid the countryside of some of its worst insect pests, especially flies, mosquitoes, gnats, and midges. Such foraging trips are made more often late in the afternoon, toward sunset, and sometimes after. The males, and occasionally a female, of many of the species around the ponds came regularly every evening to the laboratory building and hawked for food. They picked flies off the window screens and the sides of the building, they decimated the hordes of gnats and midges that swarmed in the waning sunshine, and sometimes they ascended high in the air in search of the tiny insects to be found there. Occasionally their hunting was prolonged after sunset, when the insects were particularly numerous. *Libellula luctuosa* was the most common of these visitors, but they also included *Erythemis*, *Leucorrhinia*, *Plathemis*, *Tramea*, *Pantala*, *Anax*, *Æschna*, and even *Gomphus vastus* and *G. fraternus*.

MIGRATION OF TENERALS.—As soon as possible after emerging the teneral imagos of *Libellula luctuosa* fly back onto the prairie, away from the ponds and the river. There they remain in the gullies and among the underbrush until they become ready for pairing and egg laying. A trip of a mile or two up some of the gullies leading back onto the prairie will reveal thousands of these tenerals roosting on the weeds and underbrush. Occasionally an imago of *Erythemis*, *Leucorrhinia*, some *Gomphus* species, or an *Enallagma* will be found with them. Usually there is no water within reach, but if

there happens to be a small brook at the bottom of the gully fully developed imagos of *Libellula pulchella* and *Plathemis* will be found, as is usual in such places. These hordes of tenerals are simply resting and feeding in comparative security until they become ready for the active duties of propagation. The time thus occupied is apparently about five or six days but is difficult to determine, because new tenerals are arriving and matured individuals are leaving all the time, and it is practically impossible to tell just how long any of them remain.

It is probably a similar retirement from the vicinity of the water during the interval between emergence and sexual activity that accounts for the disappearance of some of the *Gomphus* species. (See p. 188.)

The food obtained in these gullies and out on the prairie is of necessity somewhat different from that captured around the ponds, but still consists largely of flies, gnats, and mosquitoes, with an occasional lepidopter.

PERIODIC EATING.—Since most of their prey is captured while on the wing, when it is bright and sunny the imagos are eating much of the time, while in dull and cloudy weather they eat very little, if at all.

Microscopic examination of the digestive tract shows that the newly emerged tenerals do not eat anything for a day or two, until about the time their color pattern is fully formed. Probably the tenerals of *L. luctuosa* just mentioned take no food before reaching the gullies and the prairie. Other tenerals that remain near the ponds of course obtain their first food there.

Again, such an examination shows that, while the imago is voracious and often feeds all the time, we can still distinguish two periods of maximum eating, fairly well marked. Whatever is eaten during any day is all digested long before the next morning, so that imagos captured before leaving their roost in the morning will have nothing in their gizzards and very little in the intestine. Accordingly the first period of maximum eating comes in the forenoon, shortly after the imago leaves its roost, as soon as the insects which constitute its food begin to swarm. This is followed by a lull, or at least a diminution in the amount eaten, which lasts until well into the afternoon, and during this period they are occupied with mating and egg laying. The eating then increases again, and the second period of maximum feeding, which is more intensive than the first, comes toward sunset.

Of course, it will be understood that there is no intention of implying that imagos eat two meals a day, or anything of the sort. There are simply more of them feeding in the morning and late in the afternoon and more of them depositing their eggs through the middle of the day. Moreover, the gizzards of those captured at 9 or 10 a. m. and toward sunset are more apt to be well filled. They are thorough believers, however, in eating between meals, and are not restrained in their desires by any irksome rules of hygiene.

FOOD FOUND IN THE ALIMENTARY CANAL OF 218 IMAGOS OF *PANTALA FLAVESCENS* IN HAWAII.

Diptera:	
Midges, <i>Chironomus hawaiiensis</i>	I
Night mosquitoes, <i>Culex fatigans</i>	I
Day mosquitoes, <i>Stegomyia scutellaris</i>	I
Undetermined mosquitoes	3
Pomace flies, <i>Drosophilidae</i>	3
Undetermined flies	140

FOOD FOUND IN THE ALIMENTARY CANAL OF 218 IMAGOS OF *PANTALA FLAVESCENS* IN HAWAII—
Continued.

Coleoptera:

Scarabæid beetle, <i>Psammodius</i> , sp.	22
Bostrichid beetle, <i>Rhizopertha pusila</i>	1
Staphylinid beetle.	31
Undetermined beetles.	30

Hemiptera:

Plant lice, Aphidæ.	24
Water boatman, <i>Corixa blackburni</i>	4
Leaf hopper, <i>Perkinsiella saccharicida</i>	4
Leaf hopper, <i>Draeculacephala mollipes</i>	3
Leaf hopper, <i>Nesophrosyne perkinsi</i>	3
Chinch bugs, Lygæidæ.	2
Lace bugs, <i>Teleonemia lantanae</i>	4
Undetermined species.	1

Hymenoptera:

Apis, not the Honeybee.	1
Parasite, <i>Chelonus blackburni</i>	1
Parasite, <i>Paranogrus optabilis</i>	1
Undetermined Hymenopterous parasites.	3
Myrmicid ants, <i>Pheidole megacephala</i>	6
Undetermined ants.	11

Lepidoptera:

Tineid moth, <i>Cremastobombycia lantanella</i>	5
Undetermined forms.	72

Odonata: Damselfly, <i>Agrion</i> , sp.	1
--	---

Book lice: Psocidæ.	8
--------------------------	---

Thysanoptera: <i>Thrips</i> , sp.	9
--	---

Arachnida:

Mites.	1
Spiders.	2

FOOD OF *PANTALA FLAVESCENS* IN HAWAII.—This statement is inserted here for several reasons. It is by far the most complete statement of the food of a single odonate species that has ever been published. This same species is one of those around the ponds at Fairport, and it is widely distributed throughout the United States. Hence a list of its food in Hawaii will give a good idea of the kind of insects it would be likely to eat elsewhere. It is also instructive to compare the Hawaiian foods with those eaten at Fairport. We notice that flies, beetles, and Lepidoptera make up the bulk of the food of this species in Hawaii. There are also present many kinds of Hemiptera or true bugs, especially plant lice, adult water boatmen, and leaf hoppers, some hymenopterous parasites, ants, and Thrips, a tiny insect which feeds upon the flowers and leaves of some plants.

In the Fairport list there is a much greater variety of both flies and Lepidoptera, but there are no beetles at all, and the only bug is the plant louse. Their place seems to be taken by the mayflies and caddisflies, which are lacking in the Hawaiian list.

ECONOMIC VALUE OF THESE FOODS.—The chief concern here is the effect upon the life of the fish produced by such wholesale and untiring destruction of the insects around the ponds, as is revealed in these food lists. In dealing with this problem certain considerations are forced upon the attention.

It will be urged, in the first place, as in the case of the nymphs, that the killing of so many adult Chironomids, Ephemerids, and Culicids seriously diminishes the number

of egg layers around the ponds, and thus affects the supply of fish food. Would it not be better to get rid of the dragonflies and allow these other insects to breed without hindrance? At first sight it seems as if the answer must be in the affirmative, but a little reflection makes it appear differently. If the nymphs of the dragonflies make as good food for the larger fish as the larvæ of these other insects make for the smaller fish, then it is as important for the dragonfly imago to survive and lay its eggs as for any of these other species. Larger fish will not thrive well on food suitable for fry, and if something is not provided for them they will eat one another. Bass, perch, sunfish, buffalofish, catfish, and crappies are well satisfied with the larvæ of mosquitoes, gnats, and flies for a while and will thrive on them. But the time soon comes when this food no longer satisfies them and they demand something larger. (See p. 225.)

The period during which the smaller larvæ prove sufficient varies considerably with the kind of fish, but they will all thrive better if the larger food is present in the pond, so that they can change to it gradually whenever they choose. It is definitely shown in another place (p. 228) that when the young fish reaches a length of about 25 mm. it begins to eat odonate nymphs. It takes some fish much longer to reach this length than it does others, and even in the same brood some fish grow faster than others. Hence the larger food must be present all the time to accommodate the different rates of growth.

Furthermore, actual observation shows that the presence of odonate nymphs and imagos does not necessarily diminish the supply of smaller fish food. The number of dragonflies has steadily increased around the Fairport ponds during the last five years, but at the same time the number of other insect larvæ and Entomostraca has increased apparently as much, so that conditions suitable for fish culture were never better than at the present time.

Again, whatever the kinds of fish, they must be successfully carried through the winter, and there must be enough food in the pond to keep them in good condition. By the time the pond freezes over most of the young fish have become large enough to demand good-sized food, and the larger they grow the more insistent will this demand become. Moreover, some of the animals which are included among this smaller food, such as the Entomostraca and several of the insect larvæ, are much less numerous during the winter. At other times of the year odonate nymphs furnish acceptable food for fish, and there is every reason to believe that they continue to do this through the winter, which is just the season when it is most needed. Only a few fish have been examined at Fairport during the winter, but the limited observations that have been made seem to support this idea. Twelve largemouth black bass, *Micropterus salmoides*, averaging 130 mm. in length and 18 bluegills, *Lepomis incisor*, averaging 107 mm. in length, from pond 1D, 19 of the same bass, 44 mm. in length, from pond 2D, and 12 bass, 185 mm. in length, from pond 3D, were examined February 15-17, 1917. Of these 61 fish, the stomachs of 46 were found to be either entirely empty or so near it that the dèbris present was indistinguishable. The food of four of the remaining fish, two bass and two bluegills, consisted entirely of odonate nymphs, and they were probably identified in the dèbris of the stomachs of two other bluegills. This record is too meager to possess much value beside the ample proof elsewhere presented (p. 225), but it does show that the fish will eat nymphs during the winter, as suggested.

As a third consideration, although nature's equilibrium must be made subservient to man's designs and control in intensive pondfish culture, it is still true that, other

things being equal, the more natural the pond and its surroundings can be kept the greater will be the likelihood of success. Artificial conditions are usually difficult of maintenance and should be established only when necessary. The dragonflies and nymphs constitute an important factor in the environment of the ordinary fishpond, and even their voracious appetite is accounted for in nature's methods of equalizing things. This is shown by the fact that they eat one another with as much avidity and as little compunction as is shown toward any other kind of food. Their removal, therefore, would considerably disturb the balance and impose artificial conditions that might be difficult to handle. The station is having much success in rearing various kinds of fish, among which are the buffalofish and channel catfish, whose breeding is admitted to be very difficult. Some of this success may well be due to the maintenance of a natural equilibrium in the animal and vegetable life of the fishponds.

Tillyard (1917, p. 335) has suggested that such an equilibrium may be advantageously modified without in the least impairing its value:

Not only are the dragonflies the most powerful determining factor in preserving the balance of insect life in ponds, rivers, lakes, and their surroundings, but they do most certainly make war upon the flies, mosquitoes, and gnats, which we all desire to see exterminated. I believe that a successful checking of the mosquito pest in the ornamental waters of parks and gardens could be readily obtained by the introduction of species whose larvæ, as well as the imagines, would prey upon the nuisance. If a successful planting of a colony of dragonflies in such a position were to be tried, the species selected might also be chosen for its coloring, and thus add a new note of interest to the locality. The glorious red *Orthetrum villosovittatum* has now become well established in the Botanical Gardens at Brisbane (Australia) and certainly adds a vivid touch of color to its lovely surroundings.

The suggestions herein contained naturally lead up to the next consideration, which seems worthy of a separate heading.

ODONATES AS DESTROYERS OF MOSQUITOES, GNATS, AND FLIES.—The quiet waters of an artificial fishpond furnish admirable conditions for the breeding of mosquitoes, and the screens at their outlets afford similar breeding places for gnats. The mosquitoes may include, in the proper geographical localities, both *Anopheles* and *Stegomyia*, the carriers of malaria and yellow fever. Obviously in a fishpond these pests can not be kept down by treatment with an oil film, neither can they be allowed to breed unhindered. The consumption of the larvæ by young fish might furnish an important check, but in intensive fish culture very little attention can be paid to the attitude of the fish toward mosquito larvæ.

Of the nine ponds in series D at Fairport six were stocked in the spring with fish that would not eat mosquito larvæ. In some of these ponds broods of young fish were raised later in the season, but previous to their appearance the mosquitoes could breed unhindered by the fish. In at least two of the six ponds no young fish were raised, or they were removed before they had time to produce any effect upon insect larvæ. Here, therefore, so far as the fish were concerned, the mosquitoes might hold undisturbed sway during the entire season.

No fish eats adult mosquitoes; when the pupæ are once safely transformed into imagoes they are in no danger of further molestation from that source. Hence if the fishpond is to be prevented from serving as a breeding ground for these obnoxious pests some other check must be provided. Mention has already been made of the fact that the odonate nymph eats mosquito larvæ and pupæ, and the adult dragonfly is an even greater enemy of the mosquito imago. Tillyard (1917, p. 328) stated that he

had repeatedly seen *Æschnina* feeding upon gnats and mosquitoes in the late afternoon. A specimen of *Telephlebia godeffroyi* was once observed flying round and round a small bush at about 7 o'clock in the evening, when the mosquitoes were particularly troublesome. After 10 minutes it was captured and its mouth was found so full of mosquitoes that it was unable to shut it.

There must have been over a hundred all tightly packed into a black mass. I have frequently seen *Æschna brevistyla* take gnats and mosquitoes in dozens while on the wing. There can be no doubt that those dragonflies which fly late in the day are of great value in checking the spread of the various objectionable Culicidæ that are on the wing from just before sundown.

Needham and Hart (1901, p. 29) make a similar statement: "The usefulness of the *Æschnidæ* imago, especially *Anax junius*, on account of the enormous quantities of pestiferous gnats and mosquitoes which they destroy, puts them among the particular friends of mankind." The *Anax* imago hunts after sunset, continues flying as long as there is light enough to render its prey visible, and is probably the last dragonfly to go to roost. In its search for food it frequently mounts high up in the air, sometimes disappearing from sight in this manner. The male of *L. luctuosa* has similar habits, but does not carry them quite as far.

Dr. Lamborn (1890) made an investigation to determine the practicability of the artificial use of dragonflies for destroying mosquitoes and flies. While nothing very practical in the way of artificial breeding was suggested, the investigation emphasized the immense service rendered by dragonflies under natural conditions in keeping down these pests.

The members of the family Simuliidæ are even greater pests than the mosquitoes. One species, *Simulium pecuarum*, is known as the southern buffalo gnat and causes the death of many mules and other domestic animals throughout the Mississippi Valley. Another species, *Simulium meridionale*, is known as the turkey gnat, and it also infests all kinds of domestic animals, especially the turkey. "Many cases of the death of human beings from the bites of buffalo gnats have been reported, and some of them seem well authenticated" (Needham, 1903, pt. 2, p. 343). However this may be, all the species are bloodsuckers and intolerable pests, and anything which eats them is thereby distinctly beneficial.

Consequently, even if it could be proved that nymphs had a fondness for young fish, and that they were not themselves of any value as fish food, it would still seem to the present author that the incessant warfare which they wage against gnats and mosquitoes ought to earn them a cordial welcome to every fishpond. It would certainly be better for some of the fish to die than for the pond to become a breeding place for bloodsuckers and disease carriers. And if, in addition to this service, it can be shown, as has been attempted, not only that the nymphs are harmless to the fish as long as they can obtain other food (p. 206), but also that they themselves furnish one of the best of foods for the growing fish (p. 205), they become practically a necessity if fish breeding is to be carried on successfully.

Another positive benefit to mankind is the wholesale destruction of house flies by so many of the odonates. It will be noted that this disease carrier appears as an article of diet in nearly every one of the lists. *Æschna* is frequently captured while devouring flies on the screens and screen doors of dwelling houses and factories, and *Anax* has often been reported from similar localities. A list has already been given of those species which

came to the laboratory building (100 yards from pond 1D) and picked house flies, Mayflies, and the like off the window screens. In view of the present widespread movement against the house fly conducted by boards of health and hygienists everywhere in the United States, this fly-eating habit of the odonates ought to receive every encouragement.

In this connection also it is worth noting that Dr. G. D. Carpenter, during his investigation of the sleeping sickness in Africa, observed one species of damselfly and two species of dragonflies feeding upon the dreaded tsetse fly, the damselfly even picking them off the clothing of the collector. (Campion, 1914, pp. 498 and 500.)

Another record in this same paper and one by Poulton (1906, p. 399) credit the odonates with eating horseflies (Tabanidae).

ENEMIES OF ODONATE IMAGOS.

Most authors state that the imagos do not suffer much from natural enemies except during the teneral period, and this appears to be true. But during this teneral period, which lasts for a varying length of time after their emergence from the nymph skin, they are so weak and limp that they fall an easy prey to even the humblest enemies.

1. ACCIDENTS.—A small percentage always fails to emerge properly, and in collecting exuviae one will occasionally be found with the imago only partially emerged. Something prevented it from getting clear of the nymph skin, and it perished in the effort. Again, one or two of the wings may fail to expand properly after the imago has gotten safely out of the skin, and it is then unable to fly and soon perishes. Sometimes the teneral is forced to try its powers of flight too soon, and it falls into the water and drowns. The number of these accidents is probably larger than appears at first, for such drowned imagos easily disappear.

Rain sometimes catches the tenerals before they have become sufficiently hardened to withstand it. Kennedy (1917, p. 530) makes a note of this:

With many western species the most serious cause of premature death among imagos seemed to be the occasional cold rains which come even in desert regions. On Satus Creek (Yakima County, Wash.) I have seen *Ophiogomphus severus* practically wiped out for the first day or two after a rain and regaining its numbers only after more had emerged.

In the Mississippi Valley a heavy thundershower will sometimes produce the same effect upon the tenerals, the rain fairly sweeping them off their perch and drowning them in the gutters.

Usually those which perish in these different ways, however, form but a small percentage when compared with the innumerable hosts that pass through the metamorphosis successfully.

2. BIRDS.—*Libellula luctuosa* emerges mostly in the early morning, and for a long time hundreds of teneral wings of this species, easily recognizable by their markings and varnished appearance, were found every forenoon lying on the ground and among the vegetation on the embankments of the ponds. At length the culprits were caught in the very act of seizing and devouring the imagos, and they proved to be English sparrows. They flocked to the embankments at daybreak and hunted through the herbage until they found a teneral; they then seized it, beat its wings off, and either swallowed it or carried it to their young. In this way they destroyed large numbers every day and kept it up as long as the species continued to emerge. When its wings are once hardened, the sparrow can no longer catch the imago, and it is thereafter free from this enemy.

This destruction by the English sparrows is local and apparently casual; in the summer of 1917 they did not destroy as many of the teneral as in 1916. It seems to be largely a matter of chance; if they happen upon the teneral at just the right time and get a good meal, they return again and again. The localities frequented by the teneral are not the ones from which these sparrows are accustomed to get their food, however, and hence there is no systematic hunting for them.

Another bird that causes great destruction among the imagoes is the red-winged blackbird. Several pairs of these birds nested about the ponds, and they were seen repeatedly catching the teneral and eating them or feeding them to their young. A small stake projecting a few inches above the water in pond 2 was a favorite roosting place for one of the male redwings, and from the algae surrounding this stake were picked up more than 100 teneral wings of *Libellula luctuosa*. During experiments with the large breeding cage mentioned elsewhere (p. 235) adult dragonflies of several species and of both sexes were caught and placed in the cage. Every effort was made to induce them to eat, to mate, and to lay their eggs, but to no avail. One of the chief hindrances was an old male redwing who made it his duty to visit the cage as soon as possible after the dragonflies were placed in it and to pick them off through the wires. In this way he would have them all caught and devoured within a short time.

Kennedy (1915, p. 343) found teneral damselflies and dragonflies in the stomachs of four yellow-headed and one red-winged blackbird which he examined. He also stated on the same page that he believed the yellow-headed blackbirds ate most of the teneral *Anax junius* at one of the ponds where he collected. Other species, such as *Erythemis simplicicollis*, *Aeschna multicolor*, and *A. californica* escaped this peril of the birds by emerging late in the evening, so that by daylight the next morning their wings were hard enough to fly.

Both *E. simplicicollis* and *L. luctuosa* roost at night in the tall grass and other vegetation around the ponds, and when there is a rain in the night, or an exceptionally heavy dew, are sometimes so bedraggled in the early morning that they are caught by the birds.

In a later paper Kennedy (1917, p. 530) has noted that *Ophiogomphus morrisoni* at Donner Lake, Oreg., was seriously attacked by robins while emerging.

In the Canadian Entomologist, volume 5, 1873, p. 159, Mr. Gould, in a communication to the Entomological Society of London, said:

I believe that the larger dragonflies are very liable to the attacks of birds, and have no doubt that the hobby and kestrel occasionally feed upon them; with regard to the small blue-bodied species (Agrionidæ) frequenting the sedgy bank of the Thames, I have seen smaller birds, sparrows, etc., capture and eat them before my eyes after having carefully nipped off the wings, which are not swallowed. This must take place to a considerable extent, as I have observed the towpath strewn with the rejected wings.

The hobby and the kestrel are English hawks, but Fisher (1893) has recorded the swallow-tailed kite, the sharp-shinned hawk, the red-shouldered hawk, the broad-winged hawk, the duck hawk, the sparrow hawk, and the pigeon hawk as feeding on dragonflies here in the United States.

Tillyard (1917, p. 330) has stated that kingfishers are wonderfully expert at catching dragonflies skimming close to the water. That may be true of the kingfishers of Australia and New Zealand, but it is doubtful if our own belted kingfisher of the eastern

United States ever eats them. Shrikes, cuckoos, and kingbirds, however, catch and eat the imagos, even after the wings of the latter have become fully hardened. Hence they are active enemies during the entire adult life of the dragonflies and cause considerable destruction.

3. LARGER IMAGOS.—The imagos of the larger species are great enemies of the smaller species; this is especially true of the gomphids, of *Anax*, and of *Erythemis*. All of these were observed eating teneral damselflies and sometimes teneral dragonflies, and these seem to be the favorite food of the female gomphids.

An editorial in *Nature*, volume 26, 1882, page 89, related a curious fact observed by Signor Stefanelli in regard to a dragonfly (*Æschna cyanea*) often met with near Florence. There were several nymphs of this species in a cistern of water. Some which were almost ready for transformation came out of the water a little way during the night, and attacked several teneral imagos which could not yet fly and voraciously devoured them. It was suggested that this singular practice may explain why one finds such a small number of *Æschna cyanea* in comparison with the number of nymphs. But this is more easily explained by the migration of the tenerals already described (p. 188), and we must regard such a practice as this as extremely exceptional rather than as an ordinary occurrence.

4. ANTS, SPIDERS, ROBBER FLIES, AND FROGS.—These also eat teneral dragonflies, and the spiders capture fully matured adults. Two tenerals of *L. luctuosa* were eaten alive by a colony of black ants on the banks of pond 4. The ants seized them on all sides with their mandibles and tore them in pieces, dragging off the fragments to their nest.

The webs of the common black and yellow spider, *Argiope*, are thickly scattered through the vegetation along the shores of the ponds, and from them the author secured many specimens of *Ischnura verticalis*, *Enallagma civile*, *E. hageni*, *Argia putrida*, and tenerals of *Sympetrum rubicundulum*, *L. luctuosa*, and *Erythemis simplicicollis*. Williamson (1899, p. 236) has recorded a similar experience in Indiana. A large water spider, common around the shores of the ponds, also catches teneral dragonflies on the grass stems at the edge of the water.

Williamson (1899, p. 235) noted a large robber fly carrying a teneral *Sympetrum rubicundulum*, which it had doubtless killed, and Dyche (1914, pp. 151 to 153) found dragonflies in the stomachs of several large bullfrogs.

The little cricket frog, *Acris gryllus*, is also a confirmed eater of damselfly imagos. His usual roosting place is upon the floating algæ at the surface of the water, where he watches for the damselflies when they come to deposit their eggs. When caught, the damselfly is much longer than the frog's body, but the latter swallows it slowly and keeps swallowing until it has entirely disappeared.

5. PARASITIC MITES AND FLIES.—Tillyard (1917, p. 331) made the following statement:

Dragonflies whose larvæ live in still water are frequently found covered with the young of a species of small red mites (family Hydrachnidæ). The adult probably attacks the dragonfly at metamorphosis, placing either its eggs or viviparous young on the under side of the thorax, the bases of the wings and legs, or the abdomen, to which they are afterwards found clinging. In this way the dragonfly is used as a means of dispersal by the Arachnid, and the young mites are carried from one pond to another, where some of them drop off.

Ischnura and *Enallagma* among the damselflies and *Leucorrhinia* among the dragonflies seem particularly susceptible to these mites. Ten or a dozen of the young mites were found between the wing pads and around the bases of the legs on each of five *Ischnura* and seven *Enallagma* nymphs. Forty-four of them were taken from the ventral surface of the thorax of a single female imago of *Enallagma hageni* and 110 were removed from the ventral surface of the abdomen of a single male imago of *Leucorrhinia intacta*. Tillyard said that the young mites cling to the dragonfly without doing it any harm, but in this *Leucorrhinia* the considerable surface covered by the mites was badly discolored, being changed from black to a yellowish red. The points where each mite was attached were also somewhat swollen and deep red in color, so that the integument seemed to be honeycombed. So far as this particular specimen was concerned, the mites had been obtaining sustenance as well as transportation.

In the family of flies known as Asilidæ there are two genera, *Promachus* and *Lophonotus*, which have been seen to capture and eat dragonflies (Poulton, 1906, p. 342).

6. INTERNAL PARASITES.—The imagos are susceptible to intestinal parasites as well as the nymphs, and Selys-Longchamps (1850, p. 36) recorded the finding of a *Filaria* in the abdomen of a dragonfly which inflated it to such an extent as to hinder the insect's flight.

Ssnitzin (1907, p. 24) reported stages of a frog-lung fluke, *Pneumonæces variiegatus*, free in the body cavity of both nymphs and adults of the damselfly *Agrion* (*Calopteryx*) *virgo*. By feeding experiments he was able to infect frogs with these forms, showing that the damselfly here serves as an intermediate host for the frog fluke.

7. SUNDEW AND PITCHER PLANTS.—An observation of Tillyard's (1917, p. 329) is worthy of mention here. He said that in Australia the giant sundew, *Drosera binata*, takes heavy toll of those damselflies which frequent the swamps and marshes. It is doubtful whether any of our North American sundews are capable of capturing damselflies, but our pitcher plants certainly are, and it would be interesting to know if some of them do not occasionally claim odonate victims.

ODONATE NYMPHS AS FISH FOOD.

EVIDENCE FROM FISH BAIT.—The first and most obvious proof that nymphs make good food for fish is the fact that they are used successfully for fish bait. Tillyard (1917, p. 337) recorded that the larvæ of *Hemicordulia*, called appropriately by the Australians mud eyes, are much sought after as bait for trout and perch. Needham (1903, p. 212) said: "Nymphs attached to hooks were taken by trout, but not more readily than minnows, small frogs, or other bait." He could also probably have said with equal truth that they were not taken any less readily than other bait.

Fishermen in certain parts of the country use nymphs regularly as bait in the same way that "dobsons" are used for bass bait. In Michigan and Minnesota the nymphs are locally called "crabs," and it is said that the rock bass or redeye will take them when it refuses other bait. In the vicinity of Torrington, Conn., the nymphs are known as "perch bait," and boys make a business of catching and selling them to the fishermen. But, of course, the best proof that nymphs serve as fish food is the fact that they are found in goodly numbers whenever the stomach contents of fishes are examined.

EVIDENCE FROM STOMACH CONTENTS.—Prof. S. A. Forbes has made very valuable and extensive studies of the food of fresh-water fishes, of which he published a summary and discussion in 1888. In this paper he gave a detailed list of the stomach contents of many of our food and game fishes, from which we may select those which had eaten nymphs and put them in tabular form. Such a table will be useful as an indication of the kind of fishes for which dragonfly nymphs would furnish acceptable food in pond-fish culture.

FOOD OF FISHES EXAMINED BY S. A. FORBES.

Kind of fish.	Period of life of fish.		Number of fish eating—	
	Adult.	Young.	Dragon nymphs.	Damsel nymphs.
<i>Ictiobus bubalus</i> : Small-mouthed buffalo.....	×	×	4	2
<i>Ictiobus urus</i> : Mongrel buffalo.....	×		1	
<i>Moxostoma macrolepidotum</i> : Sucker.....	×			2
<i>Polyodon spathula</i> : Spoonbill cat.....	×		1	1
<i>Erimyzon sucetta</i> : Common chub.....		×		1
<i>Amia calva</i> : Dogfish.....	×		2	
<i>Lucius vermiculatus</i> : Grass pickerel.....		×	6	7
<i>Lucius lucius</i> : Common pike.....	×		1	
<i>Aplodinotus grunniens</i> : Sheephead, croaker.....	×		4	
<i>Aphredoderus sayanus</i> : Pirate perch.....	×		1	
<i>Ictalurus punctatus</i> : Channel cat.....	×		1	
<i>Ameiurus nebulosus</i> : Bullhead.....	×		6	4
<i>Labidesthes siculus</i> : Brook silversides.....	×		2	
<i>Fundulus notatus</i> : Top minnow.....	×			2
<i>Hadropterus aspro</i> : Black-sided darter.....	×			1
<i>Lepomis gibbosus</i> : Common sunfish.....	×			2
<i>Lepomis incisor</i> : Bluegill.....	×	×	2	4
<i>Apomotis cyanellus</i> : Green sunfish.....	×	×	5	
<i>Pomoxis annularis</i> : White crappie.....	×	×	1	4
<i>Pomoxis sparoides</i> : Black crappie.....	×			5
<i>Perca flavescens</i> : Common perch.....	×	×	5	4
<i>Ambloplites rupestris</i> : Rock bass, redeye.....	×		1	1
<i>Chænobryttus gulosus</i> : Warmouth bass.....		×		3
<i>Micropterus dolomieu</i> : Smallmouth black bass.....		×		2
<i>Micropterus salmoides</i> : Largemouth black bass.....	×			1
<i>Archoplites interruptus</i> : Sacramento perch.....	×			1
<i>Fundulus diaphanus menona</i> : Menona minnow.....	×			1

The numbers in this table seem very small when thus isolated; but if we compare them with the remainder of Forbes's list we find they are comparatively large and are surpassed by those of very few insects.

In his notes he stated that the various nymphs seemed to be most abundant (25 per cent) in the food of the grass pickerel, *Esox vermiculatus*, while they formed from 10 to 13 per cent of the food of the crappies, *Pomoxis annularis* and *P. sparoides*, the pirate perch, *Aphredoderus sayanus*, and the common perch, *Perca flavescens* (1888b, p. 485). Hankinson (1908, p. 234) stated that "nymphs were often found in the stomachs of rock bass and blue-spotted sunfish, less frequently in those of the common sunfish;" and in another place: "The nymphs of *Macromia illinoiensis* are much eaten by fishes" (p. 263). In his remarks upon the various species of fish he mentioned nymphs as the food of the bullhead, the rock bass, the blue-spotted sunfish, the common sunfish, the large-eared sunfish, the bluegill, and the large mouth black bass.

Baker (1916) gave the results of his examination of the stomachs of numerous specimens of different kinds of fish. He reported that nymphs of the odonata constituted 25 per cent of the food of one bullhead, *Ameiurus nebulosus* (p. 176); 62 per cent (with caddisflies) of the food of five bluegills, *Lepomis incisor* (p. 182); 15 per cent of the food of one redeye, *Ambloplites rupestris* (p. 182); 30 per cent of the food of one sunfish, *L.*

gibbosus, and 15 per cent of the food of another (p. 187); 60, 75, 85, and 100 per cent, respectively, of the food of four young yellow perch, *P. flavescens* (pp. 192, 193); 6 per cent (with Chironomid larvæ) of the food of six Manitou darters, *Percina caprodes zebra* (p. 194); 19 per cent of the food of four young grass pike, *Esox reticulatus*; and 36.66 per cent of the food of three preadults (p. 201).

Bean (1912, p. 203), in speaking of fish food said: "Important trout foods are snails, dragonflies, mayflies, and caddisflies."

A. S. Pearse, of the University of Wisconsin, in a manuscript paper seen by the present author verifies these observations and adds many other fish species which feed upon odonate nymphs.

Dr. R. A. Muttkowski has very kindly contributed some manuscript notes upon the food of fish from the vicinity of Madison, Wis. The odonate nymphs have been selected from these food data and arranged in the following table:

FOOD OF FISHES NEAR MADISON, WIS., EXAMINED BY DR. R. A. MUTTKOWSKI.

[Numerators represent number of fish in whose stomachs nymphs were found; denominators represent number of nymphs found.]

Kind of fish.	Argia, sp.	Enallagma antennatum.	Enallagma hageni.	Enallagma signatum.	Ischnura verticalis.	Nehalennia irene.	Æschna umbrosa.	Anax junius.	Cerithemis epina.	Libellula lucida.	Libellula, sp.
Ambloplites rupestris: Rock bass, redeye.....		$\frac{15}{24}$	$\frac{1}{35}$								
Ameiurus nebulosus: Common bullhead.....			$\frac{5}{6}$					$\frac{1}{1}$			
Ameiurus melas: Black bullhead.....			$\frac{2}{6}$								
Lepisosteus osseus: Long-nosed gar.....		$\frac{1}{1}$									
Eupomotis gibbosus: Common sunfish.....			$\frac{3}{5}$								
Lepomis pallidus: Bluegill.....			$\frac{5}{5}$								
Micropterus salmoides: Largemouth black bass.....			$\frac{12}{3}$					$\frac{1}{2}$			
Perca flavescens: Yellow perch.....	$\frac{1}{2}$	$\frac{18}{74}$	$\frac{29}{202}$	$\frac{12}{2}$	$\frac{5}{23}$	$\frac{1}{1}$	$\frac{4}{11}$	$\frac{2}{2}$	$\frac{2}{4}$	$\frac{1}{1}$	$\frac{1}{1}$
Pomoxis annularis: Crappie.....			$\frac{1}{1}$								
Pomoxis sparoides: Calico bass.....		$\frac{1}{12}$	$\frac{9}{30}$		$\frac{6}{89}$						
Schilbeodes gyrinus: Mad Tom.....		$\frac{12}{3}$	$\frac{12}{2}$								
Umbra limi: Mud minnow.....										$\frac{1}{1}$	

Two facts stand out very clearly in this table. The first is that the nymphs of the two species of *Enallagma*, which are common in the vicinity of Madison, form an important item in the food of the local fish. Every species of fish except the mud minnow has eaten of them in considerable numbers, and for the rock bass and calico bass they seem to constitute the chief item of diet. In all, 24 species of fish were examined, and it is worthy of note that 6 of the 12 which do not appear in this table are found in Forbes's table, where they are simply recorded as eating damselfly nymphs, without any designation of species.

The number of individual perch examined was very much larger than that of any other kind of fish, and the species of odonate nymphs found in their stomachs are corre-

spondingly numerous. They have eaten some of every kind of nymph listed, but their preference seemed to be for the damselflies rather than for the dragonflies, if we may judge by the numbers consumed. At all events, it can easily be seen that odonate nymphs are more toothsome to them than any other single article of diet.

The dragonfly nymphs recorded up to the present time are mostly Libellulides, and it is generally stated that gomphine nymphs escape the fish by burrowing in the sand, the mud, or the accumulated débris of the bottom. But even this burrowing habit does not save them from some fish. Of three spoonbill cats, *Polyodon spathula*, taken at Keokuk in May, 1916, 40 per cent of the stomach contents of one fish consisted of nymphs of *Gomphus notatus*. The second fish's stomach contained 1 *Gomphus vastus* nymph and 1 *Enallagma* nymph, constituting 10 per cent of the food; the third stomach contained 1 *Gomphus vastus* nymph, 25 per cent of the food. Of three moon-eye herrings, *Hiodon alosoides*, one taken March 24, 1916, near Hamilton, Ill., and the other two in June at Keokuk, Iowa, each contained a full-grown gomphine nymph and nothing else. A river drum, *Aplodinotus grunniens*, taken at Keokuk in June, contained a single gomphine nymph, constituting 60 per cent of its food.

Evidence from the fishponds themselves will be more convincing than that from rivers, streams, or lakes, and fortunately there is an abundance of evidence from this very source which furnishes just the proof desired. During the year from June, 1916, to June, 1917, H. E. Schradieck, an employee of the Bureau of Fisheries, was engaged in examining the food of the fishes in the very series of ponds (series D) here considered. Permission has been granted to select from his manuscript records the data relating to odonate food, and these data have been arranged in the following table:

FOOD OF FISHES FROM PONDS IN SERIES D, FAIRPORT, IOWA, EXAMINED BY H. C. SCHRADIECK.

Kind of fish.	Number of fish examined.	Pond from which taken.	Extremes in length.	Average length.	Number containing damselfly nymphs.	Number containing damselfly imagoes.	Number containing dragonfly nymphs.	Odonate food, 100 per cent.	Odonate food, 75 to 99 per cent.	Average per cent odonate food. ^a	Odonate eggs.
			<i>Mm.</i>	<i>Mm.</i>							
Micropterus salmoides: Largemouth black bass.....	144	3	$\frac{16}{105}$	50	45	2	38	24	38	68.5	.....
Micropterus salmoides: Largemouth black bass.....	136	2	$\frac{16}{92}$	40	51	2	18	8	29	62	.....
Micropterus salmoides: Largemouth black bass.....	20	3	$\frac{8}{22}$	16	1	0	0	0	0	0	.....
Lepomis pallidus: Bluegill.....	103	2	$\frac{20}{60}$	42	29	0	2	0	4	34	.....
Ictiobus bubalis: Buffalo fish.....	22	7	$\frac{33}{78}$	51	0	0	0	0	0	0	1
Ictiobus bubalis: Buffalo fish.....	350	5 & 7	$\frac{75}{235}$	.....	0	0	0	0	0	0	.....
Eupomotis euryurus: McKay's sunfish.....	120	8	$\frac{27}{64}$	41	18	0	78	14	46	68.5	.....
Eupomotis gibbosus: Common sunfish.....	173	16 B	$\frac{12}{45}$	25	8	0	2	0	0	34	.....
Pomoxis sparoides: Calico bass.....	143	8	$\frac{23}{38}$	30	5	0	1	0	1	41	.....
Ictalurus punctatus: Channel cat.....	5	9	.....	9	0	0	0	0	0	0	.....
Ictalurus punctatus: Channel cat.....	21	9	$\frac{45}{95}$	70	.....	.....	.....	.....	.....	.....	.....

^a This average includes only the fish that had eaten odonate food.

The number of fish included in this table is large enough to give considerable weight to the conclusions drawn; a thousand fish stomachs ought to furnish a fairly reliable basis for judgment. Furthermore, the fish have been taken from the ponds during every month in the year except December, January, and February, and thus include as much of the yearly life cycle as is available.

Very small fish do not eat odonate nymphs. Of the largemouth black bass from pond 3 only one, and that the largest of them all, had taken a damselfly nymph; eight specimens of bluegills, averaging less than 10 mm. in length, from ponds 1 and 2, did not show any trace of odonate food; and the five channel cats that averaged only 9 mm. in length from pond 9 had eaten nothing as large as an odonate nymph.

While these small fish refuse the nymphs, they do not refuse the eggs which the dragonflies distribute so freely about the ponds. Of the 22 buffalofish from pond 7D only 1 had eaten dragonfly eggs. But among 59 sunfish from pond 15B, 10 were found to have eaten dragonfly eggs; these 10 fish averaged but 13 mm. in length, the shortest being 10 mm. long and the longest 18 mm. Odonate eggs formed 55 per cent (average) of the food of these 10 fish and reached as high as 98 per cent in one of them. Hence for some kinds of fish odonate eggs will furnish an acceptable food, while the young fry are from 10 to 20 mm. in length.

Judging from the records of the largemouth bass, the bluegill, the common sunfish, and the calico bass, young fish must attain a length of from 22 to 25 mm. before they begin to eat odonate nymphs. From 25 to 40 mm. they take them in comparatively small numbers; from 40 to 100 mm. they eat them in much larger quantities, and often eat nothing else. In every instance where the odonate food constituted 100 per cent the fish was over 40 mm. in length and nine-tenths of them were over 50 mm. From 50 to 80 mm., therefore, may be taken as the size of fish for which odonate nymphs will prove most serviceable as food.

The stomach contents of a largemouth black bass, 80 mm. long, examined July 30, 1917, consisted of three fully grown nymphs of *L. luctuosa*, one fully grown nymph of *Erythemis*, and the remainder of the food fragments of similar nymphs too far digested for identification.

The small percentage of odonate food in the stomachs of the common sunfish and the calico bass may well be due to the small size of the fish examined. Of the 173 common sunfish included in the table, 96 were under 25 mm. in length and only 32 were 30 mm. or over in length, so that really the 10 fish which ate odonate nymphs were 10 out of 32 rather than 10 out of 173. Similarly, among the 143 calico bass there were only 21 that reached 35 mm. in length, while 100 were between 26 and 34 mm., just the size when they begin to eat sparingly of nymphs. The calico bass does not seem to begin this diet quite as early in life as some of the other fish, although the table of the Madison fish shows that the adults eat damselfly nymphs in goodly numbers. If we remove from the lists here given all the fish 25 mm. in length or under—namely, those that were too small to be expected to eat odonate food—it can readily be seen that the percentage of odonate feeders would be considerably increased.

We may next consider the fish's diet from a seasonal standpoint—the examination of fish food began in the latter part of June and continued through the summer and fall. Both the fish and the nymphs were steadily increasing in size during the period.

By following the charted records—say, of the largemouth black bass, for instance—it is very instructive to note that through June and July, while both nymphs and fish were quite small, the former do not appear in the diet of the latter. The bass began to eat nymphs about the first of August, and during that month in 10 out of the 30 bass examined odonate food reached from 90 to 100 per cent. The fish continued to eat nymphs in large quantities through the fall months. The largest bass was examined September 2 and was 105 mm. in length; 95 per cent of its food consisted of dragonfly nymphs. During the autumn of the first year, therefore, the odonates supply a very large percentage of the food of the young fish, and many fish feed entirely upon them.

Not all fish, however, will take odonate food, no matter how abundant it may be. The two examinations of buffalofish have been included in the table in order to show this fact. The first lot contained fish between 33 and 78 mm. in length, taken from pond 7D and several other ponds not in series D. These fish were all of just the right size to eat freely of the nymphs, judging by the records of the other fish enumerated. But with the exception of one which had eaten a few odonate eggs, probably accidentally, there was an entire absence of odonate food in their diet. Similarly, the 350 larger buffalofish did not show a single instance of the presence of odonate food. We may reasonably conclude, therefore, that such food is not palatable to them and will be of practically no assistance in their culture. It is worthy of note in this connection, however, that Prof. Forbes found both dragonfly and damselfly nymphs in the stomachs of adult buffalofish.

EVIDENCE FROM EXUVIÆ.—There are also other methods of obtaining evidence besides an examination of the fish's stomach. Ponds 1, 2, 3, and 4 are as nearly alike as possible in their conditions and environment, but differ considerably in their fish contents. Pond 1 was stocked in the spring of 1916 with about 4,500 small bass and bluegills, while ponds 2 and 3 contained only a comparatively small number of adult bass and bluegills, together with the season's hatch of young, the latter, of course, being too small to eat any nymphs before autumn. There was no appreciable difference in the number of dragonflies hawking and ovipositing around these ponds, but there was a very marked difference in the number of nymph skins obtained along the margins of the ponds. The north shores of ponds 1 and 2 are of the same length and have a border of *Carex stricta* of the same width, but while this border yielded 450 nymph skins on pond 2, only 150 could be found on pond 1. The difference in damselfly skins was even more marked; only 6 were found on the whole margin of pond 1, while a single reed stem in pond 2 yielded 21 skins, and the entire margin yielded a trifle over 500 skins. It would suggest, at least, that the young fish in pond 1 had reduced the numbers of nymphs by eating them, since they were of just the size to eat them freely.

The same fact is even more markedly shown in the case of the *Anax* nymphs; a few were found in all of the ponds, but when pond 4, containing only adult buffalofish was drawn 200 nymphs were obtained and after the pond was refilled 100 more transformed and left their skins around the margin of the pond. Such disparity in numbers could hardly be due to a discriminating choice on the part of the adults as to the pond in which they laid their eggs.

EVIDENCE FROM FEEDING NYMPHS ARTIFICIALLY TO FISH.—Best of all, the eating of nymphs by adult fish has been demonstrated by feeding the nymphs directly to them. Pond 6 is the smallest of all the ponds, but it contains the largest number of

adult fish, which have been taken out of the other ponds to prevent them from eating the young fish. They get hungry in this small pond and have to be fed at times. Among the foods given to them have been dragonfly nymphs, *Anax junius* and *L. luctuosa*, obtained from other ponds when the water was drawn from them. The fish in pond 6 always eat these with avidity, consuming all that are thrown to them, sometimes several hundreds.

This fact carries with it several suggestions as to the methods of dealing with these nymphs. Whenever a pond is drained, as many of the nymphs as possible should be saved for further use. If the water is lowered gradually, the nymphs, like the fish, will follow it down to the last pool, from which they can be easily removed with a dip net. They can then be used to restock the pond from which they came, after it is filled again, or they can be fed to the fish in other ponds.

Atkins in a discussion of Foods for Young Salmonoid Fishes (1908) said: "Any departure, therefore, from a live-food regimen must be regarded as having the presumption against its entire stability" (p. 841); and, again quoting from the Allgemeine Fischerei Zeitung, "for breeding fishes under all circumstances live, natural food is the most suitable" (p. 841).

Here is a live-natural food that can often be obtained in large quantities and of various sizes suited to the different growths of fish, and methods of stocking a pond with this kind of food will be discussed later (p. 234).

ODONATE IMAGOS AS FISH FOOD.

The only time that a fish gets a chance to catch a dragonfly imago is during ovipositing. The *Argia* females that back down beneath the surface of the water to deposit their eggs must face the danger of being snapped up by some hungry fish, and many of them are probably caught at such times. (See p. 257.) The same will be true of other damselfly species, since most of them alight on something at the surface, and at least thrust their abdomen into the water while ovipositing.

Both bass and sunfish jump eagerly after ovipositing dragonflies, but, like William-son, the present author has never seen a fish actually catch one of them. However, on opening the stomachs of bass from pond 6 that had been killed for experimental purposes dragonfly imagos were found in more than half of them, showing that at times they are successful in their efforts. Several times the author caught dragonflies in the net, crippled their wings so that they could not fly, and threw them on the surface of pond 6. In almost every instance they were seized and swallowed as soon as they struck the water, but two or three that failed to wiggle after hitting the water were left untouched. These fish would not snap at dead food of any sort, and they came up to these dragonflies until their nose almost touched the insect and waited patiently for some movement indicating life. If the dragonfly wiggled ever so little it was swallowed instantly, but if it remained motionless it was left untouched.

Tillyard (1917, p. 330) has the following record: "A 2-pound trout which I caught on the Macquarie River in Tasmania had in its stomach the undigested heads of 35 dragonflies, 28 belonging to the rather rare species *Procordulia jacksonensis*."

In the record of fish food given to the author by Dr. Muttkowski are two instances of fish eating imago damselflies. (See table, p. 227.) The stomach of a black bullhead,

Ameiurus meias, contained 6 *Enallagma hageni* imagos, and the stomach of a largemouth black bass contained 22 *Enallagma antennatum* imagos.

In a record made by Mr. Schradieck of the food of the largemouth black bass in ponds 2 and 3 D, a fish 48 mm. in length had for its stomach contents 95 per cent damselfly imagos and 5 per cent Chironomid larvæ. Another fish, 82 mm. long, contained nothing except a few damselfly imagos; a third, 65 mm. long, contained 50 per cent damselfly imagos and 20 per cent odonate eggs.

H. L. Canfield, superintendent of fish culture at the Fairport station, told the author that he had fed *Anax* imagos to largemouth black bass at Homer, Minn. The fish seized them avariciously and apparently swallowed them, but in a moment or two spit them out again. Perhaps the *Anax* was too large a mouthful for them, for the bass at Fairport certainly swallowed imagos of *L. luctuosa*, *Erythemis*, *Plathemis*, and *Leucorrhinia* and kept them down.

STOCKING THE FISHPOND.

Having tried to show, it is hoped with some success, that dragonflies and damselflies and their nymphs are not only desirable additions to the fauna of fishponds but that they may even prove of considerable importance, there remains the problem of obtaining a sufficient number of the right kind with which to stock a pond. How can this best be accomplished? With reference to the dragonflies several methods may be suggested and briefly discussed. Embury stated in *The Farm Fishpond* (1915, p. 242) that after the pond has been completed and filled with water:

The aquatic plants should be the first organisms to be put into the pond * * * The forage animals should be collected next. As has been stated, until more is known about the propagation of aquatic insects it will be impossible to give definite and reliable directions for their introduction. Certain desirable forms will naturally be attracted to the pond for egg laying, and for the present this natural method of propagation is the only one to be depended on.

Of course dragonflies will be among the insects naturally attracted to the pond for egg laying, but it is desired that the pond be stocked at once and with the kinds most available for forage food. The author believes that, so far as the odonates are concerned, we already possess sufficient knowledge to enable us to take the initiative, and not only to introduce desirable species, but also to exercise considerable control over their subsequent abundance.

CHOICE OF DRAGONFLY SPECIES.—The species of dragonfly best suited to any particular fishpond is not by any means necessarily the one that has been tried successfully elsewhere. The condition of the pond and its environment will have as great an influence upon the dragonflies as upon the fish with which it is stocked. In general, a common local species of dragonfly will be far better than one imported from a distance. A visit to neighboring ponds and quiet streams and a careful comparison of their conditions and surroundings with those of the proposed fishpond will be the proper method of choosing the species. Find a place as close to the fishpond and as similar to it as possible, and use this as the source from whence to obtain the stock material.

In 1889 Dr. P. R. Uhler, at that time one of the best authorities upon the dragonflies, wrote the following to Dr. Robert H. Lamborn (1890, p. 12) in reference to the breeding of dragonflies for the purpose of killing off mosquitos:

As I have raised all the common forms of our Atlantic coastal-plain region, I know that the dragonfly larvæ can be reared in vast numbers. Of course, you know that each locality supports its own species,

and the forms which develop in the brackish drains and pools near tide, where they are covered twice each day by salt water, can not flourish in fresh water. Accordingly, for the littoral belt from Long Island to Beaufort, N. C., I would select *Diplax* (*Erythrodiplax*) *berenice*, *Libellula auripennis*, and *Mezothemis* (*Pachydiplax*) *longipennis*. For the region next inland from this multitudes of common species could be had, such as *Anax junius*, *Æschna* (*Epiæschna*) *heros*, *Libellula pulchella*, *L. luctuosa*, *L. semifasciata*, *Plathemis trimaculata* (*lydia*), and most of the species of *Diplax* (*Sympetrum*). On the clear streams which rush down from the hills *Cordulia*, *Epitheca* (*Epicordulia*), and *Gomphus* prevail.

The above statement is just as good to-day as when it was written, only we must extend the area west of the Allegheny Mountains to cover the entire breadth of North America, and we must include damselflies as well as dragonflies. For the region east of the Alleghenies good damselflies would be *Lestes rectangularis*, *Ischnura verticalis*, *I. posita*, *Enallagma civile*, *E. hageni*, and *Anomalagrion hastatum*.

For the Mississippi Valley some of the desirable odonate species would be *Anax junius*, *Æschna constricta*, *Epicordulia princeps*, *Tramea lacerata*, *Libellula luctuosa*, *L. pulchella*, *Erythemis simplicicollis*, and *Plathemis lydia*, and local species of *Argia*, *Ischnura*, *Enallagma*, and *Lestes*.

West of the Rocky Mountains, *Anax*, *Erythemis*, *Tramea* and *Plathemis* would still remain, the species of *Æschna* and *Libellula* and of the four genera of damselflies could simply be changed to suit the locality, and *Sympetrum* could be added.

High up among the mountains *Anax* and *Sympetrum*, *Libellula quadrimaculata*, and *Leucorrhinia glacialis*, with local species of *Enallagma* and *Lestes*, would be most suitable.

It will appear at once that certain of the desirable forms, such as *Anax*, *L. pulchella*, *P. lydia*, and the damselfly genera *Argia*, *Enallagma*, and *Lestes* are very cosmopolitan, and their wide distribution increases by so much the chance that they will succeed wherever they may be introduced. They constitute, therefore, the very best stock material available, but still demand certain conditions if they are to be reared successfully. For example, the *Anax* female inserts her eggs into the tissue of the stems of water plants, and hence cat-tails, arrowhead, rushes, or some such water plant must be provided if this dragonfly is to breed in any numbers. On the other hand, *Erythemis* takes most kindly to floating blanket algæ; the damselflies insert their eggs in the stems of all kinds of water plants, occasionally above the surface (*Lestes*, etc.), though usually below it, the female sometimes descending several inches beneath the water for ovipositing.

The dragonfly genus *Epicordulia* deposits its eggs in long ropes of jelly coiled about the stem of some convenient water plant, while the great majority of the *Libellulids* deposit their eggs anywhere in clear water by hovering over the surface and repeatedly striking the water with the tip of the abdomen. In the latter case the eggs sink to the bottom separately and are fastened by the jelly that surrounds them to anything they may come in contact with. Hence for these different odonates the fishpond must contain water plants, with stems both above and below the surface, floating algæ, and plenty of open spaces.

PREPARATION OF THE POND.—No special preparation is required, because when a pond is suitably prepared for fish it will contain the requirements just enumerated and will be ready also for the dragonflies. While the condition of the embankments around the pond can not affect the fish or the nymphs in the water, it can and does exert an important influence on the odonate imagos. A total absence of trees, shrubs, bushes, and

weeds, with close-cut turf extending to the water's edge, may add to the sightliness of the pond, but it will operate against the odonate fauna. The larger vegetation is not necessary; an area covered with tall weeds and grass somewhere around the margin of the pond will prove amply sufficient.

If the breeding of fish and the rearing of forage for their consumption is confined to a single pond, of course that will be the place to stock with odonate eggs or nymphs. With proper care such combined breeding may be carried on successfully in the same pond, as is done at Fairport. "If not overstocked, the average pond may be managed so that it will furnish all the live food necessary for the adult fish." (Johnson and Stapleton, 1915, p. 19.)

In the last few years the forage problem in connection with fish culture has been receiving much more attention here in the United States. Embury (1915, p. 233) noted that "The propagation of minute organisms in great numbers as food for young fishes has been accomplished by the Chinese and the Japanese and more recently by the Germans," and he recommended small forage ponds in connection with the larger fish pond (p. 235):

There is good reason for believing that the supply of aquatic insects can be materially increased by building a few small breeding ponds along the margin of the main pond and excluding all fishes therefrom. Certain insects will naturally deposit their eggs in both breeding and main ponds. There are no very destructive insects in the former; hence there are sure to emerge a goodly number of adults, which, in turn, will continue year after year to repopulate the small ponds, as well as the main pond.

Needham and Lloyd have advocated the same idea in *The Life of Inland Waters* (1916). In figure 242, on page 408, they present a diagram illustrating conditions advisable for intensive fish raising on an 80-acre tract of wet upland traversed by a trout stream. The noticeable thing about it is the large area, 40 acres of ponds, to be placed under control for the production of fish forage.

Until experiments have been tried out in a practical way for some length of time, it will be impossible to decide definitely how much breeding area is necessary or advisable in order to produce the amount of food forage requisite for a given number of fish. Meanwhile, if forage breeding is to be attempted, the place to put the odonate eggs and nymphs will be with the other fish food in the breeding ponds, as well as in the main fishpond. Once well started in both places they will thereafter propagate themselves, as Embury has stated.

SECURING THE STOCK MATERIAL.—The method of securing the necessary odonate eggs or nymphs for stocking the pond will vary with the time of year. If the fishpond is to be started in the spring or fall, the best odonate material to put in it will be the nymphs. These may be collected from the nearest pond or from the still water of a stream or river. Some nymphs inhabit running water or places where there is a perceptible current, but such species are not suited for pond life.

An old ditch well choked with algæ and water plants, and in which the water stands throughout the year, is an admirable source whence to obtain the nymphs. There are two good methods of collecting them, and it would be well to use both. If there is much loose algæ and débris over the bottom of the ditch, the best implement to use is the common garden rake, as advised by Needham (1899). The collector can stand on the shore and rake the algæ and weeds out of the water onto the ground in front of him. As the water drains off the nymphs will make active efforts to get back, and are thus easily found and secured.

If there is more mud than water plants, the best implement is a sieve net like the one recommended by Needham and shown in figure 37a. With this the mud and silt can be drawn ashore and there sifted out, the mud escaping while the nymphs are retained. Much of the material pulled in by the rake can also be advantageously put through the sieve. Needham's sieve net had a framework of steel rods, sides of galvanized iron, and a bottom of galvanized-wire screen. If something of this sort can not be readily obtained or manufactured, the following may be substituted: Bend a piece of large and stiff wire 3 feet long into the shape of a stirrup, the ends coming together at the center of the curved side. Weld the ends together and insert them with a ferrule into a stout handle 6 or 7 feet long. Make a bag out of bobbinet and fasten its mouth securely to the wire stirrup. The mud will sift through this net as well as through the wire screen, but of course the net can be torn easily. Armed with such a net and a rake, a boy can easily secure several hundred nymphs in a few hours. Needham records that he once collected enough nymphs of *Gomphus desertus* to fill a quart fruit jar from Six Mile Creek near Ithaca, N. Y., in an hour's time (Needham and Betten, 1901, p. 453). The only objection to this method of stocking a fishpond is the fact that no one but a scientific expert can distinguish between the different nymphs obtained. They must all be put into the pond together, good, bad, and indifferent; but there are likely to be plenty of the desirable species among them, and the rest can be safely ignored.

In the summer the pond can be stocked much more intelligently by obtaining the eggs of desirable species and hatching them. In the case of the dragonflies this can not be done by capturing the adults and breeding them artificially or in captivity, as is the unanimous testimony of all who have made the attempt.

A. C. Weeks, at that time secretary of the Brooklyn Entomological Society, made in 1889 an extensive experiment with *Libellula pulchella* and *Diplax (Sympetrum) rubicundulum* by catching the full-grown adults and confining them in the upper story of his dwelling house, which had been cleared of its furniture and arranged with a view to attract the dragonflies. But they would neither feed nor mate nor oviposit. The same experiment was tried later on *Anax junius* with equally negative results (Lamborn, 1890, p. 78). This was in a crowded city, however, and it might well be supposed that the insects were distracted by the surroundings.

FIG. 37a.—Sieve net recommended by Needham.

To test this, the present author experimented with a breeding cage large enough to allow great freedom of motion under conditions that were ideally natural, except for the single element of restraint. This one thing proved a fatal stumbling block, and, although both sexes of *Libellula luctuosa*, *L. pulchella*, *Erythemis simplicicollis*, *Leucorrhinia intacta*, and *Anax junius* were placed in the cage at different times, they were all immediately imbued with an overwhelming desire to escape. The cage was open at the bottom and was put down over a section of pond 3D containing cat-tails, reeds, algæ, and other water plants,

everything being left undisturbed. The upper portion of the cage was covered with chicken wire whose meshes were large enough to allow free access to the insects upon which the dragonflies usually fed. But as soon as the dragonflies found they were shut in, they would neither alight on the water plants, nor touch the insects that flew through the cage, nor mate, nor oviposit. Instead, they spent their time beating their wings against the sides and top of the cage until they became exhausted and fell into the water, or were picked out through the meshes of the wire by red-winged blackbirds, which were attracted by the beating of the insects' wings.

While the dragonflies are thus averse to breeding in confinement the damselflies take kindly to it, and Balfour-Browne (1909) succeeded in obtaining a large number of eggs from specimens of two English species, *Agrion pulchellum* and *Ischnura elegans*, which he kept for a week in a cage. He fed the captives on flies and other insects captured in a sweeping net and placed alive in the cage. The eggs hatched into nymphs in about three weeks, so that he was able to determine definitely the period of incubation for these species. This method was not tried on our American damselflies, but there is little doubt that it would work as well with them as with the English species. It was found absolutely necessary to keep the cage in the bright sunlight, because in the shade and on dull days the damselflies became torpid and simply clung to the sides of the cage. It is evident, therefore, that nothing can be accomplished by endeavoring to breed dragonflies in this manner; their natural habits and instincts are against it. And although the damselflies are more susceptible to captivity, this artificial breeding is a rather laborious process for any except the scientific expert who wishes to absolutely isolate a given species.

Fortunately there are other ways of accomplishing the desired results, and these prove to be highly successful. As already stated, many female dragonflies deposit their eggs loosely in the water or upon the floating algæ by hovering close to the surface and touching the water at intervals with the tip of the abdomen. If such a female be caught as she comes down to the pond to lay her eggs or while she is ovipositing and one pair of wings be folded together over the back and held between the thumb and forefinger, leaving the other pair free, she will continue to lay eggs in large numbers if the tip of her abdomen be dipped in water in a convenient tumbler, basin, or small jar. Tillyard (1917, p. 358) claimed that it was "necessary to have the water dirty, with mud, sand, or small pieces of débris for the eggs to fall upon; otherwise the eggs will simply all stick together and quickly go moldy." While agreeing that the presence of dirt is a positive advantage in the way that Tillyard suggests, the present author can not agree that it is always "necessary." All the experiments hereinafter recorded were made in clean water, and while the eggs usually did stick together, they did not mold except in a single instance, and even then practically all of them hatched. However, if the nymphs are to be used simply to stock the fishpond, some dirt and débris are desirable, since then the conditions are more nearly natural. Similarly, when the male accompanies the female during ovipositing, on being captured the female will deposit her eggs freely in the tumbler or basin; this applies to such species as *Tramea* and *Celithemis*.

Needham recorded a female *Gomphus graslinellus* captured while ovipositing, from which he "obtained in a tumbler of water an immense number of eggs" (Needham and Hart, 1901, p. 69). Also a female *Gomphus externus*, "captured in the weeds

at the bank (Illinois River) deposited for me in a watch glass of water in a few minutes' time about 5,200 eggs. This number is an estimate from a partial count" (p. 75).

The present author stood in one spot on the bank of pond 4D and captured within half an hour six *L. luctuosa* females as they came to the pond to oviposit and from them fully 4,000 eggs were obtained.

For stocking purposes the eggs of the different species do not need to be kept separate. On another afternoon females of *L. luctuosa*, *Erythemis*, and *Leucorrhinia* were allowed to deposit their eggs in the same tumbler and all hatched out together without apparent trouble.

Armed then with an insect net and a convenient receptacle, thousands of eggs can be easily obtained in a short time at any place where the dragonflies are ovipositing and only the eggs of desirable species need be taken. These eggs can then be carried to the pond and placed loosely upon the bottom or on the floating algæ, care being taken that they do not get buried in silt or mud, but remain on the surface; or they can be kept in the original receptacle until they hatch, and then the nymphs can be turned loose in the pond, not all in one place, but well distributed. The number of nymphs obtained in this way need only be limited by the patience of the collector.

If the eggs are allowed to hatch before being placed in the fishpond, care should be taken that they do not require a long transportation. Mrs. Aaron gave this warning: "The question of transporting the young larvæ from the breeding tanks to the mosquito-infested ponds is to be considered. Although they are tough and can stand jolting, only a few can be carried in one receptacle. Twenty put in one jar would be found to be an inextricable, kicking mass of cannibals after a mile's transportation" (Lamborn, 1890, p. 63). While perhaps transportation for a mile would produce this result, no difficulty has been experienced in carrying thousands of newly hatched nymphs from the laboratory to the fishponds, a distance of 500 yards.

Anax, *Æschna*, and the damselflies insert their eggs by means of an ovipositor into living or dead vegetable tissue either beneath the water or resting upon its surface. The females of these species can be watched while ovipositing and after they have finished the leaves or stems containing the eggs can be removed and transferred to the fishpond or they may be kept in water until they hatch. These females will not deposit eggs in a tumbler or basin, like those previously mentioned, but just as many can be secured by gathering the vegetation containing them.

Sufficient experience might enable one to distinguish between the eggs of different species, but ordinarily the vegetation must be transferred to the fishpond with all the eggs it may happen to contain. It is surprising, however, to find how often it proves that practically all the eggs in a single leaf or stem are those of one species.

Females of *Enallagma hageni* were observed inserting their eggs in the tissue of crex-grass leaves that had fallen into the water. Five of these leaves that contained fully 1,500 eggs were obtained, and these were cut into short lengths and kept in tumblers of water until the eggs hatched. Similarly, *Argia mæsta putrida* was observed descending a small water-soaked branch of willow near one of the wing dams in the Mississippi River in order to deposit its eggs, the female dragging the male down with her during the process. On pulling the branch out of the water a dozen couples of this damselfly flew off from it at varying depths, and the softened wood was found to be literally filled with eggs for a distance of 2 feet. A partial count and an estimate

of the remainder indicated at least 2,000 eggs in this one branch. It also was cut into short lengths, and these were kept in tumblers of water until they hatched.

The damselflies will breed and deposit their eggs in captivity as already mentioned. (See p. 236.)

REARING THE NYMPHS.—The best method of caring for the nymphs is to place them in the fishpond as soon as they are hatched. Conditions might arise, however, which would render it desirable to rear the nymphs to a certain size before using them for fish food. And this can be easily accomplished by supplying them with requisite food.

The first lot (about 350) of nymphs of *L. luctuosa* that were hatched in the laboratory were kept throughout the entire season in a small aquarium. They were fed every two or three days with ordinary tow obtained from the river or one of the ponds. They seemed particularly fond of the minute crustacea and devoured large numbers of copepods, daphnids, and cladocerans.

Balfour-Browne fed his newly hatched nymphs upon *Paramœcium*, which he obtained by making an infusion of horse dung in water. One jar of this infusion produced for five or six months enough *Paramœcium* to supply all his nymphs. As the nymphs grew in size the *Paramœcia* were replaced by *Daphnids*, and in this way he carried the nymphs of *Agriom pulchellum* and *Ischnura elegans* through from the egg to the imago stage.

Warren placed individual nymphs in separate petri dishes as soon as they were hatched and fed them on newly hatched mosquito larvæ until the third or fourth molt. They were then transferred to larger dishes and fed on larger mosquito larvæ. In this way he carried four nymphs of *Pantala flavescens* successfully through their entire life history from the egg to the imago. Two of them were fed daily with large amounts of food, and they transformed into the imago stage in about two months. The other two were given much less food, and in consequence they required over three months for their development.

EXPERIMENTS IN HATCHING ODONATE EGGS.

There are but few records of the length of time spent by American dragonflies and damselflies in the egg state. Wm. Beutenmuller (Lamborn, 1890, p. 125) stated that *Libellula auripennis* and *L. pulchella* deposit 25 to 40 eggs each time the female dips her abdomen beneath the water. He added on the next page that eggs laid by *L. pulchella* July 23 hatched August 31, making the period of incubation 39 days. In *L. auripennis* the interval was only 8 days, in *Plathemis lydia* 10 days, and in *Diplax* (*Erythrodiplax*) *berenice* and *Sympetrum rubicundulum* 10 days.

Among the damselflies Needham (1903, p. 229) said of *Lestes* in New York State: "The eggs, deposited well above the water, develop normally from the first, and in the course of two or three weeks attain a condition which is apparently almost that in which they will hatch. They then estivate through the remainder of the summer and early autumn till the pools are refilled, and the stem and leaves, now dead, fall into the water." Eggs laid in July and gathered in October hatched within a week in his laboratory. But of course such a record would not apply to other genera and species where there is no estivation.

In view of the meagerness of American records, the following experiments at Fairport are recorded as a partial guide for the fish breeder, and there are also included descriptions and figures of the eggs and newly hatched nymphs to help in identification.

LIBELLULA LUCTUOSA.

The Egg.—The egg of this species is an almost perfect ellipse, 0.57 mm. long and 0.30 mm. wide. The neck is conical, as wide at the base as it is high, with a distinct basal segment and a divided tip. There is also a short process at the posterior end of the egg; the yolk granules are comparatively large and distinct. Eggs laid on July 12 began to hatch July 22, and the hatching was entirely completed by July 30. Several lots of eggs from this species were hatched during the summer, and the period of incubation was practically the same for each lot.

The Nymph.—The newly molted nymph is just 1 mm. in length, exclusive of the antennæ; the head and abdomen are the same width, 0.38 mm.; the head is one-fifth wider than long; the hind legs are about the same length as the body, the first two pairs are proportionally shorter; the antennæ are a little shorter than the head and rather stout. The head is a deep, sulphur yellow, the eyes are dark orange, with black spots, the digestive canal is light yellow, and the legs are banded with gray and white.

As soon as the pronymph has molted and becomes a true nymph, the latter swims up to the surface of the water, accomplishing this locomotion by means of the legs, without any help from water ejection at the rectum. Having reached the surface the nymph is able to hold itself there by clinging to the surface film with its claws. It remains there for a long time almost motionless, so that, if the tumbler be examined at any time, the undersurface of the water film will be found covered with nymphs as

FIGS. 38 to 40.—Development of *Libellula luctuosa*: 38, egg; 39, mask of newly hatched nymph; 40, newly hatched nymph.

close together as they can stick. It often happens that one coming up from the bottom finds another already clinging to the film when it reaches the latter. It then fastens to the other nymph instead of to the film, and the combined weight of the two nymphs is more than the film can sustain, so that they sink slowly back to the bottom. Under natural conditions such a seeking of the surface brings the nymphs to the floating algæ or other surface vegetation, which is evidently the location they seek for safety and food. It is also possible that the young nymph, like the teneral imago, needs the stronger sunlight for hardening its chitin integument and maturing its color pattern.

The Mask.—Mentum twice as wide as long; distal margin two times the length of the proximal; four setæ on the inner surface along either side near the lateral margin; three mental setæ on each side of the center in a straight line; a toothed prominence on the midline behind the distal margin. Lateral lobes one-half longer than wide; two marginal setæ on the outer border near the base; two laminate setæ on the blade of the lobe near the inner margin; raptorial seta just reaching the tip of the movable hook, the latter long and slender; distal border of lobe with five teeth near the outer corner, the second tooth the longest.

LIBELLULA PULCHELLA.

A pair was taken mating on the north shore of pond 4D, and the female deposited 1,500 eggs. These eggs were laid July 12; they began hatching July 22, and the hatching was completed by July 28.

The Egg.—Curiously enough, the egg of this large species is smaller than that of the little *Leucorhina*. It is ellipsoidal in form, measuring 0.48 mm. in length and 0.29 mm. in width. The neck is conical, the base nearly twice the height and without any visible segment, but the tip is divided; there is no process at the posterior end of the egg. The yolk granules are small and indistinct.

The Nymph.—This nymph is also just 1 mm. long; the head is one-third wider than long, one-fourth the entire length; the abdomen is as wide as the head, with two rows of stout bristles on the dorsal surface along either lateral margin; the latero-posterior appendages are very hairy. The antennæ are long and slender, black at the tips, with a single black band on the basal joint; the legs have black and white bands, as shown in the figure; the eyes are straw yellow, with two larger black dots and concentric rows of smaller ones; the head between the eyes and whole body is a pale yellow, deepening into orange over the gizzard and rectum; there are whitened areas along the sides of the abdomen at the posterior margins of segments 4 to 7, with darker areas anterior to them. The base of the antennæ is whitish, with a black distal band; first joint proximally gray, distally whitish; second joint nearly all dark gray, with a narrow, white distal band; third joint dark gray, except the very tip, which is

FIGS. 41 to 43.—Development of *Libellula pulchella*: 41, egg; 42, mask of newly hatched nymph; 43, newly hatched nymph.

whitish. The whole body is transparent and pale white, a little yellowish on the head and at the posterior end of the abdomen; the circulatory system is deeper white.

The Mask.—Mentum three-quarters wider than long, distal margin two and a half times the length of the proximal; four setæ on the inner surface, near the lateral margin, one proximal to them on the margin itself; three mental setæ on either side in nearly a straight line; two tiny spines at the center, near the distal margin. Lateral lobes one-fourth longer than wide; two setæ on the outer margin, near the base; two setæ on each blade; raptorial seta longer than the movable hook, the latter long and narrow; distal margin with six teeth near the outer border, the first two the longest.

HYBRID BETWEEN *LIBELLULA PULCHELLA* AND *L. LUCTUOSA*.

A male *L. pulchella* and a female *L. luctuosa* were captured mating on the shore of pond 4D July 9, 1917. The female deposited about 100 eggs in a tumbler of water, and these subsequently hatched on July 20.

The Nymph.—This nymph is unlike those of either *pulchella* or *luctuosa*, especially in its markings. The head is one-third wider than long, and the same width as the abdomen, grayish yellow; the eyes are sulphur yellow, with small black retinal dots; the rest of the body is pale yellowish, but without much color and quite transparent, except along the lateral margins of the abdomen, where each segment is dark gray anteriorly and white posteriorly. The whole body is quite hairy, with a row of stout

bristles along the dorsal surface of the abdomen, between the respiratory system and the lateral margin on either side. The antennæ are relatively large; base white with a pale grayish distal band; first joint white through the center, pale grayish at either end; second joint with proximal three-fifths dark and distal two-fifths white; third joint dark, tipped with white. These nymphs did not ascend to the surface of the water, like those of *luctuosa*, but stayed down near the bottom of the tumbler.

The Mask.—Mentum twice as wide as long; the distal border two and a half times the proximal; the lateral margins curved; three setæ on either side, near the lateral margin; three mental setæ in a straight line; a slight lobed prominence behind the center of the distal margin, without spines.

Lateral lobes one-third longer than wide; two setæ on the outer border near the base; two on each blade; raptorial seta considerably longer than the movable hook, the latter short and slender; distal margin with four teeth near the outer edge, the first two the longest.

44

0.5 mm.

FIGS. 44 and 45.—Hybrid from male *Libellula pulchella* and female *Libellula luctuosa*: 44, mask of newly hatched hybrid nymph; 45, newly hatched hybrid nymph.

ERYTHEMIS SIMPLICICOLLIS.

The first females were seen laying in pond 4D on July 12, 1917. Eggs laid July 13 hatched July 23.

The Egg.—The egg of this species is an elongated ellipse, with rather pointed ends, and is a little more than twice as long as wide, the respective diameters being 0.60 mm. and 0.27 mm. The neck has a base narrower than its height, divided at the tip; there is a small process on the posterior end of the egg; the yolk granules are minute.

The Nymph.—This nymph has the most pigment of any of those examined, and is banded brown and yellowish white; the eyes are light orange yellow with comparatively large black spots; the sides of the head are brown shading into light yellow on the median line; each thorax segment is brown

46

47

48

0.5 mm.

FIGS. 46 to 48.—Development of *Erythemis simplicicollis*: 46, egg; 47, mask of newly hatched nymph; 48, newly hatched nymph.

bordered with dark yellow along the lateral margins and light yellow in the center, thus leaving a clear yellow longitudinal streak through the center of the body; the ninth and tenth segments are yellow; the legs are dark proximally, with a white band across the distal ends of the coxæ, femora, and tibiæ. The central yellow line of the head passes over the forehead and down between the antennæ onto the labrum. On the back of the head it is widened considerably and usually runs out into two rounded points on either side, with two small, brown spots, one on either side of the midline, at the level of the posterior points. Through the thorax it is narrow, then widens again on the first three or four abdomen

segments, and fades into small, yellow dots on the anterior margins of the fifth, sixth, and seventh, and sometimes the eighth, segment, disappearing entirely on the ninth, and often on the eighth segment. The dorsal appendages on the tenth segment are light brown at the base, yellow at the tip; the lateral and inferior appendages are dark brown. The base of the antennæ is yellow distally and proximally with a narrow, black band through the center; first joint dark, with a narrow, distal, white band; second joint with a broader, distal, white band; third joint entirely blackish brown.

The Mask.—Mentum with the width to the length as 5 to 3, distal margin two-thirds wider than the proximal; three lateral setæ, one marginal seta; three mental setæ in a straight line on either side of the center. Lateral lobe with its length to its width as 9 to 7; two marginal setæ on the outer border; two setæ on the blade of the lobe; raptorial seta just reaching the tip of the movable hook, the latter long and stout; distal margin crenate, without teeth.

LEUCORRHINIA INTACTA.

The sexes remain in union only a short time and usually alight on some convenient weed or bush near the water's edge, where they can be easily secured. When thus captured, the female is ready to lay as soon as taken from the net and will deposit 100 to 200 eggs, the first 50 or 75 coming in a mass stuck together, the others coming singly. Eggs laid July 18 hatched July 30.

The Egg.—This egg is more nearly spherical than that of *Libellula luctuosa*, and has diameters of 0.60 mm. and 0.40 mm., respectively. The neck is wider at the base than it is high, and there is a distinct segmentation at about the center; the tip is not divided, and there is no process on the posterior end of egg. The yolk granules are comparatively large, and the jelly envelope is ragged around the surface of the egg and not smooth, as in other species.

The Nymph.—Although the imago of *Leucorrhinia* is much smaller than that of *Libellula luctuosa* the

FIGS. 49 to 51.—Development of *Leucorrhinia intacta*: 49, egg; 50, mask of newly hatched nymph; 51, newly hatched nymph.

nymph is considerably larger, measuring 1.20 mm. in length; the head is one-third wider than the abdomen; the front legs are the same length as the body, the others proportionally longer, and all three pairs slender. Both the body and the legs are quite transparent and pale orange yellow in color, the legs and antennæ transversely banded with gray and white, the eyes darker orange yellow, the black spots very small. The sides of the head and a wide transverse band across the anterior portion of each abdomen segment are whitish, the posterior margins of the segments are tinged with brown. The bases of the antennæ are whitish yellow proximally, with a narrow, gray, distal band; first joint entirely white, a little grayish through the center; second joint with a very narrow proximal band and a wider distal band white, grayish through the center; third joint entirely gray.

The Mask.—Mentum three times as wide as long; the distal margin twice the length of the proximal; no lateral setæ; two marginal setæ; three mental setæ on either side, not in line, but the proximal one nearest the midline; two stout spines at the center of the distal margin. Lateral lobes with length and width in the proportion of 13 to 9; two setæ on the outer margin on either side; two setæ on the blade of each lobe; raptorial seta reaching considerably beyond the tip of the movable hook, the latter long and narrow; three small teeth near the outer edge of the distal margin, the central tooth the largest, the rest of the margin smooth.

PLATHEMIS LYDIA.

The females of this species remain at some distance from the water, except at the time of ovipositing; one caught a quarter of a mile from the ponds deposited eggs freely on July 25, which began to hatch August 2, and were all hatched by August 9.

The Egg.—These eggs are elongate elliptical and rather pointed at both ends, just twice as long as wide, the two diameters being respectively 0.60 mm. and 0.30 mm. The neck is as wide at the base as it is high, with a distinct segmentation near the tip, the latter being undivided; there is no process on the posterior end of the egg.

The Nymph.—The general color of the nymph is yellowish white, with light-brown markings. On the center of the dorsal surface of the head is a longitudinal, club-shaped, brown area and on either side a broken semicircle; there is a large, irregular, brown spot in the center of the posterior thorax and anterior abdomen, and another smaller spot over the posterior end of the respiratory system. The eyes are dark brown, with black, retinal spots; the tracheal system is yellowish brown. The head is a trifle wider than long and not narrowed behind the eyes; the thorax is two-thirds as wide as the head; the

FIGS. 52 to 54.—Development of *Plathemis lydia*: 52, egg; 53, mask of newly hatched nymph; 54, newly hatched nymph.

abdomen the same width as the head, sharply pointed posteriorly, with strongly convex, lateral margins and no color markings except the two spots already noted. The base and basal joint of the antennæ are whitish; proximal end of second joint and the whole of the third joint light gray, distal part of second joint white. The legs are light gray and white; the tips of the posterior processes of the abdomen are dark brown; the terga of the thoracic segments are light gray.

The Mask.—Mentum twice as wide as long, with convex sides; distal margin two and a half times the proximal; one lateral seta near the base on each side and two marginal setæ; three mental setæ on either side of the center in a curve concave to the midline; two small spines at the center of the distal margin. Lateral lobes one-half longer than wide; two setæ on the outer border, none on the blade; raptorial seta just reaching the tip of the movable hook, the latter short and stout; distal margin with seven teeth reaching nearly the entire width, the third tooth the longest.

EPICORDULIA PRINCEPS.

The eggs of this species are laid in long, jelly-like strings, similar to those of *Tetragoneuria*. Some of these strings were obtained from the leaves of *Potamogeton illinoensis* in pond 3D on August 9, 1917; but, of course, there was no way to tell when they were laid; they began to hatch within a day or two.

The Egg.—This egg is the largest of any here described, being 0.72 mm. long and 0.40 mm. wide. The neck is a minute process of the same height and width, without segmentation, and there is no process on the posterior end of the egg.

The Nymph.—Like the egg from which it was hatched, the nymph is a little larger than any of the others here included, being 1.25 mm. long and 0.42 mm. in diameter. Its general color is white, the eyes and the center of the abdomen reddish brown, the respiratory system bright yellow. There are two comparatively large horns on the dorsal surface of the head at the posterior margin, with their tips turned back like hooks; that is, they are slightly "cultriform" (Needham). The inferior posterior appendages of the tenth abdomen segment are large and are turned over vertically at right angles to the body axis. The

FIGS. 55 to 57.—Development of *Epicordulia princeps*: 55, egg; 56, mask of newly hatched nymph; 57, newly hatched nymph.

antennæ are banded with black and white in sharp contrast; the base with a narrow, white, distal band; the basal half of the first joint black, the distal half white; the second joint the same, the third joint entirely white. The legs are transparent, with very little differentiation in color, the tips of the basal joint, the femur, and the tibia being somewhat whiter than the rest of the joint. The thorax is pale white, without any pigment; the abdomen is brownish red through the center over the intestine, with short, dark spots on the posterior margin at the outer edge of each segment, the rest white.

The Mask.—Mentum three-fifths wider than long, its sides slightly concave, the distal margin a little less than twice the proximal; one lateral seta, two marginal setæ on either side; three mental setæ on each half in a straight line, the distal one nearest the midline; four stout, sharp spines at the center of the distal margin. Lateral lobes about the same length and width; two setæ on the outer border, none on the blade of the lobe; raptorial seta reaching beyond the tip of the movable hook, the latter short and stout; distal margin with 10 teeth covering its entire width, the outer 5 much larger than the inner 5 and cultriform. Lateral seta on mentum often lacking as in figure 56.

ENALLAGMA HAGENI.

The eggs were laid in the leaves of crex grass; more than a thousand were obtained from five grass leaves July 26, 1917. These began to hatch in two weeks and continued hatching for 10 days, but, like the eggs of *Epicordulia*, there was no way to determine just when they were laid, so that the period of incubation is uncertain.

The Egg.—These eggs were in the form of an elongated ellipsoid, the long diameter four times the shorter one, the anterior end broadly and bluntly rounded, the posterior end pointed; neck short and broad and brown in color.

The Nymph.—The head is transversely elliptical in outline, the two diameters in the ratio of 8 to 5; there is a pair of setæ just inside of each eye on the dorsal surface, another pair close to the midline, just behind the anterior margin, and a single seta at the center of the margin itself. The thorax is considerably narrower, but almost twice as long as the head; the legs are long and stout, the posterior pair reaching somewhat beyond the center of the caudal gills. The abdomen is a little wider than the thorax anteriorly and does not narrow much in front of the seventh segment. The antennæ are long and stout, with a gray band at the base of each joint; caudal gills as long as the rest of the body and

cylindrical, covered with short and straight spines or setæ. All the leg joints, including the coxæ, are sparsely armed with setæ; and there is a row of setæ also along the dorsal surface of the abdomen close to the lateral margin. The color is a uniform, creamy white, except the three dark bands on the antennæ and a narrow band on each femur and tibia of the legs.

The Mask.—Mentum triangular, one-half wider than long; distal margin twice the length of the proximal; one mental seta on either side, one lateral seta at the base of each lobe, two marginal setæ; a row of nine small spines just behind the distal margin. Lateral lobes twice as long as wide, with one marginal seta and two raptorial setæ; movable hook long and stout; an accessory spine just outside the base of the distal raptorial seta.

FIGS. 58 to 60.—Development of *Enallagma hageni*: 58, egg; 59, mask of newly hatched nymph; 60, newly hatched nymph.

ENALLAGMA SIGNATUM.

These eggs were obtained from pond-lily leaves on July 28, 1917, and began to hatch 18 days later, the period of incubation being again unknown.

The Egg.—The eggs are considerably like those of *E. hageni*, but they were arranged very differently in the tissues of the leaf. Those of *hageni* were inserted without any definite order anywhere in the leaf; these were arranged in a semicircle on the underside of the leaf around some convenient hole or close to the margin. The female evidently thrust her abdomen down through the hole or down over the edge of the leaf and, reaching as far as she could, inserted the eggs into the leaf.

The Nymph.—The nymph is just 1 mm. long, exclusive of the caudal gills; head wider than long, the two diameters in the proportion of 7 to 5, the anterior and posterior margins both strongly convex; thorax shorter than the head and two-thirds as wide; abdomen the same width as the thorax and tapering gradually backward; caudal gills short and slender; legs also comparatively short and slender, the posterior pair not reaching the center of the caudal gills; claws short and stout. The antennæ are long and stout; the eyes at the center of the lateral margins project strongly. There are no setæ on the dorsal surface of the head, on the thorax, or on the coxæ of the legs; there is a single seta on the center of each abdominal segment near the lateral margin on each side; and the setæ on the legs and

caudal gills are small and scattering. The ground color is white, covered with a complicated pattern of light russet brown; last four abdominal segments, legs, and caudal gills nearly all brown, with narrow stripes of white; respiratory tracheæ bright golden yellow.

The Mask.—Mentum one-half wider than long, with slightly convex sides; distal margin nearly three times the proximal; no lateral setæ, one marginal seta near the distal end, one mental seta; distal margin smooth. Lateral lobe three-fourths longer than wide; no setæ on the outer margin; raptorial seta just reaching the tip of the movable hook, the latter long and stout; a minute accessory spine outside the base of each raptorial seta; distal margin deeply toothed, inner tooth cultriform.

FIGS. 61 to 63.—Development of *Enallagma signatum*: 61, egg; 62, mask of newly hatched nymph; 63, newly hatched nymph.

GENERAL CONCLUSIONS.

1. Odonate nymphs feed upon small mollusks, insect larvæ (including smaller nymphs), pupæ and adults, entomostraca and larger crustacea, and algæ. Some of their food, such as Chironomid larvæ, mayfly larvæ, entomostraca, etc., is the same as that of young fish, but they also eat the larvæ or adults of many animals that are directly harmful to small fishes, such as diving beetles, water boatmen, crayfish, and Cypris.

2. A few of the largest species may sometimes eat a small fish under natural conditions, but this is apparently due to stress of hunger and the lack of other food. Warren has proved (p. 206) once for all that the diet of a nymph in captivity furnishes no criterion whatever as to its natural food. Careful observations under natural conditions show that even an *Anax* nymph need not be regarded as a menace to fish culture, but that it may become actually beneficial.

3. Odonate nymphs furnish one of the very best foods for fishes; the small species and the young of the larger species are freely eaten by the fingerlings of practically all

our fresh-water game and food fish, while the larger species when fully grown are just as toothsome to adult fish. The large percentage of nymphs in the food of fishes from the Fairport ponds (table, p. 228) effectively answers the objection that odonates rob the fishes of a part of their food.

4. If the *Anax*, *Æschna*, and other large nymphs are preying upon the fish in any given fishpond, this should be interpreted by the fish-culturist as evidence that the supply of food in that pond is running low. His efforts can better be directed toward replenishing the food supply than toward getting rid of the nymphs. On the other hand, if they do not disturb the young fish the food supply is adequate, and they themselves will contribute to it in due time. They thus furnish a convenient means of testing the food supply, since it is an easy matter to examine their stomachs and find out what they are eating.

5. Odonate imagos feed exclusively upon adult insects; their prey, like that of the nymphs, sometimes includes insects that are beneficial, such as other odonates, honeybees, and hymenopterous parasites; but the bulk of their food is made up of insects that are either positively injurious or negatively of no practical importance. Among these may be mentioned gall flies, tsetse flies, plant lice, leaf hoppers, ants, and all kinds of small moths and butterflies. They also confer an inestimable benefit upon mankind by waging an incessant warfare upon house flies, mosquitoes, black flies, and gnats. This one benefit alone far outweighs any harm they may do to the fish and should earn for them a cordial welcome to every fishpond, present and future.

6. Odonate imagos, like the nymphs, furnish good food for adult fishes, as is evidenced by finding them in the stomachs of various fishes taken under natural conditions and from the fishponds. It has also been demonstrated by feeding live dragonfly imagos to game fish in fishponds.

7. Both nymphs and imagos are important factors in establishing a natural equilibrium in the fauna and flora of the fishpond and its immediate environment. Other things being equal, such an equilibrium contributes materially to success in fish culture, and it can not be obtained without the presence of the nymphs and imagos. Incidentally, if properly chosen, the imagos will add greatly to the attractiveness of the fishpond and its surroundings.

8. Hence care should be taken that the pond is supplied with odonates, as well as with fish; after the original stocking they can be left to take care of themselves. For stocking purposes use common local species of dragonflies and damselflies; *Anax*, *L. pulchella*, *Plathemis*, and the damselfly genera, *Argia*, *Enallagma*, and *Lestes* are so cosmopolitan that they will make good stock almost anywhere in the United States. Here again the odonates constitute a sort of visible pulse of the life of the pond; so long as they remain vigorous and healthy the pond life is probably moving along smoothly.

9. Small breeding ponds along the margin of the fishpond from which the fish are excluded will materially increase the supply of all aquatic insects, including the odonates. If these are started in the spring or fall, the best odonate material to put into them will be the nymphs. If they are started in the summer, they can be stocked more intelligently by obtaining the eggs of desirable odonates and hatching them.

10. Dragonflies will not feed, nor mate, nor lay their eggs in captivity, but damselflies are more susceptible, and eggs could probably be obtained from any common species. If a female dragonfly be caught while ovipositing and held by one pair of wings, leaving

the other pair free, she will deposit her eggs freely in any convenient receptacle if the tip of her abdomen be dipped in water. Thousands of eggs can be obtained in this way in a short time and kept until they hatch, or they can be placed at once in the breeding pond. The eggs of *Anax*, *Æschna*, and the damselflies can be secured by watching the females while ovipositing and then transferring the leaves or stems containing the eggs to the breeding pond.

11. If there is any necessity for rearing the nymphs before placing them in the breeding pond, they can be fed on *Paramœcium* obtained by making an infusion of manure in water, or on ordinary tow, especially the small crustacea, which they will devour in large numbers. Warren carried dragonfly nymphs successfully through their entire life history by feeding them with mosquito larvæ and pupæ.

12. Whenever a fishpond is drained, the nymphs in it should be saved; they make excellent food for fish in other ponds and can be fed to them or can be used to restock the drained pond when it is filled again.

13. Dragonfly eggs hatch in 8 to 12 days; the nymph is short and thickset, the thorax and abdomen about as wide as the head, the legs long and slender, the antennæ short and fairly stout, the eyes large, with black retinal spots surrounded by rings of colored pigment. The mentum of the mask is much wider than long, with three mental setæ on either side and a varying number of lateral and marginal setæ. The lateral lobes have a terminal, movable hook, one raptorial seta, marginal setæ on the outer margin, and usually two small setæ on the blade of the lobe. The respiratory tracheæ are convoluted in the thorax and posterior abdomen and comparatively straight between the two, and are highly colored.

14. Damselfly eggs hatch in about three weeks; the nymph is long and slender, the thorax and abdomen considerably narrower than the head; the legs relatively short and slender; the antennæ stout and long; the eyes small with few retinal spots, but each surrounded by colored pigment. The mentum is somewhat wider than long, with a single mental seta on either side and one or two lateral and marginal setæ. The lateral lobes have a stout, terminal, movable hook and one raptorial seta. The respiratory tracheæ are highly colored and are convoluted in the thorax and anterior abdomen and are comparatively straight posteriorly. The caudal gills are cylindrical, very long and slender, and taper regularly from the base to the tip.

ANNOTATED LIST OF DRAGONFLIES AND DAMSELFLIES OBTAINED NEAR FAIRPORT, IOWA.

THE GENUS *GOMPHUS*.—The nymphs of this genus live in the mud or sand on the bottom of the Mississippi and its tributaries, and thus far none of them has been found in any of the fishponds. There is no reason, however, why pond species like *graslinellus* and *submedianus* should not be found there, as they probably will be in the future. They burrow into the mud and débris, leaving only the tip of the abdomen exposed for respiration, and lie in wait for their prey. They are both rapacious and omnivorous and will eat anything and everything small enough to be caught and held by their powerful jaws. They may be recognized by their thick and hairy, four-jointed antennæ, which are usually inclined inward toward each other, by a flat labium simply folded beneath the chin, with strong grasping arms like mandibles and not extending up over the face in a

mask, and by the absence of dorsal spines along the midline of the abdomen. Their legs are stout and adapted for burrowing, the two front pairs directed forward and the posterior pair directed backward, and all three pairs armed at the tips with strong burrowing claws. Their color is similar to that of the *débris* in which they live, and the furry hairs covering their bodies and legs quickly gather a coating of mud which still further obscures them. When ready to transform they crawl up on some board surface like a floating barge, the side of a boat, the bark of a tree, or more commonly a flat mud surface close to the water. In suitable locations the mud will be found thickly incrustated with their nymph skins, and it is not uncommon to find two or more skins one on the top of another, those coming out last crawling up on the others.

The imagoes scatter quickly as soon as they are able to fly and often entirely disappear from the vicinity where they leave their nymph skins. In general, the females retire inland, while the males remain along the water front.

Their habits are very different from those of the *Libellulidæ*, the imagoes usually alighting flat on the ground or close to it, or on the surface of a log, and squatting or flattening the body down until the wings almost touch the ground, all ready to spring upon their prey. They almost never alight on twigs or grass stems, like the *Libellulidæ*. From this flattened position they dart out over the water, skimming close to the surface and going toward the center of the river or stream, and then return again to the bank. Their motion is more similar to the ordinary aeroplane than that of most *Libellulids*, and they often hover over one spot for some time. They pluck much of their prey off the surface of the water, and some species actually dive beneath the surface, entirely disappearing under the water.

Although two of the species, *externus* and *vastus*, are common about the ponds, they have never yet been observed hunting their prey over the pond surface. They do catch numbers of teneral dragonflies and damselflies, however, in the vegetation around the margins of the ponds.

The imagoes are so nearly alike in color pattern, wing venation, and even in habits, that it is very difficult for anyone but an expert to distinguish the various species, but the nymphs afford much plainer distinctive characters.

The pairing of the sexes occurs toward evening, and if one goes out just before sunset there is a good chance of obtaining the two sexes together. The male does not accompany the female while ovipositing, and the sexes never fly about together after the manner of some of the *Libellulidæ*.

GOMPHUS PLAGIATUS Selys.

Gomphus plagiatus Selys, Bull. Acad. Belgique, 1854, vol. 21, p. 57.

In the Proceedings of the Indiana Academy of Science for 1901, page 123, Williamson said: "The why, whence, and whither of imago Gomphi is a puzzle." And to no species of the genus apparently does it apply any more forcibly than to the present. The nymph skins of this species were by far the most abundant of any found along the river bank, and over 1,000 were collected during the summer. But the only imagoes caught or seen were two tenerals captured as they were emerging. The imagoes must depart as soon as they can fly at all, and apparently they remain in the place to which they go. Consequently this species can hardly be said to have any part at all in the ecology of the fishponds although such large numbers of them are transformed within a few hundred feet of the ponds.

Emergence takes place early in the season, usually during the night, so that by the next morning the imago can fly fairly well.

GOMPHUS VASTUS Walsh.

Gomphus vastus Walsh, Proc. Acad. Nat. Sci., Phila., 1862, p. 391.

This species was third in abundance, judging by the number of skins obtained, and it takes an active part in the odonate life around the ponds.

While the imagoes emerge along the river bank, and while many of them remain there, others migrate to the vicinity of the ponds. Most of these migrants are females, although there is a respectable sprinkling of males. And yet none of them ever deposits eggs in the ponds; they all return to the river. Hence the part which they play is strictly confined to the imagoes, and consists wholly in the consumption of various insects and the teneral imagoes of smaller dragonflies.

GOMPHUS EXTERNUS Hagen.

Gomphus externus Hagen, Monogr. Gomphidæ, 1857, p. 411.

This species was second in abundance, as shown by the skins collected. The sexes seemed fairly well divided, and specimens could nearly always be seen along the cinder road to the north of the ponds or in the vegetation on the embankments. They are active and restless hunters and voracious eaters. One female was observed July 18 eating an *Argia putrida* imago and was so intent upon her meal that she allowed an approach to within 2 feet. She chewed and swallowed every scrap of the large damselfly except the wings and had no sooner finished than she caught another and ate it similarly. Such gormandizing must of necessity play an important part in the ecology of the ponds. Like *vastus*, this species returns to the river for ovipositing, and its nymphs are never found in the ponds.

Like *plagiatus*, emergence takes place during the night, and many tenerals were found early in the morning at the season of transformation, which seems to last through June and July.

GOMPHUS SUBMEDIANUS Williamson.

Gomphus submedianus Williamson, Entomol. News, 1914, vol. 25, p. 54.

This species was found only at Patterson Lake and Sunfish Lake, on the Illinois side of the Mississippi River, just above Fairport. The males were plentiful along the banks of the lakes, while the females were found in swampy places some distance back in the woods. Specimens were sent to E. B. Williamson, the founder of the species, and he very kindly confirmed their identification. The males usually fly close to the surface of the water and have the habit of hovering for a short time over one spot after the manner of some of the other Gomphids. They also frequently alight upon floating logs, bushes, or some water plant. While hovering, the seventh, eighth, and ninth abdominal segments have a decided reddish tinge when the sunlight strikes them just right.

GOMPHUS AMNICOLA Walsh.

Gomphus amnicola Walsh, Proc. Acad. Nat. Sci., Phila., 1862, p. 396.

This species was especially abundant along the banks of the river just above the ponds in series B and was occasionally captured around the fishponds. While the exuviae collected give us the best idea of the actual number of imagoes of the various species, the apparent abundance does not always correspond. The present species was seen and captured as often as any other single species, but in the number of exuviae it was far behind most of the other Gomphids. Evidently these imagoes do not migrate after their emergence, but stay around in the immediate vicinity.

This dragonfly frequents the thick grass and underbrush a little back from the water's edge and can be captured with comparative ease.

The nymphs and nymph skins were all obtained from the river, and none was found in any of the ponds.

GOMPHUS NOTATUS Rambur.

Gomphus notatus Rambur, Ins. Neur., 1842, p. 162.

This dragonfly is a little larger than *amnicola*, but has similar habits; it stays out in the open rather more, but is occasionally found in the thick grass. Its favorite haunt is along the river's bank, whence it makes long flights out over the water, returning again to nearly the same place. The nymphs frequent the shallower portions of the river, and none are ever found in the ponds.

NASIÆSCHNA PENTACANTHA (Rambur).

Aeschna pentacantha Rambur, Ins. Neur., 1842, p. 208.

This species is said to have a wide geographical range, but not to occur anywhere in abundance. It was found quite plentifully around Patterson Lake and the slew leading up to it from the river. Its habits are like those of other *Æschnines*; it patrols the banks, flying back and forth over a limited area and frequently alighting and clinging to the underside of twigs and branches, its body hanging vertically and its wings drooping. In this position it is not very difficult to catch. No old nymphs or nymph skins could be found, although careful and continued search was made for them, but newly hatched nymphs were obtained in August, 1917.

ANAX JUNIUS (Drury).

Libellula junia Drury, Illust. Exot. Entomol., vol. 1, 1773, p. 112.

According to Kellicott, this species is the first to appear in the spring and almost the last to disappear in the fall. During June the imagoes were not very plentiful around the ponds, but they increased greatly in actual numbers and still more in relative abundance as the season advanced, and by the last of August they were surpassed only by *Libellula luctuosa*. This is one of the most powerful fliers and almost never alights except for ovipositing. At such times the two sexes fly about together and, alighting upon some water plant at or near the surface of the water, the male assists the female as she inserts her eggs in the tissue of the plant stem. Both sexes often have a regular beat which they patrol back and forth for a long time; they also fly later at night than any other species, sometimes high in the air, catching the numerous small insects which they find there.

Nymphs were found in all the ponds, but especially in 4 and 9, where they were not much disturbed by the fish. This nymph is probably better known and more often figured than that of any other dragonfly. It shows a great variety in its color pattern at different ages, as well as the usual differences according to the nearness of the next molt. When very small, it is a uniform greyish green; as it grows larger it becomes banded transversely with black and white, while the mature nymphs are bright grass-green, with a beautiful and intricate color pattern of cinnamon brown. Two medium-sized nymphs were taken in pond 4 that were snow white throughout and so transparent that the dark breathing tracheæ around the posterior intestine showed through plainly.

The nymphs are most abundant in waters filled with vegetation, and may be found even in small ditches and pools, and there are sometimes two broods in a year. They expel the water from their rectum with a noise like that made in ejecting saliva, and such spitting served to locate most of them in pond 4 when the water was drawn. When those that were left in this pond transformed, they seemed to find the screen across the outlet peculiarly attractive, and it was covered with bunches of skins. Two of these bunches are shown in Plate LXVIII, figure 1, the right-hand one containing six skins in a row, each fastened to the one in front of it.

ÆSCHNA CONSTRICTA Say.

Æschna constricta Say, Jour. Acad. Nat. Sci., Phila., vol. 8, 1839, p. 11.

Nymphs were found in all the ponds associated with those of *Anax*; they do not transform until mid-summer or later, and hence no imagoes are seen until then. The imagoes frequently enter houses or other buildings and may often be captured there. They wander afar in the fields and are seldom seen around the ponds, preferring some small brook among the hills. They feed on flies as well as mosquitoes and often catch house flies and stable flies around our dwellings.

MACROMIA TÆNIOLATA Rambur.

Macromia tæniolata Rambur, Ins. Neur., 1842, p. 139.

This and the following species were only found in the slews along the Mississippi River. None have ever been seen around the fishponds, nor have any nymphs or nymph skins been found there. Patterson Lake is a favorite resort of the imagoes, but careful search in its waters failed to reveal any nymphs.

MACROMIA ILLINOIENSIS Walsh.

Macromia illinoiensis Walsh, Proc. Acad. Nat. Sci., Phila., 1862, p. 397.

Like the preceding species this one is never found around the ponds, but may be seen frequently along the river bank and at sunset in the cornfields flying back and forth between the rows. At night both species congregate in favorite places upon low bushes and hang by their legs from the under side of the branches like *Nasiæschna*.

EPICORDULIA PRINCEPS (Hagen).

Epithecæ princeps Hagen, Synop. Neuropt. of N. A., 1861, p. 134.

This species is easily recognized by its large size, by the brown blotches on its wings at the nodus and stigma, and by the fact that there are never any white areas connected with these blotches as in *L. pulchella*.

The males have regular areas which they patrol incessantly hour after hour, hawking the varied insect life they may find.

The nymphs are common in all the ponds; but the imagos scatter after emerging, and only a few are seen about the ponds at any one time. The nymph is large and sprawling and can not cling well to grass stems, preferring a broad surface like a board, a stump, or even the side of a bank. Most of those taken at the ponds were found on a hard mud bank beside the cinder road. The two sexes do not fasten together during oviposition, but the female drops her eggs alone into deep water.

The imago emerges early in the morning and is one of those that consequently falls a prey to the birds, since it is helpless during the first forenoon. Some of the wings of this species were found with those of *L. luctuosa* already noted (p. 222).

PANTALA FLAVESCENS (Fabricius).

Libellula flavescens Fabricius, Entomol. System. Supple., 1798, p. 285.

This species was found more plentifully upon the Illinois side of the river, but was occasionally taken around the fishponds. Nymphs were found in ponds 4 and 8, and skins were obtained along the shores of ponds 1, 2, and 3.

The imagos are rapid flyers and very difficult to capture while on the wing; they congregate in open places near the river bank, where they may be recognized by their reddish-yellow color and strong flight.

Apparently they never become really numerous anywhere in the vicinity of the station, but are one of the rarer species.

PANTALA HYMENÆA (Say).

Libellula hymenæa Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 18.

Similar to *flavescens*, but with a distinct fuscous spot at the base of the posterior wings; common along the river bank just above the ponds in series B. Like *flavescens* they are rapid flyers and difficult to capture while on the wing, but, unlike that species, they frequently alight upon the under side of a twig of some bush or tree like *Macromia* and *Nasiæschna*, and can then be captured easily.

Nymphs were taken in ponds 3 and 4, but no skins were found in any of the counts made. Neither imagos nor nymphs occur in sufficient numbers to affect the ecology of the ponds.

TRAMEA LACERATA Hagen.

Tramea lacerata Hagen, Synop. Neurop. N. A., 1861, p. 145.

This species can be readily recognized even when flying by the large black blotches at the bases of the posterior wings. The male accompanies the female while ovipositing, and the two may frequently be seen flying tandem over the ponds. Early in the season, June and the first of July, the species is comparatively rare, but later they become more numerous and by the last of August they share with *Anax* the honors of first place. Nymphs were found in all the ponds, and skins were obtained in every count made, those in August being especially numerous.

TRAMEA ONUSTA Hagen.

Tramea onusta Hagen, Synop. Neurop. N. A., 1861, p. 144.

A single male of this species was captured on pond 8D in July, 1917, and others were seen later about several of the ponds. It can be readily distinguished from *lacerata* by the reddish color of the blotches at the bases of the wings. Neither nymphs nor skins were secured.

PERITHEMIS DOMITIA (Drury).

Libellula domitia Drury, Illust. Exot. Entomol., vol. 2, 1773, p. 83.

This is the smallest of the dragonflies and may be distinguished from the others here mentioned by its diminutive size and its amber-tinted wings. The imagoes are as common about the ponds as elsewhere, but are not very abundant anywhere. It is a slow and clumsy flyer, approaching more nearly to the damsels than to the other dragons. Its small size gives it very little confidence and it keeps well out of the way of other species, flying close to the surface of the water.

The female is usually found in the fields some distance away from the ponds, and she deposits her eggs unattended by the male.

The nymphs are found sparingly in all the ponds and were also obtained from Patterson Lake on the river; they are cleaner, as well as smaller, than most other species. The skins are always found close to the water's edge, often over the water, apparently on the first suitable stem that the nymph met with.

CELITHEMIS EPONINA (Drury).

Libellula eponina Drury, Illust. Exot. Entomol., vol. 2, 1773, p. 86.

These dragonflies can be recognized by their heavily spotted wings and by their habit of balancing upon the very tip of some convenient grass or weed stem. When disturbed they return again to the same spot, and this makes them easy to capture. Their flight is slow, and in the position and movement of the wings bears more resemblance to that of a butterfly than of other dragonflies. They are seen paired and flying tandem more often than other species, and in spite of their slow flight they are more in evidence on windy days.

The nymphs are found in all the ponds, while the skins are found close to the water's edge, like those of *Perithemis*. The small size and scarcity of both species gives them but little influence in the ecology of the ponds.

CELITHEMIS ELISA (Hagen).

Diplax elisa Hagen, Synop. Neurop. N. A., 1861, p. 182.

This species was first seen around the fishponds in the summer of 1917. One or two were seen in 1918, but none was captured. A male and female were secured on July 1, 1919, near ponds 4 and 8 of series D.

LEUCORRHINIA INTACTA (Hagen).

Diplax intacta Hagen, Synop. Neurop. N. A., 1861, p. 179.

This is another small species familiarly known as "Johnny Whiteface"; it may be recognized by its diminutive size and its snow-white face combined with a dark body and clear wings. The two sexes do not fasten together during ovipositing, but spend much of their time perched separately on some convenient object near the water. They fly only short distances from one resting place to another, but forage continuously all summer long. Their nymphs are found in all the ponds and much resemble those of *Celithemis* and *Perithemis*, but are shorter and generally show a definite color pattern of dark brown on a greenish background. They are lively and clamber about on the submerged vegetation with considerable agility.

SYMPETRUM RUBICUNDULUM (Say).

Libellula rubicundula Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 26.

This species appears early in the season and remains until after the frosts of October. At first the adults are very soft and seem to remain teneral a long time, but later they become firmer and by September are as rigid as any of the smaller species.

The imagoes are found in large numbers around the ponds, but stick to the vegetation and do not fly out over the water. The nymphs were found in all of the ponds; and nymph skins were present in all the counts.

SYMPETRUM CORRUPTUM (Hagen).

Mesothemis corrupta Hagen, Synop. Neurop. N. A., 1861, p. 171.

Appears early in the season and is common around the ponds; then diminishes gradually and by the middle of August entirely disappears.

Nymphs were found in all the ponds, and nymph skins occurred in the first two counts. It is the largest species of the genus and the strongest flyer, going out, like other dragonflies, over the water, but never in numbers, and remaining but a short time.

ERYTHEMIS SIMPLICICOLLIS (Say).

Libellula simplicicollis Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 28.

Second in abundance at the ponds, sticking close to the grass and weeds and never taking long flights. It does not perch on the sides of the grass stems like *L. luctuosa*, but prefers a horizontal blade of grass and settles down flat upon it. The females hunt almost exclusively in the grass and feed upon diptera, small butterflies and moths, and damselflies, especially teneral *Enallagma*s and *Lestes* (Pl. LXIX, fig. 2.)

Williamson (1899, p. 326) has noted a peculiar habit of the males. Two of them hover over the surface of the pond close to the water, one a few inches above and in front of the other. The lower one then rises in a curve over the back of the upper one, which at the same time moves in a curve downward, backward, and then upward, so that the positions of the two are exactly reversed. The two keep this up for several minutes and then separate; such movements may be witnessed on any clear day by watching for it.

The two sexes never fly about together, but the female oviposits alone, hovering close to the water and repeatedly dipping the tip of the abdomen beneath the surface. Both sexes alight on the floating algae and other water plants, unlike most dragon flies.

The nymphs never crawl far from the water to transform, and many of the skins are found upon rush stems standing in the water. They showed a curious preference for *Carex stricta* and *Homalocenchrus oryzoides*, and but very few skins were found on other plants. Such a preference was probably due more to the position of the plants than to any other factor. The two sexes are shown in Plate LXIX, figure 1.

PACHYDIPLAX LONGIPENNIS (Burmeister).

Libellula longipennis Burmeister, Handb. Entomol., vol. 2, 1839, p. 850.

Not very common around the ponds, although a few can be found there all through the season. The matured, pruinose males are more in evidence than the females; both sexes have the habit of drooping the wings and elevating the abdomen when they alight. Nymphs were more abundant in ponds 2 and 3, and nymph skins more numerous in July and August.

LIBELLULA LUCTUOSA Burmeister.

Libellula luctuosa Burmeister, Handb. Entomol., vol. 2, 1839, p. 861.

This is by far the most common species at Fairport and can be recognized by the broad, black bands across the wings, with chalky white spots outside of them in the male. It is very energetic and active, but alights often upon the grass and sedges and sometimes remains at rest a long time. It does not hover after the manner of some species and does not hunt late at night, being rarely seen actively flying about after sunset. It roosts in the tall grass up in the fields, holding onto the grass stem well down out of sight, and sometimes in the vegetation alongside of the ponds. Its characteristic attitude is to grasp the stem with all six legs, the longer hind legs holding the body inclined at an angle of about 45° with the stem, as shown in Plate LXVIII, figure 2. It gets thoroughly wet with the dew during the night and does not start flying in the morning until the dew has dried off.

The two sexes do not fly about together after the manner of *Anax*, *Tramea*, and *Celithemis*, but the female oviposits alone, dropping her eggs loosely in the water, and not inserting them in the tissue of any water plant.

FIG. 1.—Skins of nymphs of *Anax junius* left on the screen of the outlet of pond No. 4.

FIG. 1.—Male (upper) and female (lower) of *Erythemis simplicicollis*.

The males frequently come hawking around the laboratory building toward night, alight on the screens, and fly up and down the sides of the building, catching house flies, mayflies, and midges. They also have a curious habit of congregating around straw stacks in the open fields, probably attracted by the insects that frequent the sunny side of the stacks.

Over the ponds they do not keep to a definite beat or patrol, but wander about indiscriminately, the males frequently clashing with one another. So far as observed, the imagoes do not eat other dragonflies or any of the larger insects. Large numbers of them while teneral fall victims to English sparrows and red-winged blackbirds.

The nymphs are found in all the ponds, but most plentifully in ponds 3, 4, and 7. These nymphs are always dirty and without a color pattern, but the dorsal hooks on the abdominal segments are always visible.

Sometimes they crawl long distances from the water, but most of the skins were found in the fringe of *Carex* close to the ponds. A few live in the Mississippi River, and these climb the willow trees on the bank and leave their skins attached to the bark.

LIBELLULA PULCHELLA Drury.

Libellula pulchella Drury, Illust. Exot. Entomol., vol. 1, 1773, p. 115.

Common around all the ponds, but seeming to prefer those nearest the railroad and the ditch along the railroad track. It goes much farther from the water than the preceding species and is often found along the country roads and in the farmyards, industriously hunting the insects which occur there. Nymphs were found in all the ponds, and skins were obtained in every count, but were most abundant the last of July; they are among the largest of the Libellulid nymphs and make excellent fish food.

PLATHEMIS LYDIA (Drury).

Libellula lydia Drury, Illust. Exot. Entomol., vol. 1, 1773, p. 112.

Like *pulchella*, this species prefers the ponds and the ditch along the railroad track; the nymphs were abundant in the ditch, but rare in the ponds. The male is easily recognized by his white pruinose body and black wings; the female has spotted wings and might be mistaken for *pulchella*, but is considerably smaller, and the triangle of the front wings is entirely free from color. This species is a persistent hunter, and the males have regular beats which they patrol almost constantly.

DAMSELFLIES.—The habits of the various damselflies in ovipositing and the habits and relations of the nymphs to the fish life in the ponds are so similar that a general statement will cover them all, with the exception of a few peculiarities, which may be noted under the separate species.

When ovipositing, the male grasps the female by the prothorax and flies about with her. She does not dip her abdomen beneath the surface and wash off the eggs after the manner of some dragonflies, but alights on some convenient water plant, floating algæ, pond-lily leaf, or rush stem, or upon a floating twig or piece of wood, and places her eggs in position beneath the water, the male retaining his hold and assisting her out after she has finished. Often the male holds his body erect in the air, and floating objects are sometimes covered with the females busily ovipositing, while the males stand up from the surface like small twigs or moss stems. In some genera like *Lestes*, *Argia*, and *Enallagma* the female descends into the water and often draws the male in with her. The females of *Argia putrida* sometimes descend 9 inches beneath the surface, the female clinging to some water plant, the male holding his body erect, with the wings spread. After placing her eggs, the female releases her hold and the two rise to the surface, their buoyancy lifting the male into the air until his wings are free. He immediately begins to fly and lifts the female out of the water, and the two then go to another place and repeat the process.

However they may be laid, the eggs hatch quickly, and the ponds are swarming during the summer time with nymphs of all sizes and kinds. These nymphs have long masks which fold back beneath the head and thorax, like those of the dragonfly nymphs. But in place of the rectal respiratory apparatus of the latter, they carry three external tracheal gills at the posterior end of the abdomen. These are flattened laterally and are usually about half the length of the abdomen, their size and shape furnishing one means of identifying the species.

Their food is similar to that of the dragon nymphs, but contains a larger percentage of small animals, as would be expected (table, p. 201). One such nymph was seen by Williamson (1899, p. 234) clinging to a dead catfish and evidently feeding on its flesh.

ARGIA APICALIS (Say).

Agrion apicalis Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 40.

The male imagos of this species never become pruinose like *putrida*; one was secured from pond 5, in which the blue of segment 8 was W-shaped and restricted to the base of the segment, like that in *translata*.

The imagos were observed by Needham (1903, p. 242) at Galesburg, Ill., "feeding voraciously on adult Chironomids." The nymphs were not found at all in the ponds, but were fairly common in the river. They do not travel far when ready for transformation, but the skins are always found within a few inches of the water's edge.

ARGIA MÆSTA PUTRIDA (Hagen).

Agrion putridum Hagen, Synop. Neurop. N. A., 1861, p. 96.

The largest species of the genus; does not breed commonly in the ponds, but is very plentiful along the river. The imagos eat large numbers of mayflies, and when the latter are emerging almost every *Argia*, male and female, may be found munching one. The males quickly become pruinose, fading into a uniform bluish gray, but the colors are usually restored on immersion in alcohol.

The nymphs are numerous in the river, but only one or two were found in the ponds, and but few imagos were seen around the ponds. When ready for transformation the nymphs often go long distances from the water and even climb rough-barked trees. Ten skins were taken from the trunk of a large willow tree 60 feet from the water, and with them were found half a dozen skins of *Libellula luctuosa*.

AGRION (CALOPTERYX) MACULATUM (Beauvois).

Agrion maculata Beauvois, Ins. Afr. Amer., 1805, p. 85.

This beautiful damselfly is restricted to shady running water and is found only along a small brook one-fourth of a mile above the station. It sticks close to its haunts, although a male was seen one day fluttering along the shores of the ponds. Such visits, however, are only accidental, and the species does not enter into the life of the ponds to any appreciable degree.

THE GENUS ENALLAGMA.—*Enallagma* and *Ischnura* females, after inserting 8 or 10 eggs into the tissue of some plant, have a habit of stopping and straightening out the abdomen and stretching it, much as one stretches his fingers after prolonged writing. Evidently it requires considerable effort to thrust the ovipositor into the plant tissue, and since the abdomen is curved during the process it relieves the strain to straighten and stretch it.

Two *Enallagma* females were observed on July 26 depositing their eggs. During the process each came in contact with a partially drowned damselfly floating in the water and tossed about by the waves, which they seized, pulled out of the water and ate.

Here in the fishponds the *Enallagma* females seem to prefer the leaves of the crex grass as tissue in which to deposit their eggs. When the leaves break and fall over into the water, the part distal to the break dies and becomes apparently of just the right consistency to suit these damselflies, and nearly every such leaf contains eggs.

A pair of *Enallagma civile* was observed upon a bullrush stem in pond 1D July 20, 1917. The female backed down the stem into the water for the purpose of laying her eggs. When the water reached the male and he became half submerged, he released his hold and perched on the stem above the water. But the female continued backing down the stem until she was at least 6 inches beneath the surface. Here she remained for ten and a half minutes actively ovipositing. Then a small sunfish, *Lepomis euryorus*, caught sight of her and snapped her up instantly.

The female *Enallagma* often gets stranded on the surface of the water with her wings wet and unable to fly. When he catches sight of her in such a predicament, a male will fasten to her and try to pull her out. Such a rescue was witnessed in pond 2D; four different males fastened to this female, but the adhesion of the water was too strong for them. They could merely tow her along on the surface, each in turn giving way when he became exhausted. But together they pulled her far enough to reach some floating algæ, onto which she crawled. Such chivalry deserved a far better reward than it received; a small cricket frog seized and swallowed her while she was drying her wings.

ENALLAGMA ANTENNATUM (Say).

Agrion antennata Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 39.

This species is rare about the ponds, and only a few specimens were secured; elsewhere it is often found in large numbers and becomes the dominant species, as noted by Williamson (1899, p. 275).

ENALLAGMA CALVERTI Morse.

Enallagma calverti Morse, Psyche, 1895, p. 208.

Only a single pair was secured from pond 4, the male of which could be recognized by the excellent figures given by Williamson (1900, pl. 1).

ENALLAGMA CIVILE (Hagen).

Agrion civile Hagen, Synop. Neurop. N. A., 1861, p. 88.

This is one of the two most common species of the genus about the ponds, and its nymphs are found in every pond. In 1915 this species and *Ischnura verticalis* constituted the bulk of the damsel fauna of the ponds, but in 1916 there were fully as many of the species *hageni* as of *civile*.

Williamson stated (1899, p. 270) that old individuals of *civile* often have the wings milky or gray and the pterostigma bluish or pruinose, and this was noted in several specimens collected in September, 1915. Both the imagos and the nymphs take an active part in the life of the ponds, serving as food for fish and dragonflies.

ENALLAGMA EBRIUM (Hagen).

Agrion ebrium Hagen, Synop. Neurop. N. A., 1861, p. 89.

Moderately abundant around the ponds and found in company with other species of the genus, which it very much resembles in habits and appearance. The nymphs were more abundant than the imagos and were found especially in ponds 1, 2, 3, and 4. They are just the right size to furnish good food for young fishes.

ENALLAGMA GEMINATUM Kellicott.

Enallagma geminatum Kellicott, Etom. News, vol. 6, 1895, p. 239.

This is the smallest and most slender of the genus that frequents the ponds, but is also the most active, flying about restlessly over the water, often a long distance from the shore. It has the habit of sticking close to the surface of the water and alighting only on floating algae, which renders it difficult to capture.

ENALLAGMA HAGENI (Walsh).

Agrion hageni Walsh, Proc. Entomol. Soc., Phila., vol. 2, 1863, p. 234.

This species, with *civile* and *Ischnura verticalis*, makes up 90 per cent of the damselfly life in and around the ponds. They are found everywhere in the vegetation near the ponds and often wander long

distances into the fields and woods. They are quiet and remain well concealed, so that often when none can be seen a sweep of the net through the vegetation will reveal them.

ENALLAGMA SIGNATUM (Hagen).

Agrion signatum Hagen, Synop. Neurop. N. A., 1861, p. 84.

This is the only orange-colored species of the genus found about the ponds, and this makes it conspicuous while flying, as well as at rest. The males and the two sexes when paired frequent the lily pads and similar water vegetation, sometimes long distances from shore. It is nearly as active and restless as *geminatum* and, like the latter, flies close to the water, making it difficult to catch. The species is common along the slews of the river as well as around the ponds and probably plays an important part in the life of those localities.

HETÆRINA AMERICANA (Fabricius).

Agrion americana Fabricius, Ent. Syst. Suppl., 1798, p. 287.

This species frequents the neighborhood of flowing water, and hence is never found around the quiet ponds, but only on the river where the current runs swiftly. It is not very common anywhere near Fairport.

ISCHNURA VERTICALIS (Say).

Agrion verticalis Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 37.

This is the most common damselfly around the ponds, appearing first in the spring and disappearing last in the fall. It frequents the thick grass and other vegetation to quite a distance from the margins of the ponds. The females are dimorphic; that is, of two different colors, and the black and the orange are about equally numerous. Both sexes are weak fliers and can be caught easily in the hands. The nymphs are abundant in all the ponds, and the stem of nearly every water plant projecting above the surface is covered with their skins. The species can be raised with little trouble if suitable aquaria are provided with the stems of rushes or similar water plants projecting above the surface. As the tables show, the nymphs are eaten not only by the fish but also by the larger dragonfly nymphs. There are probably a number of overlapping broods every season.

LESTES EURINUS Say.

Lestes eurinus Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 36.

This is a large and stout species and has been found thus far only at the eastern end of the ponds; its nymphs have been taken in ponds 4 and 8, but not elsewhere. The imagoes are associated with those of *rectangularis* and *unguiculatus*, and late in the afternoon the three species can sometimes be obtained in one sweep of the net. In spite of its size this species is a weak flier, but is an omnivorous eater. Two females were captured with partly eaten brown moths in their mandibles; others were found eating butterflies, small caterpillars, and even teneral Enallagmas and Ischnuras.

LESTES RECTANGULARIS Say.

Lestes rectangularis Say, Jour. Acad. Nat. Sci., Phila., 1839, p. 34.

This is a very long and slender species and may be recognized by these characters. It is the most common species around the ponds and was taken also along the river and at both Sunfish Lake and Patterson Lake on the Illinois side. It is rather more of a woodland species, but is found as well in the open, especially where there is rank vegetation to furnish shelter. It is not as omnivorous as the preceding species, but feeds largely on gnats and midges.

LESTES UNGUICULATUS Hagen.

Lestes unguiculatus Hagen, Synop. Neurop. N. A., 1861, p. 70.

The smallest of the *Lestes* species and found along only the eastern end of pond 4, where it is fairly common. No nymph that could be identified with this species was found in any of the ponds, although it is probable that the imagoes referred to deposit their eggs in the ponds.

LESTES UNCATUS Kirby.

Lestes uncatus Kirby, Synonymic Cat., 1890, p. 160.

A single male of this species was captured in one of the runs that stretch back onto the prairie August 10, 1917. The species can not be at all common in this vicinity, since this is the only specimen secured during four years of collecting.

ISCHNURA (NEHALENNIA) POSITA (Hagen).

Agrion positum Hagen, Synop. Neurop. N. A., 1861, p. 77.

Needham (1903, p. 260) places this species in the genus *Ischnura* "chiefly because of the form of the abdominal appendages in the male and the small round postocular spots." Like *verticalis*, it appears early in the spring and continues until late in the fall, and its nymphs are associated with those of *verticalis* in the ponds. In habits and in their relation to the fish life of the ponds the two species may be treated as one.

NEHALENNIA IRENE (Hagen).

Agrion irene Hagen, Synop. Neurop. N. A., 1861, p. 74.

This tiny species is associated with *Lestes*, frequenting the grass and vegetation in damp places. Like *Ischnura*, it feeds upon gnats and midges. Neither the imagos nor the nymphs occur in sufficient numbers to affect the life of the ponds.

AMPHIAGRION SAUCIUM (Burmeister).

Agrion saucium Burmeister, Handb. Entomol., vol. II, 1839, p. 819.

A male and two females of this species were captured around the ponds below the railroad track July 26, 1917; none had ever been seen near the ponds in series D. However, this species is sometimes found in great numbers, and it may be that once obtaining a start here they will increase sufficiently to rank alongside the *Enallagma* species.

BIBLIOGRAPHY.

ATKINS, CHARLES G.

1908. Foods for young salmonoid fishes. Bulletin, U. S. Bureau of Fisheries, Vol. XVIII for 1908 (1910), part 2, pp. 841-851. Washington. Recommended different artificial foods as the result of experiments upon young fishes.

BAKER, FRANK C.

1916. The relation of mollusks to fish in Oneida Lake. Technical Publication No. 4, N. Y. State College of Forestry, Syracuse University, vol. 16, No. 21, pp. 8-366. Odonate nymphs were found in the stomachs of bullheads, bluegills, redbeyes, common sunfish, yellow perch, manitou darters, and grass pikes.

BALFOUR-BROWNE, FRANK.

1909. The life history of the agrionid dragonfly. Proceedings, Zoological Society of London, pp. 253-285, pls. 33 and 34. London. Two species, *Agrion pulchellum* and *Ischnura elegans*, were followed through their entire development from the egg to the imago. Details were given of every stage marked by the successive molts, and the development of the morphological form was fully discussed. The food on which the nymphs were reared was given in detail.

BEAN, TARLETON H.

1912. Report of the fish-culturist for 1911. Annual Report, Conservation Commission for 1911, I, pp. 159-215. Mentioned dragonflies as an important trout food, p. 203.

BENECKE, DR. BERTHOLD.

1886. The enemies of pond culture in central Europe. (Translation by Herman Jacobson of "Die Feinde der Teichwirtschaft" from "Die Teichwirtschaft," Berlin, 1855.) Bulletin U. S. Fish Commission, Vol. VI, No. 22, pp. 337-342. Washington.

BIRÓ, L.

1884. Larvæ of Libellulidæ destroy 50,000 young fishes. Rovartani Lapok i, pp. 251-253 and xxx. Budapest. (Quoted in The Entomologist's Monthly Magazine, vol. 21, p. 234, 1885. London.) Given in full and discussed on page 205.

BRANDT, A.

1869. Beiträge zur Entwicklungsgeschichte der Libelluliden und Hemipteren. Mémoires, Académie Impériale des Sciences, série 7, t. xiii, no. 1, pp. 1-33, pls. 1 and 2. St. Petersburg. Reared a parasite, *Polynema ovulorum*, from the eggs of *Agrion (Calopteryx) virgo*, and reported that some times half the eggs were destroyed in this way.

CALVERT, P. P.

1893. Catalogue of the Odonata (dragonflies) of the vicinity of Philadelphia, with an introduction to the study of this group of insects. Transactions, American Entomological Society Vol. XX, pp. 152a-272, pls. 2 and 3, 2 text figs. Philadelphia. An excellent account of the structure of the imago and nymph, the life history, the geographical distribution, and the relationship of the Odonata, with a good bibliography.
1901. On *Gomphus fraternus*, *externus*, and *crassus* (order Odonata). Entomological News and Proceedings, Entomological Section, Academy of Natural Sciences of Philadelphia, vol. 12, pp. 65-73, pl. 3. Philadelphia. Wholly systematic.
1906. Nomenclature of certain North American Odonata. Idem, vol. 17, pp. 30-31. Showed that *L. basalis* Say, 1839, must be regarded as a synonym of *L. luctuosa* Burmeister, 1839.

CAMPION, HERBERT.

1914. Some dragonflies and their prey. Annals and Magazine of Natural History (8), vol. 13, pp. 495-504. London. Thirty-six records of various kinds of prey eaten by odonates; no American species included.

CHABOT-KARLEN.

1894. Report on the fish-cultural operations of M. Durand at the school of agriculture at Beaune. (Translation by F. P. Fennell of parts of report published by the National Society of Agriculture of France, June 19, 1889.) Bulletin, U. S. Fish Commission for 1894, Vol. XIV, pp. 309-310. Washington. Observations on the rearing of Cyclops, Daphnia, and Cypris for fish food. Cypris was found to prey upon the young fish.

COKER, R. E.

1915. Water conservation, fisheries, and food supply. Popular Science Monthly, vol. 86, pp. 90-99. New York. Quotation on page 185.
1916. The Fairport fisheries biological station; its equipment, organization, and functions. Bulletin, U. S. Bureau of Fisheries for 1914 (1916), Vol. XXXIV, pp. 385-405. Washington. Quotation on page 185.

DYCHE, L. L.

1914. Ponds, pond fish, and pond-fish culture. State Department of Fish and Game, Kansas, Bulletin No. 1, 208 pp. Topeka. Included both natural and artificial ponds, with directions for building the latter; described the habits and habitat of the basses, crappies, sunfishes, and catfishes, and gave directions for the artificial culture of each; discussed the enemies of fish and the problem of artificial feeding.

ELROD, M. J.

1898. Iowan Odonata. Entomological News and Proceedings, Entomological Section, Academy of Natural Sciences of Philadelphia, vol. 9, pp. 7-10. Philadelphia. A simple list of the Iowan dragonfly fauna.

EMBODY, GEO. C.

1915. The farm fishpond. Cornell Readings Courses, Vol. IV, No. 94, pp. 213-252, 4 pl. Included types of ponds, location, water supply, pond construction, suitable fishes for the ponds, pond stocking, and pond management.

FISHER, A. K.

1893. The hawks and owls of the United States in their relationship to agriculture. U. S. Department of Agriculture, Bulletin No. 3. Washington.

FORBES, S. A.

1883. The food of the smaller fresh-water fishes. Bulletin, Illinois State Laboratory of Natural History, Vol. I, No. 6, pp. 65-94. Urbana.
- 1888a. Studies of the food of fresh-water fishes. Idem, Vol. II, Art. VII, pp. 433-473. Peoria.
- 1888b. On the food relations of fresh-water fishes; a summary and discussion. Idem, Vol. II, Art. VIII, pp. 475-538. A summary of the two preceding papers, with additional notes and data.

GARLICK, THEODATUS.

1880. A treatise on the artificial propagation of fish. Second edition, n. d., 128 pp. Cleveland. (First edition published in 1857.) One of the older treatises, but containing excellent suggestions.

GARMAN, PHILIP.

1917. The Zygoptera, or damselflies, of Illinois. Bulletin, Illinois State Laboratory of Natural History, Vol. XII, Art. IV, pp. 411-587, pls. 58-73. Urbana. Morphology of nymphs and adults, life history, habits, and classification of Illinois species, with a good bibliography, keys for nymphs and females as well as males, tables, and charts.

HANKINSON, THOS. L.

1908. A biological survey of Walnut Lake, Mich. Michigan State Biological Survey Report for 1907, pp. 156-288, 75 pls. Lansing. Odonate nymphs were given among the food of the bullhead, redeye, blue-spotted sunfish, common sunfish, large-eared sunfish, bluegill, and largemouth black bass.

1910. Ecological notes on the fishes of Walnut Lake, Mich. Transactions, American Fisheries Society for 1910 (1911), pp. 195-206. Washington. A summary of the preceding paper with additional notes and data.

HIGGINS, HELEN T.

1901. The development and comparative structure of the gizzard in the Odonata Zygoptera. Proceedings, Academy of Natural Sciences of Philadelphia, vol. 53, 3d series, pp. 126-141, pls. 2-4. Philadelphia. A detailed account of the folds and armature of the gizzard in 90 species of damselflies, nearly all foreign.

JOHNSON, ROBERT S., and STAPLETON, M. F.

1915. Fish ponds on farms. Appendix II, Report, U. S. Commissioner of Fisheries for 1915, pp. 1-28, 19 pl. Washington. Included water supply, pond construction, value of aquatic plants, fishes suitable for pond culture, natural and artificial fish foods, diseases and enemies of fish.

KAMMERER, PAUL.

1908. Symbiose zwischen *Ædogonium undulatum* und Wasserjungferlarven. Wiener-Festschriften, pp. 238-252. Wien. Claimed a real symbiosis between the alga and the nymph, each deriving benefit from the presence of the other.

KELICOTT, DAVID S.

1899. The Odonata of Ohio. Ohio State Academy of Science, Special Papers, No. 2, 114 pp., figs. 1-39. Columbus. An annotated list of Ohio species.

KENNEDY, CLARENCE H.

1915. Notes on the life history and ecology of the dragonflies (Odonata) of Washington and Oregon. Proceedings, U. S. National Museum, vol. 49, pp. 259-345, 201 text figs. Washington.
 1917. Notes on the life history and ecology of the dragonflies (Odonata) of central California and Nevada. Idem, vol. 52, pp. 483-635, 400 text figs. These two papers contain fine accounts of Pacific coast dragonflies and damselflies, with full descriptions and excellent illustrations.

LAMBORN, ROBT. H.

1890. Dragonflies vs. mosquitoes. 8vo., 202 pp., 9 pl. New York City. Introduction only by Dr. Lamborn. The dipterous enemies of man, by Mrs. C. B. Aaron; Utility of dragonflies as destroyers of mosquitoes, by Archibald C. Weeks; The destruction of the mosquito, by Wm. Beutenmuller; Dragonflies as mosquito hawks on the western plains, by Capt. C. N. B. Macauley; Can the mosquito be exterminated? by Henry C. McCook, with good bibliographies.

LUCAS, W. J.

1908. Foe of dragonfly nymphs. The Entomologist, vol. 41, p. 16. London. "Mr. O. A. Rowden, writing from Exeter (England) on Dec. 16, 1907, says that the water boatman (*Notonecta glauca*) attacks the nymphs of dragonflies."

LYON, MARY B.

1915. The ecology of the dragonfly nymphs of Cascadilla Creek (Odonata). Entomological News and Proceedings, Entomological Section, Academy of Natural Sciences of Philadelphia, vol. 26, pp. 1-15, 1 pl., 1 diagram, 3 tables. Philadelphia. Included a census of the diatoms, green and blue-green algæ, protozoa, etc., which settle on the back of odonate nymphs, the food of nymphs, and the efficiency of shelter as protection against enemies.

MARSHALL, WM. S., and GILBERT, N. C.

1905. Notes on the food and parasites of some fresh-water fishes from the lakes at Madison, Wis. Appendix, Report, U. S. Commissioner of Fisheries for 1904 (1905), pp. 513-522. Washington. Odonate nymphs were found in the stomachs of 9 yellow perch.

MARTIN, RENE.

1886. Les Odonates du département de l'indre. Revue d'Entomologie, vol. 5, pp. 231-251. Caen.

MCATTE, W. L., and BEAL, F. E. L.

1912. Some common game, aquatic and rapacious birds in relation to man. U. S. Department of Agriculture, Farmers' Bulletin No. 497, 30 pp., 14 text figs. Washington. Mentioned as eating dragonfly imagoes the killdeer plover, the common tern, and the black tern, and as eating dragonfly nymphs, the horned grebe, and Franklin's gull; 327 nymphs were taken from the stomach of a single gull.

MEEHAN, WM. E.

1913. Fish culture in ponds and other inland waters. 8°. Sturgis and Walton Co., New York. A general treatise taking up all the various aspects of the subject.

MUTTKOWSKI, RICHARD A.

1908. Review of the dragonflies of Wisconsin. Bulletin, Wisconsin Natural History Society, vol. 6, Nos. 1 and 2, pp. 57-123, pl. and map. Milwaukee. Gave briefly a history of the Odonata, the life history, the geographic distribution, the seasonal distribution, the food habits and economic value, and directions for collecting and preserving.
1910. Catalogue of the Odonata of North America. Bulletin, Public Museum of the city of Milwaukee, Vol. I, Art. I, 207 pp. Milwaukee. Included synonyms and all references of taxonomic value, as well as many of ethological and morphological character.

NEEDHAM, JAMES G.

1898. Birds vs. dragonflies. Osprey, vol. 2, pp. 85-86.
1899. Directions for collecting and rearing dragonflies, stoneflies, and mayflies. Bulletin, U. S. National Museum, Pt. O, No. 39, 9 pp., 4 text figs. Washington. "The best way to rear nymphs is to let them rear themselves;" does not include directions for feeding the nymphs.

NEEDHAM, JAMES G., and BETTEN, CORNELIUS.

1901. Aquatic insects in the Adirondacks. N. Y. State Museum, Bulletin 47, pp. 383-612, 36 pls. Albany. An annotated list of the dragonflies (Anisoptera) of New York, giving especial attention to the nymphs, with extensive keys for both nymphs and imagos.

NEEDHAM, JAMES G., and HART, CHAS. A.

1901. The dragonflies (Odonata) of Illinois, with descriptions of the immature stages. Part I. Petaluridæ, Æschnidæ, and Gomphidæ. Bulletin, Illinois State Laboratory of Natural History, Vol. VI, art. 1, 94 pp., 1 pl. Champaign. Included an excellent general treatise on the Odonata, giving the literature, the life history, the habitat of the nymphs, the food relations, and directions for collecting and rearing nymphs.

NEEDHAM, JAMES G.; MACGILLIVRAY, ALEX. D.; JOHANNSEN, O. A.; and DAVIS, K. C.

1903. Aquatic insects in New York State. N. Y. State Museum, Bulletin 68, Entomology 18, pp. 197-517, 52 pls. Albany. Included 7 parts of which Needham was the author of part 2, Food of brook trout in Bone Pond, and part 3, Life histories of Odonata, suborder Zygoptera. In the former the nymph of *Æschna constricta* was said to eat trout fry, but was also found in the stomachs of two trout. In the latter were keys for both nymphs and imagos.

NEEDHAM, JAMES G., and LLOYD, J. T.

1916. The life of inland waters. 8°, 438 pp., 244 text figs. Ithaca. An excellent account of the nature and types of aquatic environment, aquatic organisms, and their adjustment to environment, aquatic societies, and inland-water culture.

PEARSE, A. S.

1915. On the food of the small shore fishes in the waters near Madison, Wis. Bulletin, Wisconsin Natural History Society, vol. 13, No. 1, pp. 7-22. Milwaukee.

POULTON, EDWARD B.

1906. Predaceous insects and their prey. Transactions, Entomological Society of London, pp. 323-409. London. A collection of original records of the food of various predaceous insects, including dragonflies, but all foreign species.

RILEY, C. V.

1888. Larva of *Anax junius* destroys carp. Insect Life, vol. 1, p. 58. Washington. Reference quoted in full and discussed on page 204.

SELYS-LONGCHAMPS, EDM. DE, and HAGEN H. A.

1850. Revue des Odonates ou Libellules d'Europe. Paris.

SSINITZIN, D. TH.

1907. Observations sur les métamorphoses des trématodes. Archives de zoologie expérimentale et générale, t. 7, pp. 21-37. Paris. Found stages of a frog-lung fluke free in the body cavity of both nymphs and imagos of the damselfly, *Agria (Calopteryx) virgo*.

TILLYARD, R. J.

1917. The biology of dragonflies (Odonata or Paraneuroptera). Cambridge Zoological Series, 8°, 396 pp., 188 text figs., 4 pls. A general treatise, including morphology, histology, embryology, geographic distribution, classification, geologic record, and bionomics, with an extensive bibliography.

WALKER, E. M.

1915. Notes on the Odonata of the vicinity of Go Home Bay, Georgian Bay. Ontario. Supplement to 47th Annual Report, Department of Marine and Fisheries, Fisheries Branch, Ottawa. Sessional paper No. 39, b, pp. 53-94, pls. 5-9. Gave ecological, seasonal, and geographical distribution of the species at Go Home Bay.

WALSH, B. D.

1862. List of the Pseudoneuroptera of Illinois contained in the cabinet of the writer, with the description of over 40 new species, and notes on their structural affinities. Proceedings, Academy of Natural Sciences of Philadelphia, 2d series, 1862, pp. 361-402. Philadelphia.

WARREN, ALFRED.

1915. A study of the food habits of the Hawaiian dragonflies or pinau, with reference to their economic relation to other insects. College of Hawaii Publications, Bulletin No. 3, 45 pp., 5 pls., 2 charts, 3 tables. Practically confined to the nymphs and imagoes of *Anax junius* and *Pantala flavescens*; the food tables and charts are especially comprehensive and instructive.

WILLIAMSON, E. B.

1899. The dragonflies of Indiana. Twenty-fourth Annual Report, State Geologist, Indiana, for 1899 (1900), pp. 229-333, pls. 1-7. Contained a general account of the life history, food, enemies, habits, and distribution of the Odonata, with directions for collecting and preserving them, and keys for the determination of both nymphs and imagoes.
1900. Additions to the Indiana list of dragonflies, with a few notes. Proceedings, Indiana Academy of Science for 1900 (1901), pp. 173-178, 1 pl. Indianapolis.
1901. Additions to the Indiana list of dragonflies, with a few notes. No. II. Idem for 1901 (1902). pp. 119-126, 1 pl. These two papers add other Indiana species, with notes and corrections.
1912. The dragonfly *Argia mæsta* and a new species (Odonata). Entomological News and Proceedings, Entomological Section, Academy of Natural Sciences of Philadelphia, vol. 23, pp. 196-203. Philadelphia.
1914. *Gomphus pallidus* and two new related species (Odonata). Idem, vol. 25, pp. 49-58, pls. 4 and 5. One of the new species was *G. submedianus*, which is common around Patterson Lake near Fairport.

WILSON, CHAS. B.

1909. Dragonflies of the Mississippi Valley collected during the pearl-mussel investigations on the Mississippi River, July and August, 1907. Proceedings, U. S. National Museum, vol. 36, pp. 653-671. Washington.
1912. Dragonflies of the Cumberland Valley in Kentucky and Tennessee. Idem, vol. 43, pp. 189-200. Washington. These two papers are annotated lists of species, with especial reference to geographical distribution.

INDEX.

	Page.		Page.
Abundance of species	189, 191	Enemies of nymphs	209
<i>Acris gryllus</i>	224	<i>Epiaeschna heros</i>	233
<i>Aeschna brevistyla</i>	213, 221	<i>Epicordulia princeps</i>	188, 190, 233, 243, 252
californica	223	<i>Erythemis simplicicollis</i>	190, 214, 223, 233, 241, 254
constricta	190, 205, 213, 233, 251	<i>Erythrodiplax berenice</i>	233, 238
cyanea	224	Evidence from exuviae	230
multicolor	223	Evidence from feeding nymphs artificially to fish	230
<i>Agriion (Colopteryx) maculatum</i>	256	Evidence from fish bait	225
pulchellum	260	Evidence from stomach contents	226
Algae as enemies of nymphs	211	Flies	220, 224
<i>Amphiagron saucium</i>	259	Food, amount consumed	206
<i>Anax junius</i>	187, 190, 204, 205, 213, 233, 251	Food of imagos, <i>Aeschnids</i>	213
<i>Anomalagrion hastatum</i>	233	Damselfly	214
Anopheles	220	Gomphids	212
Ants as enemies of imagos	224	Libellulids	213
<i>Argia apicalis</i>	215, 256	<i>Pantela flavescens</i>	217, 218
<i>Argia moesta putrida</i>	215, 256	Food of nymphs, Fairport, Iowa	201
<i>Argiope</i>	224	Hawaii	207
		Ithaca, N. Y.	208
Bees eaten by imagos	215	Frogs as enemies of imagos	224
<i>Belostoma</i>	210	Fungi as enemies of nymphs	211
Birds as enemies of imagos	222	General conclusions	246
Birds as enemies of nymphs	211	Gizzard teeth	196, 199
<i>Calopteryx</i>	256	Gomphus <i>amnicola</i>	250
<i>Celithemis elisa</i>	253	externus	236, 250
eponina	190, 214, 227, 253	fraternus	212
<i>Ceratopogon</i>	207	graslinellus	236, 248
Choice of locality	190	notatus	250
Choice of species	232	plagiatus	188, 249
Concealment	189	submedianus	248, 250
<i>Cordulegaster maculatus</i>	205	vastus	213, 250
<i>Cordulia</i>	233	Hemiptera as enemies of nymphs	210
<i>Corixa</i>	194, 202, 204	<i>Heterina americana</i>	258
<i>Crex grass</i>	187, 188	<i>Hyallalla</i>	208
<i>Cypris</i>	204, 208	Hybrid nymph	240
<i>Cypris inequivala</i>	207	<i>Hydra fusca</i> as enemy of nymphs	210
Diet, benefits	204	Imago	193
claims of injuries	204	Imagos as enemies of imagos	224
general character	202	Imagos as fish food	231
specific differences	202	Internal parasites	225
Diplax	238	<i>Ichnura (Nehalennia) posita</i>	259
Distance traveled	191	verticalis	189, 215, 227, 233, 258
Diving beetles as enemies of nymphs	210	Lestes <i>eurinus</i>	258
<i>Dromogomphus spoliatus</i>	213, 215	rectangularis	233, 258
<i>Drosera binata</i>	225	uncatus	259
<i>Dytiscus larvæ</i>	202, 204, 210	ungiculatus	259
Economic relations	200, 213	vigilax	215
<i>Enallagma antennatum</i>	215, 227, 257	<i>Leucorhinia intacta</i>	190, 213, 225, 242, 253
calverti	257	<i>Libellula auripennis</i>	238
civile	215, 233, 257	luctuosa	187, 190, 191, 214, 222, 233, 237, 239, 254
ebrium	257	pulchella	187, 190, 192, 233, 240, 255
geminatum	257	semifasciata	233
hageni	214, 225, 227, 233, 244, 257	Life history	192
signatum	227, 245, 258	Lophonotus	225
Enemies of imagos	222		

	Page.		Page.
<i>Macromia illinoiensis</i>	252	<i>Pneumonoceres variegatus</i>	225
<i>tæniolata</i>	251	<i>Polynema ovulorum</i>	210, 260
Malformed imagos	222	Ponds, series D	186, 187
Mandibles	196	Preparation of pond for stocking	233
Mask	194	Promachus	225
Maxille	194	Protective instinct	191
Migration	188, 216	Pruinose	193
Mites	210, 224		
Mouth parts	193	<i>Ranatra</i>	210
<i>Nasiaschna pentacantha</i>	251	Rearing nymphs	238
<i>Nehalennia irene</i>	227, 259	Reptiles as enemies of nymphs	211
Nematodes as enemies of nymphs	210	Robber flies as enemies of imagos	224
<i>Notonecta</i>	204, 210		
Nymphs as enemies of nymphs	209	<i>Simulium meridionale</i>	221
Nymphs as fish eaters	204	<i>pecuarum</i>	221
Nymphs as fish food	225	<i>vittatum</i>	203
Nymph-skin counts	190	Size of prey	216
		Source of food supply	216
Odonates as mosquito destroyers	220	Spiders as enemies of imagos	224
<i>Ædogonium</i>	211	<i>Stegomyia scutellaris</i>	209, 220
<i>Ophiogomphus morrisoni</i>	223	Stock material	234
<i>severus</i>	222	Stocking the fishpond	232
		Sundew as enemy of imagos	225
<i>Pachydiplax longipennis</i>	187, 190, 233, 254	<i>Sympetrum corruptum</i>	190, 192, 254
<i>Pantala flavescens</i>	190, 205, 252	<i>rubicundulum</i>	190, 238, 253
<i>hymenæa</i>	252	<i>Telephlebia godeffroyi</i>	221
Parasitic flies as enemies of imagos	224	Teneral	193
Parasitic flies as enemies of nymphs	210	Thrips	218
Parasitic mites as enemies of imagos	224	<i>Tramea lacerata</i>	190, 233, 252
Parasitic mites as enemies of nymphs	210	<i>onusta</i>	253
<i>Peltodyes</i>	202	Tsetse fly eaten by odonates	222
Periodic eating	217		
Periodicity	188	Vorticellids as enemies of nymphs	211
<i>Perithemis domitia</i>	190, 192, 253		
<i>Philotria</i>	187	Water scorpions as enemies of nymphs	210
Pitcher plants as enemies of imagos	225	Weather	189
<i>Plathemis lydia</i>	187, 190, 192, 214, 233, 243, 255	<i>Zaitha</i>	210

CARD 1944

DEPARTMENT OF COMMERCE
BUREAU OF FISHERIES
HUGH M. SMITH, Commissioner

PROGRESS IN BIOLOGICAL INQUIRIES, 1921

REPORT OF THE
DIVISION OF SCIENTIFIC INQUIRY FOR
THE FISCAL YEAR 1921

By R. E. COKER
Assistant in Charge of Scientific Inquiry

APPENDIX VIII TO THE REPORT OF THE U. S. COMMISSIONER
OF FISHERIES FOR 1921

Bureau of Fisheries Document No. 911

PRICE, 5 CENTS

Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

DEPARTMENT OF COMMERCE

BUREAU OF FISHERIES

HUGH M. SMITH, Commissioner

PROGRESS IN BIOLOGICAL INQUIRIES, 1921

**REPORT OF THE
DIVISION OF SCIENTIFIC INQUIRY FOR
THE FISCAL YEAR 1921**

By R. E. COKER

Assistant in Charge of Scientific Inquiry

**APPENDIX VIII TO THE REPORT OF THE U. S. COMMISSIONER
OF FISHERIES FOR 1921**

Bureau of Fisheries Document No. 911

PRICE, 5 CENTS

Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

**WASHINGTON
GOVERNMENT PRINTING OFFICE**

1922

PROGRESS IN BIOLOGICAL INQUIRIES, 1921.

REPORT OF THE DIVISION OF SCIENTIFIC INQUIRY FOR THE FISCAL YEAR 1921.¹

By R. E. COKER,²

Assistant in Charge of Scientific Inquiry.

CONTENTS.

	Page.
Introduction.....	4
Studies of fishes.....	5
The Pacific salmon.....	5
Immature salmon in the ocean.....	6
Results of marking experiments.....	7
Salmon investigation in Yukon River.....	7
Chemical studies of salmon.....	9
Life histories of marine fishes.....	10
Fresh-water fishes.....	11
Whitefishes of the Great Lakes.....	11
Fishes of Wisconsin lakes.....	13
The paddlefish.....	14
Poisonous action of gar roe.....	14
Fishes of the Panama region.....	15
Pacific herring.....	16
Use of fish in combating malaria.....	16
Cooperation in antimalaria campaign.....	16
Conditions governing abundance of mosquito-destroying fish.....	17
Mosquito control in northern waters.....	18
Fish-cultural experiment work.....	19
Experiments in propagating and rearing fish in ponds.....	19
Water beetles in relation to pond culture.....	20
Studies of Salmonidæ in relation to fish culture.....	20
Minnows in relation to fish culture.....	21
A new form of pond outlet.....	21
Eradication of some objectionable plants.....	24
Studies of fish disease.....	25
Mortality in pike-perch eggs.....	25
Abnormal conditions of fish ovaries.....	25
Disease of rescued fish.....	26
Parasitic flatworms of fresh-water fishes.....	26
Treatment of Ichthyophthirius disease.....	27
Oceanographic and limnological studies.....	28
Investigations in the Atlantic.....	28
Survey of Chesapeake Bay.....	29
Survey of selected areas in Mississippi River.....	29
Studies of inland lakes.....	30
Agar-agar and other gelatins from seaweed.....	31
The oyster.....	32
Investigations of oyster culture.....	32
Effect of pollutions upon propagation of oysters.....	33
Fresh-water mussels.....	35
Propagation of mussels.....	35
Protection of mussels.....	35
Mussel survey in upper Mississippi River.....	36
Experiments relating to mussel propagation.....	36
Investigations in the Kentucky River.....	37
The biological laboratories.....	37

¹ Appendix VIII to the Report of the U. S. Commissioner of Fisheries for 1921. B. F. Doc. No. 911.

² With the collaboration of the investigators.

INTRODUCTION.

The fisheries industries are immediately confronted with such acute problems of distribution of products that it would seem only natural if attention were temporarily detracted from the underlying and enduring problems of the industry—those relating to maintenance of the resources upon which the industries are based. Nevertheless the discussions among representatives of all phases of the industry when gathered together in such meetings and conferences as have been held during the recent period of stress have always brought to the front the problems that have to do with the perpetuation of fishery resources. Such conditions as the depletion of shad, the decline of the blue-crab fishery, and the deterioration of inshore waters through pollution, command such earnest consideration on these occasions as to prove that fishermen and dealers of broad vision are not misled through immediate difficulties in one department of the industry to minimize the importance of permanent sources of supply.

Upon due thought, of course, it is evident that the problems of supply must not be forgotten even momentarily; for the difficulties of distribution can be only heightened by continued depletion of resources and an inevitably accompanying increase in costs of production relative to the costs in competing industries. Obviously it can not become easier to market fish when they become less easily obtainable relative to other materials of protein food. No economic fact can be plainer than that diminishing abundance of fish must be followed by increasing prices and decreasing consumption.

It is, then, a fundamental and enduring principle that the perpetuation of the fisheries and the maintenance of their relative rank among other food-producing industries are contingent upon the continued productiveness of the fisheries—in a word, upon conservation. Conservation in turn depends upon the exercise of intelligence and restraint in the exploitation of fisheries resources, upon sound action in removing unnecessary causes of depletion, and upon wisdom in adopting plans for bringing about where possible an increase of particular fish or shellfish. The decline of valuable fisheries has been witnessed too often to admit of continued faith in the inexhaustibility of fish or shellfish of any kind. Yet the intelligent determination of what restrictive measures are necessary, what means of exploitation are unreasonable, or what plans of propagation or development are profitable can be made only upon the foundation of full and correct knowledge of the life histories, habits, and conditions of life of the fish that are to be considered.

It seems generally agreed, for example, that the blue crab of the Chesapeake is in actual course of extermination by unwise fishery methods, although there may not yet be agreement as to the particular methods which are unwise. Recently this very important question was referred to a conference of representatives of the two States concerned, together with officers of the Department of Commerce. The practical results of such a conference depend much, of course, upon the sound practical judgment and the broad spirit of those bearing the responsibility for determination of action; but the one indispensable basis of action is an understanding of the life of the crab. The sole hope of practical results from a conference of any group of persons having this problem in view rests upon such

knowledge as we have of the life history of the crab—in short, upon the results of scientific work previously done. Emphasis must be put upon the adverb of time. The significant thing is that the work must in great part, at least, have been already done; for knowledge can not be secured immediately; one can not produce the life history of an aquatic animal upon demand; it is the result of painstaking study through a period of time which can not be fixed in advance, and by the application of methods which can not be definitely plotted beforehand.

It is work of this kind which must be done, and continuously done, so that gradually and steadily we learn more and more about our fishery animals, if we are to be ready at all times to meet the changing problems of regulation and exploitation as they arise.

The scientific knowledge which is the basis of the future welfare of the fisheries requires not only time and application, but also skill and special training. Of greatest importance are the services of men who have not only natural qualifications and the preliminary training which institutions of learning can give, but also such special experience, interest, and devotion as can be gained only as the result of prolonged application to fisheries studies. Something may be done with inexperienced and changing agents, but the most successful and economical work will be done with a trained and continuing force.

In the following report will be found not an account of what might have been done, or what ought to have been done—but rather a statement of the progress which has been attained under the difficult conditions by which the scientific work of the Bureau has been circumscribed. It may be added that the Bureau again closes the year with a less effective force than it had at the beginning. Two members of the already depleted staff have resigned to accept better paying positions elsewhere, and two (including one rendering largely volunteer service) have died and not been replaced. Special acknowledgments are due to those whose interest and loyalty have held them in the public service.

In reviewing the subject of investigation it must be understood that while the Bureau has a definite policy of restricting expenditures to investigations of the most direct practical bearing, it is not entirely untrammelled in the selection of subjects of investigation. The qualifications of the personnel available necessarily determine in part the character of problems which can be profitably attacked.

STUDIES OF FISHES.

THE PACIFIC SALMON.

When consideration is given to the magnitude of the industries based upon the salmons and their near relatives, to the unrivaled rank which some of these fishes hold in the realms of sport and recreation, to the comparative ease with which the more important species may be brought to virtual extermination, and to the fact that all important species are the subject of artificial propagation, it is apparent that no group of fishes demands a greater share of attention in the way of scientific study.

For many years investigations have been directed particularly at the Pacific salmon, and the facts of life histories which are easiest to secure have been acquired, but yet we are far from having possession of the full knowledge necessary to direct propagation most efficiently, or to determine correctly the restrictive measures which may be enforced with least interference with the proper utilization of the fishes. The problems before us now are those requiring the closest and most persistent study, and yielding solution only slowly and by small stages.

IMMATURE SALMON IN THE OCEAN.

The investigations of salmon in Pacific Coast States have been conducted by Willis H. Rich, special assistant. The study of salmon taken by troll and purse seine in the open ocean has practically been completed. A preliminary report was prepared and, by authority of this Bureau, was published by the California Fish and Game Commission. The conclusions reached may be briefly summarized.

The fish taken in the ocean off the mouth of the Columbia River contain, in the spring and early summer, approximately 70 per cent of individuals which will not become sexually mature for one or two years, but by the middle of August this condition has changed so that nearly 90 per cent are fish which will soon enter the river for the purpose of spawning. The rate at which this change takes place and the time at which it occurs have not yet been determined, but will be taken up in a later report. A comparatively small percentage of the fish found just within the mouth of the Columbia River are immature. It should be mentioned in this connection that it is only occasionally, when unusual tidal conditions obtain, that any immature fish are taken inside the mouth of the stream.

The fish taken by troll in Monterey Bay in June contain a considerable proportion of immature individuals. The data obtained in 1918 are most reliable and indicate that only about 40 per cent of the fish taken would have spawned during the same year. The data for 1915 indicate that 75 per cent were mature, but selection may well have taken place in making this collection which consisted of egg samples only.

The fish taken near Drakes Bay and Fort Bragg in July and August, 1918, contain approximately 30 per cent of immature fish. It is of interest to note that this is an approach to the conditions found off the mouth of the Columbia River in August and suggests that the composition of all the schools found near the coast changes materially during the summer season.

It is understood that the preliminary report was used to advantage in the recent movement restricting the operations of both trollers and purse seiners off the coasts of Oregon and Washington. Additional data will be embodied in a later report.

Incidental to the work with the fish taken in the ocean considerable data have been collected which will apply to the report dealing with the general life history of the chinook salmon. Progress has been made in the identification of races, and additional evidence from the scales of returned marked fish has confirmed the work done last year on the significance of the various types of nuclear growth.

RESULTS OF MARKING EXPERIMENTS.

Mr. Rich has also submitted a report on "Returns from the experiments on the marking of young chinook salmon on the Columbia River." The experiments were started in 1916-17 and described in Economic Circular No. 45.

The percentage of returns of marked salmon was rather low, but the results obtained are of some significance. Examination of the scales of the marked fish which have returned after a period of three to four years corroborates the theory that the arrangement of the concentric rings (circuli) provides an accurate record of the previous history of the fish. A study of the scales of these marked fish will, moreover, aid very materially in the solution of perplexing problems which have arisen in interpretation of the scales of the chinook salmon.

Facts gathered during the investigation throw some light upon the rate of spawning migration of adult chinooks, indicating that the rate is approximately the same as that previously determined for sockeye salmon passing through Puget Sound and the Fraser River, that is, some 10 to 15 miles per day.

Perhaps the most interesting and important contribution which these experiments have made to our knowledge of the biology of the salmon relates to the hereditary character of the factors determining the time of the year at which the adults enter fresh water and begin their upward migration to the spawning grounds. It is an important practical question whether or not it is necessary to breed from fish of the spring run in order to produce the spring-run fish, which are more desired than the fall-run fish. The evidence of the marking experiments gives some indication that spring-run fish will be derived from spring-run parents and fall-run fish from fall-run parents.

A comprehensive program of experiment has been planned to extend over a period of several years. Two new marking experiments have been started on the Columbia River in cooperation with the Oregon Fish and Game Commission, nearly 100,000 young chinooks having been marked at Little White Salmon station and the State hatchery at Bonneville.

SALMON INVESTIGATION IN YUKON RIVER.³

During 1920, from May until September, Prof. Charles H. Gilbert, temporary investigator, and Henry O'Malley, field assistant in charge of Pacific coast work, conducted an investigation in Yukon River with reference to the runs of salmon, the commercial packs in and near the mouths of the rivers, and the requirements of the natives and others dependent on the runs of salmon in the Yukon River system. Data were secured for a comparison of conditions prevailing in 1919 and 1920. The primary object was to determine whether or not commercial fishing for export should be allowed in the Yukon River and its tributaries.

While all five of the Pacific coast species of salmon make their appearance at the mouth of the Yukon, only three species have sub-

³ Cooperative investigation by Divisions of Fish Culture, Alaska Fisheries, and Scientific Inquiry. Only the biological data are summarized here. The full report is published on pp. 128-154 in *Alaska Fishery and Fur-Seal Industries in 1920*, by Ward T. Bower, Appendix VI, Report of the U. S. Commissioner of Fisheries for 1921, B. F. Doc. No. 909.

stantial runs in the Yukon River (king, chum, and coho), and of these king and chum are of the greatest importance by far. The few reds or sockeyes taken near the mouth of the river are perhaps strays, for no breeding has yet been reported from any part of the Yukon Basin. Humpbacks appear at the mouth of the river more numerous than the red salmon, but never in sufficient numbers to constitute a run even of small dimensions. As they were far advanced toward spawning in July, it was evidently impossible that they could ascend the river far with their spawning period so close at hand. The coho runs more or less numerous than the king or chum salmon and in addition is the latest to appear, often not presenting itself in any numbers in the middle and upper reaches of the river until the ice is forming in the fall.

The king salmon begins running in the last week of May or the early days of June. The run culminates quickly and then almost as quickly declines. The rate of migration was found to be remarkably high, the average rate of travel from Tanana to Dawson being slightly less than 45 miles per day, and from Pilot station to Dawson, involving practically the entire length of the river below Dawson, the average rate was 57 miles per day. No record of any other river approaches this in completeness, nor in the high rate of travel indicated. This unexampled speed with which salmon ascend the Yukon is doubtless associated with the great distances to be traversed before reaching their upper spawning areas, taken in connection with the shortness of the summer season.

The most important natural enemies of the king salmon are the white whales, or belugas, and the lamprey eels, the former being undoubtedly exceedingly destructive, while the latter, though causing scars on the fish in much greater abundance than in any other river, as observed by investigators, do not appear to effect serious injury to the fish.

The chum salmon, which is the principal food product of the Yukon River, made its appearance but a few days later than the advent of the king salmon, the rate of migration being approximately the same as that of the king.

Two phases in the development of the chum salmon are distinguished by the natives under the names of "dog salmon" and "silver salmon," the dog salmon comprising the individuals furthest advanced toward spawning. In general the "dog salmon" along any stretch of the river consist of those individuals which will turn into some adjacent tributary to spawn, while the "silvers" are on their way to the upper reaches of the river, show relatively little of the sexual changes they will exhibit on their spawning beds, and are still richly provided with the oil which serves as fuel and the principal source of nourishment during the long journey still before them.

"Dogs" and "silvers" were in general keeping apart from each other and following distinct migration routes, the "dogs" predominating on the right and the "silvers" on the left side of the stream. Heavier runs of kings and cohos were found in company with the "silvers" along the left limit of the river. It appears, therefore, that there is a prevailing use of the left shore by those fish which are found in the upper reaches of the river. This may have

connection with the fact that the majority of the tributaries of the lower river enter on the right bank.

Fishermen recognize the succession of phases in the run—the chums which accompany the king salmon being of relatively small size and poor quality, after which there is a run of bright fish of good quality, but inferior size (“silvers”), and finally the last run of “silvers” of a bright rich form and of distinctly larger size. This last run of “silvers” is ordinarily of short duration and furnishes the most highly prized fish of the season. A further more detailed study of the characteristics of the chums at different times and in different localities and the distribution of the various strains to their respective spawning areas would offer results of importance from the biological and equally from the strictly practical points of view.

The investigators record their opinion that the king salmon of the Yukon is the richest in oil of any known king salmon, and express the same view with even greater emphasis regarding the Yukon chums. In this connection it is remarked that in other river basins the chums do not travel far from the sea, but enter late in the season to seek spawning beds not far inland, while the best of the Yukon chums travel 1,000 to 2,000 miles up a river known for its consistently rapid current.

Consideration was given to the passage through which the salmon enter the river, and the investigators considered it not beyond the bounds of probability that nine-tenths of the salmon run enter by the Kwikluak Pass and its subsidiary channel, the Kwiguk.

CHEMICAL STUDIES OF SALMON.

Without expense to the Bureau, Prof. C. W. Greene, of the University of Missouri, has continued his chemical studies of material collected several years ago to determine the changes in salmon ovaries and tissues during the period of migration from sea to breeding grounds. The results of such studies can at first be given only technical expression, but they are none the less likely to yield in the end data of direct economic value.

The chemistry of the king salmon ovaries during their development in the migration period followed in the year 1908 on a series of samples collected on the Columbia River and its tributaries has been tabulated and prepared for publication.

These studies show the following major points: First, the growth of the ovary takes place primarily during the migration while the salmon is fasting. The average increase in weight is from about 135 to 150 grams at the end of the feeding period to 2,000 to 2,500 grams at maturity. In short, about 90 per cent or more of the development takes place during the prolonged fast of the migration.

Chemical analyses of developing ovaries show that between the 500-gram stage and the mature-egg stage there is a remarkable uniformity of chemical composition. The proteins are high, averaging from 29.38 to 31.16 per cent. This is undoubtedly all stored protein. The neutral fats decrease with the development and migration, from an average of 14.15 per cent at the mouth of the river to 10.83 per cent at the spawning. Phospholipins average 4.78 at the mouth of

the river and 2.85 at the spawning, showing a decrease with development. The phospholipins are much lower than in the yolk of bird eggs, the hen's egg averaging 11 per cent. The water-soluble organic extractives and the ash are both remarkably uniform, the extractives averaging 1.87 to 1.65, the ash 0.66 to 0.81 per cent. The organic extractives and ash are both low in comparison with other salmon tissues, but compare favorably with their percentages in the yolk of other eggs.

The salient points in this study are found in the showing of high protein storage in the salmon-egg yolk, the relatively low percentage of neutral fats and of phospholipins, and the decrease of neutral fats and phospholipins during development. Since in other eggs these fatty constituents are higher and tend to increase with development, it is probable that in the salmon the decrease is due to the extreme drain on the fatty deposits for the production of dynamic energy during the migration.

Determination of carbohydrate content of certain tissues of the king salmon during the spawning migration was undertaken as an accessory test. The gross samples were preserved in alcohol, and in the final analysis all glycogen was converted to glucose and the determination made in that form. The results show a very low glucose content of all organs and tissues. Glucose was present in all the tissues of the feeding salmon, Monterey Bay and Bolinus Bay specimens, but was absent or in reduced amount in the migrating and spawning salmon, with the exception of one tissue, the ovaries. In the ovaries, the percentage of glucose was practically constant throughout the migration.

LIFE HISTORIES OF MARINE FISHES.

During July and August, 1920, studies of the life histories of fishes of the middle Atlantic coast were carried on by W. W. Welsh, scientific assistant, aided by C. M. Breder, at a temporary station on Young's Pier, Atlantic City, N. J. Through the courtesy of Capt. J. L. Young, owner of the pier, a serviceable two-room building, formerly used as a wireless telegraph office, was adapted for use as a laboratory. A small hatchery, equipped with tidal box and Chester jars, was set up and supplied with filtered salt water from the pier aquarium. A great variety of material was obtained from the two pound nets operated under the pier. Eggs of several species, obtained from fish taken in these nets, were hatched in Chester jars, and the fry carried on as long as possible for study. Series of scale samples for the determination of age and growth were also taken.

Among the species studied were northern and southern king whiting (*Menticirrhus saxatilis* and *M. americanus*), squeteague (*Cynoscion regalis*), spot (*Leiostomus xanthurus*), croaker (*Micropogon undulatus*), silver perch (*Bairdiella chrysura*), menhaden (*Brevoortia tyrannus*), and puffer (*Spheroidees maculatus*).

Although the facilities generously furnished by Capt. Young could hardly have been improved upon, the work was greatly handicapped by the abnormally cold water which prevailed throughout the summer. Water temperatures ranged from 53 to 65° F. and averaged about 57° F. This low temperature is believed to be the cause of the

scarcity or entire absence of a number of species which it was hoped could be obtained and studied.

The same investigators completed during the year a valuable report on the life histories of fishes of the family *Sciænidae* of the Atlantic and Gulf coasts. The family includes some of the most important food fishes, the annual catch on these coasts approximating \$3,000,000 in value. No less than 37½ per cent of the fish landed at the municipal fish wharf, Washington, D. C., in 1919 were of this family; the principal species were the squeteague, or weakfish, often erroneously called sea trout, the highly esteemed king whiting, the red drum, or channel bass, the croaker, spot, and silver perch.

How can we act intelligently with reference to the exploitation of such resources or determine wisely how to preserve them for all time if we do not know the life histories of the fishes, when and where they breed, their migrations in summer and in winter, the rate of growth, and the food they require? The present report not only brings together the fragmentary data hitherto available but adds materially to existing knowledge by embodying the results of years of researches, particularly those of the senior author, whose death unfortunately preceded the final completion of the paper.

The report also serves the valuable purpose of making evident the gaps in existing knowledge, revealing the need of additional observations, and showing plainly the directions which further studies should follow. As similar work is done for other families of fishes we shall come nearer to realizing the practical value of applying science to the study of fishes.

Mr. Welsh also completed descriptions of seven new species of marine fishes (*Malacopterygii*) taken during the explorations of the United States Coast and Geodetic Survey steamer *Bache*, conducted in 1914 under the direction of the United States Bureau of Fisheries. The fish were taken at various stations in the vicinities, respectively, of Cape Hatteras, the Bermudas, and Bahama Islands. After Mr. Welsh's death the descriptions were prepared for publication by C. M. Breder. The report has been accepted for publication by the United States National Museum.

Both assistants have been lost to the Bureau during the year, the one by untimely death, the other by resignation.

FRESH-WATER FISHES.

WHITEFISHES OF THE GREAT LAKES.

There is scarcely a sadder feature of the history of American fisheries than the progressive depletion of the important resources of the Great Lakes, notably in respect to the whitefishes. We may have overestimated the possibilities of exploitation, we may have been shortsighted in the fishery policies we pursued, or we may not have propagated them with proper energy or efficiency. But the simple fact is that no one has had enough knowledge of the distribution, habits, and requirements of whitefishes to give proper advice. The best intentions can not save a situation when founded upon ignorance. If the whitefish fisheries of the Great Lakes are to be preserved to the future or perhaps restored in part to their earlier rank, we must study the fishes and ascertain the condition of their existence.

Therefore, for several years the Bureau has had a skilled assistant devote exclusive attention to the whitefishes and related species. This investigation, pursued by Walter Koelz, scientific assistant, is not all that is required, but it will surely provide a fund of information for more intelligent guidance in future.

The investigation of the systematic relationships and habits of the coregonines was conducted in the year 1920 on Lake Michigan. Forms allied to those which the investigations of the previous year disclosed in Lake Huron, and in addition two undescribed species, of which at least one is now known to occur also in Huron, were obtained. Diagnoses of the species have been prepared from over 2,000 preserved specimens. Data have been collected bearing on the distribution in the lake and on the spawning habits of the various forms. To avoid dissemination of premature conclusions a report will not be published until work is done upon other lakes.

These studies have been supplemented by microscopic examination of the scales and systematic investigation of the food, conducted, respectively, by John Van Oosten and Carl L. Hubbs, temporary investigators, under the direction of Prof. Jacob Reighard.

Mr. Van Oosten first determined that the scale characters of the lake herring (*Coregonus artedii*) are so well defined as to permit the determination from them of the age of individuals and the rate of growth of the species. The variations in the scales of individuals were found to be within specific limits. But scales from different parts of the body of an individual are so unlike that for comparison of individuals or species it is necessary to use scales from the same body region.

The scales of 10 specimens of each of the 10 Lake Huron forms recognized by Koelz were next compared, and it was found that 8 of them (including the two races) are discriminable. Further study will probably enable discrimination of the two other forms. It appeared that in one of these forms (*Coregonus artedii*) there are probably two geographic races which differ in rate of growth, but the matter needs further study.

Through the courtesy of Dr. C. H. Townsend, director of the New York Aquarium, it was possible to secure specimens of whitefish (*Coregonus clupeaformis*) hatched and reared at the aquarium and therefore of known age (7 years). The 10 specimens studied show that there is one annulus for each year of age. This, so far as known, is the first demonstration of this fact and enables the determination of the age of coregonine fish from scale characters to be undertaken with confidence. Two individuals of the 7-year-old whitefish were segregated at the New York Aquarium and kept living, while scales were removed at intervals of a month. A study of these scales shows that the annuli are formed in winter, fixes the time of formation, and indicates temperature change as one of the factors. It is believed that a continuation of these studies will add materially to our knowledge of age and rate of growth of coregonine fishes, aid in their systematic grouping, and lead to the discovery of local races in some of the forms.

The food of the whitefish, lake herring, and allied species of Lake Huron coregonines in the Koelz collection was investigated by a volumetric method by Carl L. Hubbs, of the Museum of Zoology,

University of Michigan. The deep-water forms, as the blackfin (*Leucichthys nigripinnis*), were found to feed almost exclusively upon the crustacean *Mysis relicta*, probably the only available food. The deep-water race of the bloater (*Leucichthys hoyi*) feeds chiefly on *Mysis*, while a 30-fathom race eats for the most part another lake crustacean, *Pontoporeia hoyi*. The food of the shallow-water forms is much more varied. The pilot or menominee (*Prosopium quadrilaterale*) is strictly a bottom feeder, subsisting on mollusks, insect larvæ, crayfishes, etc. The whitefish (*Coregonus clupeaformis*) is also a bottom feeder, but its food is, on the average, not so coarse as that of the pilot, consisting largely of insect larvæ, as those of the mayflies *Hexagenia* and *Ephemera*. The lake herring feeds in part upon the same animals, in part upon the minute Crustacea of the plankton. In reference to their available food supply the deep-water forms are absolutely competitive (more so perhaps than any other group of fishes), while the shallow-water forms are only in part competitive. It is probable, however, in view of the former greater abundance of these fishes, that sufficient food exists in the lakes to support a larger population of all the species of whitefishes.

FISHES OF WISCONSIN LAKES.

The food and distribution of the fishes in certain Wisconsin lakes have been studied by Dr. A. S. Pearse.⁴ The results indicate that in summer fishes are generally more abundant as conditions approach those in swamps and are fewest when the environment is most like that in rivers. When food is present in quantity and when other conditions are favorable, there are more fishes per unit area in certain inland lakes than in the Mississippi River or in Lake Michigan. Lakes produce considerable food supplies within themselves, while rivers are more dependent on swamps, ponds, and other tributaries. The factors of importance in limiting the distribution of fishes are discussed (shores, turbidity, depth, bottom, height of water, currents, etc.). An abundant supply of food and vegetation permits many fishes to *exist* in a lake, but other favorable conditions must be present in order that they may grow to large size.

A statistical study of the infection of fishes by parasites has been made, the Mississippi and St. Lawrence drainage systems being compared, and various types of lakes studied. The results are now being tabulated and will soon be ready for publication. A short paper on the habits of the mud puppy, in which its relations to fishes are discussed, has been published.⁵

In order to secure information on the rate of growth of cold-blooded animals in natural conditions, attempts are being made to recover the fishes and turtles tagged and released in Lake Mendota during the summer of 1919. Some specimens have already been secured.

Studies on the metabolism of fishes are being continued. In this connection quantitative analyses are being made to show the water, ash, nitrogen, and ether extractives of fishes at various stages of growth.

⁴ Pearse, A. S.: The Distribution and Food of the Fishes of Three Wisconsin Lakes in Summer. University of Wisconsin Studies in Science, No. 3, June, 1921, 60 p. Madison.

⁵ Pearse, A. S.: Habits of the Mud-Puppy *Necturus*, an Enemy of Food Fishes. Bureau of Fisheries, Economic Circular No. 49, issued May 16, 1921, 8 p. Washington.

THE PADDLEFISH.

The study of the natural history and artificial propagation of the paddlefish in Bayou Pierre at Westdale, La., was continued by Dr. A. D. Howard, scientific assistant, with the cooperation of the Louisiana Conservation Commission. During March good catches of egg-bearing females and sufficiently ripe males were obtained, but no females were ripe enough to allow of fertilization of eggs. Late in the month heavy rains flooded the Red River and Bayou Pierre and prevented the capture of fish in sufficient numbers to continue the investigation.

There are few added data regarding the breeding grounds of the fish and the time and manner of spawning. Some information of minor importance was obtained regarding certain habits of the species. Bottoms suspected of being the breeding grounds of the paddlefish were dredged for the purpose of obtaining eggs, but without success.

POISONOUS ACTION OF GAR ROE.

In a previous year experimental attempts to produce caviar of gar roe were made by Prof. C. W. Greene, temporary investigator. Out of this work it developed that the pigment in the gar roe is not a melanin as in the sturgeon roe, but a form of pigment that changes color under various chemical treatments of the roe. The pigment color is changed to an orange red on boiling the gar eggs, on treatment with alcohol or ether, and on salting. This changes the commercial quality of the product and gives easy methods for detecting the adulteration of sturgeon roe by gar roe.

The important observation, however, was the demonstration of an active physiological principle of a toxic nature present in gar roe. It is apparently this principle that gives the unpleasant acrid taste to gar-roe caviar. When tested biologically by the method of feeding the natural product the following points were made: (1) Gar roe is poisonous to the chicken and to the rat; (2) it paralyzes the neuromuscular mechanism of the chicken crop; (3) it produces in the rat an intestinal irritation with active diarrhea.

During the summer of 1920 a series of experiments were made to chemically separate and biologically test the unknown toxic substance. It was shown that (1) extracts in boiling water free from coagulable protein and (2) similar alcoholic extracts contained an active principle toxic to the heart of the frog; (3) globulin fractions made by the method of salting out, centrifuging, and purifying by dialysis were sharply toxic to the heart; (4) the globulin fractions fed to a young rat produced extreme diarrhea and death in about 20 hours, effects comparable to feeding the entire fresh ovary; (5) the effect on the chicken's crop was positively toxic; (6) not only was the crop paralyzed but an acute diarrhea occurred in the chicken through some alimentary canal poisoning; (7) these effects also occurred after feeding the purified globulin.

Attempts to isolate and identify the individual chemicals, of which at least two classes are present, have thus far not been brought to a successful issue. Further experiments are planned.

FISHES OF THE PANAMA REGION.

The Bureau of Fisheries, late in 1910, entered into an agreement with the Smithsonian Institution and the Field Museum of Natural History for a cooperative study of the fishes of the Panama Canal Zone. The work was carried on under the auspices of the Smithsonian Biological Survey of the Panama Canal Zone. The field work was done by Dr. Seth E. Meek, of the Field Museum, and Samuel F. Hildebrand, of the Bureau of Fisheries, during two expeditions made to the Canal Zone, from January to June, 1911, and January to March, 1912, respectively. The study of the collections which were sent to the National Museum was begun during the interval between the two expeditions and continued after the second visit to Panama by the collectors. After two small preliminary papers containing descriptions of new species of fresh-water fishes had been written, and a majority of the forms had been roughly identified and separated, Dr. Meek was obliged to withdraw from the work because of an illness from which he never recovered. The completion of the work was then left to Mr. Hildebrand. As other duties were necessarily assigned to Mr. Hildebrand from time to time, the completion of the study of the collections was greatly delayed. The final report on the fresh-water fishes, however, was completed and published in 1916, but the study of the marine forms was not completed until the spring of 1921. In the last months of the work the author was assisted by W. C. Schroeder.

The total number of species recorded from the coasts of Panama, either taken by Messrs. Meek and Hildebrand, or previous collectors, or both, is 640. The remainder of the species included in the paper were discussed because their known range of distribution is such that they may be expected on the coasts of the Isthmus. The fishes on the Pacific coast run larger than those on the Atlantic and are more numerous both as to species and individuals. Much more collecting, however, has been done on the Pacific side than on the Atlantic, which undoubtedly accounts in part for the large difference in the number of species recorded. The total number of species listed as common to both coasts of Panama is 72, but of these 48 are more or less cosmopolitan in their distribution, that is, they are not confined to American waters. A very large number of species considered distinct are, however, very closely related, differing only slightly but in apparently constant characters.

It was pointed out in the report on the fresh-water species that the fishes of the opposite slopes of Panama are very closely related, some of them remaining identical. This close relationship indicates that the fishes of the two slopes had not long been separated. Since the opening of the Canal they, of course, can again freely intermingle in those streams which are connected with the Canal. The close parallelism of the marine species of the opposite coasts is evidence of a comparatively recent passageway from ocean to ocean, even for salt-water forms. The genera of many families have representatives on both coasts, and if they do not include identical species they at least have very closely related forms on the opposite coasts. A few families, however, deviate from this general rule in having many more representatives on one coast than on the other. The reasons

for this may be found by consideration of the habits of the species of those families which do not conform to the usual rule. The Siluridæ (including the catfishes), for example, are very much more numerous on the Pacific coast than on the Atlantic. The Scaridæ (including the parrot fishes and viejas), on the other hand, are much more numerous on the Atlantic than on the Pacific. It is well known that most catfishes frequent water with soft or muddy bottom. The Pacific coast of Panama has many large mud flats partly or wholly exposed at low tide but flooded during high water. The Scaridæ prefer rocky bottom, and especially coral reefs, which are large and extensive on the Atlantic side. These conditions undoubtedly prevailed, in part at least, before the last passageway between the two oceans was closed, and it is probable that these families had already sought out regions best suited to their particular needs.

The commercial fisheries of Panama are still largely undeveloped. The possibilities for profitable fisheries appear to be especially good on the Pacific coast, but apparently less promising on the Atlantic side of the Isthmus. The people of the Isthmus are less wasteful of fishes than the people of the United States, as nearly all species of fish taken, including sharks and skates, are utilized as food.

PACIFIC HERRING.

During the year the Bureau issued a memorandum dealing with the distribution, migrations, sizes, and spawning times and places of the Pacific herring in southeast Alaska and British Columbia, based upon the observations of D. R. Crawford, scientific assistant.

There are apparently two races of herring (*Clupea pallasii*), one of which resides in the bays and inner waterways along the coast from Puget Sound northward to British Columbia and southeast Alaska. The other, which is composed of larger individuals, passes along the outer coasts where it is taken off Vancouver Island in June, July, and August.

The smaller race of herring is found to be sexually mature in the summer, but no milt or roe is found during the winter. Sexually mature individuals vary in size from 6 to 10 inches. The probable spawning time is late summer or early fall. The larger race of herring reaches sexual maturity in the fall and winter, the individuals varying in size from 9 to 12 inches or longer. The probable spawning time is winter or early spring.

USE OF FISH IN COMBATING MALARIA.

COOPERATION IN ANTIMALARIA CAMPAIGN.

Investigations of fishes in relation to mosquito control were conducted during the mosquito-breeding season of 1920 by Samuel F. Hildebrand, scientific assistant, working in cooperation with the United States Public Health Service. In the spring and early part of the summer Mr. Hildebrand inspected various localities in 12 Southern States where malaria-control work was to be undertaken. Suggestions were offered concerning the employment of fish for the control of the mosquito, and the waters suitable for fish control were pointed out to the officers in charge. The result of these inspections

was that the top minnow, *Gambusia affinis*, was very widely employed as an agent in the control of malaria. A report of observations made by Mr. Hildebrand during this campaign has been published by the Public Health Service.⁶

The latter part of the season was devoted to investigations at Savannah, Ga., where a special effort was made to determine the relative value as eradicators of mosquito larvæ of two other American viviparous species of fishes, *Heterandria formosa* and *Mollienisia latipinna*, both of which are abundant at Savannah. It was demonstrated that *Heterandria formosa* is of real value and is well worth careful consideration wherever it occurs. *Mollienisia latipinna*, on the other hand, appeared to be practically worthless.

The antimalaria campaigns in the various States were brought to a close early in November, in which month the annual meeting of the National Malaria Committee and the conference of sanitary engineers engaged in antimalaria work took place in Louisville, Ky., where the outcome of the past season's campaign was reported and discussed. The subject of mosquito control by the use of top minnows received extended discussion, and the fact was brought out that nearly every sanitary engineer had made use of *Gambusia affinis* as an agent in malaria control with excellent results. The saving of large sums of money was reported, because fish control replaced other methods at much less expense.

Similar advisory work was done by Mr. Hildebrand in the spring of 1921 before establishing headquarters at Augusta, Ga., for further investigations to determine more fully the conditions of effectiveness in the employment of fish for destruction of disease-bearing mosquitoes.

CONDITIONS GOVERNING ABUNDANCE OF MOSQUITO-DESTROYING FISH.

R. L. Barney and Barry Anson have continued the organization and summarizing of data collected at Mound, La., where investigations of the use of fish for control of mosquito breeding were previously conducted in cooperation with the Bureau of Entomology.

Reports⁷ printed outside the Bureau's publications demonstrate the varying seasonal frequency of *Gambusia*, the mosquito-eating fish; the seasonal variation in the proportions of the sexes and its bearing on the abundance of the species in nature; the effect of environment on the abundance of the species; and the relation of plants of varying habits of growth to oxygen supply and to the capacity of small ponds to support the top-minnow *Gambusia*. Further observations have been made on the seasonal abundance of *Gambusia*, especially in relation to the fecundity of the species. Appropriate consideration has been given certain points concerning the anatomy of the female reproductive organs of this fish.

⁶ Hildebrand, Samuel F.: Top Minnows in Relation to Malaria Control, With Notes on Their Habits and Distribution. Treasury Department, Public Health Bulletin No. 114, May, 1921, 34 p. Washington.

⁷ Barney, R. L., and Anson, B. J.: Relation of Certain Aquatic Plants to Oxygen Supply and to Capacity of Small Ponds to Support the Top-minnow (*Gambusia affinis*). Transactions, American Fisheries Society, 1920, pp. 268-278.

Abundance of the Mosquito Destroying Top-minnow *Gambusia affinis*, Especially in Relation to Male Frequency. Ecology, Vol. 11, No. 1, January, 1921, pp. 53-69.

The study of the natural history and ecology of the pigmy sunfish, *Elassoma zonatum*, has been concluded and given publication.⁸ It appears that this fish, under certain conditions, may have some value in eradicating immature mosquitoes.

MOSQUITO CONTROL IN NORTHERN WATERS.

While in northern States mosquitoes have a less acute relation to public health than in regions where malaria is prevalent, they nevertheless constitute there a distinct menace to health and efficiency, besides being effective in causing a material reduction of property values, especially in regions which are normally resorted to for purposes of recreation and recuperation of vigor. During the year Prof. J. P. Moore, temporary investigator, has completed a report upon his observations of the use of fish and other aquatic animals for the control of mosquito breeding in northeastern States. His conclusions and suggestions may be summarized.

Although no fish to which mosquitoes are more than an incidental item of the diet has been found in the fresh waters of the northeastern States, nevertheless several species of small fishes and the young of some large ones native to these waters eat mosquito larvæ, pupæ, and eggs more or less habitually. The most important of these mosquito repressors are the common sunfish, the mud minnow, and the common killifish.

Fishes are found to be far more detrimental to culicine than to anophelene mosquitoes. While in the aggregate they destroy vast numbers of eggs, larvæ, and pupæ, and (along with other enemies) probably prevent mosquitoes from becoming everywhere an intolerable nuisance, the destruction is never complete. Some breeding of mosquitoes continues in nearly all bodies of fresh water even when well stocked with mosquito-eating fishes. This imperfect suppression arises through conditions limiting the efficacy of the fishes, most important of which are (1) the barriers that almost all natural bodies of water afford and which prevent the fishes from finding the young mosquitoes, and (2) the abundance of other food for the fishes. Most native mosquito-eating fishes will not thrive in water contaminated by excess of decaying vegetation or otherwise.

The most prevalent of the barriers is the shallow water and marginal vegetation. In ponds formed by dams provided with head gates a simple, effective, and economical method of controlling and reducing marginal vegetation is by lowering and raising the water level periodically, thus alternately drying and drowning the plants. In ponds and lakes of fixed level mechanical means of clearing the margins must be employed.

The most practical method of keeping the per capita food supply low is by overstocking with a variety of small fishes. Reduction of the vegetation also diminishes the supply of fish food.

The common sunfish (*Eupomotis gibbosus*) is the most useful species for ponds and lakes generally. With it may be associated the long-eared sunfish (*Lepomis auritus*), roach (*Abramis chrysoleucus*), some of the smaller minnows, black bass, etc. If there is much

⁸ Barney, R. L., and Anson, B. J.: Life History and Ecology of the Pigmy Sunfish (*Elassoma zonatum*). Ecology, Vol. I, No. 4, October, 1920, pp. 241-256.

aquatic vegetation the blue-spotted sunfish will prove a valuable addition, and if very shallow or swampy areas occur, the mud minnow. The common killifish is very effective in fresh and brackish tidal marshes, and the translucent killifish is useful in upland creeks and dams. Rapid multiplication of small fishes should be encouraged by providing suitable nesting sites and protection for the fry.

Gambusia, the favored top minnow of southern waters, has not survived the northern winters but multiplies so rapidly that it may be used effectively against both *Culex* and *Anopheles* in small ponds and water gardens by planting a small number each spring. Small goldfishes are useful in fountain basins and small ponds with clean sides, and, for use in rain barrels and tanks, are preferable to *Gambusia*.

FISH-CULTURAL EXPERIMENT WORK.

EXPERIMENTS IN PROPAGATING AND REARING FISH IN PONDS.

The Fairport station has continued its valuable experimental work in reference to the propagation and rearing of fishes in ponds. Certain observations were made on the value of fertilizing ponds with chemicals and manure, but data obtained to date are inconclusive. Further study will be directed toward this problem.

The small pond, which for several years has been handled as a farm pond with minimum care and expense, has yielded valuable information. Originally it was stocked with bluegill sunfish. Occasionally, when necessary, the pond has been wintered out. There has been no manipulation of the pond in any respect other than the control of the number of bluegills of various ages in it. During the past year the actual production of fish meat in the ponds has been 333 pounds per acre. Of this, however, fishes of edible size represented about 33 per cent of the total fish-meat production. In this connection it may be well to note that the average annual production of beef per acre on untitled meadowland is said to be 125 pounds; that for hogs is 225 pounds.

Buffalofish, *Ictiobus cyprinella*, artificially reared in the station ponds, reached maturity and produced young for the first time at the age of 4 years. They averaged 13.6 inches in length and approximately 2 pounds in weight. The small-mouth buffalofish, *Ictiobus bubalus*, which in previous years had failed to spawn in the experimental ponds unless an artificial rise in the level of the pond was produced, spawned this year in a pond in which the rise did not occur. While the production of fry of this species does not appear to be as numerous as for those fish held in the pond with artificial rise, the occurrence indicates that the rise is not entirely necessary, though it may be advantageous.

The channel catfish, *Ictalurus punctatus*, for which this station showed the feasibility of pond culture, has continued to spawn in the experimental ponds. Certain 4-year-old offspring of wild stock came to sexual maturity during the year and produced the first brood of truly domestic fish. The adaptability of this species to pond culture is suggested by the fact that the catfish has spawned in certain of the smallest ponds on the reservation, one of which has a water-surface area, when completely full, of only 3,485 square feet (less than one-twelfth of an acre).

WATER BEETLES IN RELATION TO POND CULTURE.

CARDED 1945 - L. B. Wilson

The home fishpond is a subject of continued interest among farmers and others who value the additional table food made available or the means of recreation provided. There must be a great deal in a pond besides fish; otherwise the fish would starve. There must be small animals which serve as food to fish and still smaller animals and plants which serve as food for them. Some things in a pond are desirable, others objectionable in varying degree. The fishpond is, indeed, not a simple thing, but a very elaborate complex, the scientific unraveling of which is necessary before the best plans of pond management can be known. The unraveling of the complex can be accomplished eventually only by tracing particular threads, that is, by centering attention at one time upon a particular group or species of the inhabitants of the water. An instance of such special studies carried through to a point where helpful practical conclusions are derived is afforded by the investigation of water beetles conducted at the Fairport station.

Dr. C. B. Wilson has made a comprehensive study of the rôle beetles play in pondfish culture. He has found that larvæ and adults of the three beetle genera, *Hydrophilus*, *Dytiscus*, and *Cybister*, destroy small fish under normal conditions. The larvæ of *Dineutes* are known to have killed and eaten fish fry under certain abnormal conditions. The larvæ of three other genera (*Acilius*, *Graphoderes*, and *Hydrocharis*) are suspected of being capable of committing similar depredation.

On the other hand, both beetle larvæ and adults are eaten freely by the young of nearly all our common food and game fishes after the latter attain a length of 25 to 40 millimeters. This is just as true of the seven genera mentioned above as of the others that are harmless.

Practically speaking, only the young fish of the year are menaced by beetles. Fish a year or more old are large enough to feed on the beetles and are almost never attacked by the latter. Consequently beetles are really harmful only in breeding ponds, and even in those places, as everywhere else, they contribute materially to the available food supply for the fish.

Adult beetles migrate and travel so constantly that every fishpond is sure to be stocked with them as soon as it is completed, and yet the beetles of two ponds side by side are likely to differ radically in numbers and variety. If they occasion trouble in one pond, the temporary removal of the fish to another pond will usually prove an effectual remedy. Beetles may also be kept in check by abruptly raising and lowering the water in the pond at intervals of a week or 10 days during their breeding season in July and August.

STUDIES OF SALMONIDÆ IN RELATION TO FISH CULTURE.

In a previous report reference in detail was made to the investigations by Dr. W. C. Kendall of rainbow and steelhead trout and of some hitherto unrecognized anatomical characters of trout which seemed to have a direct bearing upon fish-cultural practices. It is worthy of note that the results of the latter investigation were deemed of such value by independent persons that the report upon them was

awarded a prize by the American Fisheries Society as the most important contribution in the application of biological science to the advancement of fish culture. A series of practical experiments based upon these results was conducted during the winter at one of the fish-cultural stations of the Bureau. Just before the close of the year they were transferred to another station where more adequate facilities were available, and it is planned to continue them during the coming fiscal year that definite results may be obtained.

MINNOWS IN RELATION TO FISH CULTURE.

The smaller members of the minnow family are important to fish culture since they represent a primary source of food for more than 20 of the larger food and game fishes. The success of the introduction of game fish into streams or ponds necessarily depends to no small extent upon the suitability of the stream or pond for the support of minnows. Hence the budget of knowledge requisite for efficient fish culture includes information regarding the food and other requirements of minnows. Therefore, while the study of minnows by C. M. Breder and D. R. Crawford, scientific assistants, was conducted almost entirely outside of office hours and represents a by-product as it were, the results gained are of practical value.

They studied six common species in the vicinity of the District of Columbia; chub minnow, *Semotilus bullaris*; red-bellied dace, *Leuciscus vandersalis*; *Notropis procne*; shiner or red fin, *Notropis cornutus*; black-nosed dace, *Rhinichthys atronasus*; cutlip, *Exoglossum maxillingua*. All were found to be predominantly carnivorous, insects forming the bulk of the food taken, although two species, *Notropis procne* and *Exoglossum maxillingua*, consumed much vegetable matter. Various worms, filamentous algæ, and diatoms entered into the food in considerable quantities. These minnows are, therefore, in direct competition with the young of important game fish and may even prey upon the fry of them. It is suggested, therefore, that if minnows are introduced into ponds as food for game fish, discretion should be exercised regarding the use of larger and more rapidly growing minnows, such as the chub minnow and red fin, which may outstrip young trout in growth and under some circumstances become a menace rather than a benefit.

In all cases the suitability of the introduction depends both upon the species of minnow and upon the species of fish which is to be fostered, as well as upon other conditions prevailing in the water and upon the degree to which the various factors are under the control of the fish culturist. Minnows seem to thrive best in streams or ponds where the banks bear overhanging vegetation that supports an abundance of insect life. Where this condition prevails there is probably less likelihood that the minnows will prey upon the eggs or young of other fishes.

A NEW FORM OF POND OUTLET.

Practical success in fish culture depends in no little measure upon economy in construction and operation of the pond and upon the convenience with which it can be drained for removal of brood stock or young, elimination of enemies, cleaning the bottom, or removing obnoxious plants. The concrete-box outlets commonly used are not

only expensive, but they are also frequently a subsequent source of annoyance, expense, and loss of fish, when damaged as the result of freezing and thawing. It is worthy of special comment, therefore, that H. L. Canfield, superintendent of fish culture at the Fisheries biological station, Fairport, Iowa, has devised a type of pond outlet which has been found, after long trial, to be both relatively inexpensive of installation and convenient and enduring in operation. The Canfield L outlet, here described and illustrated, provides both for all ordinary overflow and for draining the pond as easily and quickly as with the concrete outlet.

The outlet consists of two pieces of threaded pipe of required length screwed hand-tight into an elbow. When connected for service one pipe is joined to the drainage line, and the other, the elbow acting as a hinge, becomes a movable standpipe, the raising and lowering of which controls the depth of the water in the pond. A pipe stop about 2 feet high is arranged back of the elbow to stay the standpipe from passing the center.

Two or three cement blocks about 2 by 2 feet are set about the drainage line to anchor it and to give protection to the embankment against animals and water seepage leading into it along the line. These blocks serve also as couplings for the joining of the pipe to the drainage line and for other connections in the line as desired. When a kettle is used one block joins a side of it, anchoring the pipe connection with the drainage line and serving as a base for a walk support. A second block is placed about the drainage line approximately beneath the top and inside edge of the embankment. This is usually a drainage line connection block. If the drainage line passes entirely through the embankment a third block should be placed around it several feet into the embankment from the outside.

The outlet screen consists of a half coupling (whole coupling if desired) with a quarter-inch groove around it 2 inches below its top, to which is attached, by means of galvanized wire, a covered cylindrical screen of desired mesh, 1 foot high. This is screwed to the outlet pipe. A cylindrical or square screen of large proportion may be installed about the standpipe if maximum screen area is needed, although for general use this will not be required.

A cement kettle 12 by 6 by 1 feet set parallel to the embankment, and within this kettle a small kettle about 15 inches wide, 3 inches deep, and about 7 feet long (long enough and wide enough to admit the standpipe with screen, when down level) are used at Fairport with the L outlet. The drainpipe enters the side of the main kettle about 6 inches from the elbow and 1 foot from the end. The bottom of the inner kettle is made level with the base of the outlet pipe when it is down level in position to drain, and provision is made for the removal of the elbow by cupping out the cement beneath it and filling the space with clay, to prevent the trapping of fish when the pond is drained. The main kettle has a slight rise from the inner kettle to the sides to provide drainage.

A walk of 2-inch plank supported by 2 by 4 inch stringers is made to extend from the embankment to within a foot of the outlet screen, the stringers resting about 6 inches above the top of the outlet pipe when erect. This walk rests on two pipe supports which extend from the cement blocks in the drainage line.

The standpipe is chained to the sides of the outer walk support by a piece of galvanized pump chain the length of the distance the pipe travels. This chain passes through a loop eye in the post and is provided with a ring larger than the eye, so that the end of the chain can not be drawn through. By means of this chain the standpipe may be raised and lowered and the level of the water in the ponds adjusted and held as desired. An ordinary lock, or an iron bolt may be used to secure the chain in the loop.

Malleable iron pipe is excellent material for the outlet, but ordinary black steel pipe is cheaper and gives good service. One piece of pipe of required length for the standpipe, threaded both ends, an elbow, and about 2 to 2½ feet of pipe threaded one end, to serve as connecting pipe with the drainage line, are all the materials required for the outlet. It is recommended, however, that metal pipe be provided from the elbow well into the embankment for the better protection of the drainage line. Eight-inch pipe is recommended for ponds of 1 acre in area and proportionately smaller pipe for smaller ponds.

FIG. 1.—The Canfield pond outlet, side view.

FIG. 2.—The Canfield pond outlet, end view.

It is well to paint the pipes with waterproof paint, and a mixture of graphite and oil is recommended for use in the elbow and coupling threads. Pipe threads should penetrate elbow 1 inch, hand screwed. When the drainage line is to be of terra cotta its joints should be sealed with cement throughout the line rather than laid partly open, as is sometimes done.

The elbow and two pieces of threaded pipe comprising the outlet proper and modifications as to size and detail of the L outlet and appurtenances may be made to suit requirements and material available. If it is necessary to reduce expense, the kettles may be reduced or omitted entirely, but the installation of a kettle, even though of small size, is recommended because of its usefulness when drawing the pond and sorting the fish. The cement blocks, the chief use of which is to protect the outlet drainage line against water working an opening about it, and which also prevents animals such as crayfish and muskrats following it through the embankment, must not be omitted because without the blocks to protect and stay the drainage line leakage is certain to occur. The depth of these blocks should not be reduced, but in unfavorable soil may be increased to advantage.

All surfaces over which embankments are to be laid should be plowed before the fill is commenced, so that the earth will bind satisfactorily, and all foreign matter such as brush, rock, etc., should be excluded from the fill dirt.

The outlet is placed at the drain point and stayed as described, after which the fill is laid over it, the outlet being ready for service as soon as the fill is started. Pipe 4 to 6 inches in diameter is sufficiently large for ponds of less than 1 acre in area. It is always better to have the outlet pipe too large rather than too small.

Many of the spillways and outlets in general use give more or less trouble through leakage, and those of cement construction often freeze and crack, or settle and crack, causing serious trouble and considerable expense. Many of the outlets in use are built into the embankment, thereby weakening and subjecting the embankment to the danger of washouts. Loss of fishes often arises from screens below the water surface becoming damaged, and many outlets, when the pond is being drawn, have too much suction for the good of the little fish. These and other troubles have been eliminated in the L outlet, some favorable features of which are enumerated below:

The action of the outlet is quick and easy.

Leakage and freezing difficulties have been overcome.

The outlet operating from the surface provides minimum suction, which works to the benefit of small fish.

The screen is visible, therefore safe, and easily cleaned.

The outlet does not weaken the pond embankment.

The outlet may be assembled, installed, and maintained at low cost, and is so simple of construction that any "handy man" can build and install it.

ERADICATION OF SOME OBJECTIONABLE PLANTS.

The rank growth of cat-tails in ponds and lakes, particularly at fish-cultural stations, has often become a serious nuisance, causing a substantial reduction in the effective area of the pond. Hitherto there has been no inexpensive or practicable method of combating them, since removal by cutting alone is quite ineffectual. Superintendent Canfield has devised and demonstrated the efficacy of a method of elimination of these plants, based upon the necessity of aeration through contact of the plant or its landward roots with the air.

The water level in the pond is lowered below the limit of growth of the cat-tails, which should then be mowed as low as practicable. With spade or plow a ditch is made below the normal water line and between the cat-tails and the shore. The ditch must be sufficiently deep to sever the roots that connect the plants in the pond with the shore or with any plants that are allowed to remain above the ditch. In this way the air supply from the land roots is completely cut off. The pond should then be immediately flooded and the water

level continuously maintained above the stubble for a week or 10 days, when the cat-tails will have been killed out. It is essential to flood the stubble immediately after mowing in order to get ahead of the rapid growth of the cat-tails. If in consequence of stored oxygen in the severed roots a few weakling shoots should appear above the water surface, they should be pulled out; when this is done a few times the plants will not reappear.

STUDIES OF FISH DISEASE.

The position of fish pathologist in the Bureau was vacant during the last half of the fiscal year, the last incumbent having left the service at the end of December after a year's service. Some studies of diseases and parasites were also conducted by other investigators principally in temporary employ.

MORTALITY IN PIKE-PERCH EGGS.

The great losses in the hatching of pike-perch eggs have made this phase of fish culture a ground of repeated inquiry, although as yet no investigation has been carried to a conclusion revealing the exact causes of the high death rate. Further observations during the past fiscal year were made by Dr. Franz Schrader, who inquired into the practices of handling fish and eggs and investigated the actual changes taking place within the abnormally developing eggs. His observations point to the conclusion that the original cause of abnormal development and mortality of eggs is to be sought in physiological injuries sustained by the parent fish while held in captivity before spawn can be taken. The penning of fishes prior to spawning is a practice of long standing in the artificial propagation of pike perch and other species of fish. Some species withstand the confinement very well, while others manifest such ill-effects as hardening of ovaries, wateriness of milt, and low percentage of hatched fry—in short, degeneration of eggs and sperms. The general inference of the investigator finds some confirmation in the investigations reported in the next paragraph and also in the experiences of several superintendents who have observed that the mortality of pike-perch eggs is proportional to the length of time the fish have been retained in pens, and conversely, that the percentage of hatch is greater in the case of eggs from fish stripped as taken from the nets than in the case of eggs taken from fish that have been held in pens.

ABNORMAL CONDITIONS OF FISH OVARIES.

Dr. Schrader also conducted inquiries into ovarian conditions in fishes with the purpose of throwing light upon various difficulties arising in hatcheries, including the loss of spawning fishes, ovarian diseases, and failure of fertilized eggs to hatch, troubles which possibly have some relation to abnormal conditions of confinement, handling, or stripping. Observations were made upon developing immature eggs of the scup, the retention of eggs beyond the normal period of spawning, the reabsorption of retained eggs, and the hardening of ovaries. Abnormally retained eggs show signs of degeneration in course of one or two weeks. Reabsorption takes

place through invading cells, but is not always successfully accomplished; it apparently makes a demand upon the body of the fish, which, if excessive, may lead to death.

DISEASE OF RESCUED FISH.

Dr. H. S. Davis, temporary investigator at the Fairport biological station, has found that a high mortality may occur among rescued fishes immediately after the handling incident to rescue operations. This heavy death rate is especially characteristic of the crappies, buffalofish, and bluegills, when taken in warm weather, the first-named species being the weakest. While the mortality may be founded in part upon "shock" sustained during the seining and handling operations, it is due more directly to bacterial infection following slight injuries and gaining headway from the weakened condition of the fish. Immersion for one minute in a solution of copper sulphate in 1 to 1,000 dilution reduces the loss among rescued fishes to a minimum.

In certain experiments 75 to 100 per cent of the crappies rescued from inland sloughs and untreated were lost through death. Under similar conditions, except for a one-minute treatment with 1/1,000 copper-sulphate solution after the fish were allowed to remain a short time in fresh clean water, this experimental loss was reduced to 30 or 40 per cent. The necessity and practicability of the treatment depend upon the conditions attending work in particular fields and at particular times. It is believed that frequent tests should be made in connection with rescue operations and the prophylactic measures taken wherever a substantial mortality rate is to be expected. Dipping in a simple disinfectant can not be very expensive and will be worth while if it will increase appreciably the percentage of survivors.

Dr. Davis's experiments not only point out the possibilities of loss and the means of prevention, but they also emphasize the necessity for great care in handling rescued fish. Rough methods, including the throwing of fishes into receptacles and the abrasion of the fishes' bodies by seines, hands, or debris are the main causes of a high death rate.

PARASITIC FLATWORMS OF FRESH-WATER FISHES.

The parasitic flatworms which infest the body surface and gills of fishes (ectoparasites) may be more of a nuisance to fish culture in ponds, tanks, or aquaria than those which live within the body of the fish. The endoparasites generally can not complete the life cycle without passing different stages in two or more hosts, which are likely to be animals of widely different groups. Therefore, as regards these parasites, fish can not directly infect fish. With external parasites it is otherwise; there being no alternation of hosts, infection may proceed from fish to fish and thus multiply in such abundance as to cause extreme weakness or death of the fish. Such a parasite is *Gyrodactylus fairporti*, a new species described by Dr. H. J. Van Cleave from bullhead and carp of certain ponds at the Fairport (Iowa) station. These flatworms are very small, usually

less than half a millimeter in length, and so translucent that one may easily overlook them.

Some bullheads removed from a quarry pond near the Mississippi River died within 24 hours after being placed in an aquarium of running water. The early death of these usually most hardy fish could be explained only on the supposition that their vitality had been greatly diminished by the small and abundant trematodes (*Gyrodactylus*) scattered over the entire surface of the body. Possibly many fish in the river are unfavorably affected by these worms.

Dr. Van Cleave found a species of another genus of parasitic flatworms upon the gills of sunfish, black bass, and channel catfish, but it is believed that worms of this genus (*Ancyrocephalus*) do not cause dangerous infestations.

Very little study has been devoted to the ectoparasitic flatworms on this continent, and previously but four species have been reported from fresh-water fishes. Much attention has been given them in connection with fish culture in Europe. Treatments which European writers have recommended are: (1) A one-fourth of 1 per cent solution of salicylic acid, in which the fish remains half an hour (Hübner); and (2) a solution of 1 part of potassium permanganate to 100,000 parts of water. The treatments may require modification for our species of fish and of parasites.

Dr. Van Cleave has also described a new genus of trematodes based upon specimens taken from the white bass, *Roccus chrysops*, collected in Iowa, Illinois, and Minnesota. The parasites were found only in the digestive tract and at present are ascribed no economic significance. The parasites are not found in *Morone interrupta*, although that species is a close relative of the white bass. He finds, indeed, that the trematode parasites of the yellow bass are entirely distinct from those of the white bass, although the two related species display marked similarity in range, local preference, feeding habits, and food.

TREATMENT OF ICHTHYOPHTHIRIUS DISEASE.

One of the most troublesome external parasitic affections of fresh-water fishes in aquaria and ponds is due to a microscopic protozoan (*Ichthyophthirius*), which becomes embedded in the skin and sets up a violent irritation. H. L. Canfield, superintendent of fish culture at the Fairport station, who has conducted experiments in the treatment of channel catfish heavily infected with the protozoan parasite, reports that commercial carbonate of soda in the form of sal soda (washing soda) is effective in alleviating the trouble.

Using a receptacle other than metal to hold the solution, 150 g. of sal soda are placed in 4,000 c. c. of water, in which solution the affected fish are dipped. The diseased fish are held in troughs of lively running water, which aids in the treatment and facilitates handling. Before each treatment the fish are forced to the lower half of the trough, where they are separated from the upper half by means of a cross screen. The diseased fish are caught in a hand net, immersed in the solution until they show signs of discomfort (darting about), and then placed in the fresh water at the upper end of the trough. This process is continued until a material reduction in parasites is noticed

(usually about six days), after which the treatment is given once a day for about 10 days, which is usually sufficient to rid the fish of the parasites.

The effect of the sal-soda solution is to cause the parasites to shrink and wrinkle as they die. It is apparent that the solution kills the free swimmers, the young just attached to the fish, and all but the larger and more thoroughly embedded parasites. These last leave the fish in the natural process of development, and their offspring are killed with others after they attack the fish and before they attain their maturity. Thus in time the parasites are entirely exterminated.

The channel catfish were fed, as usual, ground liver three times a day while the treatment was in progress, and the usual care was given the fish and troughs as to cleanliness.

OCEANOGRAPHIC AND LIMNOLOGICAL STUDIES.

INVESTIGATIONS IN THE ATLANTIC.

Because of deficiency in funds and personnel the *Albatross* has not been at sea during the year.

Some brief cruises to complete the field work of the hydrographic and biological survey of the Gulf of Maine were made by the small Fisheries steamer *Halcyon* under the direction of Dr. H. B. Bigelow. The preparation of the report upon all the data gathered at different times during a period of years is now in progress, although its completion has been delayed by the death of William W. Welsh, who was giving special attention to the portion of the report dealing with the occurrence, distribution, and life histories of the fishes.

By joint action of the Governments of the United States, Canada, and Newfoundland there has been formed during the year an International Committee on Marine Fishery Investigations, with the object of bringing about a better correlation of the activities of the several Governments in fishery investigations in which two or more of the countries are directly interested. Knowledge of the cod and the conditions of its perpetual conservation, for example, possesses the same interest to Canada and Newfoundland as to the United States. No formal cooperative effort is contemplated, but it is believed that progress will be attained more rapidly and economically by regular interchange of data and counsel than by entirely detached endeavor on the part of each nation. The members of the committee are as follows: For Canada, Mr. William A. Fournier, Assistant Deputy Minister of Fisheries; Dr. A. G. Huntsman, member of the Biological Board of Canada, and Mr. Loring C. Christie, legal adviser, Department of External Affairs, Ottawa; for Newfoundland, Mr. D. James Davies, chemist to the Newfoundland Government; for the United States, Dr. H. F. Moore, Deputy Commissioner of Fisheries, Dr. R. E. Coker, assistant in charge, scientific inquiry, Bureau of Fisheries, and Dr. H. B. Bigelow, consulting oceanographer, Bureau of Fisheries.

The first meeting of the committee was held in Montreal, June 23, 1920, when, after full discussion, agreement was reached as to correlation and interchange of statistical data with regard to particular fishes, uniformity in methods of plankton study, and concentration of attention upon certain species.

SURVEY OF CHESAPEAKE BAY.

The biological and hydrographic survey of Chesapeake Bay has been continued by Dr. R. P. Cowles, temporary investigator, during the past year, and a large series of data on salinity, temperature, current velocity, and current direction has been accumulated, together with qualitative and quantitative collections of plankton, bottom samples, and many specimens of the larger animals and plants. The observations made and samples collected have not been confined merely to the surface nor to the bottom but have been obtained at definite depths, equal intervals apart, from the surface to the bottom. Probably the most valuable characteristic of the work is the fact that the observations have been made about every sixth week during the year at fixed stations arranged in lines across the bay, these lines being so placed as to adequately cover the bay from the region of Baltimore to the Capes. The Fisheries steamer *Fish Hawk* has been employed in the work on the bay.

During the year preliminary work has been undertaken to determine the hydrogen ion concentration of the sea water by colorimetry. This method has now been perfected, and the tests made on the so-called 24-hour stations, where observations are taken every $1\frac{1}{2}$ hours at definite intervals from the surface to the bottom for a period of 24 hours, have shown some very interesting conditions.

The coming year will be devoted to working over the data and material, with possibly an occasional cruise on the bay to collect information that may be lacking. The general purpose of the investigation is to gather and record the data that are necessary for the interpretation of the seasonal and irregular movements of fishes, for the solution of practical problems that arise from time to time regarding fish and shellfish, and for the conservation and development of the important fisheries of the bay.

This general survey is being supplemented by a special investigation of fishes of the Chesapeake Bay, conducted by S. F. Hildebrand and W. C. Schroeder. While many fishes, especially the younger examples of several species, have been collected in connection with the general survey, the supplemental field work on fishes was undertaken only in the last months of the fiscal year.

SURVEY OF SELECTED AREAS IN MISSISSIPPI RIVER.

In an investigation to determine the distribution of fresh-water mussels, Dr. A. D. Howard made a somewhat detailed study of the entire bottom in a portion of the Mississippi River, the area selected being 3 miles in length and situated in Andalusia Chute, one of the channels of the river in the vicinity of Fairport, Iowa. The river in this section is comparatively straight and of rather uniform character as to gradient and depth, passing over soil of clay, sand, and sedimentary rock (mostly limestone).

The life on the bottom was found to have a rather definite distribution with reference to physiographic features of the river. In general it was restricted to a zone 200 feet wide along each shore. Where islands occurred a narrower zone was found along the shores of the islands. The distribution had apparently no particular relation to depth of water, for the middle area of the stream (about 500

feet wide) was not deeper than the 200-foot strips alongshore. The zones near shore are by no means equally productive throughout, the more densely populated portions manifesting definite relations to the position of the channel and to other features of the stream, especially those that affect the stability of the bottom. Productive areas usually occur in parts of the shore strips that are bathed by the current, or where the channel approaches the shore. Character of bottom soil is a significant feature, but this is often controlled by current, topography, and other conditions.

Keokuk Lake, formed in the Mississippi River above the dam at Keokuk, has been examined some years after its formation to determine some of the effects of the changed conditions. A report of the observations is in process of preparation.

STUDIES OF INLAND LAKES.

The Bureau has continued to cooperate with the Geological and Natural History Survey of Wisconsin in biological and chemical investigations directed at the fundamental problems of the capacity of inclosed waters for support of fish life. As has hitherto been stated, the Bureau bears only a relatively small proportion of the expense of the investigation. Substantial progress has been made, as is indicated by the following outline submitted by President Edward A. Birge and Chancey Juday representing the State Survey:

1. The bulletin dealing with the quantity and chemical composition of the plankton of the lakes situated in the vicinity of Madison is now ready for the press. During this investigation 481 observations have been made on the net plankton and 182 on the nannoplankton of these lakes, making a total of 663 catches. These catches were combined into 374 samples for the chemical analyses. About 2,500 separate chemical and ash determinations have been made on these samples and 52 samples of special material obtained during the progress of this work.

The quantity of dry organic matter in the total plankton of Lake Mendota (net plankton plus nannoplankton) varied from a minimum of 230 pounds per acre in February to a maximum of 521 pounds per acre in December in the area situated within the 20-meter contour line. When the surface of the entire lake and the volume are taken into account the range is from 126 pounds per acre in February to 256 pounds in December. The live weight of the organic matter is 10 times as much as the dry weight.

Of the dry organic matter an average of 44.5 per cent consisted of crude protein, 7.5 per cent ether extract, and 5.3 per cent crude fiber, leaving 42.7 per cent to be designated as nitrogen free extract (chiefly carbohydrates). The pentosans were the only carbohydrates studied, and they constituted an average of 4.6 per cent of the organic matter.

Lakes Monona and Waubesa yielded larger quantities of total plankton. The amount in the former varied from a minimum of 276 pounds per acre in July to a maximum of 1,063 pounds of dry organic matter in October in the area bounded by the 20-meter contour. For the entire lake the range was from 111 pounds to 426 pounds per acre of surface. The maximum crop of plankton in Lake Waubesa yielded 862 pounds of dry organic matter per acre in the area bounded by the 10-meter contour, or 415 pounds per acre for the entire lake; the average for 16 samples is 216 pounds of dry organic matter per acre.

The dry organic matter in the total plankton of Lake Monona contained 57.5 per cent of crude protein, 4.8 per cent of ether extract, 4.7 per cent of pentosans, and 4.4 per cent of crude fiber. The total plankton of Lake Waubesa yielded an average of 48.6 per cent of crude protein, 4.6 per cent of ether extract, 5.8 per cent of pentosans, and 4.4 per cent of crude fiber.

2. Mr. Wilson's numerical results for the bacteria of Lake Mendota show that the average number from surface to bottom in 23.5 meters of water was 3,000 per c. c. of water in July and August, 1919; in the following autumn and

winter the number fell to 1,500 per c. c. In the spring and early summer of 1920 the number rose steadily to a maximum average of about 30,000 per c. c. from the latter part of June to the end of August. During the autumn and early winter the number gradually declined to an average of 2,000 bacteria per c. c. of water.

Many of the bacteria represent chromogenic forms, and various colors are found in the plate cultures. There seem to be some denitrifying individuals present, but conclusive evidence of the presence of lime-precipitating forms has not been obtained yet. The average size of these bacteria has been obtained so that it will be possible to estimate their live weight and dry weight as well as the organic matter in them.

3. Several reports are now in press in the Transactions of the Wisconsin Academy which deal with investigations in which the Bureau of Fisheries has cooperated. The following may be listed here: "A survey of the larger aquatic plants of Lake Mendota," by R. H. Denniston; "A quantitative study of the larger aquatic plants of Lake Mendota," by H. W. Rickett; "A quantitative study of the bottom fauna in the deeper water of Lake Mendota," by C. Juday.

Some chemical analyses of the larger aquatic plants from Lake Mendota have also been made, but this has been done independently by the Wisconsin Survey.

4. Various analyses have shown that the quantity of organic nitrogen in the lake water itself amounts to five or six times as much as that in the total plankton, and Dr. Schuette has been trying to work out a method for the determination of this dissolved organic nitrogen which will give results that are more satisfactory than the present methods of nitrogen determination. The quantities are so small that the methods now used by chemists do not always give consistent results. So far no other method has been found which will give better results than the standard methods.

AGAR-AGAR AND OTHER GELATINS FROM SEAWEED.

It is obviously unfortunate that the United States should be dependent upon other countries for its supply of a vital necessity. Agar-agar is the commercial name applied to a gelatinous product which has been imported from Japan, China, and other places, the importations in 1919 amounting to nearly half a million dollars. The importance of the material is not, however, measured by its strictly commercial value. While it is used in making food and confections, agar-agar is primarily important because it is a necessary medium for bacteriological work, and is therefore essential to medical laboratories and hospitals. It is a requisite for certain industries, for the maintenance of health, and for national security.

Marine algæ or seaweed have long been used in this country for the preparation of gelatins for particular purposes, but only the recent investigations, conducted for the Bureau by Dr. Irving A. Field,⁹ have revealed the fact that we have possible sources of supply for the most valuable gelatin of all in certain species of seaweed on the west coast. In the report for the preceding year reference was made to Dr. Field's preparation of a gelatin suitable for use in preserving fish, and to experiments in producing a substitute for agar from Atlantic coast seaweed. These experiments were not successful, but it was later ascertained that at least one species of the west coast yields agar of the best quality. Agar prepared by Dr. Field and tested at the Army Medical School in Washington was pronounced equal or superior to the imported agar. Another species yielded a product apparently of like quality. The investigation should be followed by a field survey for the purpose of definitely locating the

⁹ Field, I. A.: Sources, Preparation, and Properties of Some Algal Gelatines. Bureau of Fisheries, Economic Circular No. 51, issued Oct. 10. 1921, 7 p. Washington.

sources of supply. It was a serious misfortune that Dr. Field died shortly after completing and reporting upon his laboratory investigations.

THE OYSTER.

INVESTIGATIONS OF OYSTER CULTURE.

The investigation of oyster problems of Great South Bay and Long Island Sound was continued according to the general plan of the year before. The work was begun by Dr. E. P. Churchill, assisted by J. S. Gutsell, but Dr. Churchill left the service in August and thereafter Mr. Gutsell continued it alone. Quantitative collections and studies were made with the aid of the pumping equipment and selective screens developed by the Bureau investigators.

At Great South Bay the plan comprised chiefly an intensive study of the distribution, life, and setting of the oyster larvæ. At fixed stations located over a considerable area of the best oyster grounds in the bay quantitative collections were made as in 1919. In that year it had been found that certain of these stations were almost uniformly superior to others in their yield of larvæ, and that the set at these stations was correspondingly more abundant. The work in 1920 was planned to check up and enlarge on this evidence, to see if the general distribution of larvæ was much the same year after year. Addition to our knowledge in other aspects was, of course, to be included.

Unfortunately the season was a poor one. Oyster larvæ until after mid-July occurred scatteringly, at best in small numbers. The conditions indicated a very light set indeed. The one station which showed decided superiority was not located over oyster beds and offered no opportunity of determining a set. A return visit with inadequate apparatus late in August showed young oyster larvæ in apparently fair abundance and indicated an unusually late spawning and a possible late set.

In accordance with the scarcity of larvæ, a very light set was found in the fall; and corresponding apparently to the late spawning, a set was found in the spring which had not attained sufficient size in the fall to be noticeable. In general these sets were so light as to be commercial only to the extent of having sufficient value to repay shifting.

Thus support was given the hypothesis that a relation can be found between the observable abundance of larvæ and the amount of set, and that consequently a scarcity of larvæ indicates that the great expense of "shelling" should be avoided.

In Long Island Sound, where the oysters spawn later than in Great South Bay, the work was curtailed by the reduced personnel and was limited chiefly to the region between Milford and Bridgeport. Collecting was poor indeed except for a time in August, when moderate numbers of larvæ were obtained, particularly about Bridgeport. Something of a set was later reported there. Thus in the Sound, as in Great South Bay, there was little opportunity that season to obtain other than negative evidence as to the relation of the occurrence of oyster larvæ and the abundance and location of set.

The study, made in cooperation with the Bureau of Chemistry, of the trade-waste problem in its relation to oyster culture was continued. Before he left the Bureau Dr. Churchill performed experiments with various dilutions of standard solutions of chemicals known to occur in or to be discharged into water near oyster beds. He found the larvæ very sensitive, certain chemicals being fatal even in great dilutions. In Bridgeport Harbor late in the season samples were collected for the determination of the distribution of injurious wastes, particularly the heavy metals. As a result of the study of this harbor and of the efforts of the two bureaus, the company, which discharged much the greatest amounts of copper, was persuaded to install an electrolytic recovery process, which has given great promise both as a money saver and as a means of improving harbor conditions.

In June, 1921, the spawning of oysters in Great South Bay has been found to begin in earnest almost a month earlier than in previous years of our experience and to occur at decidedly lower temperatures. The work is being so carried on as to check up the data obtained in 1919, and already the larvæ have been found to be much more widely distributed in good numbers. In addition, as opportunity permits, data are being gathered to test out the hypothesis advanced by Dr. T. C. Nelson that oyster larvæ of the larger sizes keep from being washed to sea by sinking with the ebb tide and rising with the flood.

The study of the development and distribution of the larvæ is of interest to local oystermen and has, it is believed, influenced them in determining the times, places, and extent of planting shells for set. The immediate purpose of the Bureau, it must be understood, is to determine the possibilities of the method of larvæ survey in obtaining best results and effecting economies in planting and in the prevention of costly wastes from planting in seasons when a set is not obtainable. Once a satisfactory demonstration is obtained, the method can be applied in other localities as well as at the places where the experiments have been conducted.

EFFECT OF POLLUTIONS UPON PROPAGATION OF OYSTERS.

Pollutions may affect oyster eggs and larvæ, either directly, by the toxic effect of certain chemicals upon the young oysters, or indirectly, through the exhaustion of the oxygen supply and partial or complete suffocation of the larvæ. The latter aspect of the problem was given attention by Dr. P. H. Mitchell, director of the Woods Hole (Mass.) Fisheries laboratory.

In experiments on the effect of oxygen deprivation on oyster larvæ Dr. Mitchell found that while the embryos are sensitive to diminished oxygen supply a number of factors affect the lower limit of the oxygen content of water compatible with life of the larvæ. The factors noted were: (a) The previous history of the eggs from which the larvæ were hatched, for example, ripeness at the time of artificial fertilization and previous exposure to pollution; (b) the age of the larvæ; (c) the carbon-dioxide content of the water; (d) the hydrogen ion concentration of the water; and (e) the temperature.

Development of a satisfactory technique for handling such unusually sensitive and perishable material as oyster larvæ, in the

manipulations required for this experiment, consumed much time. Consequently the end of the breeding season for oysters came before there was opportunity to work out the relations of all these factors in an entirely quantitative manner.

Results may be summarized as follows:

With regard to the condition of the eggs, it was observed that embryos from eggs of which 50 per cent or more developed quickly to a free swimming stage withstood deprivation of oxygen better than those from eggs of which only a small proportion developed.

With respect to age, it appeared that younger larvæ endured comparative oxygen deprivation slightly longer than older ones, but the experiments were not conclusive.

It was found that embryos show some effect of oxygen lack in water containing 25 per cent of saturation of oxygen at 24° C. and a markedly increased mortality in 10 per cent of saturation. Killing time varied from 12 to 30 hours according to extent of oxygen depletion. At 28 to 30° C. embryos die much more rapidly from oxygen starvation than at 22 to 24° C.

Carbon dioxide seems to have a toxic effect other than that due to hydrogen ion concentration. Embryos died earlier in water containing sufficient oxygen but excessive CO₂ than in water of the same oxygen content and with the same P_H obtained by adding lactic acid.

Investigation of the effect of pollution on satisfactory development of eggs in gonads was also conducted. Results showed that from oysters, kept 7 to 10 days in water polluted so as to markedly lower its oxygen content, only an abnormally small proportion of eggs could be made to develop after artificial fertilization, conducted according to standardized technique, and that the embryos so obtained did not develop as far as controls.

An incidental observation proved of considerable interest. Oysters which had been in cold storage 24 days for the purpose of studying greening were found to have very full gonads. Eggs fertilized with sperm from some of the same lot of oysters developed satisfactorily, and many of the embryos reached the primitive shell stage. Some of them, indeed, were used in oxygen-requirement tests.

Observations on the cause of copper greening confirmed previous conclusions by showing that not only the amount of copper obtainable by the oysters, but also conditions of habitat determine whether or not visible green spots occur. Marked appearance of greenness after one or more weeks in cold storage was observed. It has been twice noted that with gonads filled a smaller proportion of oysters become green during storage than in other conditions. Two-year-old spent oysters, set and reared in Wareham River, did not become green during four weeks in cold storage. This is in contrast to oysters which at some time during their previous history have been in waters known to produce greenness (near Bridgeport and New Haven).

Experiments both in the laboratory and in the field indicated a positive influence of diminished oxygen supply in causing the appearance of green spots. Repeated observations of marked greening of oysters in polluted tanks of sea water were also made, thus confirming the similar results obtained during the previous summer in the Seekonk River.

FRESH-WATER MUSSELS.

PROPAGATION OF MUSSELS.

The Fisheries biological station at Fairport, Iowa, continued its practical propagation of fresh-water mussels in the Mississippi drainage at Lake Pepin and Lake Pokegama, Minn.; at New Boston, Oquawka, and Dallas City, Ill.; at Fairport, Iowa; at Hannibal and Clarksville, Mo.; and in cooperation with rescue crews along the Mississippi in Wisconsin and Minnesota. The total number of glochidia infected upon fish and liberated in public waters during the year was approximately 648,445,000, including 478,705,000 infected upon rescued fish by cooperative agents working in connection with rescue crews of the division of fish culture.

With a view to demonstrating the possibilities of mussel propagation in connection with the rescuing of food fishes, the National Association of Button Manufacturers offered to cooperate with the Bureau by providing men to accompany each rescue crew on the upper river and to inoculate all fishes with the glochidia of the Lake Pepin mucket, the most important of the local mussels. Seven agents of the button manufacturers cooperated with seven crews working under the direction of Supt. Culler, of the Homer (Minn.) station, and during October and November inoculated nearly 6,000,000 fish with glochidia.

The localities in which the work was done and the number of fish subjected to infection in each locality were as follows:

Lynxville, Wis.....	2, 025, 200
Genoa, Wis.....	1, 214, 900
Ferryville, Wis.....	907, 340
Fountain City, Wis.....	86, 510
North McGregor, Iowa.....	676, 100
Bellevue, Iowa.....	931, 500
Total.....	5, 841, 550

Material cooperation of this nature by an association of business men is a source of gratification to the Bureau, not only as evidence of a cordial spirit, but as evidence of faith in the practical value of the service rendered in the propagation of river mussels.

PROTECTION OF MUSSELS.

A prominent feature of the work of the Fairport station for several years has been the part which it has played in bringing about a strong sentiment for the protection of fresh-water mussels and the cooperation it has extended to the several States in giving aid, when solicited, in selecting the areas for closure to mussel fishing. Additional closures of streams or parts of streams has followed the beginning made in the past by Minnesota and Wisconsin. Minnesota in April closed for a period of five years parts of the Minnesota River, and the entire Cannon and Straight Rivers. Iowa, in the same month, closed for a similar period parts of the Iowa, Cedar, and Des Moines Rivers, and the entire Shellrock River.

MUSSEL SURVEY IN UPPER MISSISSIPPI RIVER.

During the months of July and August, 1920, the Bureau of Fisheries made a study and appraisal of the mussel resources in a portion of the upper Mississippi River, beginning at a point about 5 miles above Red Wing, Minn., and extending down through Lake Pepin, a distance of about 80 miles, to Lamoille, Minn. The work was undertaken with reference to recent administrative action on the part of the States of Wisconsin and Minnesota providing for the closure of certain areas for the protection of the fresh-water mussels while permitting the fishery to continue in alternate open areas. The data acquired in this investigation are expected to establish a basis for comparison of conditions before and after a period of protection. The investigation was conducted under the Fairport biological station by Dr. N. M. Grier, with two assistants. Observations were made in five open and five closed areas.

Many data were secured regarding the depletion of formerly productive areas of mussel fishery, the diminution in abundance of mussels in different beds being attributed variously to the indirect effects of the construction of wing dams as aids to navigation, to excessive fishery, and perhaps in some cases to the dumping of rubbish in the river in the vicinity of cities.

The information gained will serve also as an aid to the Bureau in the conduct of mussel propagation for the rehabilitation of depleted and protected areas.

EXPERIMENTS RELATING TO MUSSEL PROPAGATION.

Experiments in retaining in inclosures fish artificially infected with glochidia of the Lake Pepin mucket, *Lampsilis luteola*, have been continued in Lake Pepin by Roy S. Corwin, scientific assistant. It was found in certain experiments that pike perch infected as late as August 19 carried glochidia until the following May, and that mussels during the second year of growth will thrive in an inclosure with a density of 18 mussels to the square foot. Third-year mussels with eight to the square foot flourished and showed an average increase in length of more than 100 per cent in one year.

Artificial infections of the Lake Pepin mucket on pike perch retained in a fine-meshed inclosure in the lake yielded an average of 833 juvenile mussels per fish. Assuming that these fish bore the usual infection of about 3,000 glochidia per fish, the yield of young mussels was 27.4 per cent. This is a much higher percentage than has ever been assumed to result from practical operations in artificial propagation of mussels.

Dr. L. B. Arey continued his study of the encystment of the glochidia of the fresh-water mussel. It has been established that the tactile response of the glochidium alone is adequate to insure attachment. The view that glochidia regularly attached to the host through a chemical activation by blood, derived from gill hemorrhages, appears to be untenable. Cyst formation is not initiated or controlled by any vital influence of the glochidium. It has been induced by the application of tiny metallic clips to a gill filament.

INVESTIGATIONS IN THE KENTUCKY RIVER.

Prior to 1919 the Kentucky River was an unworked and practically unknown mussel stream. In the summer and autumn of 1919 and the summer of 1920 the upper part of the river was investigated by Ernest Danglade, temporary assistant. Preliminary tests were made in the summer of 1919 which indicated that good marketable shells were to be found in the headwaters; and encouragement was offered to various people who had expressed a desire to engage in mussel fishing. As a result, by the middle of July, 1919, two mussel camps were established in the upper courses.

The river was examined from near its source down to Beattyville, Ky., below which place the stream contains many locks and dams and is unsuitable for mussel fishing. In the upper parts of the stream, in the north and middle forks, numerous but small beds were encountered. Fourteen were investigated and are described in some detail in a report on file with the Bureau. Forty species of mussels were obtained, of which 22 have commercial value, the mucket being the most important. Upper Twin Shoals is remarkable for the abundance of young muckets.

THE BIOLOGICAL LABORATORIES.

The Woods Hole (Mass.) laboratory, Dr. P. H. Mitchell, director, was in operation with a limited staff during the summer of 1920. Previous mention has been made of the investigation relating to oysters and the preparation of commercial gelatins from seaweeds. Prof. Edwin Linton continued investigations of the food and parasites of fishes, and Prof. William W. Browne was engaged in completing his report upon the nature and causes of the reddening of salt fish. Because of the unavoidable limitation of the Bureau's activities, it was found impracticable to open the laboratory for the summer of 1921.

Beaufort (N. C.) laboratory has been virtually closed during nearly the entire fiscal year. Since the director, R. L. Barney, was necessarily transferred early in the year to another station, the laboratory has been without scientific direction. Mr. Barney has, however, completed a general report on the natural history and culture of the diamond-back terrapin, embodying the information available from observations and experiments as relating to growth and reproduction of wild and domestic stock, care of young and adults, feeding, housing, and hybridization. Further attention has been given to the study of the bacterial disease which has been the only serious disease affecting winter-fed terrapin. Under the superintendence of Charles Hatsel, terrapin experiments have been continued, the grounds of the station have been kept in good condition, and the buildings in such repair as was possible with the available funds.

At the Fairport (Iowa) biological station the new laboratory building was completed and occupied early in September, and shortly thereafter R. L. Barney was appointed director of the station. In response to an outside demand, the laboratory building was formally dedicated October 7. A large number of prominent persons, including scientists representing the leading universities of the country,

participated both in the exercises of dedication and in the conference on the following day, which gave consideration to the natural resources of interior waters and the possibilities of their utilization and conservation.

The interest manifested in that conference and the demonstration it afforded of the possibility of bringing about better cooperation in the conservation of aquatic resources led to a call by the Secretary of Commerce of a conference of more extended duration to meet at the station June 8 to 10, 1921. On this occasion there were in attendance about 125 persons, including biologists, chemists, sanitarians, fishermen, manufacturers, fish-culturists, game wardens, engineers, and others. During the three days of the conference there was free and informal discussion related to the three major topics suggested in the call for the gathering, viz: The depletion of aquatic resources, causes, and remedial measures; the value of swamp and shore areas and their best utilization; and a constructive program of conservation. Interest was sustained throughout, and the conference adjourned only after recording a request that a similar meeting be called the following year.

The special activities of the Fairport station have been treated under several preceding heads; investigation of the paddlefish, fish-cultural experiment work, studies of fish disease, survey of selected areas in the Mississippi River, and fresh-water mussels. The station frequently also performs services of value to fishing clubs, private hatcheries, and individual owners of lakes and ponds, furnishing advice regarding the stocking and control of ponds and aiding in the solution of such troublesome conditions as may arise. The value of these advisory services is founded upon the scientific research conducted at the station and the experience gained in propagating and rearing fish under conditions of control.

The Key West (Fla.) biological station has been without a director from the beginning of the fiscal year until within a few days of the close of the year, when the services of a competent scientist were secured for a temporary period. During the greater part of the year the station has been in the hands of a caretaker. No further constructions have been undertaken, but the grounds have been suitably fenced for protection, and some plantings of appropriate vegetation have been made.

: : : : : By Charles Branch Wilson, Ph. D.

From BULLETIN OF THE BUREAU OF FISHERIES, Volume XXXIX, 1923-24

Document No. 942 :

CARD 1945-

PRICE, 10 CENTS

Sold only by the Superintendent of Documents, Government Printing Office, Washington, D. C.

: : : : : By Charles Branch Wilson, Ph. D.

By Charles Branch Wilson, Ph. D.

Document No. 942 :

Sold only by the Superintendent of Documents, Government Printing Office, Washington, D. C.

LIFE HISTORY OF THE SCAVENGER WATER BEETLE, HYDROUS (HYDROPHILUS) TRIANGULARIS, AND ITS ECONOMIC RELATION TO FISH BREEDING.

By CHARLES BRANCH WILSON, Ph. D.,
State Normal School, Westfield, Mass.

Contribution from the U. S. Fisheries Biological Station, Fairport, Iowa.

CONTENTS.

	Page.		Page.
Introduction.....	9	The adult beetle.....	26
Mating and egg laying.....	10	External characters.....	27
The larva.....	13	Antennæ.....	27
Head.....	15	Mouth parts.....	28
Mouth parts.....	16	Front tarsus of male.....	29
Thorax.....	17	Food.....	29
Abdomen.....	17	Respiration.....	29
Locomotion.....	18	Economic relations.....	30
Breathing.....	18	Relation to vegetation.....	30
Feeding.....	19	Relation to fertilization.....	31
Food.....	19	Enemies of the eggs.....	32
The pupa.....	21	Enemies of the larvæ.....	32
Pupation.....	21	Enemies of the pupæ.....	33
Description of pupa.....	22	Enemies of the adult beetles.....	34
		General summary.....	35
		Bibliography.....	36

INTRODUCTION.

In recent revisions of the scavenger water beetles Say's species *triangularis* has been referred to the genus *Hydrous* instead of *Hydrophilus*, and the latter genus has been considerably restricted. This revision is fully accepted, but to facilitate recognition both names have been included in the title of the present paper.

The European species, *Hydrous piceus*, has been described and figured in detail by many eminent entomologists, but our American species have thus far received only scant attention. This is the more to be regretted because they differ in many important particulars from their European relatives.

The beetle of the present investigation always forms, or is likely at any moment to become, one of the important factors in the life of every fishpond. Hence, an exact knowledge of its habits and life history is essential if we are to deal with it intelligently. During the summer of 1918 an unusual opportunity for obtaining the life history of this beetle was presented at the United States Fisheries Biological

Station, Fairport, Iowa, when one of the small fishponds was drained. While the water was receding and immediately after the pond was emptied, about 100 fully developed larvæ of *Hydrous triangularis* were obtained, together with numerous specimens in younger stages. Six egg cases were found, of which one contained half a dozen newly hatched larvæ, another was full of undeveloped eggs, and the remaining four were empty.

From the shores of the pond, just above the former water line, were obtained 15 pupæ in various stages of development. Several of the mature larvæ were observed digging their way into the earth as the water lowered, and these were closely watched until they transformed into pupæ. Some of the pupæ were preserved at once, others were left until they emerged as adult beetles. In this way the entire life history was obtained, together with many suggestive facts in reference to the habits. Fifty larvæ, including some smaller ones, were cut open and the contents of their digestive canals carefully examined to ascertain their ordinary food. Owing to these unusual facilities for observation it has been possible to solve practically all the problems connected with the life history, including some that have hitherto remained unanswered by the European observers.

MATING AND EGG LAYING.

The mature beetles almost certainly live through the winter, and mating and egg laying begin in the early summer and continue at least until the last of July.

No female has yet laid more than one batch of eggs in captivity, but it seems probable that at least some of them do this in their natural environment.

The eggs are in the form of an elongated ellipsoid, 4.25 to 4.5 mm. long and about 1 mm. in diameter (fig. 1), and are bright yellow in color when first laid. As is the custom with many of the *Hydrophilidæ*, the eggs are inclosed in a silken case. In the present species this case is attached to floating leaves, bits of trash, etc., and not to living plants, and it floats upon the surface of the water.

The construction of one of these cases was described for the European species by Lyonet (1832) and afterwards by Miger and Lancret (1804). Something evidently was lacking in the aquarium experiments of these observers, because the formation of the egg case required a very long time—five hours for the female watched by Lyonet and three hours for the one watched by Miger. Possibly the European species is a slower worker than the American, or one female may work more slowly than another. At all events the following observations made by

George B. Lay in the Fairport laboratory, July 27, 1916, and witnessed in large part by the present author, show that a case can be constructed much more rapidly than this.

A female *Hydrous triangularis* was noticed starting an egg case at 1 p. m. in one of the laboratory aquaria. She abandoned this effort, however, as there were

FIG. 1.—Side view of a single egg.

not enough water plants in the aquarium to work with. After these had been supplied she began to spin another case at 1.25 p. m. Assuming a position, back downward, her body almost parallel with the surface of the water and close to it, she held herself in place by means of the floating water plants (*Potamogeton* and *Elodea*), and moved her spinneret rapidly to and fro sidewise, at the same time pushing the material backward with her hind legs. After spinning the roof of the case in this manner for a few minutes she turned over without removing her spinneret. Her body was considerably inclined, with her head some distance below the surface, and she opened her wing cases slightly to supply herself with fresh air at periods varying from 15 to 90 seconds, the shorter period the more common. This mode of taking in air through the lifting of the posterior ends of the elytra is in marked contrast to the method normally used (see p. 29). It required a longer period to make the floor of the case, since it is much more convex than the roof,

FIG. 2.—Longitudinal section through center of an egg case, showing a thick layer above the eggs, a floor beneath them, and an open chamber under the floor, in which the newly hatched larvæ gather.

FIG. 3.—End view of egg case, showing triangular plate with lunate opening beneath it. The floor beneath the eggs inside the case does not reach the side walls, leaving a free passage to the chamber beneath.

but it was finished by 2 o'clock. The ends of the threads forming the floor were apparently fastened directly at either end to the previously completed roof, leaving a ridge or seam where the two joined.

When the case was thus far completed, she began egg laying. The roof was covered on the inside with a thick layer of loosely woven silk inclosing large open spaces. From this layer the eggs were suspended with their long diameters vertical, each egg held in place by a thin meshwork of silken threads, which were attached to the thick layer above and to one another and formed a continuous floor below the egg mass (fig. 2).

At 2.15 she stopped laying and, after removing her spinneret, swam about for a time, evidently resting. On returning to the case it required several efforts to replace her spinneret in the open end, but once adjusted she began to weave the triangular plate across the upper part of the open end, leaving below it a lunate opening (fig. 3). The plate was considerably thicker than the rest of the case and was fastened on the inside to the layer of loosely woven silk that covered the

roof. Last of all she finished the mast, and while doing this she kept her wing covers separated enough to supply herself continuously with fresh air. The triangular plate and the mast were of the same bright yellow as the eggs and remained this color for several hours.

The whole process lasted only 1 hour and 20 minutes, and the actual time consumed in spinning and egg laying was exactly 1 hour. The completed egg case is ellipsoidal in shape, the roof and floor somewhat flattened, and the side walls strongly convex. One end is tightly closed and the other has a lunate opening beneath the triangular plate, which gives free access to the space beneath the egg mass. The triangular plate is narrowed above into the mast, which rises vertically about 10 mm. above the roof of the case and tapers to a rounded point. On cases found floating in the pond both the triangular plate and the mast are dark brown in color, almost black, due to the action of the sunlight upon the silk.

The mast has been represented as a small tube with dense walls, whose suggested function is the admission of air into the egg chamber. Miger and Lancret (1809, p. 442) said:

It is a mistake to suppose that the turned-up point of the cocoon serves as a mast. It is not unlikely that the drawn-out point serves for the supply of air to the cocoon.

Lyonet (1832) confessed:

I do not know the use of this little mast. Perhaps it enables the insect to get rid of an excess of silky matter.

Laker (1881, p. 82) wrote:

The spike consists of a substance somewhat thicker and stronger than the rest of the cocoon and is hollow throughout the greater part of its length, except that it is crossed and recrossed inside with a dark, threadlike substance, thus somewhat resembling a horn stuffed with tow. The apex of the spike does not, however, appear to terminate in an orifice, but is closed. It does not seem to me that this spike can serve as a balance to the cocoon, because the nests are usually attached to some kind of support. I may, however, mention that I cut off the spike from two of the cocoons, and in both these cases the eggs did not hatch. It is, however, possible that this may have arisen from some other cause, although these particular cocoons appeared to be similar in every respect to others of which the eggs matured in due course. The cocoons from which the spikes were removed subsequently sank. These nests are so constructed that when floating loose the spike retains its proper position, and even if the cocoon be held so that the spike is parallel with the water, and then suddenly released, it immediately rights itself. If, however, the spike be partially submerged and then released, the cocoon turns bottom upward.

FIG. 4.—Cross section of mast of egg case, showing how the edges are rolled back to form an open tube.

In the six egg cases examined by the present author the mast or spike is not a tube at all, but a thick flat layer of closely woven silk, whose edges curl backward and almost meet along the side next to the body of the case. In this way a partially closed tube is formed, but there is a narrow slit running its entire length which manifestly disqualifies it from serving as an air tube (fig. 4). Furthermore, as Laker says, it is closed at the apex, and we may now add that it is also closed at the base, affording no connection whatever with the inside of the case. This fact does not seem to have been noted by any of these observers, but it disposes once for all of the supposition that the mast has anything to do with supplying air to the eggs.

Laker's suggestion that the eggs did not hatch in two of the cocoons because he cut off the spike may or may not be true, but evidently the immediate cause was the sinking of the cases, or "cocoons" as he calls them. The egg case must float at the surface of the water if the eggs are to develop properly. One of those obtained by the present author had sunk to the bottom of the pond, and although the spike and every other part was normal and intact, yet the eggs were undeveloped.

It seems reasonable to conclude, therefore, that the spike or mast, if it has any function, is concerned with floating the egg case and with keeping it right side up in the water, since both of these conditions are essential to the successful hatching of the eggs.

The number of eggs in a case varies considerably, but may be given as usually between 100 and 130. Garman (1881) found 107 eggs in the single case he examined, Matheson (1914) counted 112 and 130 in two cases, and the present author obtained 121 in one case and 117 in another. The larger end of the egg is next the roof of the case, the lower end being somewhat narrowed and also in the outer row of eggs considerably tapered on the outer side, as is admirably shown in the figures given by Miger and Lancret (1809).

When the eggs hatch, the larvæ issue from the lower ends and escape into the chamber beneath the egg mass. Here they crawl about for several (about 12) hours before venturing out into the open water.

THE LARVA.

On leaving the egg case the young larva is about 9 mm. long, measured from the tips of the mandibles to the tips of the posterior cerci. At first its color is an almost uniform light yellowish brown, but the dorsal surface quickly becomes darker with the exception of two irregular lines, one on either side of the median line and quite close to it, which extend from the anterior margin of the thorax to the tip of the abdomen. The outer sides of the light dorsal lines are accentuated with black on the thorax and darker brown on the first abdominal segments. On entering the pupal chamber these color distinctions are practically obliterated and the entire surface, dorsal and ventral, becomes a uniform brownish black.

The skin is densely clothed with short hairs, giving it a velvety appearance, and scattered among them are much longer hairs or setæ irregularly arranged. Along the lateral margins where the dorsal and ventral surfaces meet is a double ridge or fold of the skin, which stands out quite prominently. On the dorsal half of this ridge is a row of small papillæ, one and sometimes two on each segment. There are two other rows of similar papillæ, one on the dorsal and one on the ventral surface, close to the ridge. Each papilla carries a tuft of long setæ, varying in number from three or four to seven or eight. This double ridge remains light yellowish brown like the ventral surface until the final change when the larva is ready to pupate. Along the dorsal margin of this ridge on either side are the spiracles, but they are closed in the larva and take no part in respiration.

At the posterior end of the abdomen, opening dorsally upward and backward, is a deep transverse groove, from the bottom of which open the large longitudinal

air tubes or tracheæ, by means of which the larva breathes. The anterior and posterior margins of this groove form a pair of lips, which can be opened or closed at will and thus control the breathing. The posterior lip extends diagonally up-

FIG. 5.—Transverse groove on dorsal surface of last segment of abdomen. *a*, anus; *c*, cerci; *fl*, chitin flap; *i*, intestine; *p*, papillæ; *t*, openings of tracheal air tubes.

ward and backward to the level of the dorsal surface of the last abdominal segment, but though it thus appears in a dorsal view it really belongs to the ventral surface. At its center is a narrow chitinous flap extending from the margin of the lip back along the outer surface (fig. 5, *fl*). The lateral edges of the flap are turned forward, giving it the shape of the letter U, and it forms the posterior or ventral cover of the anal opening. Inside of this flap the end of the intestine (*i*) projects a little from the floor of the groove and the anus (*a*) opens halfway from the floor to the edge of the lower lip. In front of the anus is a fingerlike papilla on either side, tipped with a long bristle. When the lips of the groove are closed, these papillæ (*p*) come together in front of the anus and form an anterior or dorsal cover for the anal opening. In this way the anus can operate when the lips are closed, and whatever passes out of it is kept away from the tracheal openings. The central portion of the anterior lip is also somewhat chitinized over a trapezoidal area extending from the edge of the lip forward along the dorsal surface the full length of the last segment.

On either side of the intestine, in the deepest portion of the groove, is the opening of the tracheal air tube (*t*), which is elliptical in outline, with the long diameter inclined at an angle of 45° to the body axis. Each opening is covered with a membranous valve slit along the outer margin of the ellipse, which effectually closes the opening to the entrance of water.

On the ventral surface of the last abdominal segment are the cerci, two slender cylinders from 3 to 4 mm. in length in a full-grown larva and about 0.5 mm. in diameter. They are more or less wrinkled transversely and normally are naked, but often become covered with growths of algæ and Protozoa. There is no central lumen in these cerci, but the entire space is filled with tissue and contains many muscles. When the larva rises to the surface of the water to breathe, the cerci naturally flatten themselves along the surface film at right angles to the longitudinal body axis. This not only furnishes the larva with a secure hold upon the surface film, but it also opens the lips of the transverse groove and holds them open as long as the larva remains at the surface. When the hold upon the surface film is released, the cerci trail backward in the water and close the transverse groove. In front of the

FIG. 6.—Side view of last segment of abdomen, showing depth of dorsal groove and the papilla on the ventral surface.

center of each cercus on the ventral surface of the last abdominal segment projects a short rounded knob, carrying on its tip a tiny papilla armed with a single seta (fig. 6).

FIG. 7.—Side view of head, showing its inclination to thorax.

FIG. 8.—Dorsal view of head. *an*, antenna; *e*, eyes; *lb*, labium; *md*, mandibles; *mx*, maxillae.

FIG. 9.—Ventral view of head. *an*, antenna; *lb*, labium; *md*, mandibles; *mx*, maxillae.

FIG. 10.—Dorsal view of left antenna.

HEAD.

The head has the form of an ovoid, flattened dorsoventrally, evenly rounded posteriorly, narrowed and squarely truncated anteriorly, and a little more convex on the dorsal than on the ventral surface, the latter being divided by a central longitudinal groove. The head is inclined upward at an angle of 30 to 45° with the body axis, and its outer surface is very hard chitin (fig. 7). It is brownish

yellow in color, spotted with dark brown. On the ventral surface the spots cover the whole of the basal portion and extend forward in two long points on either side. There is also a narrow band of spots across the base of the lower lip. On the dorsal surface the spots cover the basal portion behind the eyes, and there is a large patch behind and inside of each antenna (fig. 8).

The eyes (*e*) are six in number on either side and are situated outside the bases of the antennæ and behind the mandibles. Each group of six is arranged in two transverse rows, somewhat concave toward each other like parenthesis marks. The interval between the two outside eyes is longer both longitudinally and transversely than between the two inside ones. Each eye is elliptical in outline, the long axes of the ellipses in the two rows inclined toward each other. The chitin integument over each eye is transparent, and beneath it can be seen the retinal pigment, which is uniformly black. In larvæ taken from the pupal chamber this

FIG. 11.—Dorsal view of mandibles.

FIG. 12.—Ventral view of left maxilla.

black pigment entirely disappears, the eyes being apparently withdrawn preparatory to forming the compound eyes of the adult.

The antennæ (*an*, figs. 8 and 9) project from the dorsal surface of the head behind the inner corners of the bases of the mandibles. Each consists of a basal joint and three terminal joints, the former twice as long as the three latter combined and three times their diameter. The basal joint carries a fringe of long hairs along its inner margin and much smaller and widely scattered hairs over its entire surface. The three terminal joints are destitute of setæ and hairs (fig. 10).

MOUTH PARTS.

The mandibles (*md*, figs. 8 and 9) are not alike; the right one is always longer and more slender than the left, and the tooth on its inner margin is very much larger and bifid at the tip (fig. 11). Indeed, the tooth on the left mandible is hardly more than a small spine on the inner margin, and even that is sometimes wanting. The

outer margin of the base of each mandible is flush with the lateral margin of the head, and the two mandibles shut down across the mouth like the blades of a pair of scissors, the right mandible being ventral to the left. In consequence of the wide interval between their bases the mandibles have no power of chewing, but can only bite or cut.

The maxillæ (*mx*, figs. 8 and 9) are a trifle longer than the antennæ and are attached directly below them on the ventral surface of the head. Each is apparently six-jointed, the basal joint very short and wide and the second joint twice the length of the four terminal joints combined and about twice the diameter of the third joint. The four terminal joints diminish regularly in length and diameter. On the inner margin of the third joint near the distal end is a small papilla, tipped with a single bristle. The second joint is covered with widely scattered hairs; the other joints are naked (fig. 12).

Matheson (1914, p. 342) said of this maxilla: "The cardo is greatly elongated, the lacinia being reduced to a mere joint. The palpus is three-jointed." It seems better to interpret the basal joint as the cardo, the second joint as the greatly elongated stipes, and the third joint as the palpifer. The three terminal joints then become the maxillary palp, while the subgalea, the galea, and the lacinia are represented by the tiny knob on the palpifer. This interpretation corresponds exactly with that given by Dimmock (1909, p. 13) for the larval maxilla of a Carabid beetle.

FIG. 13.—Ventral (left) and dorsal views of labium. *l*, ligula; *lp*, labial palp; *m*, mentum; *p*, palpifer; *st*, submentum.

The labrum or upper lip is cut squarely across between the bases of the mandibles and apparently renders but little actual service. The labium or lower lip, on the contrary, is well developed and plays an important part in feeding. The submentum is not visible in ventral view but is clearly seen from the dorsal surface. The mentum is prolonged into a triangular lobe on either side of the palpifer; the latter has a well-defined ligula and carries on either side a two-jointed labial palp (fig. 13).

THORAX.

The thorax is made up of three segments that increase slightly in width backward. The first one is longer than the others and has a well-defined transverse groove at about its center; the other two have only lateral indentations and short transverse wrinkles that do not form continuous grooves. The second and third segments each carry a pair of spiracles, but there are none on the first segment.

ABDOMEN.

The abdomen is composed of eight segments, the first one a little wider than the last thorax segment, the second wider still, and the remaining six decreasing regularly in width, the terminal one being only one-fifth the width of the second. At first the segments are smooth and free from wrinkles, but with advancing devel-

opment transverse grooves begin to appear and increase until in the fully matured larva each segment has three or four secondary grooves, and it is very difficult to select the true intersegmental sutures.

There is a pair of spiracles on each segment, the anterior ones being larger than the posterior, with the exception of the last pair, which are much the largest of all. These open on the dorsal surface in the bottom of the groove already described and are the only ones that function during larval life.

LOCOMOTION.

The larvæ live in the water until ready to pupate and show two methods of locomotion, walking and swimming. The legs are strong, and in spite of the long abdomen the larva can crawl actively about over the bottom of the pond and even out in the open air. When endeavoring to escape impending danger, it moves with considerable rapidity, but hardly fast enough to be called running.

When pond 2E was drained, the Hydrous larvæ continued crawling about over the bottom for two days after the water had entirely disappeared. By that time the bottom had become so thoroughly dried that they could no longer find any shelter from the hot sun. One hundred or more were gathered and preserved, and probably all the others perished. During their endeavors to find shelter some traveled 100 feet, surmounting various obstacles in their way, such as stones, water-logged fragments of wood, and the débris usually found on the bottom of a pond. This shows that they can travel long distances, if necessary, when hunting for a suitable place to pupate, and the fact that they usually select a spot near the water's edge would indicate that the presence of moisture is the chief essential.

Swimming is accomplished by both leg and body movements. To increase the power of the legs as swimming organs, the femora of all three pairs have a fringe of heavy setæ along their outer margins, the tibiæ are strongly flattened and have a slightly heavier fringe along both outer and inner margins, and the tarsi are also flattened and have a very short fringe along the inner margin, each tarsus ending in a single long and stout claw. The body in swimming moves rhythmically up and down in a manner very similar to that of a leech; but the combined effort of body and legs produces only a slow progress, with frequent stops, and it is a very simple matter to catch these larvæ in a dip net

BREATHING.

The larva breathes air through the two tracheal trunks that extend the whole length of the body. So far as known there are no tissues or organs that extract air from the water. Hence it must come frequently to the surface in order to renew its air supply and is easily seen and captured at such times. When seeking fresh air, it swims almost vertically upward until close to the surface, then turns head downward and thrusts the posterior end of the abdomen and the cerci above the surface film. The cerci fall onto the surface film at right angles to the body axis, thus supporting the larva in position and at the same time opening the mouths of the air trunks. When it has finished taking in air, the tip of the abdomen is drawn beneath the surface film, thereby straightening out the cerci parallel with

the body axis and closing the mouths of the air trunks. Fifteen to twenty minutes is the length of time which usually elapses between successive intakes of air. When the larva is resting, however, it frequently remains beneath the water for a much longer period. On the contrary, when actively feeding, the larva often comes to the surface and supports itself on water plants or something of the sort in such a position that the tip of its abdomen can remain constantly out of water.

FEEDING.

The prey is caught entirely with the mandibles, which seize it like a pair of forceps. While the larva moves about continuously in search of food, it can not be said in any sense to chase its prey, but is content with whatever it happens upon. Once within its grasp the prey is squeezed to death by the powerful mandibles, if that be possible. The carcass is then manipulated between the antennæ, the maxillæ, and the labium, being turned around, moved back and forth, and folded and unfolded as if it were between the tips of four fingers and a thumb. Every second or two the mandibles close down on it like a pair of scissors, mashing it, cutting or rending it asunder, and cramming it down the throat all in one movement.

When eating snails the procedure is somewhat different. The snail is seized by the mandibles and the head is thrown backward until the snail touches the dorsal surface of the thorax. It is then held between the head and thorax as in a vise and is very quickly crushed and eaten. The outlets of the ponds at Fairport had a cement wall on either side for 10 or 15 feet. These walls were often lined with small snails just above the water's surface and made a favorite hunting ground for the *Hydrous* larvæ. The latter swim or crawl along just beneath the surface until they see a snail. The head is then thrust above the surface and the snail is grasped between the mandibles and torn loose from the wall. The larva then reverses its body, the tip of the abdomen is thrust up into the air while the head, holding the snail, is carried beneath the surface. After the snail is consumed the larva reverses ends again and hunts for another. It sometimes happens that the snail gets a chance to set itself upon the wall after it is seized. In such cases the larva is often unable to tear it away and has to leave it and try another. But occasionally, either through design or accident, it comes back and tries the same snail again in a few minutes.

Some of the authors mentioned have commented upon the skill with which the larva extracts the snail from its shell. If the contents of the digestive canal are any evidence, the larva seldom extracts the snail at all but simply crushes the shell and swallows the shell fragments along with the body of the snail.

FOOD.

The accompanying table presents the results of the examination of the contents of the alimentary canals of 52 *Hydrous* larvæ. The lengths of the larvæ are given in millimeters, and they present a range in size from 20 to 61 mm., the last six in the table being fully grown and ready for pupation.

Food of 52 Hydrus larvæ taken from pond at Fairport, Iowa.

[The figures indicate percentages, the entire food being 100.]

Number of specimen.	Length of specimen in millimeters.		Snails: Physa and Planorbis.	Chironomus larvæ.	Chironomus pupæ.	Caddisfly larvæ.	Libellulid nymphs.	Erythemis nymphs.	Anax nymphs.	Damselfly nymphs.	Crayfish species.	Cyrtis species.	Daphnia species.	Hydrus larvæ.	Hydrophilus larvæ.	Berosus larvæ.	Philhydrus species, adult.	Halipus species, adult.	Gyrinid larvæ.	Dytiscus larvæ.	Laccophilus species, adult.	Belostomid nymphs.	Tadpoles.	Fish.
1.	20	20	80																					
2.	22	60	40																					
3.	22	100																						
4.	28	30	70																					
5.	28	20	50																					
6.	30	20	80																					
7.	30	50	50																10					
8.	32	40					10																	50
9.	32	100																						
10.	33	100																						
11.	35	10	15																					75
12.	35	75	25																					
13.	36	100																						
14.	38	10	60																					30
15.	38	40	40				50																10	
16.	40	60	10																					
17.	40	15	10							25									30					50
18.	40	50	50											10	5									
19.	42	10	30					10			30								5					
20.	42	15																					100	
21.	42	75	15																				10	
22.	42	75	25																					
23.	43	60	35	5																				
24.	44	50	48						1															1
25.	44	20	30									10												40
26.	45	100																						
27.	45	100																						
29.	45	50	20																					30
30.	45	60	10											10	10			10						30
31.	45	50	20																					
32.	45	60	35	5																				
33.	45	70	30																					
34.	46	100																						
35.	46	55	20																					
36.	46	30	50								5									25				
37.	46	50	50			5	10																	
38.	47	60	35																					
39.	48	2	5						5															
40.	48	20	10				40																	
41.	48	40	40					2																35
42.	50	5	25																					30
43.	50	80	20																			20		
44.	50	100																						
46.	52	40	10												50									
47.	54	100																						
48.	55																							
49.	55	100																		100				
50.	60	20	20										2											48
51.	60	20	20	5	10			5			5	1		20		10					5	20		
52.	61	40	5				10															10		
Average.	40.7	38.25	30.5	1.25	1.50	1.50	0.50	0.50	0.25	0.75	1.00	0.60	0.50	2.00	1.00	1.40	0.60	1.30	3.25	1.30	0.60	0.75	2.50	8.25

From a study of this table several facts stand out quite clearly.

1. The chief food of the Hydrus larva consists of snails and Chironomus larvæ; a mere glance down the first two food columns is convincing proof of this. Nineteen of the 52 specimens had eaten nothing else, 3 others had eaten only Chironomus pupæ in addition, and in 4 others these two foods constituted 90 to 98 per cent of the total eaten. In other words, half of the larvæ had lived entirely upon snails and Chironomus species. Only 2 out of the entire number are credited with having eaten none of these two foods. It is also worthy of note that 4 of those that had eaten nothing else were fully grown.

2. The young larvæ up to 30 mm. in length eat nothing beside these two foods except one another, for they are confirmed cannibals, and when first hatched, unless there is plenty of acceptable food, and sometimes even when such food is abundant, they eat one another voraciously until all but one are gone; and some of them keep up this cannibalism when they are fully grown, in proof of which witness the accompanying records of Nos. 19, 30, 46, and 51. By this means their numbers are greatly reduced and they are naturally held in check. On reaching a length of 30 mm. they begin to seek larger prey and attack other beetle larvæ, dragonfly nymphs, tadpoles, and small fish. By the time they reach 40 mm. in length their diet has become quite varied. Nos. 19, 30, 39, 42, 50, 51, and 52 show a very mixed diet and, especially the last two, probably ate everything they could capture.

3. They do eat fish and in considerable quantity; 10 of the 52 had eaten fish to the extent of 30 to 75 per cent of their total food, and there were a few fishbones in the intestine of another larva.

In judging the damage thus inflicted, however, we must remember several facts. First, all the larvæ examined were taken from this one pond which contained only young buffalo fish (*Ictiobus cyprinella*), the hatch of the year. These little buffalo fish ate some of the smaller Hydrous larvæ, and possibly these constituted as large a percentage of their food as they themselves contributed to the food of the larger larvæ; but there were no fish to keep down the full-grown beetle larvæ, as there would be in a pond containing both adults and young. Consequently, the contest between the fish and the beetle larvæ was one-sided and very much in favor of the larvæ. Again, the presence of thousands of these young fish in the confined area of a small pond gave the beetle larvæ another advantage. The fish were comparatively easy to catch, and there was abundant opportunity to prey upon them. Accordingly, the percentages here obtained are probably above the average and are certainly higher than would be expected in a pond containing adult fish as well as young. Furthermore, when the larva does eat fish there is enough for it to fill up on without eating anything else.

But after making due allowance for all these considerations the fact still remains that the Hydrous larva does eat fish when it has an opportunity, and therefore becomes a menace to successful fish raising in ponds. The methods to be used in guarding against this menace will be discussed later.

THE PUPA.

PUPATION.

When the larva is fully grown, it assumes a uniform brownish-black color, as already stated, there being no difference in shade between the dorsal and ventral surfaces. It then crawls out of the water and searches for a place to bury itself. The distance to which it travels varies considerably and may be from 2 to 8 or 10 feet from the water's edge. The selection of a spot apparently depends upon the consistency of the soil as well as upon its moisture content. Black clayey loam is preferred to sandy soil, but under compulsion almost any kind of soil will answer. Two larvæ were kept in an aquarium where nothing but clear sand was available, and in this they buried, pupated, and finally emerged without apparent inconvenience.

The larva uses its mandibles to some extent for digging, biting off chunks of earth and thrusting them to one side and backward; but the burrowing is mainly accomplished by thrusting its flattened head forward and then enlarging the hole by sidewise and up-and-down movements. After reaching a depth of 2 or 3 inches in this manner the larva begins a rotary movement of its entire body, swinging both ends horizontally around the longitudinal center as an axis. During this movement the head and tail are raised until the body assumes the shape of a crescent or semicircle, the ventral surface convex, the dorsal concave (fig. 14). As a result the pupal chamber when completed is subspherical in shape, the upper portion flatter than the lower, and is usually about 40 mm. in diameter. The smoothness of the walls depends in large measure on the consistency of the soil. When the soil contains the right amount of clay and moisture the walls are very smooth, but when the soil is sandy the walls are rough.

It requires 36 to 48 hours to complete this chamber, but after it is apparently finished the larva still keeps up its rotary motion at intervals until it is ready to pupate. Pond 2E was drained July 15. From its shores were obtained two pupal chambers, apparently just formed and containing larvæ. These were transferred to the laboratory and kept on moist sand. One larva pupated during the night of July 20 and the other during the night of July 23. Both kept up the rotary motion until the day before pupation; then they remained quiet, the head and tail being withdrawn from the sides of the chamber and curled over the back. Finally, the skin split along the back of the thorax; the head was withdrawn, leaving the hard chitinous covering of the larval head, with the antennæ, the cornea of the eyes, and the mouth parts intact; the abdomen was withdrawn, leaving the larval cerci in like manner intact; and the larva was transformed into a pupa.

After pupation the larval skin, with the head and mouth parts, was pressed into the earth on one side of the pupal chamber, and the pupa assumed its characteristic position. It may be noted that Lyonet (1832) said of the larva of *Hydrous piceus*:

I therefore put it upon freshly turned-up soil, on which I scattered some grass. It made a hole, which it lined with grass, and remained within it several days in a curved position, lying on its back.

This lining of the pupal chamber with grass was probably accidental, some being carried in by the larva during its burrowing; but it is worthy of note that the larva remained in the chamber lying on its back and that the subsequent pupa rested also back downward. In our American species both larva and pupa rest upon the ventral surface.

DESCRIPTION OF PUPA.

The general form of the pupa is ovoid, narrowed to a rounded point posteriorly and strongly flattened dorsoventrally. In dorsal view the prothorax entirely conceals the head, which is folded down onto the breast, and the knees of the legs are just visible at the sides of the body, the first pair opposite the posterior margin of the prothorax, the second pair in contact with the first and opposite the groove between the pro and meso thorax, and the third pair opposite the posterior margin of the first abdominal segment. Only the bases of the elytra and wings are visible, the rest of them being carried around the sides of the body onto the ventral surface. In ventral view (fig. 16) all the body regions and their appendages are visible.

FIG. 14.—Photograph of larva inside the pupal chamber, showing characteristic position.

FIG. 15.—Photograph of pupa inside the pupal chamber, showing arched position, ventral surface downward.

The pupa is snow white throughout when first transformed, but the eyes begin to darken in a very short time, and then the various appendages, including the legs and wing pads, and finally the body itself, the color assumed being a reddish brown. Of a dozen pupæ obtained by the present author all were white when taken from the pupal chamber except one that transformed within 10 or 15 minutes. Four of them remained white on preservation, indicating that they had been formed but a short

FIG. 16.—Ventral view of pupa.

FIG. 17.—The three curved spines at an anterior corner of the pronotum.

FIG. 18.—The posterior cerci of the pupa.

time. The others turned to various shades of reddish brown within 24 hours, the depth of shade probably varying with the length of time that had elapsed since pupation. Two of them became dark brown over the entire surface, approaching black in the eyes, the maxillary palps, the tarsi of the legs, and the last two joints of the abdomen. In one pupa this color was communicated even to the bases of the cerci and the large anterior spines. If the pupa is undisturbed in the darkness of the pupal chamber, it probably remains white until the pupa skin begins to separate

from the underlying tissues preparatory to transformation. The pupa whose chamber was opened just as it was about to transform was dark gray-brown in color, but this color was in the skin, for the beetle that emerged was snow white.

The average total length of the pupæ was 35 mm., the greatest width at the third thoracic segment 15 mm., the thickness of the combined head and thorax 12 mm.; the posterior cerci were 4.25 mm. long and the anterior spines were 5.5 mm. long.

The head of the pupa is curved downward onto the chest, its anterior margin just reaching the bases of the second legs. This folding back of the head leaves the prothorax as the most anterior portion of the pupa. The eyes are partially concealed beneath the anterior corners of the prothorax, and just inside the center of each eye is a small spine. Elsewhere the head is smooth and its length is about equal to the width through the eyes. At the posterior margin of the head on the dorsal surface there is a small, transversely elliptical spot on either side of, and close to, the median line. The surfaces of these spots are depressed a little, especially on their posterior margins, and they turn much darker in color than the surrounding tissue. They entirely disappear in the adult beetle.

The antennæ, the mouth parts and legs, and the long posterior spine of the metasternum are encased in separate sheaths, the antennæ curved around beneath the eyes as in the imago and the maxillary palps extending backward ventral to all the other parts as far as the first abdominal segment. The articulations of the antennæ, the palpi, and the tarsi of the legs are distinctly visible in older pupæ. In the sheaths inclosing the legs there are separate branches for each of the large spines at the distal ends of the tibiæ.

Attached to the pupa case at each anterior corner of the pronotum are three curved styli 5.5 mm. long. They are reenforced at their bases by rootlike processes formed of folds of the pupa case, making them very strong. They taper gradually from the base to the tip, and the distal third is transversely ridged and terminates in a short and slender bristle (fig. 17). Around the posterior and lateral margins of the pronotum is a row of 12 short styli, similarly ridged for their entire length and each tipped with a bristle. On the dorsal surface of the second thorax segment is a pair somewhat larger, one on either side of the scutellum, and another pair on the third thorax segment. The dorsal surface of each abdominal segment except the last bears a transverse row of four similar styli. The two central ones are about the size of those on the thorax but the lateral ones are nearly as large as those at the anterior corners of the pronotum. The last segment of the abdomen bears a single pair smaller than any of the others and directed backward from its posterior margin just above the cerci. On the ventral surface of each abdominal segment from two to six, inclusive, close to either lateral margin is a single tiny stylus.

All these styli are ribbed for their entire length and tipped with bristles. They are also a part of the pupa case and are left behind with the case in the pupal chamber when the beetle emerges. Their use is thus explained by Lyonet (1832), who reared the larvæ of the European species *piceus*:

In the damp earth which the pupa requires the hooks fulfil a purpose of great importance. The skin of the pupa is very delicate. Lying on damp earth it could hardly escape injury, and the weight

of the body might easily give it a distorted shape; but the pupa protects itself from these dangers by assuming an unusual attitude. It extends itself back downward in a horizontal position and supports the weight of its body by the three sets of hooks as upon a tripod. In this attitude, though surrounded on all sides by moist earth, it keeps its body from actual contact with any object until it has assumed its final shape.

These observations on the attitude of the pupa and the use of the hooks were confirmed later by Miger and Lancret (1809), and are quoted by Miall (1895, p. 73). They may be true of the European *H. piceus*, but the American species here described certainly rests in the pupal chamber with the back uppermost, as noted by Matheson (1914, p. 343).

Furthermore, the body is strongly curved upward instead of being horizontal, so that the central portion is lifted still farther above the floor of the chamber (fig. 15). The reason for this, as well as another use for the spines, was revealed on digging out some of the pupæ just after a heavy rainstorm. Two of the pupal chambers were found partly flooded with water, but the pupæ, resting upon their spines, with their backs strongly arched, had thereby kept their spiracles well above the water and so prevented drowning.

The scutellum stands out prominently on the dorsal surface of the second thorax segment, the elytra being drawn away from it onto the ventral surface. These elytra pads each show four distinct longitudinal ridges beside the two margins, with broad intervening furrows. The pads of the true wings are smooth. These four pads are apparently fastened in position by being cemented to the outside of the pupa case, and also to the outside of the cases covering the second and third legs. In only one instance was this cement loosened after preservation in alcohol.

At the posterior end of the last segment is a pair of large cerci 4.25 mm. in length. Each is cylindrical, considerably enlarged at the base for a third of its length and then abruptly narrowed and of the same diameter for the rest of its length. Both portions are transversely wrinkled, and the tip is armed with a short bipartite claw, one or both of the rami being often toothed (fig. 18). These cerci are also part of the pupa case and are left in the pupal chamber when the beetle emerges. They are muscular, with considerable freedom of motion, and evidently serve the pupa partly as false legs for support in connection with the anterior spines and partly as a means for adjusting its position in the chamber. If a pupa is inverted in the pupal chamber, it can right itself by means of convulsive movements of these cerci, together with the posterior abdomen, the latter supplying the muscular power and the cerci furnishing the point of leverage with their sharp claws against the walls of the chamber. If the pupa is disturbed, it simply kicks itself about vigorously, using the abdomen and cerci in the same manner.

It is worthy of note that all the hydrophilid pupæ formed in earth chambers are similarly provided with cerci, although these differ in structure in the various species.

During the transformation from the larva into the pupa the mode of respiration is changed. The larva breathes through the posterior openings of the tracheal trunks, as already described, but these disappear in the pupa and in their place fully developed spiracles appear along the sides of the thorax and abdomen, as in

the adult beetle. These spiracles open to the exterior through the pupa case, and hence the pupa not only breathes through them but if it is submerged under water it drowns, having no provision for keeping them covered with a film of air like the adult beetle. (See p. 30.)

The length of time spent in the pupal chamber varies considerably, but averages from two and a half to three weeks. This period is divided as follows: From 5 to 8 days are passed by the larva after the pupal chamber is completed and before pupation; from 7 to 12 days are passed in the pupa state; and 4 or 5 days are spent by the adult beetle after transformation before it emerges. The table below gives these periods for four beetles that were under observation continuously.

Periods spent in pupal chambers by four beetles.

Number of specimen.	Comple- tion of pupal chamber.	Pupa- tion.	Trans- forma- tion.	Emer- gence.
1.....	July 15	July 20	July 27	July 31
2.....	do.....	July 23	Aug. 3	Aug. 7
3.....	July 16	July 22	Aug. 2	Aug. 6
4.....	do.....	July 23	Aug. 4	Aug. 9

THE ADULT BEETLE.

A pupa was dug up on July 27 that was just ready to transform, and the adult beetle crawled slowly out of the pupa case while being watched. At the instant of transformation the entire body was white, but in the sunlight to which it was exposed the head, prothorax, scutellum, and legs became a rich mahogany red even before it had entirely gotten out of the pupa case. The elytra became light salmon pink; the wings and abdomen remained white. The color first appears on the wings as a faint salmon pink along the ribs and veins, which gradually deepen to a reddish-brown. The web of the wing slowly loses its bleached-white aspect, but remains colorless, of course, even in the matured adult.

The elytra stretch to their full size almost instantly on being set free from their pads, and in the course of an hour become dark reddish-brown. The abdomen remains white longer than any other portion of the body—several hours, in fact—then gradually turns reddish-brown. The color appears first on the ventral surface along the central carina and the sutures between the segments, and gradually spreads in all directions. On the dorsal surface the last and smallest segment is colored first, then a faint line appears along the center, which slowly spreads outward on either side. The beetle above mentioned came out of the pupa case about 10 a. m., and by the next morning it was entirely black on the upper surface, while the under surface still remained a dark mahogany brown.

This rapid change of color was not due wholly to the influence of the sunlight, for the first beetle on the list just given, which transformed during the night of July 27, was entirely black on the upper surface the next morning, and it had remained in the darkness of the pupal chamber all the while. The fourth beetle on the list was taken out of its pupal chamber several times, but would not remain in the light and returned to the chamber. On August 9 it came out voluntarily

and did not return again. The final color of the adult beetle is a rich olive black, very shiny above and piceous beneath, while the antennæ, palpi, and tarsi are a deep mahogany brown, often black.

EXTERNAL CHARACTERS.

The adult beetle has the outline of an elongated oval, 34 to 40 mm. long and 15 to 16 mm. wide. The thickness of the thorax is 8 to 9 mm. The dorsal surface is not as convex as in the species *ovatus*. The prosternal prominence, into which the front end of the sternal spine fits, is closed in front, and there are more or less distinct triangular yellow spots along the ventrolateral margins of the abdomen. These color spots are more distinct on the second, third, and fourth segments than on the others and are partly due to the fact that the skin is here pubescent and partly to a lighter color in the skin itself.

This genus is distinguished first by its size, the species being fully twice as large as any other North American hydrophilid. Then, the last four joints of the nine-jointed antennæ are of peculiar shape and form a distinct club. Along the center of the ventral surface of the thorax there is a continuous ridge that projects in front into the prosternal prominence already mentioned and is prolonged behind into a large, acute spine. The tarsi of the middle and hind legs are strongly compressed and fringed with hairs, making powerful swimming organs.

The pro, meso, and metasterna, the coxæ of all three pairs of legs, the trochanters and bases of the femora of the first legs, and all of the first segment of the abdomen are covered with a dense yellow pubescence, becoming blackish in older specimens. This serves to hold the air film that covers the ventral surface when the beetle is under water. The scutellum is almost an equilateral triangle, the base being scarcely shorter than the sides. Each elytron has four rows of coarser punctures, the outer row being double, and there is an additional partial row along the distal portion of the sutral margin. Between these the surface is covered with minute wrinkles and finer, scattered punctures. There are also scattered punctures along the base of the upper lip, on the lateral margins of the head in front of and inside of the eyes, along either side of the mid line of the head, on the lateral margins of the pronotum, and in an oblique line on either side extending from behind the eyes backward and inward and not quite reaching the center. There is no definite arrangement of the punctures at any of these places, but they are very distinctly visible.

ANTENNÆ.

These are attached just in front of the eyes and curve around below them, being concealed in dorsal view. They are nine-jointed; the basal joint is longer and wider than the four that follow it and is curved. The second joint is one-fourth the length and three-fifths the width of the basal joint; the next three joints are the same size, half the length, and the same width as the second joint. The sixth joint is deeply bilobed; the ventral portion is enlarged and flattened into a spoonlike lamina, which extends outward beneath the seventh joint and covers all of it except the very tip; the dorsal portion is a short fingerlike process. Each of the seventh and eighth joints has a long process arising from its anterior margin

and curving upward and backward. These two processes and the dorsal lobe of the seventh joint are tipped with tufts of long, coarse hairs. The ninth segment is flattened into a lamina with rounded angles, which is curved upward and backward, like the processes on the preceding joints, and has a fringe of short hairs. The surfaces of these last four joints are uniformly covered with a pile of short hairs that can not be wetted by water (fig. 19). According to Miall (1895, p. 81):

The antennæ are used only for breathing by the submerged insect. Their place as feelers is supplied by the long and forward-directed maxillary palps.

MOUTH PARTS.

The mandibles are fully as powerful in the adult as in the larva. Each consists of a single chitin sclerite, curved into a clawlike tip, which is bifid and armed on the inner side with three long and stout teeth; the distal tooth is tripartite at the tip, the other two are bipartite (fig. 20).

Each maxilla is made up of two basal pieces and three outer parts with their subdivisions. The portion that joins the head, the cardo, is somewhat trapezoidal, narrowed and emarginate proximally, widened and armed with a fringe of hairs distally. The stipes is jointed to the cardo almost in a straight line and serves as a support for the outer parts. The palpifer at the distal end of the stipes is short and cylindrical; the maxillary palp attached to it is four-jointed, slender, and cylindrical, the terminal joint shorter than the second and third joints and neither enlarged nor flattened. To the outer margin of the

FIG. 19.—Right antenna of adult beetle.

FIG. 20.—Ventral view of mandible of adult beetle.

FIG. 21.—Ventral view of right maxilla of adult beetle. *ca*, cardo; *dg*, digitus; *ga*, galea; *l*, lacinia; *mxp*, maxillary palp; *pa*, palpifer; *st*, stipes; *sg*, subgalea.

stipes is attached the subgalea, which is deeply emarginate at its proximal end, while at its distal end is hinged the two-jointed galea, each joint about the same length and width. The lacinia on the outer margin of the subgalea is heavily fringed with hairs and carries a long fingerlike digitus (fig. 21).

FRONT TARSUS OF MALE.

The last joint of this tarsus is as long as the other four joints, oval in outline and strongly flattened. The dorsal claw is very long and stout, while the ventral one is much reduced in size. Along the inner margin, behind the bases of the claws, is an elliptical area whose ventral surface is covered along its margins with rows of tiny suckers, like those on the tarsi of the male *Dytiscus*, but much smaller. Those at the distal end of the area are tipped with stiff bristles, the others are naked. A long papilla extends outward from the distal end of the area between the bases of the two claws and is tipped with a tuft of stiff bristles. Another papilla, also tipped with bristles, is found on the ventral surface of the joint near its outer margin, behind the base of the small ventral claw (fig. 22).

FOOD.

Miall stated on the same page quoted above (1895, p. 81), "the food of the adult *Hydrophilus* is largely vegetable, but it will prey upon small aquatic insects." He kept four specimens in an aquarium with plenty of vegetation but no animals larger than *Daphnia*, and they remained perfectly healthy. Similarly, the present author placed in an aquarium with plenty of vegetation but no animal food two of the beetles that had been reared from pupæ. They lived for three weeks and appeared perfectly healthy, eating up the water plants every two or three days. Under natural conditions, however, the adults also eat animal food and sometimes kill and eat fish. The female that spun the egg case described on page 10 celebrated the completion of her task by killing and eating a small buffalo fish that happened to be in the aquarium. It is quite possible that out in the pond where other animal food was abundant she might have chosen something else; but since there was an abundance of fresh plant food in the aquarium, which she passed by, she evidently craved something containing proteids. The adults sometimes congregate in large numbers and would then become a serious menace if they should choose to attack the young fish. In fact, the adult, although it feeds largely upon vegetation and may live and apparently thrive for a long time without other food, nevertheless stands as a constant potential menace to the breeding of fish.

FIG. 22.—Tarsus of front leg of adult male beetle.

RESPIRATION.

The mode of respiration of the adult *Hydrous* is peculiar. It was first correctly described by Nitzsch (1811, pp. 440–458; Pl. 9) and afterwards in greater detail by Miall (1895, p. 75). This latter account agrees in every detail with that observed by the present author in the American species and may be summarized as follows:

In the adult beetle there are two pairs of thoracic spiracles and seven pairs of abdominal spiracles. Those on the meso and metathorax and the anterior abdomen segments are considerably larger than the others, and it is through these that respiration chiefly takes place. The space between the elytra and the dorsal surface

of the body is filled with a large flattened bubble of air. On the under surface also the hairy tracts already noted on the thorax and first abdominal segment and on the sides of the other abdominal segments retain a film of air. This film joins the dorsal air bubble at the groove between the pro and meso thorax and along the margins of the elytra. The spiracles open into this combined air supply, the larger ones being nearer the groove just mentioned.

When the Hydrous wishes to renew its air supply, it does not thrust the posterior end of the body out of the water as does *Dytiscus*. On the contrary, it assumes a position approximately parallel with the surface of the water and inclines the body sidewise, so as to bring the angle between the head and prothorax on one side above the surface. At this angle a funnel appears leading to the air film on the thorax below. At the same time the antenna on this side is moved outward. Its four enlarged terminal joints lie in the air film beneath the overhanging edge of the prothorax and in the space between the prothorax and the head. These joints are fringed with long bristles and covered with fine short hairs, which can not be wetted by water. Hence, when they move outward the air film is carried along with them, clinging to the hairs and bristles. As soon as any part of these unwetted joints comes to the surface of the water the air film breaks and a passage is thereby opened through the funnel from the outside air to the air film on the ventral surface of the thorax. The terminal joints are drooped downward at an angle with the rest of the antenna, and the air passage is thus inclosed between the hairy side of the thorax and the vertically arranged antennal joints, also covered with hair. The size of the opening is determined by the distance to which the antennal joints are carried from the side of the body. The vitiated air is expelled and the fresh air drawn in by rhythmical movements of the abdominal segments and the elytra.

Especial attention is called to the fact that the air enters and leaves the dorsal bubble only by way of the air film on the ventral surface of the thorax and is never taken directly into the space beneath the elytra.

ECONOMIC RELATIONS.

Having shown that both the larvæ and adults are a considerable menace to young fish and having gained a fairly complete knowledge of the life history of this beetle, its relations to pond fish culture may be discussed more intelligently.

RELATION TO VEGETATION.

The kind as well as the amount of vegetation in a pond is of great importance. Both the adult and the larva of *Hydrous* use various water plants as a hunting ground from whence to obtain their food, as a hiding place to escape their enemies, and as a means of reaching the surface to obtain oxygen. The adult beetle also feeds upon living plant tissue, and the female attaches her egg case to floating leaves or bits of dead vegetation. Accordingly, the inference would be that the greater the amount of vegetation in a pond the better it would be adapted to the breeding of these beetles, but this does not prove to be true. The adults seem to manifest a decided choice in the kind of vegetation and are easily discouraged by a superabundance, and of course the eggs are laid and the larvæ are developed wherever the adults may choose.

The four ponds of series E are as nearly alike in all their relations as possible. However, No. 1 was covered during the summer of 1918 with an abundance of blanket algæ, largely *Hydrodictyon*, while there were only floating patches along the shores of the other three ponds. No Hydrous beetles, larvæ, or pupæ were found in or around pond No. 1, although diligent search was made for them; in the other three ponds they were very abundant. The banks of earth separating ponds 1 and 2 and 2 and 3 are as nearly alike in size, height, and vegetation as could be desired. And yet when pond No. 2 was drained and the adult beetles were compelled to seek shelter elsewhere, almost without exception they went to pond No. 3 and not to pond No. 1.

Again, in series F pond No. 1 was not disturbed in 1918, while ponds 2 and 3 were drawn and cleared of water plants. In consequence pond 1 was carpeted with a dense growth of *Elodea canadensis*, excluding almost everything else, while ponds 2 and 3 contained only small amounts of vegetation. Repeated searching failed to discover a single hydrophilid or dytiscid beetle in pond 1, although there were plenty of haliplids, but they were all abundant in ponds 2 and 3, although only a few of the genus Hydrous itself were obtained.

In series D, ponds 1, 3, and 6 were filled with water plants in 1918, 1 and 6 containing abundant blanket algæ, while 3 was entirely carpeted with *Naias* and *Potamogeton*. Beside the Haliplidæ almost no beetles were obtained from these three ponds, while in ponds 2, 4, 5, and 7 other families were abundant both in species and in actual numbers.

From these data it would seem fairly conclusive that the adult beetles both possess and exercise a definite choice of habitat; and though a moderate amount of water vegetation may prove attractive it is possible to have too much, and thereby repel the beetles. Hence, if the fishpond be kept abundantly supplied with water plants there will be little danger from Hydrous; it will not breed in sufficient numbers to become a menace.

RELATION TO FERTILIZATION.

In order to secure the propagation of small Crustacea, insect larvæ, and other minute organisms in great numbers as food for young fishes, various organic fertilizers have been used. Our knowledge of the economic importance of these fertilizers, and especially of the relative value of the different kinds, is still very rudimentary and incomplete. We do know, however, that by placing well-rotted manure in a limited amount over the bottom of a pond that has no appreciable current running through it the supply of animal food for young fishes will be greatly increased. An experiment of this nature was conducted in pond No. 2E during the season by H. W. Clark, of the Fairport staff. The pond was drained, manured, and refilled in May. The fact we wish to note here is that the presence of the manure proved attractive to beetles, especially the Hydrophilidæ, as well as to other insects and Crustacea. When the pond was drained in July, it proved to be literally swarming with beetle larvæ and adults, while the pupæ were equally abundant around the shores. In all, 15 species of beetles were obtained from this one small pond, an eighth of an acre in area, with the larger genera, Hydrous, Dytiscus, and Hydrophilus in especial evidence. All the material for the present paper was secured here, and in addition

an abundance reserved for future use. It would seem, then, that if fertilizers are used to increase the food supply the fish breeder must be prepared to find also an increased number of these obnoxious beetles.

ENEMIES OF THE EGGS.

The eggs are so well protected in their floating silken case that they are seldom destroyed. Sometimes, however, the egg case gets overturned by being driven into the rushes and other water plants along the shore during a high wind. Apparently this is fatal to the hatching of the eggs. Two such overturned egg cases, with dead eggs partially developed, were found on the shores of pond 2, series E. It is not probable, however, that this accident occurs with any frequency, the cases being so well balanced that it is difficult to overturn them.

Again, the Ichneumon flies, which work such havoc with the eggs of many other water insects, seem unable to get at the eggs of Hydrus. This is apparently due to the density of the triangular plate that covers the upper, exposed part of the open end of the case and also to the thick layer of porous silk that lines this plate and covers the top of the egg mass, the only points from which the flies can get access to the eggs.

ENEMIES OF THE LARVÆ.

The Hydrus larva is its own worst enemy, and a very generous percentage of larvæ hatched are eaten by their brothers and sisters. This is especially true if an abundance of attractive food is not forthcoming at the time of hatching, and it continues to operate during the entire life of the larva. Referring to the table already discussed (p. 21), the fact may be emphasized again that they often eat one another voraciously until all but one are gone. By this means alone, therefore, they will be kept within certain bounds, for as soon as there is any danger of overproduction other food becomes scarce and they fall to eating one another. It is hardly too much to say that this cannibalistic habit is the salvation of the other insect denizens of the fishpond. Otherwise they would have very little chance in the struggle for existence.

Certain of the dragon-fly nymphs, especially those of Anax, Aeschna, and the larger Libellulids, eat Hydrus and Dytiscus larvæ. This has been discussed in a previous paper upon the economic relations of the dragonflies (Wilson, 1920, p. 201).

The common bullfrog must be reckoned as a possible enemy of the Hydrus larva. Dyche (1914, specimen No. 129, p. 153) examined the stomach of a large bullfrog, which contained "a larva over 2 inches long of a water beetle." This may have been either Dytiscus or Hydrus, it is not stated which, but if the frog can eat one it can eat the other, and in all probability it does so occasionally.

Several of our common fishes, notably the green sunfish (*Lepomis cyanellus*) and the bluegill (*Lepomis pallidus*) are fond of Hydrus larvæ and frequently eat them. This has already been noted by Forbes (1888), and his observations have been confirmed at Fairport, the exact data being reserved for future publication. On many occasions during the summer seasons of 1917 to 1921 the author threw full-grown Hydrus larvæ either into pond 6, series D, which is stocked exclusively with adult large-mouthed black bass, or into one of the tanks in the tank house,

where specimens of the same bass are often kept under experimentation. In every instance the larva was instantly seized and swallowed, sometimes almost before it struck the surface of the water. This indicates that not only do these fish eat the larvæ when they can get them, but that the larvæ ought to make successful bait when fishing.

ENEMIES OF THE PUPÆ.

It might seem at first sight that the pupa was admirably protected by being buried in the moist earth, but even there it is subject to certain dangers. The first of these is from ants. Two pupæ were unearthed in July that were half eaten up by small ants, which literally filled their pupal chambers. Of course, a larva when ready to pupate will seldom choose an ants' nest in which to form its pupal chamber, and it will not often happen that ants drive one of their galleries into a pupal chamber after it is formed; but the finding of these two half-eaten pupæ shows that this does happen occasionally, and the larger the number of ants along the shores of a pond the greater are the chances of its occurrence.

Another and much more serious danger for the pupa lies in a change in the moisture content of the earth in which the pupal chamber is built. If the amount of moisture in the soil is greatly changed in either direction, it is likely to prove fatal to the pupa. If it be raised excessively, then the chamber will be flooded and the pupa will be drowned. It is to guard against this very accident that the pupa skin is provided with the long curved spines described on page 24, while the pupa also arches its body strongly upward in order to lift the spiracles above any ordinary flooding. However, the pupal chamber is never far from the water's edge, and any continued rise in the water will flood it so completely that these safeguards will no longer avail. Two pupal chambers on the shore of pond 2, series E, were filled with water, and as a result the two pupæ they contained were drowned within a few minutes.

On the other hand, the soil that was moist enough when the larva began its pupal chamber may become baked and dried by the time the adult beetle is ready to emerge, and the latter may thus become imprisoned and unable to get out. The abrupt draining of this same pond 2, series E, caught some beetles in just this way. As long as the water remained at its normal level the soil would have continued soft and moist; but when the water was entirely removed the hot sun soon dried and baked the mud so firmly that the adult beetles were caught and imprisoned in the pupal chamber. Two were found thus imprisoned on August 12. They were alive and vigorous and would possibly have remained so until released by the resoftening of the earth after the pond was filled again. Similarly, a piece of moist earth from the pond shore containing three pupæ of *Berosus*, another hydrophilid genus, was brought into the laboratory July 16. It was not known at the time that it contained these pupæ, and after it had served its purpose it was allowed to become dry and hard. When thrown out on August 15, it broke and revealed three live adult beetles, which could never have escaped through their own efforts.

In *The Canadian Entomologist* for January, 1894, Ashmead published the descriptions of two new hymenopterous parasites from water beetles. These had been reared by H. F. Wickham—one from the pupa of a *Gyrinus* species and the other from the pupa of *Dineutes assimilis*. Similarly, half a dozen hymenopterous

larvæ were obtained from a Hydrous larva just as the latter was about to pupate after remaining several days inside its pupal chamber. Evidently some hymenopter had succeeded in laying its eggs in this larva while it was hunting for a suitable spot for its pupal chamber. The eggs had hatched into maggots and these were busy devouring the tissues of the beetle larva. It is doubtful whether this larva would have been able to pupate, but even if it did the maggots would have continued their destruction and there would not have been enough of the pupal tissues left for the final transformation into the adult beetle. These Hydrous larvæ usually escape such attacks, because of the shortness of the interval between coming out of the water and burrowing into the earth, but evidently they do get caught sometimes.

ENEMIES OF THE ADULT BEETLES.

Dyche (1914, p. 149) has stated that the common bullfrog is especially fond of the larger water beetles, Hydrous and Dytiscus. Thirty frogs were captured from the ponds on the State hatchery grounds near Pratt, Kans., in April, 1910, and their stomach contents were examined. No effort was made to distinguish the two genera of beetles from each other. Twelve of the frogs had eaten these beetles, and amongst them had consumed 27 specimens, over two apiece. Another large frog captured the following year contained four of these beetles (p. 155). Dyche added that more than half the food mass of frogs taken from natural lakes and ponds in Kansas was frequently made up of insects, and that these large water beetles usually formed a considerable percentage of such insect food. Unfortunately the bullfrogs also eat many small fish and hence could not be utilized to keep down the beetles.

Two little green herons were shot on one of the fishponds August 10. On examining their stomachs the remains of adult Hydrous beetles were found in one of them.

McAtee and Beal (1912, pp. 19 and 24) stated that various beetles, chiefly aquatic, compose 23.3 per cent of the food of the horned grebe (*Colymbus auritus*), and that the black tern (*Hydrochelidon nigra surinamensis*) feeds extensively on dragon-fly nymphs, dytiscid beetles, and crawfishes. A bird that eats dytiscid beetles eats also hydrophilid beetles in all probability, and it is reasonable to suppose that other water birds, with reference to whose food we have no data, eat these beetles in considerable quantities.

During the seasons when the beetles migrate from one locality to another they are often attracted by the electric lights in large towns and cities at night and can be found in the morning upon the pavement or earth beneath. Blatchley (1910, under *Hydrophilus triangularis*, p. 255) said: "Sometimes attracted by thousands to electric lights in Indianapolis and the larger cities."

William J. Gerhard, of the Field Museum of Natural History of Chicago, has records (unpublished) of the finding of Hydrous and hydrophilids under the electric lights of Chicago before the use of arc lights was discontinued 10 years ago. These records show that the finding of Hydrous in varying numbers was a regular occurrence every spring toward the last of May, and when we remember the other large cities which are as favorably situated as Indianapolis and Chicago we are

impressed with the magnitude of this agent of destruction. It must cause the death of almost unbelievable numbers of these beetles every year.

Under certain conditions, particularly in early summer, large numbers of insects are sometimes found along the shores of the Great Lakes. Needham has published a paper on this subject in *The Canadian Entomologist* for 1904, but he failed to mention any of the large water beetles as being destroyed in this way; but Carl L. Hubbs, of the Field Museum at Chicago, noted May 20, 1917, on the beach near Winnetka, Ill., amongst a similar lot of insects a hundred or more *Hydrous triangularis* (unpublished records). These insects had been washed ashore after a storm, but it was not ascertained definitely whether they were all dead, although it is probable that most of them were. Evidently this is another way in which numbers of these beetles may be destroyed yearly. Cinnamon teal, pintail, and wood ducks were recorded by D. C. Mabbott (1920, p. 62) as eating species of adult *Hydrous* beetles, but not in sufficient numbers to make them serious enemies.

GENERAL SUMMARY.

Both sexes of *Hydrous triangularis*, in the larval as well as the adult stage, feed upon fish fry whenever conditions are favorable, and thus may become a serious menace to pondfish culture. If adult fish are kept in the same pond with the fry, it is not probable that the beetle larvæ will more than hold their own. Many adult fish, notably the sunfishes, eat *Hydrous* larvæ and thus keep them within due bounds; but if the fry are placed in a separate pond, and especially if any effort is made to increase the supply of natural food, precautions against the beetles may become necessary.

There are several ways in which the beetles may be checked. If the pond is thickly carpeted with such water plants as *Najas* or *Potamogeton*, or is plentifully supplied with blanket algæ, duckweed, or *Elodea canadensis*, the danger from these water beetles will be greatly diminished; but this kind of vegetation is not altogether desirable in such quantity.

The mating season of the adults comes about the last of May, and at that time both sexes fly about at night in considerable numbers. If a trap lantern be constructed according to any of the standard patterns close to the shore of the pond and be furnished with a light for two or three weeks at that season, it is probable that many of the adult females could be caught before they began to lay eggs, and in this way the larvæ could be reduced in numbers.

Again, if the pond be raised 15 or 20 inches for two or three hours once a week during July and August when the larvæ are pupating, the pupal chambers will be flooded and the pupæ will all be drowned. This reduces the number of adults, and there are not as many to produce larvæ; but it is a precaution against the future rather than a remedy for the present.

When full-grown larvæ actually appear in sufficient numbers to menace the fish fry, they must be removed at once, if the remedy is to be effective. The best and practically the only way to do this is to drain the pond, removing the fish fry temporarily to another pond or to large aquaria. After the water is out the large beetle larvæ become very conspicuous and may be quickly and entirely removed.

In half an hour after being drained, pond 2, series E, which furnished the material for the present paper, was entirely freed from Hydrous larvæ, and they did not appear in it again during the summer. After the larvæ have been removed the fry may be returned to the pond with safety.

The adults, being vegetable eaters, do not kill fish except rarely, and then in such small numbers that the loss is never serious. While Hydrous larvæ have become a nuisance several times in the Fairport fishponds and have necessitated the removal of fish fry to other ponds, there has never been an instance when the adult beetles have been known to attack the young fish.

BIBLIOGRAPHY.

ASHMEAD, W. H.

1894. Descriptions of two new hymenopterous parasites from water beetles. The Canadian Entomologist, vol. 26, pp. 24-26. London, Canada.

BERLESE, ANTONIO.

1909. Gli Insetti: loro organizzazioni, sviluppo, abitudini e rapporti con l'uomo. 1. Embriologia, e Morfologia. X+1004 pp. con 1292 fig. e 10 tav. Milano Societa editrice libraria. [*Hydrophilus piceus*, p. 832.]

BLATCHLEY, WILLIS STANLEY.

1910. On the Coleoptera known to occur in Indiana. Indiana Department of Geology and Natural Resources, Bulletin No. 1, 1386 pp., 590 figs. Indianapolis. [p. 255.]

BROCHER, FRANK.

1912. L'appareil stridulatoire de l'*Hydrophilus piceus* et celui du *Berosus aericeps*. Annales de Biologie Lacustre, T. 5, pp. 215-217, 3 figs. Bruxelles.

- 1912a. Recherches sur la respiration des insectes aquatiques adultes. L'Hydrophile. Étude physiologique et anatomique. *Ibid.*, pp. 220-258, 22 figs.

- 1912b. Recherches sur la respiration des insectes aquatiques. * * *. Hydrophile. * * *. Societas entomologica, vol. 27, No. 21, pp. 91-93, No. 22, pp. 102-103. Stuttgart.

DIMMOCK, GEORGE, and FREDERICK KNAB.

1904. Early stages of Carabidæ. Bulletin No. 1, Springfield (Mass.) Museum of Natural History, 55 pp., 4 pls., 1 fig.

DYCHE, L. L.

1914. Ponds, pond fish, and pond-fish culture. State Department of Fish and Game, Kansas, Bulletin No. I, 208 pp. Topeka.

ERICHSON, W. F.

1841. Zur systematischen Kenntniss der Insectenlarven. Wiegmann Archiv für Naturgeschichte, Bd. VII, pp. 60-110. [Hydrous larva, p. 108.]

FOLSOM, J. W.

1906. Entomology, with special reference to its biological and economic aspects. vii+485 pp., illus. Philadelphia. [Adaptations of aquatic insects, pp. 184-192.]

FORBES, S. A.

1888. On the food relations of fresh-water fishes: A summary and discussion. Bulletin, Illinois State Laboratory of Natural History, Vol. II, pp. 475-538. Peoria, Ill.

FRICKEN, W. VON.

1887. Über Entwicklung, Atmung, und Lebensweise der Gattung *Hydrophilus*. Tageblatt der LX. Versammlung deutscher Naturforscher und Ärzte, pp. 114-115. Wiesbaden.

GANGLBAUER, LUDWIG.

1904. Die Käfer von Mitteleuropa. Vierter Band, erste Hälfte. * * *. Hydrophilidæ. pp. 141-286. Wien.

GARMAN, W. H.

1881. The egg case and larva of *Hydrophilus triangularis* Say. The American Naturalist, Vol. XV, pp. 660-663, 3 figs. Philadelphia. [Abstract in Annals and Magazine of Natural History, Vol. 15, 1881, p. 66.]

HAUPT, H.

1907. Was mich eine Hydrophilus (Hydrous-) Larve lehrte. Wochenschrift für Aquarienkunde, Bd. 4, pp. 326-328. Braunschweig.
1909. Zur Biologie der Hydrous- (Hydrophilus-) Larve. Zeitschrift für Naturwissenschaften, Bd. 81, pp. 301-304. Leipzig.

HENTSCHEL, ERNST.

1909. Das Leben des Süßwassers. Eine gemeinverständliche Biologie. IV+336 pp., 299 fig., 17 Taf. München. [Hydrous, p. 236.]

LAKER, ABBOTT G.

1881. The cocoons of *Hydrophilus piceus* and *Hydrobius fuscipes*. The Entomologist, vol. 14, pp. 82-84. London.

LYONET, PIERRE.

1832. Recherches sur l'anatomie et les métamorphoses de différentes espèces d'insectes, ouvrage posthume by Pierre Lyonet. Publié par M. W. DeHaan. Accompagnées de 54 planches. iv+580 pp. Paris. [Scarabée aquatique, pp. 127-151.]

MABBOTT, DOUGLAS C.

1920. Food habits of seven species of American shoal-water ducks. U. S. Department of Agriculture, Bulletin No. 862, 70 pp., VII pls. Washington.

MATHESON, ROBERT.

1914. Notes on *Hydrophilus triangularis* Say. The Canadian Entomologist, Vol. XLVI, pp. 337-343, Pl. 22, figs. 29-31. London, Canada.

MCATEE, W. L., and F. E. L. BEAL.

1912. Some common game, aquatic, and rapacious birds in relation to man. U. S. Department of Agriculture, Farmers' Bulletin No. 497, 30 pp., 14 figs. Washington.

MEGUŠAR, FRANZ.

1909. Lebensgeschichte der Hydrophiliden. Verhandlungen der k. k. zoologisch-botanischen Gesellschaft in Wien, Bd. LIX, pp. 278-287.

MIAL, L. C.

1895. The natural history of aquatic insects. ix+395 pp., 116 figs. Macmillan & Co., London and New York. [The great water-beetle (*Hydrophilus piceus*), pp. 61-87, figs. 13-18.]

MIGER, FÉLIX, et LANCRET.

1804. Sur les larves Hydrophyles et Dytiques. Bulletin, Paris Société philomatique, T. 3, pp. 229-234.

1809. Mémoires sur les larves des insectes Larves des insectes coléoptères aquatiques. Annales du Museum d'Histoire naturelle, T. 14, pp. 441-459. Paris.

NEEDHAM, JAMES G.

1904. Beetle drift on Lake Michigan. The Canadian Entomologist, Vol. XXXVI, pp. 294-296. London, Canada.

NITZSCH, CHRISTIAN L.

1811. Über das Athmen der Hydrophilien. Archiv für die Physiologie von Reil, Bd. 10, pp. 440-458, Pl. 9.

ORCHYMONT, A. D'.

1913. Contribution à l'étude des larves hydrophilides. Annales de Biologie Lacustre, T. 6, pp. 173-214. Bruxelles.

PLANET, LOUIS.

1891. Développement de l'Hydrophile brun (*Hydrophilus piceus*). Hydrophilus piceus, Métamorphoses. Le Naturaliste; revue illustrée des sciences naturelles, 2^e Série, 13^e Année, pp. 259-260. Paris.

POUJADE, G. A.

1901. Sur l'*Hydrophilus piceus* Linn. Bulletin de la Société entomologique de France, T. 70, pp. 229-230. Paris.

1902. Note sur l'*Hydrophilus piceus*. *Ibid.*, T. 71, pp. 206, 219, 238.

REITTER, EDMUND.

1909. Coleoptera. In Die Süßwasserfauna Deutschlands, hrsg. von A. Brauer. iv+235 pp. Jena. [Hydrophilidae, p. 51.]

RENGEL, C.

1901. Zur Biologie des *Hydrophilus piceus*. Biologisches Centralblatt, Bd. 21. pp. 173-182, 209-220. Berlin.

RILEY, C. V.

1881. Notes on *Hydrophilus triangularis* [Say]. The American Naturalist, Vol. XV, pp. 814-817, 2 figs. Philadelphia.

SAUNDERS, WILLIAM.

1879. *Hydrophilus triangularis*: Habits and transformations popularly noticed. Canadian Entomologist, Vol. XI, p. 223, fig. 14. Montreal.

WILSON, CHARLES B.

1920. Dragonflies and damselflies in relation to pondfish culture, with a list of those found near Fairport, Iowa. Bulletin, U. S. Bureau of Fisheries, Vol. XXXVI, 1917-1918 (1921), Document No. 882, pp. 181-264, Pls. LXVII-LXIX, 63 text figs. Washington.

DEPARTMENT OF COMMERCE.

HERBERT HOOVER, Secretary of Commerce.

BUREAU OF FISHERIES.

[HENRY O'MALLEY, Commissioner.]

Chief functions.—Propagation of useful food fishes, including lobsters, oysters, and other shellfish, and their distribution to suitable waters.

Investigations relating to fish culture, fish diseases, conservation of fishery resources, and development of commercial fisheries.

Study of methods of fisheries and fishery industries and utilization of fishery products.

Collection of statistics of fisheries.

Administration of Alaska salmon fisheries, Pribilof Islands fur-seal herd, and law for protection of sponges off Florida coast.

BUREAU OF NAVIGATION.

[D. B. CARSON, Commissioner.]

Chief functions.—General superintendence of commercial marine and merchant seamen.

Supervision of registration, licensing, numbering, etc., of vessels under the United States flag and annual publication of list of such vessels.

Enforcement of navigation and steamboat inspection laws and laws governing radio communication, as well as duties connected with fees, refunds, taxes, fines, etc., originating under such laws.

COAST AND GEODETIC SURVEY.

[E. LESTER JONES, Director.]

Chief functions.—Survey of coasts of United States and territories and publication of charts. Among other things, this includes base measure, triangulation, topography, and hydrography; deep-sea soundings, temperature, and current observations; magnetic observations and researches; gravity researches, etc.

Publication of results of this work in annual reports and in special publications, including charts of coasts and harbors. Tide tables are published annually in advance, as well as other information of use to navigators.

BUREAU OF THE CENSUS.

[WILLIAM M. STEUART, Director.]

Chief functions.—Decennial census covering population, agriculture, manufactures, mines and quarries, and forest products.

Decennial report on wealth, public debt, and taxation.

Decennial statistics relating to inmates of institutions, including paupers, insane, prisoners, and juvenile delinquents.

Census of agriculture in each middecennial year, biennial census of manufactures, quinquennial census of electrical public utilities, statistics of marriage and divorce.

Annual financial statistics of State and municipal governments.

Annual statistics of births, deaths, causes of death, etc., in the registration area of the United States.

Quarterly statistics of leaf-tobacco stocks and of production, stocks, and consumption of fats and oils.

Monthly or semimonthly statistics of cotton ginning, cotton stocks and consumption, the production, stocks, and consumption of hides and leather, the production of shoes, and of active textile machinery.

Compilation and publication, in Survey of Current Business, of monthly commercial and industrial statistics.

BUREAU OF STANDARDS.

[GEORGE K. BURGESS, Director.]

Chief functions.—Custody of standards adopted or recognized by the Government.

Construction of standards when necessary. Testing and calibration of apparatus and the comparison of standards used by scientific or other institutions with those in custody of bureau.

Determination of physical constants and properties of materials.

Testing of materials and establishment of standards and processes in cooperation with commercial firms or organizations.

Collection and dissemination of information showing approved methods in building, planning, and construction, including building materials and codes and such other matters as may encourage, improve, and cheapen construction and housing.

Studies on simplified commercial practices and their establishment through cooperative business organizations.

BUREAU OF LIGHTHOUSES.

[GEORGE R. PUTNAM, Commissioner.]

Chief functions.—Establishment and maintenance of lighthouses, lightships, buoys, and other aids to navigation on sea and lake coasts and on rivers of the United States, including Alaska, Hawaiian Islands, and Porto Rico.

Publication of Light Lists, Buoy Lists, and Notices to Mariners, including information regarding all aids to navigation maintained by Lighthouse Service.

STEAMBOAT INSPECTION SERVICE.

[GEORGE UHLER, Supervising Inspector General.]

Chief functions.—Inspection of vessels, licensing of officers of vessels, and administration of laws relating to such vessels and their officers. Certification of able seamen who form crews of merchant vessels.

Inspection of vessels, including hulls, life-saving equipment, and types of boilers; testing of all materials subject to tensile strain in marine boilers.

BUREAU OF FOREIGN AND DOMESTIC COMMERCE.

[JULIUS KLEIN, Director.]

Chief functions.—Compilation of timely information on world market conditions and openings for American products in foreign countries secured through commercial attachés and trade commissioners of Department of Commerce and foreign service of Department of State.

Distribution of such information to American business through weekly Commerce Reports, special bulletins, confidential circulars, and news and trade press.

The maintenance of commodity, technical, and geographical divisions in Washington to afford special service to American export industries.

Compilation and distribution of names of possible buyers and agents for American products in all parts of the world and publication of weekly lists of specific sales opportunities abroad.

Maintenance of 33 district and cooperative offices in 33 cities in the United States to expedite delivery of market information to business men and to keep department advised as to more urgent requirements of American trades and industries.

Publication of official statistics on imports and exports of the United States.

WATER BEETLES IN RELATION TO POND FISH CULTURE, WITH LIFE HISTORIES OF THOSE FOUND IN FISHPONDS AT FAIRPORT, IOWA : By Charles Branch Wilson

From BULLETIN OF THE BUREAU OF FISHERIES, Vol. XXXIX, 1923-24

Document No. 953

561
CARP 1945

PRICE, 30 CENTS

Sold only by the Superintendent of Documents, Government Printing Office, Washington, D. C.

WATER BEETLES IN RELATION TO PONDFISH CULTURE, WITH LIFE HISTORIES OF THOSE FOUND IN FISHPONDS AT FAIRPORT, IOWA : By Charles Branch Wilson

From BULLETIN OF THE BUREAU OF FISHERIES, Vol. XXXIX, 1923-24

Document No. 953 :

PRICE, 30 CENTS

Sold only by the Superintendent of Documents, Government Printing Office, Washington, D. C.

FIG. 1.—*Hydrotus triangularis*.

FIG. 2.—*Dytiscus hybridus*.

FIG. 3.—*Cybister fimbriolatus*.

FIG. 4.—The pier of pond 3D, showing practically all the adult *Dineutes americanus* in the pond assembled in its shade.

FIG. 5.—The boat wharf on the river, showing a swarm of *Gyrinus analis* on its down-river side.

WATER BEETLES IN RELATION TO PONDFISH CULTURE, WITH LIFE HISTORIES OF THOSE FOUND IN FISHPONDS AT FAIRPORT, IOWA.

By CHARLES BRANCH WILSON, Ph. D.

State Normal School, Department of Science, Westfield, Mass.

Contribution from the U. S. Fisheries Biological Station, Fairport, Iowa.

CONTENTS.

	Page.		Page.
Introduction.....	232	Enemies of adults.....	247
Importance of water beetles.....	232	Turtles.....	247
Ignorance of American species.....	232	Birds.....	247
Lakes versus fishponds.....	233	Toads and frogs.....	248
Methods.....	233	Electric lights.....	248
Ecology.....	235	Beetles as fish eaters.....	249
Modifications of structure and vestiture.....	235	Fish as beetle eaters.....	252
Locomotion.....	235	Evidence from fish bait.....	252
Migration from one pond to another....	237	Evidence from fish stomachs.....	253
Distribution according to size.....	238	General summary and suggestions.....	260
Structural adaptations.....	238	Beetle distribution in Fairport fishponds....	263
For locomotion.....	238	Source of material.....	264
For respiration.....	239	Influence of environment.....	264
For flotation.....	241	Restriction of species.....	266
For sex functions.....	242	Relative importance of species.....	267
For sight.....	242	Systematic description of Fairport species....	267
Enemies of larvæ.....	242	Key for identification of larvæ.....	268
The larva.....	242	Key for identification of pupæ.....	269
Time of pupation.....	243	Peltodytes.....	271
Dragonfly nymphs.....	243	P. edentulus.....	271
Mites.....	244	Haliphus.....	273
Hydra.....	244	H. ruficollis.....	274
Ants.....	244	Coptotomus.....	275
Turtles.....	244	C. interrogatus.....	275
Frogs.....	244	Cybister.....	277
Snails.....	245	C. fimbriolatus.....	277
Parasites.....	245	Dytiscus.....	282
Enemies of pupæ.....	245	D. verticalis.....	282
Water.....	245	Hydroporus.....	285
Imperfect pupation.....	246	H. niger.....	285
Parasites.....	246	Laccophilus.....	286
The black horsefly.....	246	L. maculosus.....	286
Ants.....	247	L. proximus.....	290

Systematic description of Fairport species—

Continued.	Page.
<i>Thermonectes</i>	291
<i>T. basilaris</i>	291
<i>T. ornaticollis</i>	296
<i>Acilius</i>	299
<i>A. semisulcatus</i>	299
<i>Dineutes</i>	302
<i>D. americanus</i>	302
<i>Gyrinus</i>	308
<i>G. ventralis</i>	308
<i>G. limbatus</i>	308
<i>Berosus</i>	309
<i>B. striatus</i>	309
<i>B. pantherinus</i>	311
<i>B. peregrinus</i>	312
<i>Hydrophilus</i>	314
<i>H. obtusatus</i>	314

Systematic description of Fairport species—

Continued.	Page.
<i>Laccobius</i>	315
<i>L. agilis</i>	315
<i>Enochrus</i>	316
<i>E. nebulosus</i>	318
<i>E. diffusus</i>	320
<i>E. perplexus</i>	321
<i>Tropisternus</i>	321
<i>T. lateralis</i>	321
<i>T. glaber</i>	326
<i>T. mixtus</i>	329
<i>Hydrous</i>	332
<i>H. triangularis</i>	332
<i>Donacia</i>	332
<i>D. æqualis</i>	332
Cap attachment on egg case.....	332
Bibliography.....	334

INTRODUCTION.

IMPORTANCE OF WATER BEETLES.

The beetles are far more numerous than any other order of insects and are very cosmopolitan in their distribution. Every natural pond, river, and stream is peopled with them, and if one constructs an artificial fishpond in all probability beetles will constitute its first and most permanent insect inhabitants. Pondfish culture, therefore, in order to prove successful, demands sufficient acquaintance with the water beetles to yield a workable knowledge of their economic relations to the fish. The following paper is a beginning toward such an acquaintance and endeavors to suggest lines of research that may prove both interesting and profitable to the fish-culturist.

IGNORANCE OF AMERICAN SPECIES.

Unfortunately, while our American water beetles are fairly well known to the systematist, so that they appear in museum collections and lists of species, very little is known about their life histories, their habits, and their economic importance. According to Comstock (1912), at least 300 species of carnivorous diving beetles (*Dytiscidæ*) occur in this country, 40 species of whirligig beetles (*Gyrinidæ*), and 150 species of water scavenger beetles (*Hydrophilidæ*). Moreover, there are 25 species of herbivorous water beetles (*Haliplidæ*), a family only briefly mentioned by Comstock. Out of this total of more than 500 species, which is probably far below the actual number, the habits and complete life histories of only about 20 are known. The partial development of 15 other species has been recorded, chiefly the egg cases and newly hatched larvæ of hydrophilids by Richmond (1920). This excellent paper also gave valuable keys for the identification of the egg cases, larvæ, and pupæ of the *Hydrophilidæ*, but nothing of the sort has been published for the other families.

Abstracts of one or two of these published life histories, which are important from the standpoint of fish culture, are included in the present paper, and in addition those of 20 other common species are presented, together with the economic relations of the entire group.

With our present meager knowledge outside of the Hydrophilidæ it is not safe to name the larvæ and pupæ of any species, even tentatively, by basing our judgment on the known fauna of the pond from which the specimens were taken, on their size, or on any likeness they may show to European forms. All but one of the species here presented has been reared from the larva to the imago, thus making its identity certain.

LAKES VERSUS FISHPONDS.

Attention should be called to one very pronounced difference between the fauna of a lake and that of an ordinary fishpond. In the former water beetles are almost entirely lacking; in the latter they are one of the most abundant groups present.

Muttkowski (1918, pp. 413, 414), in discussing the fauna of Lake Mendota, said:

With all their manifold adaptations to an aquatic life, aquatic beetles, except for a few species, are scarce in the lake complex * * *. The Hydrobiidæ, Dytiscidæ, Hydrophilidæ (except Berosus), Donaciinæ, and Gyrinidæ, the latter despite the water-breathing larvæ, are practically absent from the lake community. The typical lake Coleoptera are the Haliplidæ in the vegetation zone and the Dryopidæ in the rocky and gravelly areas, while several species of adult Dytiscidæ are locally abundant * * *. The difference between the lake and other aquatic communities is very marked in late summer, when sheltered water, such as the lagoons in the parks and the several ponds and creeks about the lake, teem with young dytiscid larvæ of several species, while such larvæ are conspicuously absent from the lake.

Baker (1916, p. 308), in his discussion of the relations of mollusks to fish in Oneida Lake, N. Y., gave a list of the plants and animals found associated with the mollusks. There were included only two species of dytiscids, one haliplid, three gyrids, and two hydrophilids. Of these, two species were found only in the stomach of the painted terrapin, leaving six species for the fauna of a lake 21 miles long and 5.50 miles wide.

Sherman (1913, p. 44), in summing up the habits of the Dytiscidæ, said:

In the larger bodies of water it is very difficult to locate any beetles, and in them, whether swamps, ponds, or rivers, the beetles seem to occur only in very limited spots, which are usually separated from the main sheet of water, such as the eddies or small pools along the shore. In fact, the small water bodies are often best, and the time most favorable for collecting is when the water is low or almost dried up.

In marked contrast to this scarcity in large bodies of water is the abundance of beetles in the smaller ponds. The largest of the Fairport ponds is but a trifle more than an acre in area, and yet in the fauna of them all beetles are among the most numerous insects both in number of species and in individuals. Pond 5D, just an acre in area, yielded 39 species, while 2E, only 0.13 of an acre, contained 31 species, and 12B, less than 0.02 of an acre, contained 17 species.

METHODS.

All the different beetle larvæ that could be obtained were first studied in detail until they could be easily recognized. When the larva leaves the water in order to pupate, it either buries itself in the mud or constructs a pupal chamber, and on transforming throws off the old larval skin. As a part of this skin the chitinous covering of the head remains entire, with the antennæ and mouth parts still

attached, and the species can be recognized as easily from these discarded skins as from the living larvæ.

Then a search for as many pupæ as could be found was made along the shores of the ponds, and in every instance care was taken to secure the old larval skin from the inside of the pupal chamber. In this way the larvæ and pupæ were definitely related, one to the other, and the pupæ were then kept in suitable terraria until the adult beetle emerged. On transforming from the pupa to the adult the old pupa skin is thrown off and may be obtained from the pupal chamber and used to identify the species.

One of the best methods with the larger species, when a pupal chamber is found on a pond shore, is to leave it as nearly intact as possible. By cutting around it with a knife blade a small cube of earth containing the chamber may be removed. This cube can then be kept in a terrarium until the adult beetle emerges, and the chamber will contain both the larval and pupal skins. If the chamber has been opened during the removal, it should be covered again with a pellet of mud before being placed in the terrarium. Darkness is necessary for the best success in rearing the specimens. In the case of the smaller species, and often with the larger ones, the natural pupal chamber is destroyed when the pupa is found. In such cases they will thrive equally well in an artificial chamber, made as nearly the size and shape of the original as possible, and with a removable cover, so that the development of the pupa may be watched from day to day. Frequently the pupal chamber will be found to contain a larva not yet transformed, and sometimes a larva can be obtained that has come out of the water but has not yet begun to build its pupal chamber. These can be dealt with in the same manner as the pupæ, and if placed in artificial chambers will go on with their transformation.

A convenient terrarium can be made as follows: Punch the bottom of a small cylindrical tin box full of holes and stand it upright in the center of a large iron pan. Fill the pan half full of sand around the upright box, then pour water into the latter until the sand is thoroughly wet. The cubes of earth containing natural pupal chambers and the artificial ones made in imitation of them can be placed upon the wet sand, which will keep them from drying up. By renewing the water in the central box as fast as it disappears the sand, and with it the pupal chambers, may be kept at just the right degree of moisture, which should be the same as that of the earth from which the larva or pupa was originally obtained.

Certain habits of the larvæ and adults, such as swimming and breathing, can be watched better in an aquarium in the laboratory than in their natural environment. There are other habits, however, such as feeding, deposition of the eggs, and formation of the pupal chamber, upon which reliable information can be obtained only by watching the beetles in their normal habitat. When transferred to aquaria both adults and larvæ will eat almost anything that is furnished to them. Carnivorous species usually devour animal food and herbivorous species vegetable food. If kept in confinement, however, under stress of hunger they may radically change their diet. It is probable that they are rarely compelled to do this under natural conditions. What they eat in an aquarium, therefore, is an excellent criterion of their ability to adapt themselves to circumstances and shows

how far they are able to overcome adverse conditions. It may also be extremely useful in suggesting available food upon which they can be reared during experimentation, but it does not indicate their natural food preference any more than a prison menu indicates the preferences of a convict. The food of the species here given is to be understood as the result of observations made in the ponds. What they were known to eat in the laboratory is so stated and is included for the reasons just given.

Much also can be learned under artificial conditions about the methods employed by the different species in the construction of their pupal chambers; but the distance they travel from the water's edge and the kind of a location they choose can be judged only by finding the pupæ *in situ* on the shore of the pond.

The same is true of the materials used. There is no sand on the shores of any of the ponds, and of more than 100 pupal chambers of *Dineutes americanus* collected during the last three summers, every one was made of moist earth pellets. Yet when six larvæ, whose freshly made pupal chambers had been hopelessly broken, were transferred to a suitable terrarium and each constructed a new chamber, two used entirely moist sand instead of earth pellets. The methods employed with both materials were exactly the same, however.

ECOLOGY.

MODIFICATIONS OF STRUCTURE AND VESTITURE.

All beetles that live in the water show some modifications of structure and vestiture to fit them for their aquatic life. This fact was noted by Leng (1913, p. 32) in a paper on aquatic Coleoptera in the Journal of the New York Entomological Society. He added that the modifications were more noticeable in the adults than in the larvæ. These modifications serve varied and quite different uses and may be concerned with locomotion, with sex activity, with flotation, with respiration, and with sight. They can be considered most conveniently in connection with the various functions they assist.

LOCOMOTION.

The beetle larvæ can all walk, but none of them move fast enough to warrant the assertion that they run. Most of them can swim, and a few can jump; that is, they can throw the body a short distance by kicking with the legs or by suddenly flexing the posterior portion of the abdomen. The relative locomotor ability of the various larvæ is given under each species separately. In general, the dytiscid larvæ are excellent walkers and swimmers, and some of them can jump. The two species of *Laccophilus* are the best walkers and the most agile larvæ of all those studied, the two species of *Thermonectes* are the best jumpers, and the *Cybister* larva is the most active swimmer. The hydrophilid larvæ are fair walkers and good swimmers, but none of them so far as known can jump. The gyrid larvæ are good walkers and excellent swimmers, while the *Dineutes* larvæ can jump, although not as well as the *Thermonectes* larvæ. The haliplid larvæ can only crawl, they can neither swim nor jump, and all their movements are extremely

slow. Yet the *Peltodytes* larva, when ready to pupate, travels farther from the water's edge than the much larger *Cybister* or *Hydrous* larva.

Leng (1913, p. 35) made a curious statement with reference to these larvæ: "The larvæ of the Haliplidæ, Dytiscidæ, Hydrophilidæ, Gyrinidæ, and Parnidæ are purely aquatic, living wholly in the water, but not swimming." This applies only to the Parnidæ and Haliplidæ; the others can and do swim.

The adult beetles can walk, run, jump, swim, and fly with varying ability. Flying is the means of locomotion by which they travel from one body of water to another and so disseminate their species. The larger species of dytiscids and hydrophilids can cover long distances and are sometimes found at night around electric lights far removed from any water. Many instances of their capture about these lights are recorded by Sherman (1913) in his paper on "Some Habits of the Dytiscidæ." Needham in "Fresh-water Biology" (1918, p. 905) said of *Hydrous*: "It is attracted to electric lights in vast numbers in the spring, where it falls beneath them and flounders around in the dust of the street. * * * Another hydrophilid, which often swarms into trap lanterns set over streams, is *Berosus*." Yet most of the adults can be safely kept in an open aquarium. Though the gyrinids have to climb up on some support above the water before they can spread their wings for flight, yet once started, they prove to be strong fliers, for Fall (1901, p. 55) has recorded: "I have seen hundreds of *Gyrinus consobrinus* about the electric lights at Riverside (Calif.) in May."

The order of excellence in swimming and walking amongst a series of representative adult dytiscids has been determined by student classes at Lake Forest for a number of years, and, with the addition of jumping, was published in the *American Naturalist* (Needham and Williamson, 1907, p. 480). The general conclusion that increasing fitness for swimming accompanies increasing unfitness for walking and running seems to be well established. Incidentally it may be noted that the Gyrinidæ show this nearly as well as the Dytiscidæ. Swimming with such swiftness and agility that it is almost impossible to catch them without a net, once they are removed from the water they prove to be very poor walkers, and can not run at all.

Jumping seems to be a function peculiar to the dytiscids and gyrinids, and so far as known is not found at all among the hydrophilids and haliplids. There is another dytiscid whose jumping ability exceeds that of *Laccophilus maculosus*, the champion of the Lake Forest tournaments. This is *Thermonectes ornaticollis*, which, when captured in a net, leaps about like a small frog. Another peculiarity, not mentioned by Needham and Williamson, is that both *Laccophilus* and *Thermonectes* can jump when lying on their backs as well as when right side up. The ability to jump is evidently dependent upon the flattening of the hind legs, which brings the basal joints into one plane of action, and greatly increases their efficiency in that plane. To compensate for the lack of ability to jump, all the adult hydrophilids and haliplids are good walkers, and many of the former can run with agility.

The relative swimming ability of the dytiscid and the hydrophilid is well shown when they come to the surface for fresh air. The hydrophilid swims well but not

rapidly, turns on its side as it reaches the surface, pauses an instant, and then swims back to the plants below. The dytiscid sweeps to the surface like a flash and without a sensible pause darts back again. The direction of its movement is the only indication that it has obtained a new supply of air. The actual taking of the air is too rapid to be detected, although it can be plainly seen in the hydrophilid. Miall (1895, p. 74) has noted another difference between the swimming of the hydrophilids and dytiscids. The former, together with the haliplids, use their oar legs alternately, whereas the latter move them in unison. In other words, the dytiscids gallop, but the hydrophilids and haliplids merely trot, and there is a corresponding difference in the rapidity of the resultant motion. The inability to jump on the part of these last two beetle families may be due to the fact that they can not, or at least do not, move their hind legs in unison.

To summarise, the adult dytiscids are excellent swimmers, excellent jumpers, and poor walkers, without any ability to run. The hydrophilids are good swimmers, good walkers, and good runners, but can not jump at all. The gyrinids are excellent swimmers, fair walkers, poor jumpers, and can not justly be classed as runners. The haliplids are excellent walkers and can run with considerable agility, but are very slow swimmers and can not jump.

MIGRATION FROM ONE POND TO ANOTHER.

The marked differences in the fauna of adjacent ponds and the restriction of so many species to comparatively limited areas is the more remarkable in view of the rapidity with which a new pond is populated when filled with water for the first time.

The following is taken from manuscript notes made by Geo. B. Lay during the summers of 1916 and 1917: On the morning of July 22, 1916, water was first let into two newly constructed ponds, numbered 2 and 3, series E. At 4.30 p. m. the ponds were full of water, but absolutely devoid of beetles.

After standing for 24 hours the following beetles were obtained from the two ponds, *Dineutes americanus*, *Gyrinus ventralis*, *G. limbatus*, *Hydrous triangularis*, *Tropisternus lateralis*, *Coptotomus interrogatus*, *Berosus striatus*, *Peltodytes edentulus*. On the 25th *Laccophilus maculosus* was fairly abundant, and a few *Laccophilus proximus*, *Acilius semisulcatus*, and *Haliplus triopsis* were taken. One *Hydroporus consimilis* was captured. On the 26th seven adult *Hydrous triangularis* were secured from pond 3, and 18 from pond 2. Two egg cases were found in pond 3 and one in pond 2, and in both ponds the eggs hatched a few days later. On the 27th six more adult *Hydrous triangularis* were captured in pond 2 and five in pond 3. On the 28th *Dytiscus hybridus* was taken in pond 3, and there were a few small larvæ in both ponds. These observations show how quickly any pond situated near others will become populated with adult insect life.

In 1918 pond 2E was drained July 9 and left absolutely dry until August 15, when it was refilled. During this month the bottom of the pond became hard and thoroughly baked in the hot sun, so that all insect life was destroyed. The present author examined the pond August 16, the morning after it was filled, and found the following beetles in it: *Tropisternus lateralis*, abundant; *Coptotomus*

interrogatus, common; *Tropisternus glaber*, two specimens; *Berosus striatus*, abundant; *B. perigrinus*, one; *Philydrus ochraceus*, one; *Peltodytes edentulus*, a few; *Laccophilus maculosus*, one. Yet *Berosus striatus* and *Peltodytes edentulus* were two of the beetles that were not found in pond 9D, although they were common in 8D, next to it.

DISTRIBUTION ACCORDING TO SIZE.

Needham and Williamson, in the paper already referred to, while discussing the distribution of the Dytiscidæ in the "Gym" pond at Lake Forest, made the following statement (1907, p. 478):

The shoreward distribution of these beetles corresponds roughly with their size; the largest are found in the deepest water, the smallest nearest shore.

On the following page this statement is somewhat modified.

It must not be understood that there is any such definite and sharply limited zonal distribution as aquatic plants on such a sloping shore often exhibit. That is not to be expected in animals possessed of such excellent powers of locomotion. We have meant to indicate merely the favorite haunts of each species, and the general correspondence between the size of the beetle and the depth of the water.

If the beetle list be extended to include the Hydrophilidæ and Haliplidæ, the modified statement probably still holds good, but it does not apply at all to the Gyrinidæ. Moreover, it is profoundly modified by the breeding habits of the various species. During the breeding season beetles of all sizes gather indiscriminately in the shallower waters near the shore for the purpose of depositing their eggs. In June, July, and August, the months during which the present investigations have been conducted, there is practically no distribution according to size. The same sweep of the net will capture *Hydrous triangularis*, the largest beetle in the ponds, and such microscopic forms as *Laccobius agilis* and *Hydrovatus pus-tulatus*. Another sweep will bring up *Dytiscus hybridus* and *Bidessus lacustris*, with beetles of various intermediate sizes. *Hydrophilus obtusatus* and *Tropisternus nimbatus* are nearly always associated, and yet the former is fully twice the size of the latter. After the breeding season is over, however, the beetles probably separate more or less according to size, the same as the other denizens of the pond.

STRUCTURAL ADAPTATIONS.

FOR LOCOMOTION.

Doctor Sharp (1882) in his monograph on the Dytiscidæ called attention to certain structural modifications which help in adapting the beetles to their aquatic life. These were afterwards explained in greater detail by Needham and Williamson (1907) and may be briefly summarized as follows: The three principal adaptations that are concerned in locomotion are an increased body rigidity, a diminished resistance to the water, and an increased swimming efficiency of the hind legs. Body rigidity has been secured by compacting together the various parts of the body, thereby greatly reducing, and usually entirely eliminating, the flexibility found in land beetles. The head is immersed in the front of the thorax; the three divisions of the thorax and the abdomen segments are tightly telescoped together; the elytra are closely joined to the prothorax in front, to each other along the mid line, and to the sides of the abdomen along their lateral margins.

Diminished resistance to the water has been effected first and most notably by this very compacting together of the body parts, thereby getting rid of gaping joints, interstices, and irregularities of the surface; by the rounding and smoothing of the body contours into a boat-shaped form; by the reduction of spines, hairs, and sculpture on the body, especially on the dorsal surface; by the reversal of the antennæ, and in the Dytiscidæ and Gyrinidæ by the folding of the first two pairs of legs into concavities on the ventral surface of the thorax, and by the conspicuous flattening of the hind legs.

The increased swimming efficiency of the hind legs has been brought about by the transformation of the coxæ into large flattened plates, securely welded to the ventral surface of the metasternum, thus furnishing an exceptionally rigid supporting base; by the flattening of the remaining joints of the leg into one horizontal plane; by the shortening of the proximal and the lengthening of the distal joints; by the development of swimming fringes of long hairs along the margins of the tarsus and sometimes of the tibia, and by the reduction of the terminal claws.

FOR RESPIRATION.

Since both the larva and the adult live in water, some provision has to be made to supply them with oxygen. In discussing the various methods by which this is accomplished it will be convenient to separate the two stages.

In the adult beetles the modifications of structure for the purpose of breathing are as interesting as those concerned in locomotion. They consist in a migration of the spiracles onto the dorsal surface of the body, so that they are entirely covered by the elytra. Attention has already been called, in the compacting of the body, to the tight joints made by the elytra with the prothorax, with each other, and with the sides of the abdomen. A reservoir for air is thus formed between the elytra and the dorsal surface of the body, which when filled enables the beetle to breathe while it is beneath the water. This reservoir is supplied in various ways.

In the Dytiscidæ the posterior end of the abdomen is projected above the surface of the water and the elytra are lifted slightly, enabling the air to enter directly. According to Brocher (1911a) the beetles in this family breathe by drawing in air through the last two abdominal spiracles and expelling it through the others, particularly the anterior pair. He also found in *Cybister* air pockets in the muscles of the meso and meta thorax, directly connected with the anterior spiracles, but he did not think any large amount of air was stored in them.

In the Hydrophilidæ the elytra are strongly arched, thus creating a relatively large reservoir for storage of air. This is not filled directly by thrusting the posterior end of the body above the surface, as in the Dytiscidæ. On the contrary, the angle between the head and the prothorax on one side is brought to the surface and the club-shaped antenna on that side is carried outward until it comes in contact with the air above the water. It is then folded back again, carrying a bubble of air with it. Some of this air is spread over the ventral surface of the body in a thin, silvery film, and some of it finds its way to the reservoir under the elytra through a groove between the meso and pro thorax. Thus, the structural modifications for respiration in this family include the arching of the elytra, the modi-

fied antennæ, whose enlarged club-shaped terminal joints are covered with a dense coat of fine hair, the groove opening into the dorsal reservoir, and an enlargement of the meso and meta thoracic and first abdominal spiracles.

In the Haliplidæ the elytra are held firmly in place by groovings in the pleura and by knoblike structures at the outer ends of the posterior coxæ. The latter are not soldered fast to the metasternum as in the other families, but are free and project backward far enough to cover from three to five abdomen segments. The posterior end of the body is thrust out of the water, and air is admitted to the space between the broad posterior coxæ and the ventral surface of the abdomen. This air finds its way to the reservoir beneath the elytra through a groove in the pleurum at the anterior end of each coxa. The structural modifications in this family thus include the peculiarly modified posterior coxæ, the grooves leading to the dorsal reservoir, and the enlargement of the metathoracic and first abdominal spiracles.

In the Gyrinidæ the lateral or outer margin of each elytron is turned downward and a little inward and its free edge is grooved. The lateral margins of the meso and meta thorax and the anterior abdomen segments are fused and raised into a longitudinal ridge, which fits into the groove along the edge of the elytra, the two locking together like the lateral hinge on a fresh-water mussel. Opposite the junction of the meso and meta thorax is a rounded peg just inside the edge of each elytron, which fits into a socket in the thorax and holds the elytron securely in place. In Dineutes at the posterior end the under surface of each elytron and the upper surface of the abdomen segment immediately beneath it are covered with short hairs, which make a tight joint when the elytra are closed. In Gyrinus the same closing of the joint is accomplished by a transverse ridge, which runs around the posterior end of each elytron on the under surface. The air enters the dorsal reservoir through a groove just inside the posterior end of the turned-down lateral margin of each elytron. In this family, accordingly, the structural modifications for breathing consist in the interlocking margins of the elytra and the body, in the peg for fastening the two together, and in the posterior groove for the admission of air. The spiracles are all about the same size.

In the larvæ there are two methods of supplying the lateral tracheæ with air—one by direct admission above the surface of the water, the other by infiltration. For the former it is necessary that the tracheæ open externally at the posterior end of the body; that this opening be closed in some way while the larva is beneath the water; and that some provision be made for holding the larva at the surface long enough to thoroughly aerate the tracheæ. In the dytiscid larvæ the tracheæ open at the extreme posterior end of the body close to the dorsal surface. Beneath them on the ventral surface are given off a pair of cerci which are heavily fringed with setæ. The extensor muscles operating these cerci run from the base of the latter to the dorsal surface of the abdomen, around the tracheæ. They are so arranged that when the cerci are extended parallel with the body axis or nearly so the posterior openings of the tracheæ are closed by the contraction of the muscles.

When the larva thrusts the posterior end of the body above the surface of the water to breathe, the cerci are turned down at right angles to the body axis on

top of the surface film. This is done by contracting the flexor muscles and relaxing the extensors, thereby opening the tracheæ. In the hydrophilid larvæ the tracheæ open in the bottom of a transverse groove, which is connected with the base of the cerci in such a way that it is kept closed when the cerci are extended but is opened when they are flexed. Incidentally the turning down of the cerci onto the surface film of the water supports the larva while it is breathing. The operation of the cerci in both these families has been well described and figured by Brocher (1913, *Dytiscidæ*, p. 125, text figs. 2 and 5) and d'Orchymont (1913, *Hydrophilidæ*, p. 202, text figs. 22 and 23).

An infiltration of air occurs in the haliplid and gyrrinid larvæ and in exceptional genera of the *Dytiscidæ* (*Coptotomus*) and the *Hydrophilidæ* (*Berosus*). This is accomplished by the presence in the larvæ of lateral gills along the sides of the abdomen and in the haliplid larvæ by jointed spines on the dorsal and lateral surfaces of the thorax and abdomen. Branches of the lateral tracheæ run out into these gills or spines and there give off fine tracheoles, through whose thin walls the air infiltrates from the water.

FOR FLOTATION.

Formerly the film of air clinging to various parts of the bodies of adult beetles was universally regarded as designed for breathing purposes. Brocher (1914a), however, has clearly demonstrated that it is not used for that purpose but for something very different, and his idea has been accepted by Leng (1913) and others.

According to this interpretation the air film of a beetle corresponds to the air bladder of a fish and is concerned with flotation or the maintenance of equilibrium. In the *Dytiscidæ* the dorsal surface of the abdomen behind the elytra is covered with a heavy pubescence to which a bubble of air clings when the beetle dives. But this is an exhaled bubble and not one that is to be inhaled.

In the *Hydrophilidæ* the terminal joints of the antennæ, the ventral surface of the thorax, the whole of the first and varying amounts of the succeeding abdomen segments are covered with a fine pubescence, which retains a film of air when the beetle is submerged. Since the hair by entangling the air keeps the body dry, it has received the name of hydrofuge pubescence. Its real use, however, is not to keep the water away from the body, but by entangling the air to lessen the specific gravity of the beetle and thus aid it in locomotion.

In the *Gyrinidæ* also the ventral surface of the body is covered with short hairs, which entangle a film of air, and this aids in supporting the body upon the surface of the water. This film seems intended entirely for flotation, and none of it, as far as known, is used for respiration.

In the *Haliplidæ*, as in the *Dytiscidæ*, there is often an air bubble at the posterior end of the elytra. This must be exhaled air, however, since the air supply enters the dorsal reservoir by way of the coxal plates and the pleural grooves. The tip of the abdomen is hairy on the dorsal surface, and the pleural grooves are lined with fine hairs. These seem rather to prevent the entrance of water than to retain an air film, and the latter is not present in any of the genera. Evidently there is enough buoyancy in the air carried under the coxal plates and beneath the elytra to obviate the necessity of an air film.

FOR SEX FUNCTIONS.

Certain structural modifications that are evidently designed for sex functions are found in the males of these beetles. Amongst these is the enlargement of one or both of the anterior pairs of tarsi, which is carried much farther than in terrestrial beetles. Attention has already been called to the smooth and polished surface of the adult beetle as a help in locomotion through the water; but such a surface is very difficult to grasp and hold by any ordinary means. Accordingly, the tarsi of the males are modified in many of the genera by the dilation of the basal segments, by the formation of palettes or suckers on the ventral surfaces of these expanded segments, and by the secretion of a peculiar viscid fluid. This fluid is secreted by glands inside the tarsus and is carried by ducts to the base of the columella or stalk on which the palettes are borne. The stalk is hollow and conveys the fluid to the disk of the palette whenever the latter is pressed against any surface. The fluid spreading over the surface of the disk affords a secure attachment on any smooth surface to which the disk may be applied. The arrangement of the dilated segments and their disks will be described under the separate species.

FOR SIGHT.

Another remarkable structural modification is concerned with sight and furnishes the most distinctive characteristic of the Gyrinidæ. Their eyes are completely divided by the lateral margins of the head, leaving half of each eye on the upper surface of the head with which to look into the air and half on the lower surface with which to look into the water. They are thus admirably suited for their whirligig mode of life on the surface of the water. No such modifications are found in any of the other families of water beetles.

ENEMIES OF LARVÆ.

THE LARVA.

The larva itself is its own worst enemy. All the larger larvæ among the Dytiscidæ, Hydrophilidæ, and Gyrinidæ are cannibals, and when kept together eat one another relentlessly until only one remains. *Hydrous triangularis* spins a silken cocoon in which are deposited about 100 eggs. When these hatch, the tiny larvæ begin their warfare on one another as soon as they are born, and many of them are eaten before they ever leave the cocoon. Not even the presence of an abundance of suitable food affects their cannibalism in the slightest. The first question for settlement with them is the survival of the fittest, and as long as another of their kind is present and the two can find each other, this question demands an immediate answer. Some of the smaller species of these three families and all the haliplid larvæ are free from cannibalism. In consequence they may be safely kept together in an aquarium and their entire life history worked out in detail. This has actually been accomplished by Matheson (1912) for some of the Haliplidæ, by Needham and Williamson (1907) for *Hydroporus*, and by the writer for both *Hydroporus* and *Enochrus*.

On the other hand, cannibalism in so many of the species is a very serious obstacle to the attainment of their full life history. Needham and Williamson (1907) related a characteristic experience with one of these species. They tried various devices to prevent them from eating one another; they even went so far as to construct a series of small wire chambers in which individual specimens could be kept separately. The partitions between the chambers projected some distance above the surface of the water, but in the night the isolated larvæ climbed out of the water and over the tops of the partitions and ate one another just the same, leaving but a solitary victor in the morning. The present author has experimented with all but one of the species whose life history is here given and several besides. *Hydroporus*, *Enochrus*, and *Tropisternus mixtus* are the only ones outside of the *Halipidæ* whose larvæ could be induced to live together in peace.

TIME OF PUPATION.

This is a critical period in the life of a larva; it must then emerge from the water and either build its pupal chamber or find a place where it can hollow out one in the mud. The danger varies with the length of time the larva remains uncovered, and in this particular those that bury in the mud have a decided advantage. The larva of *Berosus*, *Tropisternus*, *Laccophilus*, or *Coptotomus* does not travel far from the water's edge before it begins to burrow into the mud, where it is soon covered and protected. Once beneath the surface of the ground it can take as much time as necessary in fashioning its pupal chamber.

On the other hand, a larva like that of *Thermonectes* must gather mud into pellets and build itself a chamber, and not until the latter is fully completed is the larva safe from its enemies. It is even worse in the case of the *Dineutes* larva, whose pupal chamber is constructed with more care, and hence requires a much longer time for its completion. Such enemies as parasitic Hymenoptera and Diptera, Carabid beetles, and the like, have more time to locate these larvæ, and it is not unusual to find the beetle pupæ infested with the larvæ of these parasites. Then, too, there are enemies like the frogs and turtles, which sit on the bank and watch for their prey. The mud-burrowing larvæ quickly bury themselves and escape notice, but the movements of *Thermonectes*, *Dytiscus*, and *Dineutes* larvæ attract attention and reveal the presence of the larvæ to their enemies.

Again rapidity of movement, especially locomotion, becomes a vital factor at this critical period. *Thermonectes* is very agile in all its movements and quickly throws together the fragile walls that constitute its pupal chamber. This partially compensates for the attention it attracts and helps it to escape danger. *Dineutes* however, is slow and sluggish and does nothing with rapidity, and hence it more often becomes infested with parasites. The *Berosus* larva is another slow mover, and many more of them than of the agile species fall victims to the parasites.

DRAGONFLY NYMPHS.

The larger nymphs, like those of *Aeschna*, *Anax*, and *Libellula*, eat beetle larvæ, even including those of *Hydrous* and *Dytiscus*. The mature nymphs in June and July can easily overpower a dytiscid or a hydrophilid larva an inch or

more in length, and of course any of the smaller species. The voracious *Tropisternus* larvæ frequently finish a long orgy of gluttony and cannibalism by passing down the throat of an *Anax* nymph. Five half-grown *Anax* nymphs were captured July 20, 1920, in pond 5D with *Tropisternus* larvæ in their jaws.

MITES.

As a rule, beetle larvæ are free from mites and pests of similar kinds, but several larvæ of *Cybister fimbriolatus*, captured in pond 5D in July, 1920, were each infested with a single large mite, which had fastened to their leg and was distended with blood. One such parasite could do but little harm, but if the number were increased they might easily become a menace.

HYDRA.

While examining some *Spirogyra* and other filamentous algæ for haliplid larvæ a considerable number of hydras were found. One of them had captured a young larva of *Laccophilus proximus* and was ingesting it. Of course, this might have happened during the handling of the material, but the fact that the larva had been paralyzed and was being eaten would show that small larvæ are subject to this peril if they once come within reach of the hydra. To this danger the slow-moving haliplid larva, which feeds upon the algæ, must be especially subject.

ANTS.

Ants of many species swarm everywhere around the margins of the ponds and are always on the alert to seize any larvæ they can overcome. Most of the larvæ are too large and active for them, but occasionally one of the smaller species gets crippled and is then quickly pulled in pieces and devoured.

TURTLES.

Small turtles are apparently fond of both larval and adult beetles. Baker (1916, pp. 231-233) reported the examination of the food contents of 15 specimens of the painted turtle (*Chrysemis picta*). Three of them had eaten beetles including both land and water species. In one 60 mm. long the wing cases of beetles formed 5 per cent of the food mass in the intestine. Another, 41 mm. long, had eaten 9 adult *Hydrovatus pustulatus* and 10 larvæ of *Peltodytes*, forming 40 per cent of its food. The third, 40 mm. long, had eaten 10 adult *Hydrovatus pustulatus* and 1 larva of *Peltodytes*, constituting 15 per cent of its food.

FROGS.

Two frogs are very common around the shores of the ponds—the leopard frog (*Rana pipiens*) and the little cricket frog (*Acris grillis*). Many specimens of both these frogs were examined and the contents of their digestive canal carefully listed. Every one with a single exception had eaten either land or water beetles, sometimes both, and while beetle larvæ constituted but a small percentage of their food there were enough to show that the frogs are dangerous enemies of the larvæ.

SNAILS.

Cooke (1895), in his "Molluscs," of the Cambridge Natural History series, noted on page 34 that Lillian's pond snail (*Lymnaea stagnalis lillianæ*) feeds on dytiscid larvæ, snails, and minnows. This fact, of course, suggests that it may also eat the larvæ of other water beetles, and that other carnivorous snails may also feed upon them.

PARASITES.

The parasites do not usually get a chance to infest the larva until it comes out of the water to pupate, and the injury that they inflict is not manifest until the pupal stage. For that reason this enemy belongs to the pupal stage and will be discussed there.

ENEMIES OF PUPÆ.

WATER.

Strangely enough the worst enemy of the pupa is undoubtedly water, although both the larva and the adult live in the water. The pupa possesses none of the structural modifications found in the larva and adult which enable them to swim and breathe while in the water, and hence it is absolutely helpless in such a medium. Furthermore, it is confined within the narrow pupal chamber, whose diameter is often less than its own length. If this pupal chamber becomes filled with water the pupa is quickly drowned, and this is also true of the larva after it has burrowed into the ground and before it has transformed into a pupa and of the beetle imago after emerging from the pupa and before leaving the pupal chamber. The devices possessed by the larva and adult for maintaining a supply of fresh air will not function within the narrow confines of the pupal chamber. There is thus often two or three days previous to pupation and two or three days after emergence as well as the entire pupal stage during which the presence of water in any amount is fatal. When the larva comes out of the pond and burrows into the ground, he stakes his very life upon the weather conditions during the next two or three weeks. If it is pleasant or with only a normal amount of rain, the chances are all in the larva's favor; but if there comes a severe storm and the pupal chamber is filled with water, either from surface drainage or from the raising of the surface of the pond, it results in the death of the larva, pupa, or imago, whichever is caught in the chamber. In digging for pupæ along the shores of the fishponds in 1920 many pupal chambers were opened that had been flooded in this manner. Four larvæ of *Hydrous triangularis*, 19 pupæ, and 2 imagos were found dead; 2 larvæ of *Tropisternus lateralis*, 8 pupæ, and 1 imago; 2 pupæ and 1 imago of *Thermonectes ornatocollis*. The absence of smaller larvæ and pupæ was probably due to the fact that they had been carried off bodily by ants. All the larger ones had been thoroughly decimated by the same scavengers and much of the softer tissues removed.

IMPERFECT PUPATION.

In pupating the head is withdrawn from the chitinous larval covering, and the latter is left entire. In all the larvæ studied the base of the head is narrower than the central portion, and hence in order to be withdrawn successfully the base must be opened. This is usually done by a division along the dorsal mid line. If for any reason the chitin covering fails to divide, it may become impossible to withdraw the contents of the larval head, and the pupa will be malformed. Figure 94 (p. 307) represents such an occurrence in *Dineutes americanus*. One of the pupal chambers brought into the laboratory did not hatch with the others. On being opened a distorted adult beetle was found inside, with a portion of its head, including the antennæ and mouth parts, still inside the old larval covering. The rest of the beetle was perfect, but, of course, it would have died very soon, since it could not even get out of the pupal chamber, and if it had done so it could not have eaten anything.

PARASITES.

A hymenopterous parasite (*Spilocryptus incertus* Cresson) was found within a cocoon of *Dineutes americanus* by Dimmock and Knab (1904). They also gave the life history of a bombardier beetle (*Brachinus janthinipennis*) whose larva is parasitic upon the pupa of *Dineutes americanus*. Wickham (1894) was the first to find this beetle parasite inside of the pupal chamber of *Dineutes*, but he could not secure sufficient material to make a detailed study of the parasite. Dimmock and Knab were more fortunate and secured an abundance of material from pupal chambers found about a reservoir in Holyoke, Mass. They said (1904, p. 35): "The larva of *Brachinus*, until about ready for pupation, keeps its mouth parts most of the time imbedded in the pupa of *Dineutes*, and pupation takes place in the mud cell made by its host." Wickham (1893, p. 332) also mentioned that the parasite larva, "perhaps on account of the partial decomposition of the *Dineutes* pupa, on which it was originally feeding, consented to complete its growth on the pupa of *Tropisternus glaber*, which I killed and opened for it." Wickman also found a hymenopterous parasite (*Cyrtogaster dineutis* Ashmead) upon a *Dineutes* larva, an ichneumonid parasite (*Gausocentrus gyrini* Ashmead) upon two pupæ of a species of *Gyrinus*, and a dipterous parasite (*Phora* sp.) upon a pupa of *Tropisternus glaber*.

Attention has already been called to the fact that the mud-burrowing larvæ are better protected against these parasites than are those which construct a pupal chamber. We see from the above, however, that even the mud burrowers get caught sometimes.

THE BLACK HORSEFLY.

Both the larvæ and the pupæ of the black horsefly (*Tabanus striatus*) are common in the mud around the shores of the ponds and are frequently dug up when searching for beetle pupæ. In a single instance a larva was obtained from the shore of pond 5D, August 10, 1920, that had nearly consumed a pupa of *Tropisternus lateralis*. These larvæ have been recorded as attacking and eating the grubs of *Phyllophaga* and *Cyclocephala*. In all probability when they are as common as around these fishponds they consume many of the beetle pupæ.

ANTS.

It was noted above that the ants consumed the softer portions of the bodies of beetle larvæ, pupæ, and adults which had been drowned inside the pupal chamber. They are not content with being scavengers, however, and they frequently kill both larvæ and pupæ. Their depredations would be much more numerous were it not for the fact that the beetle usually constructs its pupal chamber in earth too moist for the ants.

ENEMIES OF ADULTS.

TURTLES.

Mention has already been made on page 244 of certain adult beetles eaten by turtles. A medium-sized snapping turtle was caught August 7, 1920, in one of the ponds and placed in a large metallic tub. It disappeared over night but left behind excreta containing 1 adult *Hydrous triangularis*, 2 *Cybister fimbriolatus*, 1 *Dytiscus hybridus* and 1 *Tropisternus lateralis*, these beetle remains constituting fully 50 per cent of the excreta.

BIRDS.

McAtee and Beal (1912, p. 19) recorded the food of a horned grebe (*Colymbus auritus*) as containing 23.3 per cent beetles, chiefly aquatic. Two little green herons (*Butorides virescens virescens* Linn.), shot at one of the fishponds in Fairport August 10, 1918, were examined and their stomach contents listed. Among other things one had eaten an adult *Hydrous triangularis*, which formed 25 per cent of its food. The other had eaten two *Donacia* adults and one *Laccophilus maculosus*, which together formed 30 per cent of its food.

The shoal water ducks must also be recorded among the more important enemies of adult water beetles. In a paper by W. L. McAtee (1918) a summary was given of the items of food identified in the stomachs of three species of mallard ducks. Out of 2,398 stomachs examined Haliplidæ were found in 25, Dytiscidæ in 139, Gyrinidæ in 9, Hydrophilidæ in 99. This is a total of 272, a little more than one-ninth of the whole number. What was said with reference to the common mallard (McAtee, 1918, p. 8) may be taken as applying to all three species.

The mallard's attention to insects is divided about equally among beetles, bugs, and dragonflies, which together constitute more than half of the insect food. The beetles include both larvæ and adults of the Haliplidæ, 20 different kinds of Dytiscidæ, both adults and larvæ, Hydrophilidæ and Gyrinidæ.

A paper by D. C. Mabbott (1920) gave the items of food of seven species of shoal water ducks. These contributed to the destruction of beetles in the following manner:

The most common Coleoptera [in gadwall stomachs] were water scavenger beetles (Hydrophilidæ), predacious diving beetles (Dytiscidæ), ground beetles (Carabidæ), leaf beetles (Chrysomelidæ), and weevils (Rhynchophora). * * *. Of the 362 birds taken during the fall and winter months only 23 had eaten beetles, and these never amounted to more than 4 per cent of the stomach contents. Of 11 ducklings taken in July, however, all but one had eaten beetles; in three instances these amounted to 15 per cent and constituted 7.09 per cent of the food of all [p. 9].

More than two-thirds of the insects eaten by the baldpate (0.29 per cent of the whole) were beetles. These included water scavenger beetles (Hydrophilidæ), found in 8 stomachs, predacious diving beetles (Dytiscidæ), in 2, * * *, and unidentified fragments of beetles in 16 [p. 15].

Those [beetles] most commonly taken [by the green-winged teal] were predacious diving beetles (Dytiscidæ), water scavenger beetles (Hydrophilidæ), crawling water beetles (Haliplidæ), snout beetles and other weevils (Rhynchophora), and ground beetles (Carabidæ) [p. 21].

Beetles (Coleoptera) amounted to 2.62 per cent of the food of the blue-winged teal, or less than one-tenth of the total animal matter eaten. Ten species of predacious diving beetles (Dytiscidæ) were noted, five of water scavengers (Hydrophilidæ), four of crawling water beetles (Haliplidæ), * * *, and one of whirligig beetles (Gyrinidæ) [p. 27].

Over half of the insect food of the series of cinnamon teals (5.40 per cent of the whole) consisted of beetles (Coleoptera). Disregarding several unidentified fragments, only four families were represented, the predacious diving beetles (Dytiscidæ), water scavenger beetles (Hydrophilidæ), leaf beetles (Chrysomelidæ), and snout beetles (Curculionidæ) [p. 30].

Beetles (Coleoptera), amounting to 0.93 per cent of the total food of the pintail, consisted largely of three families, the predacious diving beetles (Dytiscidæ), water scavenger beetles (Hydrophilidæ), and ground beetles (Carabidæ) [p. 36].

Beetles of at least 15 families were represented in the food of the wood ducks examined. Of these the water scavenger beetles (Hydrophilidæ), predacious diving beetles (Dytiscidæ), and leaf beetles (Chrysomelidæ) were most commonly taken. * * *. Two other strictly aquatic families—the whirligig beetles (Gyrinidæ) and crawling beetles (Haliplidæ)—were well represented. * * *. Peculiar little silken cases containing eggs of water scavenger beetles, usually attached to a submerged leaf or to the body of the female beetle herself, are not infrequently found in duck stomachs [p. 47].

TOADS AND FROGS.

In discussing the natural history and utilization of frogs Wright (1920, p. 41) made the following statement:

Coleoptera, mainly ground, lamellicorn, and click beetles, and weevils constitute 27 per cent of the food of the toad, while in the animal food of the leopard frog beetles form 33 per cent of the whole, the principal groups being ground, tiger, and snout beetles. In the food of the wood frog, pickerel frog, and green frog the proportion is equally large, while in the diet of the bullfrog the beetle element is surprisingly large. No doubt water beetles of the surface enter into the food of the bullfrog more than into that of the other species of frog.

Of 10 leopard frogs (*Rana pipiens*), captured on the shores of the fish ponds at Fairport in August, 1920, 8 had eaten adult water beetles, and 1 of the other 2 had eaten land beetles. Of 15 cricket frogs (*Acris grillis*) captured at the same time, every one had eaten adult beetles, and in the diet of 8 of them some form of water beetle was included. The simple fact that beetles constitute so large a percentage of the food of the toad and the various frogs indicates that all of these batrachians probably eat water beetles whenever they get a chance.

ELECTRIC LIGHTS.

Reference has already been made under locomotion to the fact that the adult beetles while migrating from place to place are often attracted by electric lights. Although some escape this peril many fall beneath the lights into the dust and perish. This is especially true of the larger species but applies also to the smaller ones. Trap lanterns that are set for moths usually capture a considerable number of water beetles, and the nearer to the water they are set the greater the danger to the beetles.

BEETLES AS FISH EATERS.

The food of the various larvæ and adults will be given under the separate species, and it will be sufficient here to make a few general statements. On the whole, the larvæ of the Dytiscidæ, Hydrophilidæ, and Gyrinidæ are carnivorous, while those of the Haliplidæ are strictly vegetarian. Of the adults the Dytiscidæ and Gyrinidæ eat animal food, whereas the Hydrophilidæ and Haliplidæ eat vegetable food of various kinds. Neither the plant-eaters nor the animal-eaters are strictly confined to their own kind of diet, however. Under stress of hunger or when for any reason the natural food supply fails they both show great ability to change their diet. Some species probably combine the two kinds under normal conditions. The thing that concerns us most in connection with their food is the fact that some of them eat small fish, and this is worthy of careful consideration. In considering this problem it will be convenient to separate the larvæ and adults and discuss them separately.

In searching for the food of the larvæ no information can be obtained from an examination of the contents of the stomach and intestine if the larva belongs to the Dytiscidæ, the Gyrinidæ, or the Haliplidæ. In these three families the larval mandibles are either grooved or pierced for the passage of fluids only. Hence, the fluid contents of the food are all that is swallowed, and obviously they furnish nothing that could identify the species of plant or animal from which they came.

The hydrophilid larva, on the contrary, chews up its prey and swallows the solids as well as the liquids. Instead of being pierced or grooved its mandibles are toothed on the inner margins to fit them for chewing. Accordingly, in this family we can obtain the very best information by an examination of the contents of the stomach and intestine. This has already been done with the larvæ of *Hydrous triangularis*, and fish remains were found in the stomachs of 12 out of 50 larvæ examined (Wilson, 1923). In the present investigation the stomach contents of 50 larvæ of two species of *Tropisternus* have been examined, but no fish remains were found in any of them. The larvæ of *Berosus* are too small to yield much that is of value from such examinations. For these small hydrophilids and for all the larvæ in the other families actual observation is the only source of information in reference to the food. The problem of beetle larvæ as fish eaters, therefore, narrows down to answers to the following questions: What kinds of beetle larvæ have been seen eating fish and under what conditions? What kinds are likely to eat fish either under normal conditions or from stress of hunger? Of the Dytiscidæ the larvæ of various species of *Dytiscus* and *Cybister* have been observed eating fish even when an abundance of other food was available. By reason of their voracity these larvæ are commonly called water tigers. Kellogg, in his *American Insects* (1908, p. 257), said of the Dytiscidæ:

Both larvæ and adults are fierce and voracious, and the larger species attack and kill small fish. In the middle States these beetles actually do much damage in carp-ponds.

When stationed at the U. S. Fish Hatchery in Homer, Minn., H. L. Canfield had occasion late in August, 1913, to draw down one of the ponds containing small-mouthed black bass fingerlings from 2 to 2½ inches in length. As soon as they felt

the pond begin to lower the fingerlings swarmed to the surface near the outlet. At the same time numbers of these water tigers appeared and attacked the fish from all sides. The dytiscid larva seized the fish by its throat and plunged its powerful mandibles into the flesh near the heart. After sucking the blood a moment it dropped the fish and attacked another, until the destruction became enormous. Similar attacks have been witnessed in the fishponds at Fairport, Iowa, but the number of fish killed was much less, owing to the smaller number of dytiscid larvæ present.

On May 18, 1916, 4,500 fry of *Ictiobus cyprinella*, the common buffalofish, were placed in pond 14B, from which all the larger fish had been previously removed. From the time these fry were placed in the pond repeated search for them failed to reveal their presence. On July 12 the pond was drawn, but no buffalo fry were found. Many dytiscid larvæ, however, appeared, and it was felt that they, with other enemies, might have contributed to the disappearance of the fish fry. No positive proof of this could be obtained, and since the dytiscid larva does not chew its prey but merely sucks its juices, it would seem as if there should have been some of the dead fry floating in the pond if the dytiscid larvæ were really responsible for their disappearance.

One of these attacks of a water tiger upon a small fish has been made the subject of a movie film. While this particular attack was undoubtedly staged for effect, it does reveal the voracity and tigerlike nature of the larva. There is no objection to artificial conditions when the reality has been repeatedly observed under perfectly natural conditions. Fortunately the larvæ of other dytiscid genera are too small to function as enemies of fish. None of them, so far as known, have been reported as attacking young fish, and it is probable that ordinarily they are satisfied with other food.

Of the Hydrophilidæ the larvæ of various species of the genus *Hydrous* have been captured while eating fish both in Europe and in America. The following is another instance to be added to a list that is already rather long. Ten thousand small fry of the buffalofish (*Ictiobus cyprinella*) were placed in pond 3E, June 1, 1918. During the month many *Hydrous* larvæ appeared in the pond and the buffalo fry began to disappear. By watching the pond closely the beetle larvæ were actually captured while eating fish on July 3. The pond was then drained and the fry removed and about 150 full-grown *Hydrous* larvæ were picked up, while many more larvæ and pupæ were obtained from pupal chambers around the pond shores. In this instance, therefore, it was actually proved that the beetle larvæ were responsible for the disappearance of some of the fish. Of the remaining genera of the Hydrophilidæ, *Hydrophilus* is about the only one whose larvæ would be large enough to become a menace to small fish. It has not been reported as actually seen committing this depredation, but it might do so under stress of hunger.

Of the Gyrinidæ the larvæ of *Dineutes americanus* have been seen eating small fish. In the early summer of 1916 the channel catfish (*Ictalurus punctatus*) in pond 9D for the first time spawned and hatched a brood of young. During the subsequent lowering of the pond in order to secure and remove these fry, George Lay observed large numbers of *Dineutes* larvæ attacking the young fish. Several

would mob together and seize the fish from different sides, and they kept up the attack until the fish succumbed. Of course, when the pond was lowered all its animal fauna was crowded together into a limited space, and the relations of the various species to one another became somewhat abnormal. If these larvæ attack fish under such conditions, they might repeat the performance at another time, especially if their food supply became scarce. So far as known no other gyrenid larva has ever been reported as attacking fish.

The haliplid larvæ are all strict vegetarians and are so small and inactive that they do not catch any living animal, much less attack small fish.

To summarize, therefore, the larvæ of *Dytiscus*, *Cybister*, and *Hydrous* are known to eat small fish as a part of their regular diet. The larvæ of *Dineutes* have been observed killing fish fry under somewhat abnormal conditions and might do the same thing whenever they had a chance. The larvæ of *Acilius* and *Hydrophilus* are large enough to overpower very small fish fry, but thus far there is no positive proof that they actually do this. The other beetle larvæ are too small to be reckoned as a menace to fish culture.

With reference to the attacks made by adult beetles upon fish the testimony is much less satisfactory. Von Mentzschefahl in 1778-79 mentioned two species of adult water beetles (*Dytiscidæ*) that attacked the perch in a pond in Silesia. Similar destruction of young fishes by adult water beetles was noted by Elles in 1830, by Dale in 1832, by Riley in 1885, and by Dimmock in 1886.

Elles wrote as follows (1830, pp. 148-149):

I observe that one of your correspondents notices the probability of ponds in elevated situations being stocked with fish through the agency of the water beetle. If this active and voracious little creature were really useful in that way, it might in some measure atone for its other mischievous propensities; for I do not know a more destructive little insect to fish themselves, besides devouring the spawn. A neighbor of mine lost several hundred of the fry of the gold and silver fish by this little pest; and, to leave no doubt about the matter, he caught one and placed it in a large basin of water, to which he shortly after added a little fish. The beetle immediately made a dead set at the fish, which completely paralyzed the poor little animal, for it was soon after seized near the tail by the beetle without making any effort to escape, and never left until it was a perfect skeleton similar to numbers, that he had previously found.

Elles gave no hint as to the genus and species of this beetle, although the query was made by a correspondent in Volume IV of the same magazine, and Elles's attention was called to it by Dale on page 668 of Volume V.

Riley stated (1885, p. 311):

The large water insect which attacks and kills young carp is evidently some species of *Cybister* or *Dytiscus* of the coleopterous family *Dytiscidæ*.

Dimmock's testimony was quite different; he said (1886, p. 357):

I have seen a dead rat in a small pond surrounded by a great swarm of these beetles (*Dytiscidæ*) and they prefer such food to living food.

Garman said (1890, p. 163):

Both adults and young (*Dytiscidæ*) lead a predatory life, attacking and devouring whatever they can master. They do not hesitate to attack animals many times larger than themselves and are very destructive in fishponds to young fishes. They are in turn eaten by the larger fishes.

The writer (Wilson, 1923) has recorded the killing of a young buffalofish in an aquarium at Fairport, Iowa, by a female *Hydrous triangularis* just after she had completed spinning an egg case.

None of these accounts are very convincing. If the neighbor mentioned by Elles had actually seen a beetle killing his goldfish fry, there was no need of further proof. If he had not, the placing of the two together in a basin of water with the resultant death of the fish certainly did not furnish such proof. There are large water bugs belonging to the family Belostomidæ which are just as likely to kill young carp as are the two beetle genera mentioned by Riley. Garman's statement is a general one without the citation of anything to prove its validity. The writer, in his record above cited, called attention to the fact that the conditions under which the killing of the buffalofish occurred were artificial and abnormal. Consequently, while it is highly probable that these large beetles do sometimes kill small fish, we have to admit in all fairness that their guilt has not yet been legally established. It is also worthy of record that while Cybister and Dytiscus and Hydrous are common in nearly all the fishponds at Fairport, no one has ever seen an adult beetle attacking one of the fish fry.

FISH AS BEETLE EATERS.

Having ascertained how many and what species of beetle larvæ and adults prey upon fish fry, we may turn about and inquire what kinds of fish ordinarily eat beetle food. Our inquiry now is much more easily answered, since it does not involve any watching of the fish. We have simply to examine the contents of the fish's digestive canal to obtain exact information both as to the quality and the quantity of food consumed. Moreover, the beetles eaten are more readily recognized than almost any other kind of food. The hard chitin covering of the head of the beetle larva, together with the antennæ and mouth parts, remain sufficiently intact to be readily recognized. For the adults the entire beetle is sometimes practically uninjured and may even make a respectable specimen after a temporary sojourn inside a fish's stomach. In case it is mutilated, there is always enough of the hard chitin parts to render identification easy and certain.

EVIDENCE FROM FISH BAIT.

So far as known neither the beetle larvæ nor the adults are used anywhere in the United States as fish bait, but there is apparently no reason why they would not make excellent bait. The larva of the horned *Corydalis* or dobsonfly (*Corydalis cornuta*) is known to fishermen everywhere as the dobson, crawler, and a variety of other names and is much prized as fish bait, especially for black bass.

The larva of *Hydrous triangularis* closely resembles the dobson in size and general appearance, and it is greedily eaten by bass whenever offered to them. Large-mouthed black bass are used in many of the experiments at Fairport, and there are some of them in the tanks most of the time. Hydrous larvæ of all sizes up to full development have been fed to these fish during the summer. They have always eaten the larvæ with great avidity, and if they were hungry it sometimes seemed as if the larva did not fairly strike the surface of the water before it was snapped

up. It is not probable that a bass thus greedy could distinguish between a dobson and a Hydrous larva when placed on a fishhook as bait. Accordingly, it seems probable that the beetle larva would make fully as successful bait as the dobson.

EVIDENCE FROM FISH STOMACHS.

The data in the five tables in this section on the beetle food found in the stomach contents of food and game fishes examined by scientific men in various localities present ample evidence that beetle larvæ and adults constitute an important item of fish food.

Food of the fishes of Illinois, by S. A. Forbes.

Kind of fish.	Terrestrial beetles, adults.	Terrestrial beetles, larvæ.	Undetermined aquatic adults.	Undetermined aquatic larvæ.	Hydrophilidæ, adults.	Hydrophilidæ, larvæ.	Dytiscidæ, adults.	Dytiscidæ, larvæ.	Gyrinidæ, adults.	Gyrinidæ, larvæ.	Helophilidæ, adults.	Chrysomelidæ, adults.
<i>Abramis chrysoleucas</i> , roach or bream.....	+				+		++					
<i>Ambloplites rupestris</i> , red-eye.....		+			+							
<i>Ameiurus nebulosus</i> , common bullhead.....	+						++	+	+			
<i>Ameiurus nebulosus marmoratus</i> , marbled bullhead.....	+				+	+						
<i>Aphredoderus sayanus</i> , pirate perch.....				+								
<i>Aplodinotus grunniens</i> , sheepshead or croaker.....					+					+		
<i>Argyrosomus arctedi</i> , cisco.....	+											
<i>Catostomus nigricans</i> , hog molly, stone roller.....	+			+								
<i>Chænobryttus gulosus</i> , warmouth bass.....	+											
<i>Dorosoma cepedianum</i> , gizzard shad.....	+											
<i>Eupomotis gibbosus</i> , common pumpkin seed.....	+				+							
<i>Eupomotis heros</i> , southern pumpkin seed.....					+		+				+	
<i>Fundulus diaphanus</i> , Menona top minnow.....	+				+							
<i>Fundulus notatus</i> , common top minnow.....	+				+	+						
<i>Hybopsis kentuckiensis</i> , river chub.....	+											
<i>Hyodon tergisus</i> , toothed herring.....	+		+		+		+					
<i>Ictalurus punctatus</i> , channel cat.....	+				+	+	+					
<i>Ictiobus bubalis</i> , small-mouthed buffalofish.....	+				+	+	+					
<i>Ictiobus cyprinella</i> , red-mouthed buffalofish.....	+	+		+								
<i>Ictiobus urus</i> , mongrel buffalo fish.....	+											
<i>Lepomis cyanellus</i> , green sunfish.....	+				+		+					
<i>Lepomis megalotis</i> , long-eared sunfish.....	+											
<i>Lepomis pallidus</i> , bluegill.....	+				+	+	+		+	+		+
<i>Micropterus dolomieu</i> , small-mouthed black bass.....	+	+					+		+			
<i>Moxostoma aureolum</i> , common red horse.....					+	+				+		
<i>Moxostoma macrolepidotum</i> , large-scaled red horse.....	+					+						
<i>Notropis atherinoides</i> , silverside shiner.....	+									+		
<i>Notropis cornutus</i> , common shiner.....	+											
<i>Notropis hudsonius</i> , spot-tailed minnow.....	+									+		
<i>Notropis whipplii</i> , silver-fin shiner.....	+	+										+
<i>Placopharynx duquesnei</i> , pavement-toothed red horse.....		+				+						
<i>Polyodon spathula</i> , spoonbill cat.....	+						+					
<i>Pomoxis annularis</i> , crappie.....		+					+			+		
<i>Roccus chrysops</i> , white bass.....		+										
<i>Schilbeodes gyrinus</i> , tadpole cat.....			+									
<i>Semotilus atromaculatus</i> , horned dace.....	+				+						+	+

These records by Forbes (1888) are very valuable, since they include so many of our food and game fish, and it is to be regretted that they do not contain more data on the size of the fish and the relative proportions of the various beetle foods. The larvæ and adults of terrestrial beetles have been included, because the fish that will eat them will probably not refuse aquatic forms when available. This is

abundantly shown by the fact that two-thirds of the fishes enumerated in this list have eaten both terrestrial and aquatic beetles. Among the aquatic forms the Hydrophilidæ serve as food more often than any of the other families, possibly because they are more numerous.

Of the fishes included the bluegill is the most omnivorous, eating everything on the menu except the Haliplidæ. However, if the terrestrial beetles were separated into families corresponding with the aquatic forms, the toothed herring would have to stand first, since it seems to eat anything and everything that comes its way.

Forbes himself offered the following comment upon his list (1888, p. 484):

Larvæ of aquatic beetles, notwithstanding the abundance of some of the forms, occurred in only insignificant ratios, but were taken by 56 specimens, belonging to 19 of the species—more frequently by the sunfishes than by any other group. The kinds most commonly captured were larvæ of the Gyrinidæ and Hydrophilidæ, whereas the adult surface beetles themselves (Gyrinus, Dineutes, etc.)—whose zigzag-darting swarms no one can have failed to notice—were not once encountered in my studies.

He was at fault, however, in this last statement, since he noted, on page 519 (1888), that a common bullhead (*Ameiurus nebulosus*) had eaten gyrinid adults.

Food of the shore fishes of certain Wisconsin lakes, by A. S. Pearse.

[Figures in the food columns are percentages by volume, the entire food being 100.]

Kind of fish.	Number of fish examined.	Average length of fish, millimeters.	Gyrinidæ, adults.	Gyrinidæ, larvæ.	Haliplidæ, adults.	Haliplidæ, larvæ.	Dytiscidæ, adults.	Dytiscidæ, larvæ.	Hydrophilidæ, adults.	Hydrophilidæ, larvæ.	Undetermined beetles.
<i>Abramis crysoleucas</i> , golden shiner.....	3	122.6	.....	.....	.....	.....	1	.....	.....	.....	.....
<i>Ambloplites rupestris</i> , redeye.....	5	77	.....	.....	2.6	.....	2	.....	3.4	.....	.....
<i>Ameiurus melas</i> , black bullhead.....	1	274	.....	6	.....	.....	.....	2	.....	.....	.....
<i>Ameiurus nebulosus</i> , common bullhead.....	33	36	0.5	.....	.....	.....	.....	.....	.....	.....	.....
<i>Catostomus commersonii</i> , common sucker.....	3	51.8	.....	.....	.....	.....	2.3	.....	.....	.....	.....
<i>Cyprinus carpio</i> , German carp.....	4	20	.....	2.5	.....	.....	.....	2.5	.....	.....	.....
.....	18	31.8	.....	.....	.....	0.1	2.5	.....	.....	0.3	.....
.....	18	29.5	.....	.....	1.5	.....	.....	.....	.....	.....	.....
<i>Etheostoma Iowae</i> , Iowa darter.....	4	48.5	.....	11.2	.....	.....	.....	.....	.....	9	.....
<i>Fundulus diaphanus menona</i> , top minnow.....	49	35.4	.....	.....	.....	.....	.....	.....	.....	.....	0.6
.....	10	38	.....	.....	.....	.....	.....	.....	.....	.....	6
<i>Lepomis incisor</i> , bluegill.....	2	116	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	10	54.8	.....	.....	.....	2.5	.....	.....	.....	.....	.....
.....	10	45.4	.....	.....	.....	.3	.....	.....	.....	.....	.....
.....	3	69.6	.....	.....	.....	.2	.....	.....	.....	.....	.....
.....	3	30.6	.....	.....	.....	.6	.....	.....	.....	.....	.....
<i>Micropterus salmoides</i> , large-mouthed black bass.....	10	136	.....	.....	.....	.....	5	.....	.....	.....	.....
<i>Perca flavescens</i> , yellow perch.....	1	200	.....	.....	.....	.....	.3	.....	.....	.....	.....
<i>Pomoxis sparoides</i> , black crappie.....	1	126	.....	.....	3	.....	.....	.....	.....	.....	28
<i>Salmo irideus</i> , rainbow trout.....	18	103	.....	.....	.....	.2	1.1	2.3	.....	.....	.....
<i>Salvelinus fontinalis</i> , brook trout.....	9	42.6	.....	.....	.....	.....	.....	.....	.....	.....	33.2
<i>Schilbeodes gyrinus</i> , tadpole cat.....	9	51.1	.....	.....	.2	.....	.....	.....	.....	.....	.....
<i>Umbra limi</i> , mud minnow.....	10	49.3	.....	.....	2.5	.....	.....	.....	.....	.....	.....
.....	14	20.6	.....	.....	.....	.....	.....	.....	.....	.....	3.5

The relative amounts of beetle food given in this table seem at first sight so small as to be hardly worth considering, but such is by no means the case. The total number of fishes examined by Dr. Pearse (1918) was 1,576. In the general summary of foods eaten by these fishes the largest single item was that of insects, 36.30 per cent, nearly twice the size of its nearest rival, the Entomostraca. The insects contributing the most food were the Diptera, those second in order were the

Ephemerida, and the Odonata and Coleoptera were tied for third place. Pearse divided the fish foods into nine classes, the first four of which in the order of their importance were: (1) Insect larvæ, oligochaetes, and leeches. (2) Entomostraca. (3) Fishes and frogs. (4) Insect pupæ and adults. In the present instance the larvæ and adults are combined in one table, while the pupæ, transforming out of water, are never eaten by fish. This beetle food, therefore, belongs partly to the class considered of greatest importance and partly to the class placed fourth in the list.

Pearse's table may well supplement the preceding one, since it includes several kinds of fish not mentioned by Forbes and also adds new items to the diet of other species. Of greatest interest is the inclusion of the German carp, of which 40 young specimens, varying from 15 to 64 mm., were examined. These had eaten freely of gyrenid larvæ, haliplid adults and larvæ, dytiscid adults and larvæ, and hydrophilid larvæ, the sum total forming an amount of food surpassed only by the Diptera and Entomostraca. Pearse said (1918, p. 258):

The German carp during its first few weeks after hatching from the egg feeds largely on entomostracans and rotifers; after that it turns more to insect larvæ.

And of this insect food the beetles are second in importance.

It is also worthy of note that three young suckers, averaging 2 inches in length, had consumed enough dytiscid adults to form a respectable percentage of their total food. The little Iowa darter subsists almost entirely upon amphipods and insect larvæ, and among the latter the beetles are second only to the Diptera.

The only family of aquatic beetles not found in the food of the bluegill as given by Forbes was the Haliplidæ. All of the 25 specimens of bluegill examined by Pearse contained haliplid larvæ, the larger fish containing the greater amount.

The large-mouthed black bass, the yellow perch, the black crappie, the golden shiner, and the mud minnow did not appear in Forbes's list.

Food of trout, by Chancey Juday.

Kind of trout.	Locality.	Number examined.	Length in centimeters.	Number eating Coleoptera.	Average percentage of Coleopterous food. ¹
<i>Salmo sebago</i>	Twin Lakes.....	19	20-70	4	73
<i>Salmo stomias</i>	do.....	64	10-20	25	42.7
<i>Salmo irideus shasta</i>	do.....	106	15-45	37	22.2
<i>Salvelinus fontinalis</i>	do.....	29	2.5-5	1	5
.....do.....	do.....	126	10-33	43	15.7
<i>Salmo whitei</i>	Kaweah River.....	12	14-20	6	30
.....do.....	Soda Creek.....	6	11-18	2	12.5
.....do.....	Little Kern River.....	41	12-20	38	15
<i>Salmo roosevelti</i>	Volcano Creek.....	18	12-28	12	2

¹ The total food is considered 100 per cent.

It should be noted first of all that Doctor Juday (1907) made no distinction between aquatic and terrestrial beetles, nor between adult and larval forms. In all probability terrestrial species formed a large proportion of the total amount. This is especially true of the trout captured in running water. To judge from the long

list of terrestrial beetles recorded by Forbes, many of whose fish were taken in rivers and streams, it would seem reasonable to infer that in the trout recorded by Juday from rivers and creeks much of the beetle food was terrestrial. This, however, does not in any way affect the conclusions that follow, since the trout that captured and swallowed a terrestrial species would do the same to an aquatic species, if the opportunity offered. Beetle systemy will not, to any appreciable extent, affect a trout's appetite.

Of the 421 trout examined by Doctor Juday 40 per cent had eaten beetles, and in their stomachs the beetles formed on an average one-quarter of the total food. Such a percentage is large enough to constitute an important factor in the food supply of these fish. It will be noted that a larger number of individuals taken in running water had eaten beetle food, the percentage reaching as high as 92.68 in the Little Kern River. On the contrary the relative amount of beetles in the total food was greatest in the trout from the quiet waters of the Twin Lakes, reaching an average of 73 per cent in the four landlocked salmon. Again the smaller fry, from 2.5 to 5 cm. in length, consumed practically no beetles, whereas the medium-sized fish, from 10 to 40 cm. in length, consumed the greatest amount.

The largest landlocked salmon was 70 cm. in length and the smallest one 20 cm., and although no data were given as to the length of the four that had eaten beetles, we may infer from the other statistics in the table that they were among the smaller rather than the larger ones. Beetles, therefore, do not become a factor in the food of trout until the fish have reached a length of 7.5 cm. (3 inches). The fingerlings then begin to eat them freely, and during the period of growth from 10 to 30 cm. beetles form an important part of the total food.

For trout above 30 cm. in length other fish become a more and more important item of food until they practically supplant everything else. Of the 64 greenback trout (*Salmo stomias*) only four had partaken of fish; none of the small brook trout had touched them, and only two of the 126 large brook trout and none of the trout from the creeks and rivers had eaten fish. On the other hand, seven of the landlocked salmon, presumably the larger ones, had eaten nothing but fish, that item constituting 100 per cent of their food.

The percentages given for each species in this table were obtained by dividing the sum of the per cents of the different food items by the number of stomachs containing food. Of the 12 food items of the landlocked salmon, fish was the only one that surpassed beetles. In the greenback trout, also with 12 food items, Crustacea and beetles were the two largest, the former 0.22 per cent larger than the latter. In the rainbow trout, with 17 food items, beetles were the third in abundance, being surpassed by fish and vegetable débris. In the large brook trout, with 16 food items, beetles were surpassed only by vegetable débris and Hymenoptera. For the small brook trout beetles formed the smallest of the 10 food items.

Food of Louisiana fish, by H. E. Schradieck.

[Figures in the last five columns are percentages, the total food being 100.]

Kind of fish.	Num- ber of fish ex- amined.	Ex- tremes in length of fish, milli- meters.	Num- ber of fish contain- ing beetle food.	Length in milli- meters of fish contain- ing beetle food.	Terres- trial beetles, adults.	Hydro- philid beetles, adults.	Hydro- philid beetles, larvæ.	Dytis- cid beetles, adults.	Hali- plid beetles, adults.
<i>Chaenobryttus gulosus</i> , warmouth bass.....	16	25, 115	1	45	-----	65	-----	-----	-----
			2	103	-----	50	-----	-----	-----
<i>Gambusia, affinis</i> , viviparous top minnow.....	31	13, 32	1	13	85	-----	-----	-----	-----
<i>Lepomis cyanellus</i> , green sunfish.....	86	26, 73	1	41	-----	-----	25	-----	-----
			2	50	-----	10	-----	-----	-----
			3	50	15	-----	-----	-----	-----
			4	50	-----	40	-----	-----	-----
			5	54	1	-----	-----	-----	-----
			6	60	-----	10	-----	-----	-----
			7	60	-----	-----	20	-----	-----
			8	60	2	-----	-----	-----	-----
			9	70	-----	-----	-----	45	-----
<i>Lepomis megalotis</i> , long-eared sunfish.....	17	50, 100	1	38	-----	30	-----	-----	30
			2	90	-----	-----	10	-----	-----
			3	90	-----	-----	15	-----	-----
			4	92	-----	-----	10	-----	-----
<i>Lepomis miniatus</i> , scarlet sunfish.....	14	70, 120	1	85	-----	-----	-----	10	-----
			2	94	-----	10	-----	-----	-----
			3	100	-----	10	-----	-----	-----
			4	100	-----	20	-----	-----	-----
			5	110	-----	25	-----	-----	-----
<i>Lepomis symmetricus</i> , symmetrical sunfish.....	1	60	1	60	-----	10	-----	-----	-----
<i>Pomoxis sparoides</i> , calico bass.....	32	45, 70	1	70	-----	-----	-----	-----	8

The data for this table of the food of Louisiana fish were taken from manuscript notes by H. E. Schradieck on file in the office at the U. S. Fisheries Biological Laboratory at Fairport, Iowa.

None of these fish that ate beetle food were under 40 mm. in length, with the exception of the single top minnow and one long-eared sunfish. The former is easily accounted for by the fact that it feeds at the surface, and the beetles it had eaten were land species that had fallen into the water and were floating on the surface. The sunfish were so near 40 mm. in length that it does not constitute a real exception.

The adult hydrophilid beetles furnished the most attractive food, probably because they were more numerous in the localities from which the fish were obtained. If we include the larvæ with the adults, the Hydrophilidæ served as food for 16 out of the 23 fish that ate beetles, or more than 75 per cent. In the next table, the data for which were taken also from manuscript notes by H. E. Schradieck on file in the office of the U. S. Fisheries Biological Laboratory at Fairport, Iowa, this order is reversed and the Dytiscidæ have twice the percentage of the Hydrophilidæ.

Food of fish in fishponds at Fairport, Iowa, by H. E. Schradieck.

[In the last five columns the figures are percentages, the entire food 100.]

Kind of fish.	Fish-pond from which taken.	Number of fish examined.	Ex-treme lengths of fish ex-aminated, millimeters.	Length of fish eating beetles, millimeters.	Uniden-tified beetles, debris.	Hydro-philid beetles, adults.	Hydro-philid beetles, larvæ.	Dytis-cid beetles, larvæ.	Hali-plid beetles, adults.
Eupomotis gibbosus, common sunfish.....	16B	173	10 45	14 20 26	10 8 22	.....	.....	.....	.....
Ictalurus punctatus, channel catfish.....	4E	10	85 108	98 108	.....	.....	3	.....	46
	1E	3	93 110	93 98	.....	5	.....	12	.....
Ictiobus bubalis, small-mouthed buffalofish	4D	40	13 25	.....	97	.....	3	.....	.....
	16B	38	11 24	.....	.....	.....	.....	.....	.....
	5D	3	90 135	135	.....	.....	50	.....	.....
	7D	8	57 80	76	.....	.....	.....	6	.....
Lepomis pallidus, bluegill.....	2D	103	20 74	41 44 44 45 45 48 52 54 55 56	.....	25 5 25 30 5 45	25 5 25 30 45	.....	.....
	8D	136	11 56	50	.....	20	15	10	15
Micropterus salmoides, large-mouthed black bass..	2D	22	43 80	45	.....	15	10	.....	.....
	3D	89	12 45	22 24 24 24 28 28 35 37 39 41 41 42 42 42 45	.....	10	8	20 25 5	12
					12	.....	.....	15 15 35 50 30 55 70 50 7 20	.....
					.....	.....	.....	.....	20

This table is of considerable interest for several reasons in spite of the fact that it contains but five different kinds of fish. In the first place, these fish are widely distributed and represent 10 different ponds, whose contents of animal and vegetable life are very diverse. In consequence the record has a broader significance than it would otherwise possess. Again, three of these fish—the common sunfish, the channel catfish, and the small-mouthed buffalofish—appear only in Forbes's record, where there were no data as to the size of the fish or the amount of food. A fourth, the large-mouthed black bass, appears only in Pearse's record. where the amount of beetles consumed was insignificant.

The present record supplies these missing details and, so far as the bass is concerned, entirely changes the diet statistics. Of the small-mouthed buffalofish the examination of two lots from separate ponds, totaling 78 fish, none of which ate any beetle food, have been included for the sake of the contrast in size. The

largest of these fry was only 25 mm. in length. Both of the ponds from which they were taken contained an abundance of beetle adults and larvæ of many species, and the fact that the buffalofish fry ate none of them shows that at this early stage they prefer other food. The two that did eat beetle larvæ were much larger fish, and in one of them hydrophilid larvæ constituted half the entire food, although there were 13 other food items.

Of the 89 bass examined from pond 3D, 16 were less than 20 mm. and 20 were between 20 and 25 mm. in length. The smallest bass that ate any beetle larvæ was 22 mm. long, and the largest percentage of beetle food was found in those from 35 to 45 mm. in length. A bass, then, begins to eat beetle larvæ as it approaches 25 mm. in length and increases the amount of this food up to at least 50 mm. in length. Above that we have no records, but probably beetles continue in the diet somewhat longer, for some of the larvæ are of good size. Eventually, of course, the bass becomes almost exclusively a fish-eater. The preference for dytiscid larvæ in these bass was very marked, although there were nearly as many species of hydrophilids in the pond, and at least four of them were abundant and one (*Tropisternus lateralis*) a prolific breeder.

In the case of the bluegills also fully one-third (37) of those from pond 2D were under 40 mm. in length and nearly two-thirds (90) of those from pond 8D. The bluegill does not eat beetle larvæ until it reaches a length of 40 mm., or twice the length of the bass; but, on the other hand, it never becomes a fish eater like the bass and probably continues to take at least some beetle food as long as it lives.

In support of this an interesting observation was made by Mr. Lay in the summer of 1916. Pond 1D contained that year 26 adult bluegills and 4,258 young fish 2 to 3 years old. Noting that this was the only pond upon which no gyrenids were to be seen, Mr. Lay, as an experiment, caught and liberated on the pond at different times during the summer numbers of *Dineutes americanus* adults. In every instance these were immediately eaten by the bluegills, who kept this pond clear of gyrenid adults all summer. That this was a matter of choice, or was due to the fact that the beetles attracted attention through their movements, seems evident, because the other kinds of food in the pond were very varied and abundant, insect larvæ, pupæ, and nymphs, Crustacea, mollusks, and a rich assortment of vegetation. Pond 2D, which is separated from 1D by a narrow bank of earth only 15 feet in width, contained that summer bluegill fry and yearlings, which were eating freely of beetle adults and larvæ, but they did not keep that pond free from gyrenids. Most fish do not eat gyrenid adults, perhaps on account of the peculiar fluid which they exude when captured, which has a disagreeable odor; but neither that nor anything else deterred these bluegills in pond 1D. It will be noted, furthermore, from the table that the bluegills are impartial in their choice of beetle food. Pond 2D contained about an equal number of dytiscids and hydrophilids, and their larvæ were about equally divided in the fish food.

The beetle food of the small sunfish from pond 16B was unidentified and might well have contained the remains of terrestrial species. The pond, however, contained six dytiscid and eight hydrophilid species, most of which were breeding freely.

GENERAL SUMMARY AND SUGGESTIONS.

1. The larvæ of three beetle genera—*Dytiscus*, *Cybister*, and *Hydrous*—are positively known to destroy small fish under normal conditions. Ordinarily they are kept in check by their enemies and do not become a serious menace to fish culture, but sometimes under specially favorable conditions they breed in sufficient numbers to kill the newly hatched fish fry about as fast as they appear. The adults of these genera have also been known to kill young fish under somewhat abnormal conditions, but even then they are much less destructive than the larvæ. Adult beetles belonging to each of these genera are present in most of the Fairport fishponds but have never been observed attacking fish fry, although they have had repeated opportunities.

The larva of another genus—the whirligig beetle *Dineutes*—has been known to kill fish fry under abnormal conditions. The larva of the scavenger beetle *Hydrophilus* has been suspected of being capable of committing similar depredations, but there is as yet no actual proof. All the evidence at hand seems to indicate that both these larvæ are usually perfectly harmless. There has never been even a suspicion against the adults of either genus. These are the only beetle genera capable of injuring fish fry; all the others are too small. Consequently, the problem is reduced practically to guarding against these genera; the others are negligible.

2. On the other hand, beetle larvæ and adults are eaten freely by the young of nearly all our food and game fishes after the latter have reached a length of 25 to 40 mm. As the fish increase in size they eat the larvæ of the five genera mentioned above, even after these larvæ have become full grown. Many fishes continue to eat beetle food as long as they live. All beetle larvæ that live in the water, therefore, and the adults of the numerous smaller species constitute a very important item of fish food.

3. It is only young fish of the year that are seriously menaced by these beetles. Fish a year old have acquired sufficient ability to escape the attacks of the beetles and in their turn have begun to eat freely of beetle larvæ and adults. Hence, beetles can do very little harm in a pond that is stocked with fish a year old or over; on the contrary they contribute materially to the available food supply. Such a pond, therefore, will not require watching as far as the beetles are concerned. If the fish are breeding and young fry appear, however, then the pond must be guarded to prevent the dangerous beetle species from becoming too numerous or too ravenous.

4. In case any of the beetles here mentioned should become obnoxious in a breeding pond there are two possible methods of dealing with them. Either they may be gotten rid of or the fish fry may be removed to another pond, and thus be freed from them. The former would seem to be the easier method, but there are strong objections to it and many obstacles that are hard to overcome. In the first place, it is very hard to weed out the larger dangerous species and leave the smaller harmless ones. Any means used to exterminate one species will operate also against all the others. There will thus be destroyed a considerable amount of excellent fish food which might otherwise have been utilized. There are only three beetle species, one for each of the three genera, *Dytiscus*, *Cybister*, and *Hydrous*, in the Fairport fishponds that are really dangerous, while there are 50

others that are eminently desirable. Even if it were possible to eliminate these three species they are themselves good food for older fish and are as freely eaten as any of the other species, so that it would seem to be poor economy to kill them off.

Again any attempt to eliminate the obnoxious beetles must employ mechanical means since chemicals are out of the question. This being true it will be found difficult to get rid of the beetles without sacrificing the other kinds of insect larvæ which can not consistently be spared since they furnish the very food upon which the young fish most depend.

Trap lanterns set at night around the shores of the fishpond will capture many of the adult beetles. The larger species are the ones most accustomed to flying at night and they are easily attracted by a bright light. If this mode of attack is started by the middle or last of May, before the beetles begin to breed, and is consistently followed, it will destroy large numbers of the very species that are most obnoxious. However, this is a preventive measure, to be applied beforehand, and not a cure after the infection has appeared. It is tedious, involves considerable expense, and has no effect upon the larvæ but only upon the adults. What the fish-culturist really wants is a remedy that may be applied with sufficient celerity to save the remainder of the hatch when once the beetles have begun their ravages, since ordinarily there is no necessity for preventive measures.

The use of a dip net in the shallow waters around the shores of the pond, pushing the net towards the shore and to the very water's edge, will capture many of the larger larvæ and adults. If persistently followed, it will materially reduce the numbers of the obnoxious species and might check their ravages sufficiently; but it is a slow and very laborious method at the best and does not appeal to the average fish-culturist as possessing the requisite celerity.

The only method of removing the beetles quickly and thoroughly is by draining the fishpond. If the fry can be kept an hour or two in a large tank after the pond has been nearly drained, the draining may then be fully completed. The large beetle larvæ and adults thus become conspicuous, traveling around in search of water, and practically every one of them may be captured. Witness the draining of one of the Fairport fishponds as related on page 250. The fish may then be returned with safety to the pond as it is refilled. This method has certain disadvantages noted below, and it will also be necessary after the larvæ have been destroyed to make sure that a second brood does not appear. There may be many pupæ in chambers around the edge of the pond which would emerge as adults if left alone. They may be destroyed by raising the pond level 8 to 12 inches, keeping it up for half a day and then lowering it again. If this were done once a week during the summer, it would mean that no beetle larvæ could develop into the adult stage, since they would all be drowned while in the pupal chamber (see p. 245). Such universal destruction is not at all desirable, but it indicates the effectiveness of the remedy. Any of these methods of getting rid of the beetles is only to be used in emergencies as a sort of last resort. The second method mentioned above, that of removing the fish fry to another pond, is much to be preferred and is worthy of separate discussion.

5. If a second pond is available, transferring the fry to it will effectively rid them of their enemies. The original pond can then be stocked with larger fish that will

use the beetles for food. Of course, in making such a transference care must be taken that the same species of beetles are not present in the second pond. This will almost never happen, however, even when the two ponds are close together and to all appearances the conditions are the same. During the summer of 1920 the only fishpond at Fairport in which any *Cybister* larvæ were found was pond 5D. Adults were found in several adjacent ponds but no larvæ. Similarly, Hydrous larvæ were confined to ponds 3E, 4E, and 14B, and nothing but straggling individuals appeared elsewhere. *Dytiscus* adults were fairly common in ponds 2, 3, 4, and 8, in series D, and in 16B, but not a single larva was captured during the entire summer in any pond. The larvæ of *Thermonectes ornatcollis* were confined to pond 12B, and none were found in any other pond, although the adults were common enough. In 1921 the large dytiscid larvæ described on page 284, which were probably those of *Acilius semisulcatus*, were found only in pond 7D; none could be found in ponds 5, 6, or 8, all of which are very close to pond 7. The buffalofish fry taken out of pond 3E (see p. 250) in July, 1918, were carried only a short distance to another pond in the same series, but there they were entirely free from attacks of beetle larvæ. Such a transference of the fish fry, therefore, is the simplest, the most reasonable, the quickest and the most effective method of freeing them from the attacks of beetles. It must be borne in mind, however, that in draining a pond either for the destruction of the obnoxious beetles or for the transference of the fish fry these latter are always subject to increased depredation by the beetles during the operation. The lowering of the water brings the larvæ and fish fry together in a steadily diminishing area. The beetles are almost certain to take advantage of this opportunity and kill many of the fry; but the danger is only temporary, and as it can not be avoided it must be accepted as one of the means necessary to the ultimate deliverance of the fish from their enemies. As in all warfare some sacrifice is necessary in order to secure final victory.

6. There is also another method that merits at least some attention, namely, the wintering out of a breeding pond. If a pond is drained in the fall and left dry through the winter, all the insect larvæ it contains, including any beetle larvæ that might possibly remain, will be destroyed. The adults will migrate elsewhere or will be killed, and in the spring the pond will be clean and free from all obnoxious pests. If a pond were persistently infested with any insect enemies of young fish, it might be advisable to winter it out. The chances of reinfection during the following year will thereby be greatly diminished, and in the majority of cases it will remain free from the pests for several years. Here again, however, it must be remembered that such a procedure gets rid of all the insect fauna, the beneficial as well as the harmful. Consequently, there will not be as much fish food the following year, and the fry will be compelled to depend upon whatever happens to get into the pond unless they are fed artificially. If the latter method be adopted, or if the pond be filled with water pumped from a river or lake, there will probably be plenty of food for the fry. In such cases the wintering out of a fishpond is one of the most effective methods that can be adopted for getting rid of obnoxious insects. On the contrary, if the pond be fed from springs, some provision must be made for a food supply the following year.

BEETLE DISTRIBUTION IN FAIRPORT FISHPONDS.

The first of the two following tables shows how the beetles were distributed in the various ponds at Fairport, Iowa; the second shows how they were distributed according to beetle families.

Beetle distribution in the Fairport (Iowa) fishponds.

[a, abundant; c, common; f, few in number; r, rare. *See text, p. 264.]

Beetle species.	Pond number and series.															
	12 B	13 B	14 B	15 B	16 B	1 D	2 D	3 D	4 D	5 D	6 D	7 D	8 D	9 D	1 E	2 E
Halipidæ:																
<i>Haliphus borealis*</i>						r	f	a	c	f	c	c	c	c	---	c
<i>Haliphus punctatus</i>						r	f	a	c	r	---	r	r	r	r	r
<i>Haliphus ruficollis</i>	r	r	r	r	r	f	c	a	c	r	---	r	r	r	r	r
<i>Haliphus triopsis*</i>															r	r
<i>Peltodytes edentulus</i>	r	f	c	f	c	c	c	c	c	c	---	c	c	---	c	c
Dytiscidæ:																
<i>Acilius semisulcatus</i>								a	---	r	---	a	a	---	c	c
<i>Agabus gagates</i>					r	r	r	a	r	f	---	r	f	---	r	---
<i>Bidessus flavicollis</i>						r	r	r	r	f	---	r	r	f	---	---
<i>Bidessus fuscatus*</i>															r	---
<i>Bidessus lacustris</i>			a	a	---		f	r	---						r	r
<i>Coelambus acaroides</i>	r	---					r	---		r	---				r	r
<i>Coptotomus interrogatus</i>			r	---	c	r	c	c	c	c	---	c	c	c	c	f
<i>Cybister fimbriolatus</i>		r	r	---		r	a	r	r	a	---	r	c	c	c	f
<i>Dytiscus hybridus</i>										f	---					f
<i>Dytiscus verticalis</i>			a	---	c	---	c	c	c	f	---	r	c	---	a	c
<i>Graphoderes fascicollis</i>										r	---				f	---
<i>Graphoderes liberus</i>										r	---					---
<i>Hydrocanthus tricolor</i>												r	r	---		---
<i>Hydroporus consimilis</i>	r	---			c	r	r	---		c	---				r	---
<i>Hydroporus niger*</i>						r	r	r	r	r	---	r	r	---		r
<i>Hydrovatus pustulatus</i>						r	r	f	r	f	---					---
Hybys biguttulus	a	c	a	f	a	a	a	a	a	a	---	a	a	c	a	a
<i>Laccophilus maculosus</i>		f	---		a	a	a	a	a	a	---	a	a	a	a	a
<i>Laccophilus proximus</i>							r	---			---				a	a
<i>Laccophilus undatus*</i>											---				a	c
<i>Thermonectes basilaris</i>	r	---								r	---	f	---		r	r
<i>Thermonectes ornatocollis*</i>	a	---								r	---				r	c
Gyrinidæ:																
<i>Dineutes americanus</i>	a	a	c	c	a	---	a	a	a	a	a	a	a	a	a	a
<i>Gyrinus analis</i>															a	c
<i>Gyrinus limbatus</i>							r	c	c	r	---	r	r	---	a	r
<i>Gyrinus minutus*</i>										c	---					r
<i>Gyrinus ventralis</i>		c	---				r	c	c	r	---	r	r	---	a	r
Hydrophilidæ:																
<i>Berosus pantherinus*</i>									r	r	---	f	---		r	r
<i>Berosus perigrinus</i>	r	---					r	---			---				r	---
<i>Berosus striatus</i>			r	r	a	r	a	a	a	a	---	a	a	a	a	a
<i>Creniphilus despectus*</i>										r	---				r	---
<i>Creniphilus digestus</i>							r	---	r	r	---					---
<i>Creniphilus subcupreus</i>							r	r	r	r	---	r	r	---		---
<i>Enochrus diffusus</i>	r	f	a	f	r	f	a	a	a	a	---	r	a	---	f	---
<i>Enochrus hamiltoni*</i>											---				r	r
<i>Enochrus nebulosus</i>	c	c	r	---			c	r	f	---	c	---			r	r
<i>Enochrus ochraceus</i>					a	---	f	a	a	a	---					---
<i>Enochrus perplexus</i>								r	r	r	---					---
<i>Helophorus lacustris</i>					r	---					---					---
<i>Helophorus lineatus*</i>							r	---			---					---
<i>Hydrochus squamifer</i>							r	---			---					---
<i>Hydrophilus obtusatus</i>	a	---							c	r	---	r	r	---	r	a
<i>Hydrous triangularis</i>	c	f	r	r	r	c	c	c	c	c	---	c	c	---	c	a
<i>Laccobius agilis*</i>										r	---				c	a
<i>Tropisternus glaber</i>	a	r	---	r	c	c	c	c	c	c	---	c	c	c	c	c
<i>Tropisternus lateralis</i>	a	a	r	a	a	a	a	a	a	a	---	a	a	c	a	a
<i>Tropisternus mixtus*</i>	c	---								f	---					---
Donaciidæ: <i>Donacia aequalis</i>						c	c	c	c	c	---	c	c	c	c	c

Distribution in the Fairport (Iowa) fishponds according to beetle families.

Pond number and series.	Hali-plidæ.	Dytis-cidæ.	Gyrini-dæ.	Hydro-philidæ.	Total.	Pond number and series.	Hali-plidæ.	Dytis-cidæ.	Gyrini-dæ.	Hydro-philidæ.	Total.
12B.....	2	6	1	8	17	7D.....	4	12	3	9	28
13B.....	2	2	2	5	11	8D.....	4	12	3	7	26
14B.....	2	5	1	5	13	9D.....	3	3	1	4	11
15B.....	2	2	1	5	10	1E.....	2	7	1	5	15
16B.....	2	5	1	8	16	2E.....	4	15	3	9	31
1D.....	3	7	0	5	15	3E.....	3	11	3	10	27
2D.....	3	13	3	13	32	4E.....	3	10	3	5	21
3D.....	3	10	3	9	25	1F.....	2	3	3	4	12
4D.....	3	9	4	12	28	2F.....	2	6	3	6	17
5D.....	4	18	3	14	39	3F.....	1	4	2	5	12
6D.....	1	0	1	4	6						

SOURCE OF MATERIAL.

In the summer of 1916 Geo. B. Lay collected and identified the various insect forms found in the Fairport fishponds, and in 1917 Dr. R. A. Muttkowski checked the species thus obtained and, with Mr. Lay, completed their identification. Both made out reports of their work, containing in addition to the check list some notes on the habits of certain of the insects in relation to fish breeding. The writer has used their check list in its entirety as the basis of the one here presented, chiefly because it was prepared during the same years that Mr. Schradieck was listing the food of the fish and Dr. Emmeline Moore was studying the plant fauna of the ponds. For this reason the beetle list, the plant list, and the fish-food list exactly supplement one another. The first shows the kinds of beetles found in the ponds from which the fish were taken, the second explains the relative abundance of the beetles in the different ponds on the basis of their plant environment, and the third indicates the choice the fish made of the beetles that were available.

Every species in this beetle list has been verified by the present author during the years 1918, 1919, and 1920, and to it have been added other species that either escaped capture in 1916 and 1917 or have appeared more recently in the pond fauna. These additions are indicated by a star (*) following the species name and include only two forms that are anything more than occasional interlopers, namely, *Haliphus borealis* and *Thermonectes ornaticollis*.

INFLUENCE OF ENVIRONMENT.

Dr. Muttkowski called attention in his report to the remarkable difference in both the quantity and the quality of the population of the various ponds. This is the more noteworthy because of the contiguity of the ponds. Those in the same series are separated from one another by narrow banks of earth, 12 to 15 feet in width, and pond 4E is separated from pond 5D by a similar narrow bank. Pond 6D is very small and is used as a natural aquarium in which to keep the large bass to prevent them from eating other fish. They are so hungry most of the time that they keep the pond cleared of all animal food throughout the summer. This accounts for the meagerness of its insect fauna, and it can not be fairly considered in comparison with the others. Ponds 1 and 2D are contiguous, are about the same size and depth, and are surrounded with the same vegetation. They were

FIG. 6.—Pond 1D covered with blanket algae and containing very few beetles in 1920 and 1921.

FIG. 7.—Pond 2D free from blanket algae and containing over 30 species of beetles in great abundance.

also treated alike the previous year; that is both were wintered full and not dry. Yet pond 2 contained more than twice as many beetle species as pond 1, and while in the former seven species were abundant and eight were common, in the latter only two were abundant and four common, and all six were small species and mostly vegetable eaters.

A partial explanation of such a radical difference may be found in the statement of Dr. Moore (1920, p. 11), which was as follows:

Physiologically, however, they are more or less distinct because of the dissimilar character of the vegetation in them. Pond 1D has been richly stocked with floating algae, which at times have covered the surface. Few of the larger-rooted aquatics are present. Pond 2D has no algal mats or blankets, but fully one-tenth of the surface area has been covered by the large-rooted aquatic *Potamogeton illinoensis*, interspersed in places with the nonrooted *Ceratophyllum*, or hornwort.

These two ponds furnish such striking differences in their beetle fauna that they have been photographed as illustrations of the presence and absence of floating algae and are shown in Figures 6 and 7 as they appeared in 1921. In pond 1D (fig. 6) the algal blanket described by Dr. Moore has persisted from year to year and has covered practically the entire surface. As a result the beetle fauna of 1916 has steadily declined in numbers and variety until in 1921 there were only straggling specimens left, outside of the halipids. The dytiscids were reduced to the minute species of *Bidessus* and *Hydroporus*, and the hydrophilids to those of *Berosus* and *Philydrus*. One of the species that was abundant in 1916 (*Laccophilus maculosus*) had entirely disappeared, and the other (*Tropisternus lateralis*) was reduced to a minimum and would have to be classed as rare.

In contrast with this the photograph of pond 2D (fig. 7) shows no algae but a limited area of *Potamogeton*. This also has persisted from year to year and has increased in extent until in 1921 it covered about a third of the entire surface. The beetle fauna has steadily increased in number and variety, particularly of the dytiscids and hydrophilids. The seven species that were abundant in 1916 have remained so, and five of the eight species that were then common have become abundant.

A similar result has been observed to follow the presence of duckweed on the surface of a pond. The little pond, 13B, only 25 feet square, was fairly swarming with hydrophilid beetles in 1919. The latter part of that summer, however, it developed a blanket of duckweed which remained through 1920 and 1921. In consequence every beetle species except the halipids disappeared. We may reasonably conclude, therefore, that the presence of a blanket of any sort that covers the entire surface of a pond is extremely unfavorable to beetle development. The diving beetles require open water in order to obtain their air supply, and even the scavenger beetles are seriously hindered by such a blanket in securing sufficient oxygen. The gyrenids are, of course, absolutely banished, since there is no water surface left upon which to perform their whirling movements. The little halipids are the only ones that can successfully compete with such restrictions.

Ponds 8 and 9, D, are also contiguous, are practically the same size and depth, and are surrounded with identical vegetation. Pond 8D, however, contained more than twice as many beetles as 9D, and whereas in the former six species were

abundant and seven common, in the latter only one was abundant and six common. Here, again, we must seek an explanation in the physiological differences of the two ponds, due to the dissimilar character of the vegetation. Pond 9D contained an abundance of the blue-green alga (*Aphanizomenon flos-aquæ*). Dr. Moore stated (1920, p. 12) that when first called to her attention "It was so abundant that the water appeared blue-green and oily." Multiplication continued to take place with great rapidity "until the maximum was reached in the interval of July 24 to 30, when the algæ could be rolled up from the bottom like mush." The beetles seem to have been as much prejudiced against mush under foot as they were against an algal blanket overhead.

In series E pond 2 was manured in 1918 and pond 3 in 1919. As a result they proved very attractive to the beetles, and pond 2 had the highest number of dytiscid species and the largest aggregate of hydrophilid individuals of all the ponds examined. It is significant that these two ponds in 1920 were covered with a heavy blanket of *Hydrodictyon*, which greatly reduced their beetle fauna both in numbers and variety. The dytiscids and gyrinids practically all removed to other ponds, leaving only the haliplids and a few hydrophilids. Furthermore, in 1920 and 1921 the blue-green algæ in pond 9D almost disappeared, and as a result the beetle fauna noticeably increased. The influence of the algæ, therefore, is only temporary, and once they are removed the beetle fauna quickly recovers.

RESTRICTION OF SPECIES.

Species are often restricted to one or two ponds and are not found in any of the others. In the table here presented 8 species are confined to a single pond and 10 others are found in only 2 or 3 ponds, usually contiguous in the same series. This is a third of the entire number, and there are also some of the others whose distribution is far more limited than the table would seem to indicate.

In contrast with these there are certain other species that may be classed as cosmopolitan, for the Haliplidæ (*Peltodytes edentulus*), for the Dytiscidæ (*Lacophilus maculosus*), for the Gyrinidæ (*Dineutes americanus*), and for the Hydrophilidæ (*Tropisternus lateralis* and *T. glaber*) are found in all the ponds except one or two. *Hydrous triangularis* is also reported from every pond except two, but it can not be included with these others because it is restricted in its breeding and the larvæ rarely appear in more than a single pond during any one season.

In 1920 *Thermonectes ornaticollis* was present and breeding in large numbers in pond 12B but was found only rarely in any of the other ponds. Two specimens of this species were all that were obtained in 1916—one in pond 8D and one in pond 1E. Similarly, *Thermonectes basilaris* was confined to pond 5D in 1919, to pond 8D in 1920, and to pond 7D in 1921. *Cybister fimbriolatus*, although the adults have been found in a dozen ponds, including some of every series, has never been known to breed anywhere except in 5D, with the exception of a single pupa found on the shore of 13B in the summer of 1921. In general, ponds 2, 3, 4, 5, and 7, D, and 2 and 3, E, are the richest both in variety of beetle species and in numbers of individuals, while the B series of ponds are the poorest.

RELATIVE IMPORTANCE OF SPECIES.

In these tables the Haliplidæ are represented by 5 species, the Dytiscidæ by 22, the Chrysomelidæ by 1, the Gyrinidæ by 5, and the Hydrophilidæ by 20, a total of 53 species. Many of these, however, as just stated, are so rare or occur in such small numbers that they do not enter at all into the ecology of the fishponds. Once listed as having been found and identified with reasonable certainty, they may be conveniently dropped from further consideration without affecting at all the ultimate results. Such a procedure reduces the number of species that really deserve consideration so much that they can be intelligently and profitably discussed within the limits of a single paper. On this basis there will be left 2 haliplids, 11 dytiscids, 2 gyrids, and 10 hydrophilids, a total of 25 species out of the 53 enumerated. With these, mention should be made of the chrysomelid (*Donacia aequalis*), both the adults and larvæ of which are common in nearly all the ponds. The adults are only semiaquatic and are found upon the leaves and stems of pond lilies, arrowhead, pickerel weed, reeds, and sedges, while the larvæ live upon the outside of the submerged roots of these plants. Both larvæ and adults are eaten freely by fish.

SYSTEMATIC DESCRIPTIONS OF FAIRPORT SPECIES.

The part that follows is as much for the ordinary fish-culturist as that which has preceded. Having convicted three of the prisoners brought before the bar, justice demands that their likenesses and individual descriptions, as well as their criminal records, be published, so that they may be recognized whenever they attempt any nefarious work. The fish breeder, if he desires success, ought to be able to tell these offenders at sight and so guard against their depredations. The easiest method of doing this is to become familiar with their pictures and habits. With this object in view, photographs of an adult *Cybister*, an adult *Dytiscus*, and an adult *Hydrous* are here presented (figs. 1, 2, and 3, frontispiece). These are the only genera whose adults kill fish fry, and the photographs will constitute a sort of rogue's gallery for the fish-culturist. There is no necessity of determining the particular species. Any beetle that lives beneath the water in a fishpond and comes to the surface to breathe is a water beetle, and if it resembles any of these figures in size and shape it may safely be condemned and destroyed.

A fully developed larva of any of these three genera can be told by its size, but younger stages are not as readily identified. The best means of recognition is the head, and for that reason there will be found on the following pages an enlarged figure of the head of each larva described. These give enough detail for identification, because the individual characters remain practically the same throughout the life of the larva. The half-grown or quarter-grown larva may be recognized in this way with nearly as much certainty as after it becomes fully matured.

It is not, of course, intended that the average fish breeder should become a systematic entomologist; that is not necessary. He may be fortunate enough never to have occasion to identify any of these beetles either as larvæ or as adults. Should such a necessity arise, however, the figures here given will afford a quick and ready means of recognition. Unfortunately, none of these larvæ or adults have a common name except the larvæ of *Cybister* and *Dytiscus*, which are called

"water tigers" indiscriminately; but it is not a difficult task to learn the three generic names, and there is no need of distinguishing species among the larvæ any more than among the adults. Use the photographs and figures of larval heads, therefore, for identification and the text for habits and food.

The descriptions of the larvæ and pupæ have been made as scientifically accurate as possible, in order that they may serve as a contribution to economic entomology. As was stated in the introduction, our knowledge of the life histories of the North American water beetles is still deplorably limited. It is hoped that the present paper will contribute a little to that desirable knowledge.

The keys that follow include the larvæ and pupæ of those genera found in the Fairport ponds. Richmond (1920, p. 83) gave more detailed keys of the larvæ and pupæ of the Hydrophilidæ and also one of the egg cases. His keys contained 22 genera of the single family included, and may be used to supplement those here given.

KEY FOR IDENTIFICATION OF LARVÆ.

1. Tarsi with two claws, mandibles suctorial.....2
1. Tarsi with only a single claw, mandibles manducatory.....3
 2. Abdomen with slender lateral filaments, which serve as tracheal gills, its apex armed with four prehensile hooks.....GYRINIDÆ.....4
 2. Abdomen with neither filaments (except *Coptotomus*) nor hooks; larvæ elongate, slender and agile.....DYTISCIDÆ.....5
3. Eyes in groups of five; larvæ vegetable eaters.....HALIPLIDÆ.....16
3. Eyes in groups of six; larvæ carnivorous.....HYDROPHILIDÆ.....17
 4. Lateral filaments of abdomen all plumose; mandibles with fine teeth on the inner margin.....GYRINUS.
 4. First two pairs of lateral filaments not plumose in mature larva; mandibles without teeth on the inner margin.....DINEUTES.
5. Abdomen with slender lateral filaments which serve as tracheal gills; cerci long, slender, and densely plumose.....COPTOTOMUS.
5. No lateral filaments on the abdomen; cerci shorter and less plumose.....6
 6. Mandibles attached diagonally to ventral surface of head and shutting up against the tip of the proboscis, visible both dorsally and ventrally.....7
 6. Mandibles attached beneath the frontal margin of the head, toothed on their inner margin, not visible dorsally.....8
 6. Mandibles attached to the anterior margin of the head and shutting past each other like a pair of shears, visible dorsally and ventrally.....9
7. Proboscis broad, with a notch on either lateral margin; labial palps two-jointed, seven times as long as the labium.....HYDOPORUS.
7. Proboscis narrow, club-shaped, not notched; labial palps three-jointed and not longer than the labium itself.....HYPHYDRUS.
8. Mandibles slender, narrowly sulcate at the tip, simple; third joint of antennæ more than twice as long as the fourth.....HYDROCANTHUS.
8. Mandibles stout, bifid at the tip; third joint of antennæ no longer than fourth.....CANTHYDRUS.
9. Maxillæ filiform, eight- to ten-jointed, not enlarged at the base.....10
9. Maxillæ only five or six jointed, distinctly enlarged at the base, with a well defined four-jointed palp.....11
 10. Larger, 50 to 75 mm. long; antennæ 7-jointed; frontal margin of head evenly rounded; cerci long and densely plumose.....DYTISCUS.
 10. Larger, 50 to 75 mm. long; antennæ 9-jointed; frontal margin of head very uneven; no cerci.....CYBISTER.
 10. Smaller, 20 to 25 mm. long; antennæ 7-jointed; cerci long with scattered hairs only.....HYDATICUS.

11. Prothorax two or three times as long as wide; cerci short and naked; labium with a large ligula; stipes of maxilla as long as the palp.....12
11. Prothorax a little longer than wide; cerci half the length of the abdomen and densely plumose; labium without a ligula.....LACCOPHILUS.
11. Prothorax considerably wider than long; cerci long and plumose; labium without a ligula; maxillary palp much longer than stipes.....13
12. Ligula tipped with two long, jointed spines.....THERMONECTES.
12. Ligula without terminal spines.....ACILIUS.
13. Larger, 15 to 20 mm.; cerci densely plumose.....14
13. Smaller, 8 to 12 mm.; cerci with scattered hairs only.....15
14. Maxillary stipes slender, with concave sides, armed on the inner margin with a long seta and a single spine.....COLYMBETES.
14. Maxillary stipes stout, with convex sides, armed on the inner margin with two or three spines and a row of setæ.....RHANTUS.
15. Maxillary stipes armed on the inner margin with two long curved claws and many small spines and setæ.....ILYBIUS.
15. Maxillary stipes armed on the inner margin with small spines and setæ only; no curved claws. AGABUS.
16. Body segments with filiform tracheal appendages as long as the body itself; tip of abdomen bluntly rounded.....PELTODYTES.
16. Body segments with short triangular appendages; tip of abdomen acuminate, ending in two filiform, jointed setæ.....HALIPLUS.
17. Epicranial suture wholly lacking; each mandible with a terminal seta, a simple lobe or lacinia mobilis, and an inner tooth.....HYDROCHOUS.
17. Epicranial suture present; mandibles without a terminal seta or a lacinia mobilis, but with one or more inner teeth.....18
18. Abdomen with seven pairs of long lateral filaments, which serve as tracheal gills; mandibles with two or three teeth.....19
18. Tracheal gills reduced to mere tubercles or wanting; mandibles with only one or two teeth....20
19. Second joint of antenna with finger appendage outside of the terminal joints; no stigmatic atrium at tip of abdomen.....BEROSUS.
19. No finger appendage on antenna; ninth and tenth abdominal segments forming a stigmatic atrium.....HYDROPHILUS.
20. Second joint of antenna with finger appendage outside of the terminal joint; mandibles not grooved internally; femora without a fringe of swimming hairs.....21
20. No finger appendage on the antenna; mandibles definitely grooved internally; femora with a fringe of long swimming hairs.....22
21. Labium without a ligula; tarsus as long as the tibia.....LACCOBIUS.
21. Labium with a ligula, which is longer than the basal joints of the palpi; tarsus much shorter than the tibia.....PHILYDRUS.
22. Mandibles each with a single inner tooth; ligula not as long as the basal joints of the palps. HYDROUS.
22. Mandibles each with two or more inner teeth; ligula distinctly longer than the basal joints of the palps.....TROPISTERNUS.

KEY FOR IDENTIFICATION OF PUPÆ.

1. Tibiæ of first two pairs of legs folded tightly against the femora and the two inclined forward at an angle of 45° with the body axis; knees projecting strongly and armed with spines; antennæ folded across the eyes; no posterior cerci.....HALIPLIDÆ.....2
1. Femora at right angles to the body axis, tibiæ not folded against them; knees neither projecting nor armed with spines; antennæ not crossing the eyes; a pair of stout posterior cerci, jointed or bifid; styli long and jointed, with an enlarged basal portion.....HYDROPHILIDÆ.....3
1. Femora at right angles to body axis, tibiæ not folded against them; first pair of knees projecting but not armed with spines; each compound eye divided into a dorsal and ventral half, separated somewhat; no posterior cerci; styli in the form of short bristles, not jointed.....GYRINIDÆ.....8

1. Femora at right angles to body axis, first pair of tibiae folded against them, but not the other two pairs; knees neither projecting nor armed; posterior cerci in the form of stout spines, not jointed nor bifid; styli in the form of short spines, also not jointed.....DYTISCIDÆ.....9
2. Styli in the form of long, curved, linear spines, not jointed; wings folded tightly against the body and smooth.....PELTODYTES.
2. Styli in the form of short triangular spines; wings loosely held against the body and very rough.....HALIPLUS.
3. Styli on dorsal surface of abdomen in transverse rows of four on each segment; spiracles partly concealed by lateral tubercles.....4
3. Styli on dorsal surface of abdomen in transverse rows of six on each segment; spiracles not concealed, no tubercles.....7
4. Two supraorbital styli over each eye; basal portion of pronotal styli not annulate; no metasternal spine; cerci long, slender, moniliform.....5
4. One supraorbital stylus over each eye or none; metasternal spine prominent; basal portion of pronotal styli multiannulate; cerci short, stout, and bluntly bifid at the tip.....6
5. 24 pronotal styli; no inner spur on mesotibia; tarsi all tipped with stout spines; eighth abdominal segment with a pair of dorsal appendages resembling cerci.....LACCOBIUS.
5. 26 pronotal styli; inner spur on mesotibia prominent; no spines at tips of tarsi; no appendages on eighth abdominal segment.....BEROSUS.
6. Larger, 25 to 30 mm. long; one supraorbital stylus; posterior cerci superficially annulate and bifid.....HYDROUS.
6. Smaller, 12 mm. long or less; no supraorbital stylus; cerci not annulate, but bifid and acute.
TROPISTERNUS.
7. Larger, 13 mm. long or more; 32 pronotal styli; eighth abdominal segment with two small dorsal tubercles, each tipped with a stylus; cerci bifid and acuminate.....HYDROPHILUS.
7. Smaller, 8 mm. long or less; 24 pronotal styli; no dorsal tubercles on the eighth abdominal segment, but with a pair of styli; cerci not bifid but long and linear.....PHILYDRUS.
8. Larger, 10 mm. long or more; bristles arranged as in Figures 92 and 93 (p. 307); labrum prominent and well defined.....DINEUTES.
8. Smaller, 6 mm. long or less; bristles not definitely arranged; labrum less prominent.
GYRINUS.
9. Posterior margins of first six or seven abdominal segments raised into prominent transverse ridges dorsally; cerci short, stout, and straight.....10
9. Dorsal surface of abdomen smooth, without transverse ridges; cerci long, narrow, and crooked, or club-shaped.....13
10. Eighth abdominal segment much narrower than the seventh; metatibial spur large and prominent.....11
10. Eighth abdominal segment nearly as wide as the seventh; metatibial spur scarcely visible.....12
11. Larger, 30 mm. long or more; styli in the form of stiff bristles; cerci simple and acute.
CYBISTER.
11. Smaller, 15 mm. long or less; styli with a stout basal portion and a slender terminal seta; cerci bifid and blunt.....THERMONECTES.
12. Larger, 10 mm. long or more; styli with a short enlarged basal portion; anterior margin of pronotum three-quarters as wide as the posterior.....ILYBIUS.
12. Smaller, 6 mm. long or less; styli with a short enlarged basal portion; anterior margin of pronotum only one-third as wide as the posterior.....AGABUS.
12. Smaller, 4 to 5 mm. long; styli in the form of stiff bristles, without enlarged basal portion; anterior margin of pronotum three-quarters as wide as posterior.....LACCOBIUS.
13. Anterior margin of pronotum much narrower than posterior; styli in the form of slender bristles, without enlarged basal portion.....14
13. Anterior margin of pronotum nearly as wide as posterior; styli with a short enlarged basal portion and a long terminal seta.....15
14. Larger, 35 to 40 mm. long; pronotum with two raised processes on the anterior margin; cerci club-shaped and densely plumose.....DYTISCUS.

14. Smaller, 17 mm. long or less; anterior margin of pronotum smooth; cerci crooked, tapering, sparsely setose.....COLYMBETES.
15. Body densely covered with setæ; cerci also setose; metatibial spine short and hardly discernible. HYDOPORUS.
15. Body with few setæ; cerci naked; metatibial spine long and very prominent; five supraorbital styli above each eye.....COPTOTOMUS.

Genus PELTODYTES Régimbart.

Peltodytes (Régimbart, 1878, p. 450).

Cnemidotus (Erichson, 1832, p. 48).

A genus of small beetles, both the larvæ and adults of which feed exclusively upon algæ. They are yellowish or reddish with black spots on the elytra, which vary in number, size, and arrangement in the different species. They may be distinguished from the other haliplids by the terminal joint of the labial palps, which is longer than any of the preceding joints, and by the coxæ of the hind legs, which cover all but the last segment of the abdomen. The genus is represented in the Fairport fishponds by a single species.

***Peltodytes edentulus* (Leconte).** Figures 8 and 9.

Cnemidotus edentulus (Leconte, 1863, p. 21).

Peltodytes edentulus (Matheson, 1912, pp. 174 and 186; fig. B, text; pl. 10, figs. 2, 5, 6, 9; pl. 13, figs. 20, 21, 23, 25-27, 29-31; pl. 14, figs. 33-35).

Peltodytes edentulus (Roberts, 1913, p. 122).

The eggs.—The eggs are fastened individually to filaments of *Nitella* or *Chara*. The average time required for hatching is about two weeks.

Habits of the larva.—The natural history of the Haliplidæ has been admirably worked out by Robert Matheson and was published in 1912. The complete life history of the above species was also secured by the writer, and it confirms the statements published by Matheson, except in regard to the duration of the prepupal and pupal periods. This larva can only crawl about slowly over the algæ, trailing its long spines. It can not run or swim at all, but it is a most persistent crawler and, when hunting for a place to pupate, travels a longer distance from the water's edge than any other larva studied, except that of the gyrrinid (*Dineutes americanus*).

It is the only larva that constantly refused to pupate in an artificial mud cell. It always persisted in crawling out and making its own pupal chamber somewhere else. In spite of its porcupine coat of bristles it can burrow readily into mud considerably hardened. It feeds entirely upon filamentous algæ, such as *Spirogyra* and *Mougeotia*, and the structure of its mouth parts and legs is peculiarly adapted to this sort of food. It breathes through tracheoles in the long jointed spines, and thus has no need to come to the surface for air. It has no visible spiracles.

Description of the larva.—General form an elongated cone 6 mm. in length, the thorax and the first four abdomen segments about the same diameter, the last five abdomen segments tapered to a blunt point. The head is considerably narrower than the thorax, somewhat depressed, turned downward almost at right angles to the thorax, and tapered anteriorly. The prothorax is armed with six dorsal jointed spines, nearly as long as the body. Four of these are close to the anterior margin, two lateral and two dorsal, and have enlarged bases; the other two are dorsal and farther back. The meso and meta thorax and the first seven abdomen segments each have a transverse row of four spines, two lateral and two dorsal. The last two abdomen segments have only two dorsal spines apiece, each 4.5 mm. in length, and no lateral ones.

The number of joints in these spines varies from 11 in the posterior dorsal pair of the prothorax to about 18 in the meso and meta thorax. The basal joint is rather long, the next two or three are very short, and the remainder are of varying lengths. These 46 spines give the larva very much the appearance of a porcupine with abnormally developed quills (fig. 8).

The antennæ are four-jointed with a terminal spine, the last segment consisting of two fused pieces placed side by side. The mandibles are short and wide with rounded ends; the sharp tip is on the inner

FIG. 8.—Larva of *Peltodytes edentulus*, side view, showing the linear, tracheated, and jointed spines on each segment of the thorax and abdomen. FIG. 9.—Ventral view of the pupa of *Peltodytes edentulus*. FIG. 10.—Antenna of larva of *Coptotomus interrogatus*. FIG. 11.—Mandible. FIG. 12.—Maxilla, ventral view. FIG. 13.—Labium, ventral view. FIG. 14.—Antenna of adult beetle. FIG. 15.—Labial palp of adult beetle, side view.

margin and not at the apparent end of the appendage; it is also hollow and communicates with a tube that opens into the mouth. Each maxilla is made up of a smaller basal segment and a larger second segment, which has a two-jointed palpus on its tip and a chitinous projection covered with setæ at its inner distal corner. The labial palps are one-jointed.

In the first legs the penultimate segment is prolonged at the inner distal corner, and the projection is toothed along the margin that faces the last joint, against which it shuts, forming a sort of chela. There is but a single terminal claw, with a short basal spine.

Pupation.—From 20 to 25 days after hatching the larva is ready to pupate. It crawls a long distance from the water's edge and forms its pupal chamber in rather dry mud. Into this it pushes for half an inch or more and there hollows out a spherical chamber about 5 mm. in diameter. It remains inside of this chamber from four to six days before transforming. The jointed spines are all discarded with the larval skin; of course many of them get broken during the formation of the pupal chamber, especially the long, narrow ends where the tracheoles are located. It would seem, therefore, as if the spiracles must begin to function before the transformation takes place. They become visible during this prepupal period, and with the disappearance of the tracheolar spines they assume their proper functions.

Description of the pupa.—General form an elongated oval, 3.5 mm. long and 1.75 mm. wide. It is white or sometimes cream-colored, with a decided yellowish tinge, the eyes black or dark brown. The most striking feature is the position of the two front pairs of legs. In these the tibiae and tarsi are in a straight line and are folded tightly against the femur. The three are then turned forward until they stand at an angle of 45° with the body axis, the knees projecting a considerable distance on either side of the head. The anterior margins of the front legs touch the eyes, and the antennæ are carried diagonally across the anterior half of the eyes. Each knee of these two anterior pairs is armed with a stout spine; the head has two short spines between the eyes and one posterior to each eye; the pronotum has 10 long, curved, simple styli on its dorsal surface, and a short jointed one on either side of the posterior margin close to the mid line. The meso and meta thorax have four short dorsal spines, two on each segment. Each of the first six abdomen segments has on its dorsal surface four long styli, two lateral and two dorsal, and between the latter a short spine on either side of the mid line. The seventh segment has four shorter styli and the last segment has six.

The pupa lies on its back more than any of the other pupæ studied, but also rests upon its ventral surface, with the body arched strongly upward, like the other pupæ. When in this position, it is supported on the spines at the knees of the first two pairs of legs and the styli on the last abdomen segment. Of 16 pupæ reared to the adult stage, 12 remained in the pupa stage 12 days and four transformed at the end of the tenth day (fig. 9, p. 272).

Habits of the adult.—The adults swim slowly and with considerable effort, moving the legs alternately as in walking. The tibiae of the first and second pairs of legs and the tarsi of all three pairs have long fringes of swimming hairs. In marked contrast to their labored swimming they walk and run on land with great agility, but can not, or at least do not, jump at all. They fly readily from pond to pond, but apparently can not cover very long distances. They live among the plants in shallow water and are not found in the open parts of the ponds. As far as observed they feed entirely upon Chara and Nitella.

Description of the adult.—General form elongate-ovate, quite strongly convex; color pale straw-yellow with black markings; length 3.5 to 4 mm. Head with a large crescentic black spot between the eyes, punctate except in front of the black spot; eyes nearly circular in outline. Pronotum with a pair of basal black spots, rather sparsely punctate. Legs pale yellow except the femora of the third pair, which are dark brown ringed with yellow at their distal ends. Posterior coxæ reaching the last segment of the abdomen, punctate. Elytra each with 10 rows of punctures and a partial row between the third and fourth rows, and with seven or eight black spots more or less confluent.

Genus HALIPLUS Latreille.

Haliphus (Latreille, 1802, p. 77).

Another genus of small beetles, which, both in the larval and adult stages, feed exclusively upon algæ. They, too, like the members of the preceding genus, are yellowish or reddish in color with black spots on the elytra. They may be

distinguished from other haliplids by the fact that the terminal joint of the labial palps is much shorter than the preceding joint, while the coxæ of the hind legs cover only the first three segments of the abdomen and the fourth tarsal segment is much shorter than the first.

***Haliplus ruficollis* (DeGeer).**

Dytiscus ruficollis (DeGeer, 1774, p. 204; pl. 16, fig. 9).

Haliplus immaculicollis (Harris, 1828, p. 164).

Haliplus ruficollis (Schjødte, 1864, p. 161; pl. 8, figs. 1-12).

Haliplus ruficollis (Matheson, 1912, p. 169 and 186; fig. C, text; pl. 13, figs. 22 and 24; pl. 14, figs. 32 and 36).

The eggs.—The female cuts a hole with her mandibles in the side of a filament of *Nitella* and deposits several eggs within the algal cell, which hatch within 10 or 12 days.

Habits of the larva.—This larva also crawls about slowly over the algæ and can not run or swim. It feeds exclusively upon algæ, and for this purpose seizes the algal filament in its modified fore legs and passes it backward until it finds a broken end. It then punctures the wall of the filament with its mandibles and sucks out the fluid contents through the mandibular tubes. This larva has no tracheolated spines for breathing, but spiracles are present on the last two thoracic and the first seven abdominal segments. Aeration is apparently accomplished in some way through these.

Description of the larva.—Body very long and slender, made up of a head, three thoracic segments, and 10 abdominal segments. Head short, depressed, narrower than the thorax. The three thoracic and the first six abdominal segments about the same width, the seventh and eighth segments slightly narrowed, the ninth half the width of the eighth, and the tenth less than half the width of the ninth. This last segment is much prolonged and ends in two long spines, which are not jointed; the spines end in long setæ. The first seven abdominal segments are each armed with two dorsal plates, the eighth and ninth with a single plate, all closely set with short spines.

The antennæ are four-jointed, the last joint made up of two longitudinal parts side by side, the outer one terminated by a short spine. The mandibles are short and highly chitinated; each ends in a curved hollow point or tip, which opens on its inner margin into a tube that runs to the base of the mandible and there opens into the mouth. The maxillæ approach those of the adult much more closely than in any other beetle here described. The cardo is distinct and pyriform, the stipes very broad with a row of setæ along the outer margin and two large spines at the inner distal corner. At the outer distal corner is borne the palpifer and the three-jointed palp, the two basal joints of which are equal and half the length of the terminal one, each with a seta on the outer margin. Along the terminal margin is borne the galea, which is broad, bluntly rounded and well armed with setæ and spines. The labium is narrow and elongate and is tipped with a row of long spines; the palps are two-jointed, the terminal joint considerably longer than the basal, and both joints unarmed.

The front legs are transformed from locomotor into grasping organs for the purpose of seizing and handling the algal filaments upon which the larva feeds. In these legs the penultimate segment has a process on the inner distal corner which extends outward beside the last segment and reaches the tip of the latter. This process carries a spine on either side and two spines at the tip, between which the terminal claw of the last joint shuts down. The process and the last joint together form a sort of chela, guarded by the spines and the terminal claw, and form an admirable organ for handling filamentous algæ.

Pupation.—Matheson (1912) found the eggs of this species and reared the larvæ up to the point where they began to enter the soil for pupation, but unfortunately was compelled to give up the work before any larva actually transformed. Schjødte (1864) described in detail the larva of this beetle but said nothing about the pupa, and it remains still unknown. We may safely say, however, that pupation takes place within an earthen chamber formed by the larva in much the same way as that of the *Peltodytes* larva.

Description of the pupa.—The pupa of this species is unknown, but Schjødte obtained the pupa of *Haliplus variegatus*, and from it we may obtain a good idea of the pupæ of the genus. It showed the same turning forward of the two front pairs of legs, with the knees projecting on either side of the head, but they are not armed with spines in Schjødte's figure. In place of the long curved styli on the pronotum of *Peltodytes* we find two short triangular spines at each anterior corner and two others on either side of the mid line, with a row of four along the posterior margin. The mesonotum and metanotum each

FIG. 16.—Larva of *Coptotomus interrogatus*, dorsal view. FIG. 17.—Head of same enlarged, showing color pattern. FIG. 18.—Anterior margin of head. FIG. 19.—Portion of same, highly magnified. FIG. 20.—Larva of *Laccophilus maculosus*, dorsal. FIG. 21.—Larva of *Acilius semisulcatus*, dorsal.

carry six similar spines; the first seven abdominal segments each have four spines; the last segment is unarmed. In addition to these dorsal spines the lateral margins of the first seven abdominal segments are prolonged into spines, which extend outward on the anterior segments and gradually turn backward on the posterior segments. The knoblike prolongations of the posterior coxæ and the corresponding indentations of the elytra and wings appear plainly.

The adult beetle.—General outline oval, the wider end anterior; body strongly convex. Total length, 2.5 to 3 mm.; greatest width, 1.5 mm. The head and thorax pale yellow, with a small depression on either side of the thorax near the base. Elytra also yellow, each with five black spots, all rounded, the two median ones more or less fused. The eyes are smaller and not as convex as in other species.

These beetles swim very poorly, although their hind legs are armed with fringes of long swimming setæ; but on the land they walk very well and can run with considerable agility, lifting their body high above the ground on their long hind legs. Like other haliplids they secure their supply of fresh air by means of the posterior coxal plates and lateral grooves in the pleura. They feed exclusively upon filamentous algæ.

This species has been found in every one of the fishponds except 6D and 3F, but was abundant only in the single pond 3D. Both the larvæ and the adults furnish excellent fish food and are themselves too small to menace young fish.

Genus COPTOTOMUS Say.

Coptotomus (Say, 1834, p. 443).

A genus of medium-sized oval dytiscids having the terminal joint of both labial and maxillary palps somewhat compressed laterally and notched at the tip. The prosternum has an elevated carina and its process is much swollen along the middle. The claws of the tarsi are equal or nearly so, are pressed closely together and appear like a single claw. There is but a single species found in the Fairport ponds, whose life history follows.

Coptotomus interrogatus (Fabricius). Figures 10-19, 22.

Dytiscus interrogatus (Fabricius, 1801, p. 267).

Coptotomus interrogatus (Say, 1834, p. 443).

Eggs.—Deposited singly in the stems of various water plants with no preference for any one kind. The eggs hatch in six to eight days.

Habits of the larva.—This larva swims well, using mainly the fringe of hairs on the lateral margins of the ninth segment and the much denser fringe on the sides of the cerci, propelling itself by a vertical undulatory movement. The legs assist materially, their length compensating for the scanty fringe of swimming hairs they possess. While swimming, the lateral gills are trailed inertly along the sides of the body.

Breathing through these gills the larva does not need to come to the surface for an air supply and remains continually beneath the water, crawling about over the vegetation. It eats in true dytiscid style, sucking the juices of its victims through its mandibles. It seems to prefer small damselfly and mayfly nymphs, with an occasional chironomid or beetle larva. In an aquarium it feeds greedily upon *Laccophilus* larvæ and also eats others of its own kind smaller than itself. It is thus cannibalistic, although the notes of Needham and Williamson (1907, p. 486) do not apply, because the larvæ they obtained were not those of this species, notwithstanding that the figure they gave has been published as authentic several times.

Description of the larva.—General form spindle-shaped, narrowed anteriorly and posteriorly. Total length, 12 to 14 mm.; cerci, 2 mm. additional. Greatest width, at the first abdomen segment, 2 to 2.5 mm.

Head contracted posteriorly to half its anterior width; prothorax one-fourth longer than wide, contracted anteriorly into a long neck, a little wider than the posterior portion of the head. First six abdominal segments diminishing regularly in width backwards, each with a pair of long and slender tracheal gills. Seventh segment reduced abruptly to three-fifths the width of the sixth segment; eighth segment elongate, narrow, tapering to a rounded point, with lateral fringes of long hairs; cerci filiform, as long as the eighth segment and densely fringed with long hairs. General color light brownish yellow, a little darker on the dorsal surface; eyes black.

Head one-half longer than wide, strongly flattened, widest through the bases of the antennæ, which are attached near the anterior corners behind the bases of the mandibles. Sides of the head behind the eyes contracted in a uniform curve to a short neck at the posterior margin. Behind each group of eyes on the lateral margin is a tuft of silky hairs, and the curve from there to the neck is thickly set with short spines, nine or ten in number. At the center of the anterior margin on the dorsal surface is a short rounded rostrum, about one-quarter as wide as the head itself. The frontal border of this rostrum has a fringe made up of two rows of rigid flattened processes similar to those on the larva of *Laccophilus maculosus*. In the present larva, however, the difference in the lengths of the processes of the two rows is much greater, and in the ventral row of longer processes there are two lengths alternating with each other. The rostrum is strongly arched dorsally and is flanked on either side by a small projection tipped with three similar processes.

The antennæ are attached to the lateral margins behind the bases of the mandibles, are filiform and four-jointed, the terminal joint minute. The mandibles are slender, bluntly pointed, and grooved on the inner margin nearly to the base, which has a small tooth at its center on the dorsal surface. The maxillæ have a short and narrow cylindrical cardo and a much wider stipes, whose tip is covered with short spines and whose inner margin is set with a dense fringe of short hairs, in the midst of which are two long curved spines or claws. The galea is a short fingerlike process tipped with a single seta; the palpifer is short, but the palp is long, filiform and three-jointed, the joints about the same length. The labium is short and twice as wide as long, its terminal margin armed with short, blunt, cylindrical processes. The labial palps are long and slender and two-jointed, the basal joint considerably longer and stouter than the terminal, though both are almost filiform. The ligula is wanting.

The legs are long and slender, with a fringe of short hairs. Each tracheal gill of the abdomen contains a minute central tracheole, which is given off from the lateral trachea and is unbranched. From its dorsal wall a short tube leads to the spiracle in the same segment, which is inoperative during the larval stage. In the first segment the distance from the lateral trachea to the base of the spiracle tube is considerable, but this distance diminishes in each successive segment and becomes very short in the sixth segment. The spiracles on the seventh segment are ventral to the tracheæ and are not visible in dorsal view.

The general color of the fully matured larva is yellow with a light tinge of brown. On the dorsal surface of the head are two dark-brown spots, shaped together like the letter H, one on either side just in front of the eyes. Behind each group of eyes is an irregular spot extending backward and inward toward the mid line. The mandibles are brown, darker toward the tip; the center of the first joint of the antennæ is slightly darker in color, while the center of the second joint is almost black; the ends of both joints are white. There is a dark-brown spot on either side of the neck at the base of the head, a ring of brown around each joint of the legs, and a narrow band at the base of the cerci, with a wider one at their tips. On the dorsal surface of each segment of the thorax and abdomen is a pair of sclerites faintly marked in brown; on the eighth and ninth segments these are fused and extend around the segment as in the *Laccophilus* larva.

Pupation.—When fully grown, the larva crawls out on the land and burrows into the earth from three-quarters of an inch to an inch and a half below the surface. Here it hollows out a pupal chamber 10 to 12 mm. in diameter, and after resting from 24 to 48 hours it pupates. As soon as it comes out of the water its spiracles begin to function and its lateral gills dry up and shrivel. Usually by the time pupation begins most of them are broken off, and the larval skins found inside of the pupal chambers seldom have more than one or two of them left still attached.

Description of the pupa.—General form ovate, not much widened anteriorly, rather bluntly rounded posteriorly. Total length, 6.75 mm.; cerci, 2 mm. additional. Greatest width, at the second abdominal segment, 3 mm. Color brownish-white except the eyes, which are black.

The head is sunken deeply in the prothorax and has a row of five small styli in front of, and another row of six behind each eye on the top of the head. The anterior and lateral margins of the pronotum are densely fringed with similar styli, and there are about eight along the posterior margin at each corner. The mesothorax and metathorax each have a group of five styli on either side of the mid line, and another group of three at the base of each elytron and wing. Each of the first seven abdominal segments has a group of from three to five styli on either side of the mid line and another group of two or three behind each spiracle. The eighth segment has two on either side of the mid line and one on each lateral margin.

At the posterior end of the abdomen are the pupal cerci, which are very slender, 2 mm. in length and only one-seventh as wide at the base.

The antennæ extend obliquely outward and backward beneath the first and second legs; the maxillæ extend to about the center of the second legs; the labial palpi are longer, reaching the posterior margin of the second legs.

The femora of the first two pairs of legs are at right angles to the body axis, and the tibiæ and tarsi extend obliquely inward and backward to meet on the mid line. The third legs are similarly arranged, except that the femora are pulled so far forward as to become diagonal to the body axis.

There are large branches on the third legs for the spines at the distal ends of the tibiæ.

The pupa is not very active in the pupal chamber and spends much of the time lying on its side. However, the normal position seems to be with the dorsal side uppermost and the body strongly arched. Of 10 pupæ reared to the adult stage 7 emerged 4 days after pupation, 2 five days after, and 1 six days after.

Habits of the adult.—The adult beetle swims rapidly and with considerable agility, the tarsi of the hind legs being especially well armed with swimming setæ. When captured in the net, it proves to be a good jumper, but can not equal *Laccophilus* and *Thermonectes*. On the land it can not lift its body clear of the ground, and hence flounders around rather helplessly. The only food that any of the adults were seen to eat was the nymphs of damselflies, but it is almost certain that their diet is not confined to these.

Description of the adult.—General shape an elongated oval, broadest anteriorly, the dorsal surface subconvex; total length 7 mm., width 4 mm.

The head, thorax, and entire under surface of the body are reddish-brown, the reddish tinge rather brighter in the male. The vertex of the head is black, and the prothorax has a narrow black line across the base and apex. The apical line stops on either side at about the center of the eye and does not reach the lateral margin. The basal line is only half the width of the thorax and is slightly enlarged at either end. The elytra are dark brown with numerous very small pale yellow markings. The basal portion of the elytra in the female is not as shiny as in the male and is sculptured with short and indistinct striae.

The antennæ are 11-jointed, joints about equal; the mandibles have a rounded tooth on the dorsal surface of the inner margin near the tip and a fringe of short bristles behind the tooth. In the maxillæ the palps are four-jointed and subclavate, the terminal joint distinctly notched at the tip. The labial palps are also notched at the tip, but the notch can be seen only in side view. The prosternum is keeled along the mid line and the process it gives off is swollen through the center.

In the male the first three joints of the tarsus in the two anterior pairs of legs are slightly dilated and furnished with a dense fringe of stiff hairs along the lateral margins, each hair tipped with a minute disk. The ventral surfaces of these joints are covered with scattered disks, somewhat larger, each at the tip of a long stalk whose diameter equals that of the disk. On the sides of the stalks and around the margins of the disks are a few minute hairs. The tarsal claws are equal and so tightly appressed laterally that they often appear as one; those on the front feet are long and emarginate at the base. The hind legs are well developed, the femora with small laminae at the apex and the tarsi lobed externally.

Genus CYBISTER Curtis.

Cybister (Curtis, 1827, p. 151).

This is a genus of large beetles considered the highest and most completely developed of the dytiscids. Both the adults and the larvæ are voracious and will destroy young fish whenever opportunity offers. They have broad and powerful hind legs and are strong swimmers; the hind claws are very unequal, the inner one being obsolete or wholly wanting. In the males the front tarsi are strongly dilated and bear four rows of disks.

Cybister fimbriolatus Say. Figures 23–33, 51.

Cybister fimbriolatus (Say, 1825, p. 91).

Cybister fimbriolatus (Sharp, 1882, p. 715).

Cybister fimbriolatus (Dugès, 1885, p. 26; pl. 2).

Eggs.—Deposited singly in slits made in the stems of rushes, cat-tails, arrowhead, etc. The eggs hatch in six to eight days.

Habits of the larva.—These larvæ are excellent swimmers; the legs are not very heavily fringed with swimming hairs, but their length compensates for this. There is also an excellent swimming fringe along the lateral margins of the last two abdominal segments. Ordinarily they use their legs in moving through the water, but when alarmed or wishing to move more rapidly they wriggle the whole body. By lashing the abdomen up and down they can dart with considerable rapidity.

When coming to the surface to breathe, their body is inclined with the head upward, but on reaching the surface they assume a horizontal position instead of completely reversing the body like the hydrophilids. Sometimes they assume this horizontal position quite a distance below the surface and then float slowly upward. At the surface the base of the head and the prothorax as well as the last abdominal segment rest in the surface film, while the center of the body is arched downward. When out of the water, the larva crawls along slowly, dragging its abdomen, but it can jump vigorously by lashing with the last two abdominal segments.

The larva eats tadpoles of the leopard frog, nymphs of mayflies and dragonflies, and the larvæ of other water beetles, even those of *Dytiscus* and *Hydrous*. This is one of the three genera whose larvæ eat fish, and when full-grown the larva is so large and powerful that it has no difficulty in killing fish of considerable size. They are also cannibals, and whenever two come together they fight until one or the other gains the victory. The winner then sucks the juices from the body of his unfortunate competitor, leaving nothing but the tough skin. Such skins are often found in the ponds during the summer and may be recognized by the rents made at intervals where the sharp mandibles of the victor pierced them.

If several larvæ are put in the same jar on a collecting trip, the chances are that only one will be alive on reaching the laboratory, and this is just as true when the jar contains numerous smaller and weaker larvæ of other kinds as when it contains only the dytiscids. This chronic cannibalism is the salvation of the other denizens of the pond, since it furnishes a very efficient means of reducing the number of *Cybis*-ter larvæ.

Description of the larva.—General form elongate and spindle-shaped (fig. 51, opp. p. 291), tapering both anteriorly and posteriorly. A full-grown larva is 75 mm. long and 7.5 mm. wide through the second and third abdominal segments.

The head is contracted posteriorly to half its anterior width, forming a short neck. The thorax widens posteriorly, the hind margin being more than twice the width of the front margin. The abdomen is made up of eight segments, the first five about the same width, the last three strongly tapered, and the last two with wide lateral fringes. The lateral margins of the first six abdominal segments, and to a lesser degree those of the mesothorax and metathorax, project as a rounded longitudinal ridge. The base of this ridge forms a well-defined groove on the dorsal and ventral surfaces of the second, third, fourth, and fifth abdominal segments, with traces on the other segments.

The head, the thorax, and the legs are reddish-yellow, inclined to orange on the dorsal surface and flecked with brown pigment. The abdomen is brown on the dorsal surface, yellow along the lateral ridges and on the ventral surface, and brown in the ventral grooves bordering the lateral ridges.

The head is widest across the anterior border, which is emarginate and very irregular, with a long and narrow conical process on the mid line, a shorter and wider one on either side of it, and rounded lateral corners. Each of the three processes is tipped with a dense fringe of hairs, and there is a tuft of hairs inside each lateral corner. The lateral margins of the head are fringed with scattered and very unequal hairs.

The antennæ are filiform and nine-jointed, the relative lengths of the joints being 32, 44, 15, 14, 12, 13, 13, 17, 4; the second, third, and fourth joints bear one or two setæ each. The mandibles are sickle-shaped, perforated near the tip, the perforation opening into a tube that extends along the inner margin of the mandible and opens at the base on the dorsal surface. The inner margin of the mandible has a fringe of short, stiff, blunt spines along its center, leaving the base and tip smooth. At the distal end of this fringe the entire surface of the mandible is covered with long hairs. At the base of the mandible on the ventral surface is a flattened, knoblike process, which fits into a socket in the chitinous covering of the head.

The maxillæ (fig. 26) are reduced to a single filiform ramus of 10 joints; the basal joint carries three setæ, the second joint one, the fourth and fifth joints tufts of small setæ near their tips, and the seventh and ninth joints one seta each. At the base of the appendage on the ventrolateral surface is a small process bearing a tuft of setæ. The labium is small and its anterior margin is deeply emarginate, bearing

FIG. 22.—Ventral view of pupa of *Coptotomus interrogatus*. FIG. 23.—Dorsal view of head of larva of *Cybister fimbriolatus*. FIG. 24.—Antenna. FIG. 25.—Dorsal view of right mandible. FIG. 26.—Maxilla. FIG. 27.—Labium. FIG. 28.—Plumose hair from prothorax. FIG. 29.—Posterior end of abdomen. FIG. 30.—Labium of adult beetle. FIG. 31.—Foreleg of male, showing enlarged tarsal joints and sucking disks.

in the center a short and narrow ligula, with a tuft of setæ on either side (fig. 27). Each palp is four-jointed, the second joint with a tuft of setæ on the inner margin at the distal end, the terminal joint tipped with two tiny sensory processes.

The sclerite of the prothorax extends around the lateral margins and onto the ventral surface as far as the base of the legs; the sclerite of the mesothorax stops at the lateral margins; and the sclerite of the metathorax stops at the base of the lateral ridge. These three sclerites do not quite reach the posterior margins of their respective segments. The sclerites of the first six abdominal segments are very short and narrow, covering less than a fifth of the length and about half the width of each segment. The sclerites of the last two segments are entire, covering the lateral and ventral as well as the dorsal surfaces. Each sclerite of the first six abdominal pairs has two longitudinal dark stripes, and the brown of the dorsal surface of each segment is deepest along the lateral margins. The last segment ends in two tracheal tubes which project slightly. Just in front of the tip on the ventral surface is a pair of tiny triangular processes, each bearing two long setæ (fig. 29). The anus opens on the ventral surface about a quarter of the length of the segment in front of its tip. The sides of the thorax and the lateral ridges along the first six abdominal segments are clothed with short, scattered hairs of unequal length. On the dorsal surface of the lateral ridges near the anterior margin of each of the first six abdominal segments and on the sides of the meso and meta thorax are the spiracles. Behind the spiracles, near the longitudinal center of each segment, is a brown pigment spot. From the center of each of these spots, from a corresponding position on the prothorax and from each of a row of tiny spots across the dorsal surface near the anterior margin of the prothorax projects a plumose hair (fig. 28). The base of each of these hairs is a single thick trunk, which is divided and subdivided dichotomously until there are from 12 to 20 resultant branches.

Pupation.—A larva was found on the bank of pond 5D July 24, about 2 feet from the water's edge. It was hunting for a place to pupate and so was brought into the laboratory and placed in an artificial pupal chamber, whose size was proportioned to that of the larva. At first it stretched itself at full length upon the floor of this chamber, bending its head downward at right angles to the thorax and burying its mandibles for their entire length in the mud. It remained in this position for a week, scarcely moving at all, and then some water was put in the bottom of the jar and allowed to soak up through the floor of the chamber. Apparently this was what it was waiting for, since just as soon as the mud became soft enough it built a new pupal chamber inside of the artificial one. Although the larva was 75 mm. in length this new chamber was only 35 mm. long, 30 mm. wide, and 25 mm. high, outside measure. It was made of mud pellets half the size of a pea, which were cut out by the mandibles, rolled into form between the mandibles and labium, and then pressed into place, one against another.

Inside of this chamber the larva rested upon its back and folded its body in exactly the same manner as the *Thermonectes* larva, the posterior portion of the abdomen being turned forward above the anterior portion, and the head and thorax turned backward above the two. It remained in this position until August 8 before pupating, when the skin split along the dorsal mid line from the base of the head to the posterior margin of the sixth abdominal segment. The contents of the larval head and of the last two abdominal segments were withdrawn *in toto*, and the skin was then flattened back against the inside of the wall of the chamber. The adult beetle emerged August 22.

Another larva was obtained from a loosely constructed chamber close to the water's edge. This chamber also was made of mud pellets, but fragments of leaves and small sticks were mixed with them and the walls were so fragile that they could not be removed to the laboratory. Accordingly the larva was placed in an artificial chamber, which was made much smaller, profiting by previous experience. It was evidently still too large, however, for the larva constructed a new and smaller one inside of it, in which it pupated August 6, and the adult beetle emerged August 19.

Description of the pupa.—On first emerging from the split larval skin the pupa is creamy white in color, and its skin is shiny like the wings of a teneral dragonfly. Its total length is 35 mm. and the greatest width 13 mm. The only pigment visible is a lavender band around the anterior margin of each compound eye, and just behind this the six larval eye spots, which are black. Five of these spots are arranged in a row close to the posterior margin of the lavender band; the sixth one is a little farther back, between the second and third spots of the row. The first (dorsal) spot in the row and the sixth one are elongated at right angles to the longitudinal axis of the head, the others are circular.

At this stage the pupa is at least one-half longer and narrower than subsequently, and its first act is to stretch itself vigorously. The abdomen is arched upward until it becomes nearly a half circle, and the two ends of the pupa thrust the discarded larval skin against the walls of the pupal chamber. The hind legs are but a trifle longer than the first and second pairs, and the tarsi of all three pairs are deeply cleft. The legs, antennae, and mouth parts stretch with the rest of the body and quickly assume their normal proportions, and the clefts at the tips of the tarsi gradually fill out and disappear. The abdomen shortens and widens, and the compound eyes become entirely pigmented. By the third day the pupa turns over and rests upon the dense bristles at the anterior margin of the prothorax and upon the posterior spines, the body being arched strongly upward.

The general shape of the pupa at this stage is that of an elongated ovoid, just twice as long as wide, considerably narrowed, and rather pointed anteriorly. The front margin of the prothorax projects over the base of the head and is armed with a dense row of short and stiff bristles, and there is another row, much less dense, along the hind margin. On the mid line of the dorsal surface, near the anterior margin of the prothorax, and at the center of the mesothorax and metathorax are small areas covered with bristles. Each of the first six abdominal segments is raised into a dorsal ridge near its posterior margin, the ridges being highest on the third and fourth segments and diminishing both anteriorly and posteriorly. Each ridge carries a single row of bristles. The ventral surface of the seventh segment is covered with a hard, smooth plate, armed with scattered short bristles. At the posterior end of the body are two stout curved spines; the lateral margins of each abdominal segment and the ventral surface are armed with scattered short setae (fig. 33, p. 283).

The antennae are twisted around beneath the femora of the first legs; the labial palps reach nearly to the posterior margin of the bases of the second legs. The legs are short and rather stout and are bent in such a manner that their tips meet on the mid line; the tip of each leg in all three pairs is emarginate. The wings are also very short, hardly reaching the fourth abdominal segment.

The color of the pupa is white, tinged with light brown on the back, the eyes brown, the bristles reddish. In later development the head and prothorax and the last two abdomen segments become reddish brown, while the elytra are tinged with dark brown, almost black. The spiracles are on the dorsal surface and close to the anterior margin of each segment, the anterior ones slightly larger than the posterior.

Habits of the adult.—In this genus is shown the highest development of those modifications which are adapted to swimming and diving, and as a result the beetle displays great rapidity and agility when in the water. On being removed to the land, however, it makes only a poor attempt at walking and can not run at all or jump.

In breathing Brocher (1911a) claims to have discovered that the last pair of spiracles are the only ones that possess an apparatus for filtering the air. Furthermore, and of greater importance, the last two pairs of spiracles are provided with a special tubular trachea, which extends forward to the metathorax. Hence, he concludes that inhalation takes place through the last pair of spiracles, exhalation through the other abdominal spiracles.

The adult beetles have been accused along with *Dytiscus* and *Hydrous* of catching and eating small fish, but the testimony against *Cybister* seems mostly derived from analogy. Although this species is abundant in at least three of the fishponds they have never been known to attack a fish either in the ponds or in aquaria in the laboratory. They have been seen eating dragonfly and mayfly nymphs, together with those of *Corixa*, *Notonecta*, and *Benacus*.

Description of the adult.—The newly emerged adult is a beautiful yellowish white without any pigment except in the legs, which are reddish, and the black eyes. General shape obovate with the posterior end pointed. Color brown with a decided greenish tinge; a broad yellow band along the margins of the thorax and elytra; the front of the head, the two front pairs of legs, and spots on the ventral surface at the sides of segments three to six of the abdomen are also yellow. The thorax and elytra of the female are covered with impressed lines of varying length and not parallel, even anastomosing in places. The thorax and elytra of the male are smooth and shining.

The front tarsi of the males are attached at an angle to the tibiae and point backward toward the body. The first three segments of the tarsus are enlarged into a disk, which together with the tibia forms a triangle, whose apex is proximal and base distal. In dorsal view the tarsus is apparently joined to the base of the tibia instead of its tip. On the bottom of the disk are four transverse rows of small, equal-

sized cupules on long stalks. The basal segment has two rows, one of 15 cupules across the center of the segment and another of 20 cupules along the distal margin. The proximal half of the basal joint is covered with fine hairs. The second segment has a single row of 21 cupules, and the third segment a single row of 20 cupules, both along the distal margins. There is also a band of short hairs on the ventral surface of the basal joint of the tarsus of the second legs and three or four coarse folds at the apex of the hind coxæ.

Wickham has given a short description (1893, p. 324) of the male tarsus of this species with a figure (pl. 5, fig. 2). He also described and figured the male tarsus of *Cybister explanatus* from California (pl. 6, fig. 4), and described without a figure that of *Cybister tripunctatus*, an African species. The obsolete claw of the hind tarsus of the female varies much in size. In one specimen it could scarcely be detected; in another it was nearly a third as long as the large claw.

In all the other beetles raised from larvæ the adult emerged perfectly formed, except in one instance. Of the *Cybister* adults, however, 75 per cent were malformed in some particular. A front leg was lacking in one, a hind leg in another, some of the mouth parts in a third, a fourth had a wry neck, and so on. Whether this is true also of those that emerge under natural conditions could not be determined.

Genus DYTISCUS Linnaeus.

Dytiscus (Linnaeus, 1758, p. 411).

This is another genus of large beetle, of which both the larvæ and the adults kill and eat young fish. These beetles are dark, olive-brown in color, with a dull yellow stripe along the sides of the thorax and elytra; the front and hind margins of the thorax are also usually yellow. The claws are equal in both sexes, and in the males the basal joints of the front tarsi are broadly dilated and armed with sucking disks of different sizes.

***Dytiscus verticalis* Say.** Figures 34-38.

Dytiscus verticalis (Say, 1825, p. 92).

Eggs.—No direct observations have been made with reference to the eggs of this species, but they are probably deposited singly in incisions made by the female with her ovipositor in the stems of water plants in a manner similar to that followed by the female of *Dytiscus marginalis*.

Habits of the larva.—The material for this species consists of three adults, one of which was taken from a pupal chamber, a larval skin from the same chamber, and two larvæ nearly full-grown. This larva, like that of *Cybister*, swims more by means of the fringe along the lateral margins of the last two abdominal segments than by its legs. The latter are poorly fringed with swimming setæ, but make up for it in their length. When swimming slowly, the legs are used alone, but in rapid locomotion the whole body contributes. This larva also can jump to a considerable distance by sudden flexure of the last two abdominal segments, and it can do this on land as well as in the water. According to Brocher (1913, p. 125) when the *Dytiscus* larva breathes it may either stand upon some sort of vegetation and reach upward, thrusting the tip of its abdomen above the surface of the water, or, releasing its hold on the vegetation, it may float slowly upward, the abdomen preceding, until the tip of the latter reaches the surface; or, when the specific gravity of the body is greater than that of water, it may swim with its head directed upward and on reaching the surface turn parallel to the latter and thrust its abdomen above the surface. In all three cases the cerci are turned down against the surface film, this action both opening the posterior spiracles and supporting the larva while it breathes.

With reference to food we find the following statements, which were made not of this particular species but of the genus in general. Evermann and Clark (1920, Vol. I, p. 639) stated that the larvæ of *Dytiscus* attack the tadpoles of the leopard frog and devour them. *Dytiscus* larvæ were found by Needham and Williamson (1907, p. 485) in the "Gym" pond on the campus at Lake Forest, Ill., feeding upon *Corethra* pupæ. Wright (1920, p. 42) stated: "The water beetles, especially their larvæ (water tigers) and dragonfly nymphs also take their heavy toll of tadpole lives." Miall (1895, p. 47) made the statement: "Almost all kinds of aquatic animals, snails, worms, insects, tadpoles, and fishes are devoured by the insatiable *Dytiscus* larvæ." Garman (1890, p. 163) testified: "Both adults and young lead a predatory life, attacking and devouring whatever they can master. They do not hesitate to attack animals many times larger than themselves and are very destructive in fishponds to young fishes. They are in turn eaten by the larger fishes."

FIG. 32.—Side view of pupa of *Cybister fimbriolatus*. FIG. 33.—Ventral view of same. FIG. 34.—Dorsal view of head of larva of *Dytiscus verticalis*. FIG. 35.—Antenna. FIG. 36.—Maxilla. FIG. 37.—Labium. FIG. 38.—Posterior end of abdomen, showing cerci.

They are also cannibals like the *Cybister* larvæ, and whenever two come together they fight until one or the other gains the victory, and the winner then sucks the body of his vanquished foe.

Description of the larva.—General form a flattened spindle 70 mm. in length, tapering both anteriorly and posteriorly, widest through the mesothorax and metathorax, 7 mm. Each of the three thoracic and the first six abdominal segments has a pair of dorsal sclerites which meet at the center and cover nearly the whole dorsal surface. Head (fig. 34) wider than long, considerably flattened, its anterior margin evenly rounded and fringed with short spines. Antennæ filiform, the second, fourth, and sixth joints several times the length of the first, third, and fifth, the terminal joint but little more than a spine. Mandibles similar to those of *Cybister*, with a basal process on the ventral surface, but without a fringe of bristles along the inner margin. Maxillæ (fig. 36) uniramous, eight-jointed, the first, fourth, and sixth joints longer than the others; the basal joint stout, somewhat curved, with a rudimentary process on the inner margin at the distal end. Labium (fig. 37) wider than long, deeply emarginate anteriorly; labial palps three-jointed, the basal joint longer than the other two; ligula wanting; inside the base of each palp are two short and stout spines. Legs long and fringed with short hairs.

Last two joints of the abdomen much narrowed and heavily fringed with stout swimming setæ. Terminal joint with two long cerci on the ventral surface near the distal end, which are about half the length of the joint and are also heavily fringed with setæ. These are chiefly used to suspend the larva from the surface film of the water when it is breathing. Color a dark olive-brown, deepest on either side of the mid line, along which extends a much lighter stripe.

Pupation.—After the larva is fully developed it leaves the water and breathes now through the thoracic and abdominal spiracles, which have opened for use. We are told that the *Dytiscus* larva makes a rough cell in the earth along the pond shore or on the bank of a stream, but we are not informed whether this pupal chamber is simply hollowed out in the soft earth or is made of mud pellets like that of *Cybister*. Theoretically, the latter seems much the more probable, and the chamber from which the larval skin and newly emerged adult were taken was made of pellets.

Description of the pupa.—So far as known the pupa of this species has never been seen except by Wickham (1894), and he has not given us any description of it. We can only give the characters of *Dytiscus* pupæ in general. The prothorax projects over the head, hiding a portion of the eyes. The elytra and wings are short and reach only to the third or fourth abdomen segment. The hind legs are also short and do not reach beyond the seventh segment. Each of the first six abdomen segments is raised into a ridge on its dorsal surface near the posterior margin, but these ridges are much less prominent than those on the *Cybister* pupa. In the figure of a European species published by Miall (1895) from Schiødt the dorsal surface is nearly flat and there are no perceptible ridges. At the posterior end of the abdomen are two cerci, which are oblong and project for a considerable distance. In the European species they are fringed with setæ, but in an American species figured by Kellogg (1908) they are without setæ.

Miall (1895) said that the pupal stage in summer lasts only a fortnight or so, but Kellogg (1908) said that it lasts three weeks. Fortunately we have a statement with reference to the present species. Wickham (1895a, p. 71) said in the *Canadian Entomologist*:

The length of time spent in this latter pupa stage must vary greatly in different broods and with the various species, but it was found to be 10 or 11 days in the case of *Dytiscus verticalis*, of which a larva, taken at Bayfield, Wis., pupated July 18, the beetle appearing on the 28th.

Habits of the adult.—The long hind legs are admirably adapted for swimming, though they are not as powerful as in *Cybister*; but they are not suited for walking, and the beetle flounders about clumsily on the land. It flies well and is frequently captured at night around trap lanterns. With reference to its food, two of the quotations already given under the habits of the larva apply also to the adult. In addition, Cooke in his "Molluscs" (1895, p. 59) cited the case of a *Dytiscus* in an aquarium that killed and devoured seven *Lymnaea stagnalis* in one afternoon. These beetles also ate *Lymnaea peregra*, but seemed to prefer *stagnalis*.

This beetle was abundant in two of the ponds and common in eight of the others; yet only two larvæ were found in three seasons of work on the water beetles, and in spite of the abundance of the adult beetles not one of them has ever been seen attacking young fish either in the fishponds or in aquaria.

Description of the adult.—Like *Cybister* the adult when it first emerges is soft and pale in color, the only pigment appearing in the legs and eyes. Several days elapse before it hardens and assumes the

dark, olive-brown color of the fully matured adult. The shape is regularly oval, with the posterior margin evenly rounded and not pointed as in *Cybister*; length 35 mm., width 20 mm.

The clypeus is separated from the head by a distinct suture, the thorax is not margined, and the claws are equal in both sexes. The elytra are smooth and do not show the numerous short impressed lines found in the *Cybister* female. Near the posterior end of each is a narrow and oblique subapical crossbar of yellow. The abdominal segments are uniformly black, and there are no yellow spots along the lateral margins.

In the male the enlarged tarsus of the front legs is nearly circular in outline and the sucking disks on its ventral surface vary greatly in size. Near the base are two which are very much enlarged, their combined diameters almost equaling the width of the swollen basal joint of the tarsus. The other disks are smaller and rather irregularly arranged.

Genus *HYDROPORUS* Clairville.

Hydroporus (Clairville, 1806, p. 182).

A genus of small species, all very similar to one another and hence difficult to distinguish. The adults are oval in form and dark brown in color; they swim well and when taken out of the water can jump quite a distance. The larvæ are spindle-shaped and may be recognized by the fact that the head is much narrowed in front of the antennæ and the clypeus is prolonged into a sort of rostrum whose anterior margin is armed with rows of wide laminæ. The mandibles also are set at an angle and shut up against the lower surface of the rostrum instead of shutting past each other.

***Hydroporus niger* Say.** Figures 79–83.

Hydroporus niger (Say, 1825, p. 102).

Eggs.—Nothing is known of how or where the eggs are laid or of the length of time that elapses before they hatch. In the species whose larvæ have been described by Schiødte and Meinert nothing was said about the eggs.

Habits of the larva.—The larvæ live among the Mougeotia and other filamentous algæ, over which they crawl almost ceaselessly. They swim very slowly, because their legs are short and have no swimming fringes but only a few scattered setæ. When out of the water they can walk quite rapidly, but can not run or jump. The larva has no lateral gills and does not come to the surface for its supply of oxygen, but is enabled in some way to obtain it from the water. It feeds upon the larvæ commonly found among the algæ, such as *Chironomus*, *Epiphragma*, *Odontomyia*, *Corethra*, *Probezzia*, and *Palpomyia*. They do not appear to be cannibals and can be kept together in confinement without eating one another, as was noted by Needham and Williamson (1907).

Description of the larva.—General form spindle-shaped, narrowed only a little anteriorly, very much posteriorly; length 7 mm., width 1.6 mm. Body made up of a head, three thoracic and eight abdominal segments, widest through the mesothorax and metathorax, whose diameter is about one-fifth of the body length, exclusive of the posterior cerci. The thorax and first six abdominal segments are covered dorsally with chitin sclerites; those of the last two segments cover the lateral and ventral surfaces as well as the dorsal.

Color light brown on the dorsal surface, the head and the last two segments of the abdomen yellow; a broad Y-shaped brown mark on the head, following the sutures; antennæ, mouth parts, legs, and entire ventral surface white, tinged with brown on the thorax. Each sclerite covers the whole dorsal surface of its segment and is armed with setæ along its lateral margins and a transverse row across its posterior margin. The sclerites of the sixth and seventh segments are prolonged into small papillæ at their posterior corners. The lateral areas of the head and the rostrum are also covered with setæ.

Head ovate, one-half longer than wide, the clypeus prolonged into a broad and bluntly rounded rostrum, extending far in front of the antennæ. The top of the head and the rostrum are strongly convex, and the tip of the rostrum is curved over ventrally. On this turned-down anterior margin is borne the characteristic dytiscid fringe of this genus. In the present species it consists of three rows of flattened

lamellæ; those in the terminal row are large and broadly ovate, in the second row much smaller and narrowly obovate, and in the third row triangular with all three margins concave. The sides of the rostrum are indented about one-third of the distance from the tip to the base, and the broader basal portion is fringed with setæ along its lateral margins and several transverse rows across the top. The epicranial suture is about one-fourth the length of the head, and each fronto-antennal suture is curved like the letter S, joining the lateral margin of the rostrum in front of the antennæ.

The prothorax is one-half wider than long, the mesothorax three times, and the metathorax four times as wide as long. The abdominal segments decrease regularly in width and the last one takes the form of a triangle with a bluntly rounded tip, its length more than three times its width. To its center on the ventral surface are hinged the cerci close together on the median line. Each is two-jointed, slender, tapering, and about one-third as long as the body.

The antennæ are four-jointed, the second and third joints the same length and much longer than the first and fourth. The mandibles are curved and deeply grooved along the inner margin. They are attached not to the corners of the frontal margin as usual, but to the ventral surface of the head posterior to the bases of the antennæ, and their bases are not visible in dorsal view. Furthermore, they are attached at an angle, so that instead of shutting past each other like a pair of scissor blades they shut in diagonally, their tips just meeting against the ventral surface of the rostrum inside the fringe. Each maxilla consists of a stout basal joint armed with three large setæ on its ventral surface and a three-jointed palp, whose second joint is three-fourths as long as the first, and the third half the length of the second and tipped with two minute setæ. The labium is wider than long, the palpiger heavily armed with stout setæ on its ventral surface; there is no ligula. The labial palps are two-jointed, the terminal joint a little shorter and more slender than the basal and tipped with two tiny setæ. These palps are nearly as long as the maxillæ and are sparingly armed with setæ. The tarsal claws are alike, very long, slender and acuminate.

Pupation.—The species reared by Needham and Williamson (1907) pupated without making any chamber, while another species (*septentrionalis*) found by Matheson (1914) in the Salmon River near Truro, Nova Scotia, constructed a pupal chamber out of pellets of sand under flat rocks on the river bank.

Description of the pupa.—None of the larvæ of the present species could be induced to pupate, and we have to be satisfied with a general description applying to the genus as a whole. The pupa is white in color, except the eyes, which are pigmented. The head is withdrawn into the prothorax and is well provided with short and strong styli. The anterior margin of the pronotum is also armed with a row of short styli, and others are scattered over the dorsal surface of all the thoracic segments. In the abdomen the posterior margin of each segment is raised into a transverse ridge, which is armed with a row of styli. The abdomen ends in a pair of large and long spines or cerci, which help to support the pupa inside the chamber. Matheson (1914) said that the species he studied rested upon its back in the pupal chamber, but the row of stout styli along the front of the pronotum and the strong cerci would indicate that they are used to support the pupa at least a part of the time. If this be true, then it rests also upon its ventral surface with the body arched strongly upward like the other pupæ.

Habits of the adult.—The hind legs are rather weak, but are heavily fringed with swimming setæ, so that the beetle moves through the water quite rapidly and shows considerable agility. On the land it is not as clumsy as many of the dytiscids but walks fairly well and can jump a short distance. These beetles are rather difficult to watch, because they stay among the filaments of the algæ most of the time. The only thing they were seen to eat was *Chironomus* pupæ.

Description of the adult.—General form an elongate oval, slightly narrowed posteriorly; width considerably more than half the length; length 4 mm., width 2.5 mm. The dorsal surface is uniformly black, with the head and legs reddish-brown; antennæ dark brown, the base lighter in color. Thorax and elytra finely and evenly punctured and covered with scattered soft hairs. Both the adults and the larvæ of these beetles furnish excellent fish food.

Genus LACCOPHILUS Leach.

Laccophilus (Leach, 1817, p. 69).

These are small but very active beetles whose bodies are considerably depressed and usually spotted in color. The hind legs are well developed, and they are strong

swimmers in consequence. In the male the tarsi of the two front pairs of legs are dilated and covered on the ventral surface with spongy hairs. There are also rows of fine ridges on the plates of the hind coxæ, which form a stridulating organ when rubbed by the hind femora. Two species are common in the Fairport fishponds and a third is found rarely.

Laccophilus maculosus Say. Figures 20, 39, 41, 43, 44, 46, 48, 50.

Laccophilus maculosus (Say, 1825, p. 100).

Eggs.—No eggs of this species were obtained, but it is probable that they are inserted singly by the female in the stems of water plants after the manner of other dytiscids.

Habits of the larva.—The larvæ are excellent swimmers, and when out of the water are much the most agile of any larvæ here described. The swimming fringes are well developed on all the legs and carry the larva through the water without any movement of the body itself. The resultant motion is rapid and exceptionally uniform, the abdomen and cerci being used for steering purposes only. When out of the water, the body is considerably shortened by the telescoping of the segments, the abdomen is lifted well above the surface of the ground on the long legs and inclined slightly upward, and the larva walks with great rapidity or even runs and can turn and dodge with agility.

Kept in an aquarium with plenty of water plants the larvæ are quiet and do not show their cannibalistic tendencies at once. They crawl about over the plants very slowly, feeling about with each foot before putting it forward and keeping the abdomen elevated at an angle of 45°. They breathe by raising the tip of the abdomen to the surface of the water while still standing on the plants, at the same time inclining the cerci ventrally until they rest upon the surface film. The two posterior spiracles are opened in a manner similar to that in the *Dytiscus* larva. Having filled the air tubes, this larva can remain an hour or more beneath the surface. In clear water they are obliged to swim to the surface in order to breathe. In doing this the head is kept upward until close to the surface, then the tail is elevated in a broad curve and an effort is made to throw the cerci out horizontally on top of the surface film. Often several efforts are made before this is accomplished, but once successful the body is dropped into a vertical position and hangs supported by the cerci. When the breathing is completed, the cerci are elevated and the larva sinks beneath the water.

If put in a dish of clear water, some of them betray cannibalistic tendencies by forthwith attacking the others, and the one first grasped by the other's jaws gives up without a struggle, even when his head is left free so that he could fight if he would. The victor then swims about sucking the juices of his victim until they are all extracted, the empty skin being finally thrown away.

In the ponds these larvæ frequent the open water between the rush stems but do not take kindly to *Hydrodictyon* or similar blanket algæ. They do, however, crawl about among the *Spirogyra* and *Mougeotia* and feed on the larvæ usually found there—*Corethra*, *Ceratopogon*, *Dixa*, etc.—and occasionally they eat a larva of *Peltodytes*, *Haliphus*, or *Hydroporus*, which are found in the same localities.

Description of the larva.—General form spindle-shaped, 7 to 9 mm. long, the body being widest through the metathorax where it is 1 to 1.5 mm. broad, and tapering slightly forward and backward (fig. 20, opp. p. 275). The head is comparatively large, widest through the eyes, where it is the same width as the thorax, and contracted posteriorly to less than half that width. The lateral margins behind the eyes are armed with a row of five or six short and stout spines on either side. The prothorax is a trifle longer than wide, the anterior margin half the width of the posterior, the sides strongly convex. The mesothorax and metathorax each increase slightly in width, while the abdomen segments diminish regularly, the last one being rather abruptly contracted posteriorly at the base of the cerci (fig. 20).

The sclerite of the prothorax extends laterally nearly to the bases of the first legs; those of the mesothorax and metathorax and the first five abdominal segments do not reach the lateral margins; that of the sixth abdominal segment extends onto the ventral surface, covering three-quarters of the entire circumference, and those of the seventh and eighth segments extend around the body, covering the entire surface, dorsal, lateral, and ventral.

The abdominal segments are capable of considerable telescoping, and when the larva is taken out of the water, or when it crawls out of its own accord, the body is much shortened by the pushing of the anterior end of each segment into the posterior end of the segment in front of it. In preservatives also the body of the larva is usually telescoped in the same manner, but occasionally it remains extended.

FIG. 39.—Dorsal view of head of larva of *Laccophilus maculosus*, showing color pattern. FIG. 40.—The same, *Laccophilus proximus*. FIG. 41.—Anterior margin of head, *maculosus*. FIG. 42.—The same, *proximus*. FIG. 43.—Mandible of *maculosus*. FIG. 44.—Maxilla of *maculosus*. FIG. 45.—Maxilla of *proximus*. FIG. 46.—Labium of *maculosus*. FIG. 47.—Labium of *proximus*. FIG. 48.—Pupa of *maculosus*. FIG. 49.—Pupa of *proximus*. FIG. 50.—One segment of the foreleg of a male *maculosus*, showing the form of the sucking disks.

The last segment is prolonged backward on the dorsal surface into a short papilla, from beneath whose base arise the divergent cerci, which are as long as the last three segments and are heavily fringed with hairs. The entire surface of the last two segments is sparsely covered with short hairs, others are found on the lateral margins of the other segments, and each sclerite bears a row of short spines along its posterior margin. The legs are comparatively long and slender but are strong enough to support the larva and are well fringed with swimming setæ.

The antennæ are not on the dorsal surface but on the lateral margins of the head behind the bases of the mandibles (fig. 39). Each is four-jointed, the three basal joints about the same length, the terminal joint less than a fourth as long. The labro-clypeus has a peculiar fringe on its anterior margin, which helps to identify the larva. It is made up of two rows of processes of the form shown in Figure 41, one row dorsal to the other. The processes of the dorsal row are much larger and longer than those of the ventral row and alternate with them.

The mandibles are long, slender, and grooved on the inner margin nearly to the base; when closed they overlap more than half their length. In the maxillæ the cardo is short and narrow, the stipes much longer and wider, the palp three-jointed, the joints about the same length, while the galea is reduced to a fingerlike process tipped with a sensory papilla and two small setæ, and the lacinia is wholly wanting, or may be represented by two stout curved spines inside the base of the galea. The tip of the stipes is densely covered with short hairs. The labium is twice as wide as long, and the palps are attached to its antero-lateral corners; they are two-jointed, the joints about the same length and unarmed; there is no ligula. Inside of each palp are a long hair and a stout jointed spine, and there is a pair of much smaller simple spines near the mid line; the mentum also bears a pair of small spines (fig. 46).

The color of the living larva is a pale, greenish-yellow, unmarked on the ventral surface except on the last two segments of the abdomen. On the dorsal surface, however, the following parts are more or less brown: The mandibles, the frontal margin of the head, the lateral margins behind the eyes, the brown widening as it approaches the thorax, a fleur-de-lis design at the center of the head, its lateral arms extending outward and forward toward the eyes, and each of the dorsal sclerites. The anterior and posterior margins of the sclerites are considerably darker in color than the rest of the surface, and in the last two segments the brown and the deeper margins follow the sclerites around the body, becoming the exceptional markings on the ventral surface mentioned above. There is a very narrow brown line along the margin of each leg, another along the inner margin of each femur, and a ring around the top of each leg joint. In some larvæ the brown of the dorsal surface has a decided greenish tinge, while in others it is deepened almost to black, especially along the margins of the sclerites, but in preservatives the green entirely disappears and the black is considerably lightened. The contents of the digestive canal show as a black streak through the center of the body and often surge backward and forward in rhythmic pulsations.

Pupation.—As would be expected from its locomotor ability, this larva travels from the water's edge when ready to pupate as far as, and often farther than, the larger species. Having found a suitable place, it burrows into the earth and forms its pupal chamber less than half an inch beneath the surface, often near a grass or plant stem. Having completed the chamber, the larva remains in it for one or two days before pupating.

Description of the pupa.—Length 5 mm., width 3 mm. The pupa is greenish-white in color, the green being deeper through the center of the body, and is very frail. It must be handled with the utmost care to avoid crushing it out of shape. It is not at all active, but lies inertly in the pupal chamber in whatever position it may be placed. After a time, however, it readjusts itself and assumes the usual position, the body arched upward into a semicircle, the dorsal surface uppermost, resting upon the stout spines of the prothorax, the tips of the third legs, and the two strong cerci.

The head is drawn into the prothorax and down onto the metathorax. There are three styli inside the anterior end of each eye, two inside the posterior end and two on the base of the labrum. Along the anterior and posterior margins of the pronotum are 12 or 14 styli on either side running inward from the lateral margins, but leaving a wide vacant space in the center. On the dorsal surface near the center of the segment is a single seta on either side. The mesothorax and metathorax have two styli at the base of each elytron and a wing and a row of 10 or 12 on the posterior margin across the center. There is a similar row across the posterior margin of each of the first seven abdominal segments, the lateral styli being longer than those in the center; there is a row of five along each lateral margin of the eighth segment.

The eyes are large, light reddish-brown in color, and widely separated; the antennæ extend diagonally outward and backward to the edge of the elytra; the maxillary palps are short and reach just beyond the first legs. The femora of the first and second legs are at an angle of 45° with the body axis, the tibiae and tarsi are nearly in a straight line and overlap at the center of the body; the femora of the third legs are at an angle of 90° with the body axis, or drawn a little farther forward than that; the tibiae and tarsi are in a straight line and overlap as in the other legs, their tips reaching the middle of the penultimate abdominal segment (fig. 48).

The following table gives the time spent in the pupal chamber before pupating and the length of the pupal stage in 10 specimens:

Entered chamber.	Pupated.	Emerged.	Entered chamber.	Pupated.	Emerged.
1919.			1920.		
July 12.....	July 13.....	July 18.	Aug. 6.....	Aug. 8.....	Aug. 14.
July 15.....	July 17.....	July 23.	Aug. 8.....	Aug. 9.....	Aug. 15.
July 17.....	July 19.....	July 24.			
			1921.		
1920.			July 14.....	July 17.....	July 23.
July 16.....	July 17.....	July 23.	July 18.....	July 20.....	July 26.
July 20.....	July 22.....	July 26.	July 19.....	July 21.....	Do.

Habits of the adult.—The hind legs of this species are very heavily fringed with swimming setæ, and hence it can swim rapidly and with much agility. It is also the best jumper of all the beetles studied with the exception of *Thermonectes ornaticollis*, and the jumping is accomplished by the hind legs. This beetle is found in every fishpond except 6D, and could probably be found there if the search were made persistent enough. Its small size makes it harmless to the fish, and in its turn it serves as food for fish, frogs, and some of the other beetles.

Description of the adult.—General outline ovate, nearly elliptical, but somewhat narrowed posteriorly and strongly depressed. Total length 6 mm., greatest width 3.50 mm. Thorax very short, more than three times as wide as long and without widened margins; scutellum practically invisible; elytra widest near the center, obliquely truncated anteriorly and posteriorly, with one or two rows of minute punctures. Tarsi of the first two pairs of legs in the male enlarged and armed with spongy, prehensile hairs, two rows on the basal joint and one row on the second and third joints. The coxæ of the third legs are expanded into broad processes, concealing the coxal cavities. The coxal plates in the male are furnished with a stridulating file, whose ridges begin at the inner margin near the center and extend outwards and backwards. The third legs are much flattened and armed with two rows of long swimming setæ; the spines on the inner margin of the tibia near its distal end are unequal and distinctly emarginate at their tips. The antennæ are cylindrical, filiform, and 11-jointed; the mandibles have a wide terminal margin, which is only slightly reentrant, with an acute ventral tooth and a blunt dorsal one. The maxillary palps are four-jointed, somewhat club-shaped and rather short; the labial palps are very short and two-jointed. The head, thorax, and under parts are reddish-yellow, the elytra black, each with four submarginal spots and three basal lines of greenish-yellow.

Laccophilus proximus Say. Figures 40, 42, 45, 47, 49.

Laccophilus proximus (Say, 1825, pp. 101 and 514).

Eggs.—In this species, as in the preceding one, the eggs are probably deposited singly in the stems of water plants.

Habits of the larva.—This larva has the same habits and eats the same food as the *maculosus* larva, but is much less cannibalistic. Indeed, not once did it betray any such tendencies, and when the two species were kept together, although the *maculosus* larvæ attacked one another and also killed and ate the *proximus* larvæ, the latter never retaliated.

Description of the larva.—This species is considerably smaller than the preceding for two reasons—the first three and the last abdominal segments are actually shorter, and then the larva keeps all the segments telescoped even when suspended from the surface film during breathing. Hence, while the *maculosus* larva averages about 8 mm. in length when fully grown, the *proximus* larva is only from 6 to 6.5 mm. long.

Proximus is also much the darker of the two, the entire upper surface being dark brown, with the margins of the sclerites nearly black. In the center of the dorsal surface of the head is a dark brown

FIG. 51.—Larva of *Cybister fimbriolatus*, dorsal view. FIG. 52.—Larva of *Thermonectes basilaris*. FIG. 53.—Larva of *Thermonectes ornatocollis*. FIG. 54.—Side view of head of basilaris, showing deep penetration of dorsal eyes. FIG. 55.—Mandible of adult beetle, *T. basilaris*. FIG. 56.—The same, *T. ornatocollis*.

triangular shield, clearly outlined by a very narrow yellow margin. The apex of the triangle is posterior and the base anterior, each of the three sides are emarginate, and the anterior corners are broadly rounded. From each side a broad ribbon of dark brown extends a short distance outwards and backwards, then turns at a right angle forwards and outwards to the eyes (fig. 40, p. 288). The brown band along each lateral margin behind the eyes is much wider than in the preceding larva, and there is often a large brown spot on the base of each mandible.

The labrum, with the peculiar fringe on its anterior margin, is relatively wider and fills nearly the entire space between the bases of the mandibles. The sculpture on its surface is also radically different, being made up of longitudinal instead of transverse lines. The maxilla differs as in Figure 45 (p. 288); the labium is relatively longer and narrower; in *maculosus* the palpiger is more than four times as wide as long, but in the present species it is only a little more than twice as wide as long (fig. 47, p. 288). There are other minor differences, but the present larva can be easily recognized by its darker color, by the telescoping of the body segments, by the shortness of the first three abdominal segments, and by the tapering of the dark figure in the center of the dorsal surface of the head.

Description of the pupa.—This pupa is 4.5 mm. long and 2.5 mm. wide, light green in color, darker on the dorsal surface and through the center of the body, with the posterior portion of the digestive canal a dark brown, almost black; the wings, legs, and mouth parts are white, the eyes and posterior cerci light brown. In comparison with the pupa of the preceding species the head is more quadrangular, with a truncated anterior margin, slightly emarginate at the center. The femurs of the first legs extend outward at right angles to the body axis, and the tarsi are turned backward parallel with the axis and some distance apart. The tarsi of the second legs are crossed but reach back nearly to the posterior ends of the wings. The tarsi of the third legs are also crossed and extend backward only to the sixth segment. The eighth segment is much shorter than in *maculosus* and the cerci are narrower and straighter.

Description of the adult.—Sharp (1882), in his excellent memoir of the Dytiscidæ, said with reference to this species: "In the three individuals I have examined I can find no distinction from *maculosus* except the darker color and more indistinct markings of the elytra, which, however, are so similar in the two that I am inclined to think them one species." Blatchley (1910), however, in his *Coleoptera of Indiana*, distinguished them as separate species, and an examination of the mouth parts confirms his opinion. In the mandibles the terminal tooth of the present species is longer and more slender, the secondary dorsal tooth is farther removed and its inner margin reaches nearer to the base of the appendage, and the ciliated ridge does not reach the base. In the maxillæ the palp is longer and more slender; the rest of the appendage is much shorter and thicker. In the lower lip the mentum is much longer and narrower and of an entirely different shape; the labial palps are longer, much thicker, and more densely setose. These differences, combined with those found in the larva and pupa, fully warrant the separation of the species. This beetle is not quite as widely distributed as the preceding, but is still common in most of the ponds. Both larvæ and adults are so small that they can not harm young fish but furnish excellent food.

Genus THERMONECTES Crotch.

Thermonectes (Crotch, 1873, p. 402).

A genus of medium-sized, rather convex species, which are excellent swimmers and agile jumpers. The head is dull yellow with the vertex and an M-shaped mark black; the thorax is also yellow with two transverse black lines. In the males the front tarsi are strongly dilated and bear two or three large basal sucking disks and numerous smaller unequal ones. The hind tarsal claws are unequal. Neither the larvæ nor the adults ever menace young fish or display any tendency toward cannibalism, but are exceptionally peaceable.

***Thermonectes basilaris* (Harris).** Figures 52, 54, 55, 57, 58, 60, 62, 64, 65, 67, 69, 70, 72, 73.

Acilius basilaris (Harris, 1828, p. 8).

Thermonectes basilaris (Sharp, 1882, p. 684; pl. 17, fig. 212).

Eggs.—The eggs are laid singly below the surface of the water in the stems of crex grass, rushes, or other water plants and hatch in four or five days.

Habits of the larva.—Four of these larvæ were captured August 6 and kept in an aquarium for a week, when two of them died and the other two pupated on being placed in artificial mud chambers. This

FIG. 57.—Dorsal view of head of larva of *T. basilaris*, showing color pattern and frontal border. FIG. 58.—Antenna of *basilaris*. FIG. 59.—Antenna of *ornaticollis*. FIG. 60.—Mandible of *basilaris*. FIG. 61.—Mandible of *ornaticollis*. FIG. 62.—Maxilla of *basilaris*, dorsal view. FIG. 63.—Maxilla of *ornaticollis*. FIG. 64.—Ventral view of labium of *basilaris*. FIG. 65.—Dorsal view of same. FIG. 66.—Ventral view of labium of *ornaticollis*. FIG. 67.—Front tarsus of *basilaris*, showing size, number, and arrangement of sucking disks. FIG. 68.—The same, *ornaticollis*.

larva swims with an even and rapid motion, propelling itself by short strokes of the legs, twisting and turning its body in different directions. During its progress it thrusts its tail frequently to the surface for breathing and seems unable to remain long under water. While at the surface it holds itself in place by depressing the cerci down upon the surface film. When disturbed, it snaps its body, often to quite a distance, by a sudden contraction of the longitudinal muscles of the abdominal segments. The same convulsive movement is made when the larva is placed in a preservative. It is aided considerably by the fringes of swimming hairs along the lateral margins of the last two abdominal segments. Sometimes a flexion of these two segments upon the segment just in front of them can be seen, and at other times a flexion of the abdomen upon the thorax, but usually no such movement is visible, because of its abruptness.

When swimming about, the last two segments of the abdomen are almost always carried at an elevation of 45° dorsally, as though constantly reaching for the surface. At the same time the abdomen between the thorax and the penultimate segment is curved downward. Whenever swimming ceases the buoyancy of the posterior end of the body carries it rapidly upward in a sinuous path, due to the curve of the abdomen and the angulation of the last two segments. There is seldom any need of positive effort in reaching the surface. Whenever there is the larva approaches the surface either tail first or head foremost indifferently; in the latter case it stops just before reaching the surface and inverts its body.

This larva feeds close to the surface upon whatever it can catch and snaps continually at the *Notonecta* and *Belostoma* nymphs that are swimming there. After seizing its prey it swims about, holding it in its mandibles, and jerking its head and prothorax from side to side much as a terrier shakes a rat. This movement evidently assists it in thrusting its mandibles through the hard skin of its prey. After the mandibles are fixed satisfactorily it remains quietly suspended from the surface film and sucks the juices out of its prey. When it wishes to obtain a new hold, it again swims about and shakes its prey and then quiets down, repeating this until all the juices have been extracted and nothing but the shell of the body is left.

In the aquarium they were fed with dragonfly and damselfly nymphs, mayfly larvæ, the nymphs of *Belostoma* and *Notonecta*, and the larvæ of *Tropisternus*. Out of these they always selected the *Tropisternus* larvæ first and ate them until they were all gone, then took the *Belostoma* nymphs, and finally the *Notonecta* nymphs. They refused to touch any of the other food, and they showed no tendency to fight with one another no matter how hungry they became. Some of the *Tropisternus* larvæ were larger in diameter, though not as long as the *Thermonectes* larvæ, but the latter had no difficulty in killing them because of superior agility.

Description of the larva.—General form spindle-shaped, narrowed strongly both anteriorly and posteriorly; length 17.5 mm., greatest width, through the second and third abdominal segments, 2.5 mm. (fig. 52, opp. p. 291). Head yellow on the dorsal surface with the following parts reddish-brown: The mandibles, the tips of the antennæ, the tips of the labial and maxillary palps, the anterior margin of the frons, irregular figures along the median line, across the head, and along the lateral margins behind the eyes; eyes black. Thorax and abdomen reddish-brown on the dorsal surface, white on the ventral surface except the last two abdominal segments, which are reddish-brown like the back. On the dorsal surface there is a curved yellow diagonal line on each of the first six abdominal segments, about half-way between the mid line and the lateral margin and extending backward nearly across the segment. A second spot, outside of the first and more inclined, appears on the second, third, fourth, and fifth segments.

Chitin sclerites cover the entire tergum of the thorax and abdomen and extend onto the pleurum a short distance on either side, so that their lateral margins are not visible in dorsal view. These margins and also a projection which extends forward beneath the preceding sclerite are considerably darker in color. Inside of the lateral margin is a second narrow dark line on the mesothorax and metathorax and on the fifth and sixth abdominal segments; there are two such lines on the first four abdominal segments.

The sclerite on the mesothorax does not reach the spiracle, that on the metathorax just covers it, and those on the abdomen segments extend slightly beyond it. The sclerites of the last two abdominal segments extend entirely around the body, and the spiracles of the seventh segment open on the ventral surface. The ventral margins of the pleura of the first six abdominal segments are fringed with short silky hairs. On the sixth segment this fringe curves outward and becomes continuous with the much longer

lateral fringes of the last two segments. There is a pair of oblong chitin plates on the mid line of the prothoracic sternum, which together are about half the length and width of the segment. The tracheae show through in the last two segments as longitudinal dark brown lines.

Head obovate, widest through the eyes; its length to its width as 11 to 8, narrowed into a short neck posteriorly. Epicranial suture more than half the entire length; frons triangular with convex sides and prominent knobs at the anterior angles. The fringe along the frontal margin is made up of four rows of club-shaped processes diminishing in size from in front backward. There are no lacinate laminae as in the *ornaticollis* larva, nor any sharp spines as in the *Acilius* larva. The two large eyes protrude as black hemispheres from the dorsal surface; only two of the other four are visible in dorsal view, and they are minute.

The prothorax is twice as long as wide, the posterior margin a little more than half as wide again as the anterior, the sides nearly straight. The mesothorax and metathorax increase in width, the latter being twice as wide as long. The abdominal segments increase regularly in length; the first two increase slightly in width, the third is the same width as the second, and the remaining segments diminish regularly in width. The last segment is broadly rounded at the tip and carries two slender cerci on its ventral surface a short distance in front of the end.

The antennae are six-jointed, the second and fourth joints short and subspherical, the sixth joint also short but finger-like. The mandibles have a fringe of long hairs on the outer margin near the base.¹ The maxillae are curved considerably and have a decided hunchbacked appearance; the spinous process is acuminate and has a row of minute hairs along its inner margin; the inner distal corner is sharply rounded and bears a tuft of small spines, which are continued down the inner margin. There are two longitudinal rows of stiff spines on the dorsal surface, the outer one strongly curved to follow the contour of the outer margin, the inner one much less curved. The palps are four-jointed, the third joint spherical, the basal joint shorter than the second and fourth, which are about equal (fig. 62, p. 292).

The labium is narrow and elongate; on the dorsal surface the palpiger has a raised and papillated margin on all four sides, covered with minute hairs and with a row of short spines across the distal margin. The ventral surface is smooth and bare, except for two long setae near the base of the ligula. The palps are two-jointed, the joints about the same length, the basal joints with a row of spines along their outer margins, the terminal joints with a few spines on the outer margins at the base and on the inner margins at the tip. The ligula is long, narrow, and tapering, and carries at its tip two short, divergent, two-jointed spines. The legs are long and slender and well supplied with swimming setae.

When taken from the pupal chamber just before pupation, the larva has diminished to 15 mm. in length, the width has increased to 2.9 mm. The color is now a uniform brown on the dorsal surface and light yellowish-white on the ventral surface, except the last two segments, which are brown. The head also is brown on both surfaces, the sclerites have lost their lateral dark lines, and the spiracles show through them as black dots. The four small eyes are black, the two larger ones have a decided reddish tinge.

Pupation—When the larva is fully grown, it selects a spot on the land that is well shaded and where the mud is rather soft. Here a foot or more from the water's edge it constructs its pupal chamber, which is subspherical in shape and 12 to 14 mm. in diameter. It is made of little pellets of mud stuck together rather loosely and rests upon the surface of the ground. Its walls are so thin and friable that it is practically impossible to pick it up intact, except by cutting out a section of the mud beneath it. The building of the chamber occupies one to one and a half hours, and when it is completed the inside is smoothed by the larva rubbing it with its body. The larva then folds the last two segments of the body forward and the head and thorax backward above them, like the *Dineutes* larva, and rests upon its back on the bottom of the chamber. The prepupal period lasts one and a half to two days. At the end of that time the skin splits along the dorsal mid line from the base of the head to the penultimate abdominal segment and is flattened out against the inner wall of the chamber, to which it adheres firmly. The pupa emerges upon its back on the bottom of the chamber and rests there for 24 hours, then it reverses its position and rests upon the long styli on the pronotum and the cerci at the posterior end of the abdomen, the dorsal surface uppermost and the body strongly arched.

¹ This fringe was accidentally omitted from Fig. 60; it should be the same as in Fig. 61.

Description of the pupa.—The pupa is white in color, except the eyes, which are dark reddish-brown and the face, which has a reddish tinge (fig. 69, p. 297). It is 8 mm. long, including the caudal cerci and 5 mm. wide. It is obovate in outline and quite strongly depressed. The segmentation is distinct and is rendered more conspicuous by the rolling up of the posterior margin of each segment into a ridge, which is low and flat on the ventral and lateral surfaces but stands out prominently on the dorsal surface, being highest at the mid line. The prothorax projects forward around the base of the head and carries on its frontal margin a fringe of long hairlike styli. On each lateral margin is a short process armed with five spines, and on each side of the dorsal mid line is a group of three stout styli. On the dorsal surface of the second thoracic segment are three spinelike styli on either side near the anterior margin and close to the mid line. On the third segment are four similar styli near the anterior margin, three near the posterior margin, one on the posterior margin near the base of the wing, and another near the mid line, nine in all on each half of the segment. On each of the first four abdominal segments are three large isolated styli on either side of the mid line along the posterior crest and one at the side of the segment behind the spiracle. The fifth segment has only two near the mid line and one behind the spiracle; the sixth and seventh segments carry a single pair of stout clawlike styli on the mid line and one behind the spiracle. The eighth segment has a compound handlike spine with three fingers on each lateral margin anteriorly and a single spine posteriorly. Its ventral surface is split back at the center, and the rudimentary ninth segment protrudes a pair of caudal cerci, short, stout, and bifid at the tip. When the pupa is on its back, all these styli and spines help to keep it above the earth floor of the pupal chamber.

The antennæ lie along the front margins of the elytra, and the maxillary palps extend straight backward beyond the tibiæ of the first legs. The femur of the first legs stands at right angles to the body axis, and the tibia is folded back tightly against it; the two tarsi are parallel to the body axis and well separated. In the second legs the tibiæ and femora are at right angles to each other, and both at an angle of 45° to the body axis; the tarsi are parallel to the axis and only slightly separated. In the third legs the tibiæ and femora are arranged like the second pair, but the tarsi are in line with the tibiæ and meet on the mid line. The time spent in the pupal stage is four or five days; two larvæ were taken from the pupal chambers they had constructed on the shore of pond 5D on July 6 and placed in artificial mud cells; they pupated July 7, and the adults emerged July 11. A male pupa reared in August, 1921, remained six days in the pupa stage.

Habits of the adult.—The adults swim with an even rapid motion, the posterior legs being the chief propelling organs. They rest at the surface with the posterior legs extending out at right angles from about the center of the body and the posterior end of the abdomen elevated above the surface film. When out of water, they move with considerable agility and can jump well, though not quite as vigorously as the following species. As indicated in the table, this is one of the rarer species, and it was fortunate that its life history could be secured.

Description of the adult.—General form elliptical in outline, a little broadened anteriorly and more pointed posteriorly, with a length of 10 mm. and a width of 6 mm. In the female the transverse yellow bar on the thorax is enlarged and turned diagonally backward at either end but does not meet the yellow on the lateral margins. In the male it is not enlarged or turned backward at the ends and it does meet the yellow margin. In both sexes the elytra are black with a transverse row of spots near the base and a wide margin yellow. The black is not an even wash of color but is made by many small black dots, more or less confluent.

The antennæ are 11-jointed, all the joints about the same length and width, except the basal one, which is lengthened at the expense of the second joint. Joints 3 to 7 each carry a small seta on the outer margin at the tip, and joints 3 to 11 have a sensory papilla on the inner margin near the distal end. The mandible is very thick, with a blunt emarginate tip, ending in an acute point at the ventral corner and a rounded tooth at the dorsal corner. The maxillæ are well developed with long, four-jointed palps; the labial palps are also long but only three-jointed and emarginate at the tips. The tip of the second joint develops broad dorsal and ventral wings, armed with sensory papillæ, on the inner margin.

In the males the front tarsi are broadly dilated and bear three larger basal disks and numerous smaller unequal ones. The basal joint carries the 3 large ones and 5 smaller ones, the second and third joints carry 6 each, all small but unequal in size. The largest basal one is twice the diameter of the other two, and they in turn are twice the size of the smaller ones. The fringing hairs are evenly developed and are not interrupted at the point where the tarsus joins the tibia (fig. 67, p. 292).

The femora of the second legs are armed on the posterior margins with long conspicuous setæ, increasing in length towards the tip. The coxæ of the third legs are large, the spurs at the tips of the tibiæ are unequal and distinctly emarginate, the tarsi are armed with long swimming setæ, and the claws at their tips are unequal.

Thermonectes ornatocollis (Aubé). Figs. 53, 56, 59, 61, 63, 66, 68, 71, 74, 147, 148.

Dytiscus ornatocollis (Aubé, 1838, p. 140).

Thermonectes ornatocollis (Sharp, 1882, p. 673).

Eggs.—The eggs of this species are probably deposited singly in the stems of water plants like those of the preceding species.

Habits of the larva.—It swims usually with a uniform motion and fair rapidity, but without any movement of the body. When disturbed, however, it snaps its body like the *basilaris* larva by suddenly lashing the last two segments of the abdomen against the water. This ability to jump or snap the body is retained after the larva comes out of the water, and even after it is inside of the pupal chamber. If an attempt is made to pick up such a larva, it will sometimes jump 8 or 10 inches in this manner. Its breathing habits are similar to those already described for the preceding species.

In the pond it swims about close to the surface and snaps up the copepods and Entomostraca that swarm there. It frequently seizes small objects floating on the surface and draws them beneath the water. After testing them in its mandibles it rejects those that are unfit for food and retains the others. In an aquarium it eats mayfly larvæ, is very fond of the larvæ of both species of *Tropisternus*, and is able to kill them when they are fully as large as itself. As both species of *Tropisternus* are abundant in the ponds from which the *Thermonectes* larvæ were taken it is probable that they constitute at least a portion of the regular food of the latter. After it has killed its prey it usually swims to the surface and hangs from the surface film by means of its cerci, breathing and sucking the juices of its victim. It is much the most graceful and beautifully colored larva of any here described. It is easily recognized, is harmless, and furnishes good fish food.

Description of the larva.—The general structure is the same as that of the *basilaris* larva, but the following differences may be noted. Its total length, including the posterior cerci, is 22 mm., its greatest width is 3.5 mm. In color the dorsal surface of the head and neck is yellow, with the following black markings: The tips of the antennæ and maxillary palps; the bases of the maxillæ and mandibles; two circular spots close together, one on either side of the mid line, near the anterior margin of the head another pair of triangular spots behind the eyes, fused on the mid line, with a wide band extending from the side of each to the lateral margin of the head behind the eyes; the entire eye areas; a semicircular spot on either side of the neck behind the head. The dorsal surface of the thorax and abdomen is light yellowish-brown, the sclerites narrowly edged with black, with a secondary edging on the lateral margins inside of the first. Inside of this row of secondary edgings is a longitudinal stripe of dark brown, connecting anteriorly with the black line on the lateral margin of the head and running the whole length of the body. There is another dark brown stripe on either side close to the mid line; along the mid line and between the stripes are bands of light yellowish-brown.

The terminal joint of the antenna is relatively larger than in the *basilaris* larva; the mandibles have a fringe of hairs on the outer margin near the base and a row of fine teeth in the groove near the tip. The maxillæ are similar with a fringe of long hairs along the outer margin and the addition of a dense covering of spines and hairs over the inner half of the basal portion. The labial palps are armed with short spines on the outer distal margin of the basal joint and on the outer margin of the terminal joint near the base and at the tip. The inner margins of the terminal joints are sinuate for their distal half. The ligula is relatively shorter than in the preceding species, but the two-jointed spines at its tip are longer, being fully as long as the ligula itself.

Two of the eyes—the dorsal members of the anterior and middle pairs—are much larger than the others, are reddish in color, and protrude strongly from the surface of the head. The posterior pair are much smaller and are close together on the lateral surface of the head, only the dorsal member of the pair being visible from above. The ventral members of the first two pairs are on the ventral surface of the head and are separated from the dorsal members by wide intervals, the space between the two members of the middle pair being fully four-fifths of the thickness of the head. None of these last four eyes project at all from the surface of the head. The underlying pigment of the two larger eyes is not confined to the surface immediately beneath the skin but penetrates downwards and backwards nearly

FIG. 69.—Ventral view of pupa of *Thermonectes basilaris*. FIG. 70.—Side view of same, showing arrangement of spines. FIG. 71.—Ventral view of pupa of *T. ornatocollis*. FIG. 72.—*T. basilaris*, antenna of adult beetle. FIG. 73.—Maxilla of adult beetle. FIG. 74.—Maxilla of adult *T. ornatocollis*.

to the ventral surface. This arrangement of the eyes and penetration of the pigment is the same in the two species here described, and in the *Acilius* larva, which follows, but nothing like it was noted in any of the other larvæ. It thus serves to denote the close relationship of this genus with *Acilius*.

Pupation.—This larva does not travel as far from the water's edge as the preceding but builds out of mud pellets a similar pupal chamber, which is ellipsoidal and about 14 by 16 mm., outside measure. This is often built beside a grass or rush stem or under a pile of rubbish and its walls are so thin that the larva often tears them asunder by snapping about when disturbed. Since the inner diameter of the chamber is only a trifle more than half the length of the larva, the latter is of necessity folded upon itself, like the species already described. Similarly the skin splits open along the dorsal mid line from the base of the head to the seventh abdominal segment and is flattened against the inside of the chamber wall. About 30 hours elapse between the completion of the chamber and pupation.

Description of the pupa.—This pupa differs from the preceding in the following particulars. In size it is half as large again, measuring 13 to 14 mm. in length and 6 to 7 mm. in greatest width. The front margin of the prothorax is armed with a row of short spines rather than long styli and there are no processes on its lateral margins. The antennæ are longer and reach nearly to the tips of the wings. The first and second legs are not as long, and the latter do not reach the tips of the elytra; the third legs are the same length, but all three pairs are much stouter. The length of time spent in the pupal stage varies considerably as can be seen from the following table compiled from eight larvæ reared to the adult stage.

Completion of chamber.	Pupation.	Emergence.	Completion of chamber.	Pupation.	Emergence.
Aug. 3.....	Aug. 4.....	Aug. 8.	Aug. 4.....	Aug. 4.....	Aug. 8.
Do.....	do.....	Aug. 9.	Do.....	Aug. 5.....	Aug. 10.
Do.....	do.....	Do.	Do.....	do.....	Do.
Do.....	Aug. 3.....	Aug. 7.	Aug. 5.....	Aug. 6.....	Aug. 11.

Description of the adult.—This beetle may be distinguished from the preceding species by the following differences: In size it averages fully one-half longer and one-third wider, having a length of 15 to 16 mm. and a width of 8 to 8.5 mm. In color the sides of the M-shaped mark on the head do not touch the eyes, but there is a distinct yellow band between the two, whereas in the preceding species they do touch the eyes and there is no band. On the thorax of *basilaris* the two transverse black bands touch the anterior and posterior margins, respectively, and there is a single yellow band between them. In *ornaticollis* they do not touch these margins and there are three yellow bands. Across the bases of the elytra in the preceding species is a black band, which turns backward a short distance at the outer corners; in the present species the bases are yellow, and this color extends along the inner margins nearly or quite to the posterior ends. In *ornaticollis* the distal half of the lateral margins of the elytra is heavily fringed with long hairs, in *basilaris* it is nearly smooth. The rounded tooth at the dorsal corner of the mandibles of the preceding species is bordered on either side by a deep sinus; in the present species there are no sinuses. The labium here is relatively shorter and wider; in the preceding species it is longer and narrower. In the dilated tarsus of the male of this species the basal joint is longer than the second and third joints together, and carries 10 disks, 2 large ones on the proximal and 1 on the distal margin, the 3 about the same size and forming a triangle, the other disks much smaller and unequal on the lateral and distal margins. The second joint carries 5 on the inner and 2 on the outer margin; the third joint carries 10 irregularly arranged, 5 of medium size and 5 smaller ones. In the preceding species the basal joint is also longer than the second and third joints together, but it carries only 8 disks, 1 large one at the outer proximal corner, 1 half as large at the inner proximal corner, another the same size on the distal margin, and 5 much smaller ones along the outer distal area. The second and third joints each carry 6 disks about the size of the smallest ones on the basal joint along the inner and distal margins.

These differences in the adult beetles, together with the life histories here presented, effectively establish the present as a distinct species rather than a variety of *basilaris*. Blatchley (1919) arrived at the same decision from his study of the adults in opposition to Leng and Mutchler (1918, p. 90), who considered *ornaticollis* as a mere variety of *basilaris*.

Genus ACILIUS Leach.

Acilius (Leach, 1817, p. 69).

This is a genus of medium-sized species, which are somewhat obovate in form and have the upper surface in the male smooth and regularly punctate; in the female usually sulcate but still distinctly punctate. The front tarsi in the male are dilated and armed with one large and two medium-sized disks and a number of smaller ones. The middle tarsi are equal, and the hind claws are equal. Neither the larvæ nor the adults have been known to attack or injure young fish, and the larvæ show no cannibalistic tendencies but live peaceably with one another, even in an aquarium.

Acilius semisulcatus Aubé. Figures 21, 75-78.

Acilius semisulcatus (Aubé, 1838, p. 132).

Eggs.—Miall quoted Régimbart as saying that *Acilius* lets its eggs drop at random upon the mud while swimming about (Miall, 1895, p. 40), but it would seem probable, judging from its ovipositor, that some are inserted in the stems of water plants.

Habits of the larva.—Thirty larvæ were obtained from pond 7D when it was drained and were kept in an aquarium for 10 days. Nearly every kind of larvæ in the ponds was offered to them as food, but the only thing they ate, as far as observed, was a few small snails. Efforts were also made to induce them to pupate but without success. From their great similarity to the larvæ of the two species of *Thermonectes*, from their size and from their close correspondence to the known larvæ of *Acilius* as found in Europe, it is reasonable to assign them to the genus *Acilius*. And since *semisulcatus* is the only species found in the ponds they have been referred to this species.

They are larger and even more graceful and agile than the larvæ of the two *Thermonectes* species just described. They swim rapidly and easily, always keeping the abdomen curved upward, often at an angle of 45°. When resting on the bottom or on any support, the abdomen is curved into a crescent shape, the center of the curve in contact with the support. When they wish to rise to the surface, they can usually do so by simply letting go of the support. The air within the tracheæ is then buoyant enough to carry them up tail first. Occasionally they are forced to swim with slight movements of the legs or by a sort of jerking motion of the abdomen, and the tail is still kept upward. At other times they swim up head first and when near the surface elevate the tail and thrust it above the water. After doing this the body is allowed to drop downward, and they hang from the surface film for a long time, supported by their cerci.

Like *Thermonectes* they can flex the body suddenly at the first abdominal segment and straighten it with equal rapidity, both movements being imperceptible to the naked eye. The result is a snap or jump that often throws the larva several inches. This is undoubtedly the "peculiar indescribable motion of the whole body away from the point of disturbance" declared by Needham and Williamson (1907) to be characteristic of one of the larvæ studied by them. They added also: "Sometimes it makes just one quick dodge, and sometimes it goes through a series of wriggling movements so swiftly executed that the eye can not follow them" (1907, p. 489). They ascribed their larva to a species of *Acilius*, which it may well have been, since the figure they gave (fig. 8, b, p. 491) of the maxilla compares favorably with Figure 76, although the palp had not yet acquired the short spherical penultimate segment. When a larva dies and sinks to the bottom of the aquarium, it is always found with the body sharply flexed at the first abdominal segment and must be straightened before being preserved.

Description of the larva.—General form an elongate spindle 24 mm. long and 3.15 mm. wide, narrowed considerably both anteriorly and posteriorly, widest through the third and fourth abdominal segments, whose diameter is a little less than one-seventh of the body length. The color pattern affords the readiest means of recognition and is given in detail. General color olive yellow; head with the following black—the tips of the antennæ, maxillæ, and palps, the eye areas, the anterior margin of the labro-clypeus, a spot on either side of the mid line just behind the anterior margin, a broad band connecting the posterior ends of the eye areas, and irregular spots on the sides and dorsal surface at the base of the head. On the dorsal surface of the thorax and abdomen the sclerites cover the entire tergum and extend onto the pleurum, so that their lateral margins are invisible in dorsal view. Each sclerite is narrowly bordered

FIG. 75.—Dorsal view of the head of *Acilius semisulcatus*, showing the color pattern. FIG. 76.—Maxilla, dorsal view. FIG. 77.—Labium, ventral view. FIG. 78.—Labium, dorsal view. FIG. 79.—Dorsal view of larva of *Hydroporus niger*. FIG. 80.—Frontal margin of proboscis, ventral view. FIG. 81.—Side view of head. FIG. 82.—Mandible. FIG. 83.—Maxillae and labium, ventral view.

with dark brown along the anterior and lateral margins and much lighter brown along the posterior margin. On the lateral margins of all except the prothorax there is a second narrow dark line above the one along the edge, and on the first six abdominal segments a third much wider line and a fourth very narrow line. On the prothorax a narrow brown band runs from the anterior margin nearly to the posterior margin on either side of the mid line. These bands widen and diverge slightly posteriorly. Beginning again in the mesothorax and a little wider, they extend to the posterior margin of the seventh, abdominal segment, being interrupted by narrow yellow transverse lines near the posterior margin of each abdominal segment. Outside of these bands and separated from them by a longitudinal yellow stripe is a wider brown band on either side, beginning with the third and ending with the seventh abdominal segment. All these brown bands deepen in color posteriorly and the two on either side fuse just in front of the transverse yellow line in each segment.

On the central bands are small areas much deeper in color, a pair at the anterior margin of each segment. Those on the mesothorax and metathorax and the first two abdominal segments are minute and are partially concealed beneath the posterior margin of the sclerite in front. On the seventh segment the brown bands fuse across the posterior two-thirds of the segment, leaving only the mid line yellow. On the eighth segment the entire surface is yellow, with a narrow black band at the extreme posterior end and the two tracheæ showing as a dark longitudinal line on either side. The fringes along the lateral margins of the seventh and eighth segments are dark brown, almost black; the cerci are a much lighter brown. On the legs the edges of all the joints are pencilled with dark brown. The entire under surface is yellowish-white, except the seventh segment, which is tinged with brown. There is a fringe of silky black hairs along the ventral margins of the abdominal pleura on either side and scattered hairs across the posterior margin of the second, third, fourth, and fifth abdominal segments. The spiracles and the tubes connecting them with the tracheæ are jet black; those of the seventh abdominal segment open on the ventral surface.

Head an elongate trapezoid, one-half longer than wide, widest through the eyes, narrowest at the posterior margin, with straight sides. Epicranial suture nearly half the length of the head; frons triangular with curved sides, the anterior margin bordered with a thick fringe composed entirely of short stout spines, arranged in several rows. There is a transverse row of long setæ just in front of the dark spot on the frons. Between the fringe and this row of setæ the surface is covered with scattered minute spines. Around the dark spot and through its center longitudinally are short setæ.

The antennæ are six-jointed, the first, third, and fifth joints stout and about the same length, the second and fourth joints almost spherical and less than one-fourth as long, the terminal joint a narrow fingerlike process of about the same length as the second and fourth joints. The mandibles are of the usual dytiscid form, rather short and stout, and they do not overlap much when closed. The maxilla is similar to that of *Thermonectes* and consists of a long curved basal portion with a single row of spines on its dorsal surface, a fringe of long hairs along its outer margin, another fringe of short hairs along its inner margin, and a slender, acute spine at the distal end. The palp is four-jointed, the first, second, and fourth joints about the same length, the third joint spherical and much like the similar ones in the antennæ. The labium is elongate; the palpigier is one-half longer than wide and rounded at the distal end. Its dorsal surface along the lateral margins and across the distal end is raised somewhat and thickly set with small spines. Each palp is composed of two slender joints, of about the same length and together reaching the tip of the maxilla. The terminal joint is sparsely armed with small spines; the ligula is slender, as long as the basal joint of the palps, and sparsely armed with spines.

The prothorax is twice as long as wide, the posterior margin where it is widest being twice the width of the anterior, the sides concave. The mesothorax and metathorax are one-half wider than long; the abdominal segments increase regularly in length backwards, the first three increase slightly in width, the fourth is the same width as the third, and the remaining segments decrease rapidly. At the posterior end of the body are two slender cerci, one-third as long as the last segment.

Habits of the adult.—This beetle is an excellent swimmer, being surpassed in this respect only by *Cybister* and *Dytiscus*, and in its jumping ability it comes very close to *Thermonectes* and *Laccophilus*, but it is a very poor walker and flounders along awkwardly. In the ponds it is active and restless, moving about almost continuously and scarcely pausing except now and then to eat its prey. It feeds upon dragonfly and damselfly nymphs, the nymphs of *Belostoma* and *Notonecta*, mayfly larvæ, and the larvæ of hydrophilid beetles. It did not attack any of the dytiscid larvæ in the ponds, possibly because they are difficult to catch.

Description of the adult.—General form broadly obovate, 14 to 15 mm. long, 7 to 8 mm. wide; dull yellowish-brown on both dorsal and ventral surfaces, the thorax and elytra with yellow margins and the posterior abdominal segments with ventral yellow spots on either side. Head with the base and a broad M-shaped mark black; thorax with a narrow black line near each lateral margin of the disk and two wider transverse ones. In all the females obtained the elytra were broadly sulcate or grooved; in the male they were smooth with a subapical yellowish cross bar. The front tarsi of the male are broadly dilated; the basal joint bears a large sucking disk at its posterior proximal corner and two very much smaller ones on its anterior margin. The second and third joints bear numerous rows of minute hairs terminating in sucking disks along both anterior and posterior margins, and the posterior ones extend onto the basal joint distal to the sucking disk. These tarsi are thus quite different from those in other genera and help in identification.

Genus DINEUTES MacLeay.

Dineutes (MacLeay, 1825, p. 30).

This is a genus of fair-sized beetles belonging to the Gyrinidæ, or whirligig beetles; they are more or less oval in form and quite strongly depressed. The upper surface is bronzed, shining, and finely reticulate, and in the only species found in the Fairport ponds the ventral surface is black and shiny. The front tarsus of the males is dilated only a little and is clothed with rows of short tubular suckers. The adults are harmless and never injure or attack young fish, but the larvæ have been known to kill and eat small fish under somewhat abnormal conditions.

Dineutes americanus Say. Figures 84-94.

Dineutes americanus (Say, 1825, p. 107).

Cyclinus assimilis (Kirby, 1837, p. 78).

Dineutes assimilis (Wickham, 1893a, p. 330, pl. 9; 1894, p. 39).

Eggs.—The eggs were found in clusters varying from 7 to 40 in number on the under surface of the leaves of *Potamogeton illinoensis* in pond 2D. They were white in color and were arranged diagonally at an angle of 45° with the mid rib of the leaf, all on one side near the base. They were regular elongated ellipsoids, 1.85 mm. long and 0.64 mm. in diameter. The egg shell consists of a thin and smooth inner membrane covered with a much thicker layer composed of short cylinders placed end to end and packed so closely together as to become more or less hexagonal. The cylinders are of different diameters and their outer ends are rounded into hemispheres. This thick prismatic layer covers what may be called the top of the egg, namely, the surface next to the leaf, runs down on either side and onto the bottom surface, but leaves quite a wide strip through the center of this surface uncovered. The two edges of the thickened layer meet at the posterior end of the egg but not at the anterior end. Each egg is glued separately to the leaf by a transparent colorless cement, which extends the whole length of the egg and projects slightly beyond the ends. The egg is apparently not flattened at all on the top next to the leaf. The larva is folded lengthwise inside the eggshell in the same manner that the mature larva afterwards folds itself inside the pupal chamber. The dorsal surface of the thorax and the first five abdominal segments are next to the surface of the leaf, the rest of the abdomen is folded up against them and the head is folded against this posterior abdomen with the antennæ and mouth parts fully extended. The lateral gills are closely appressed to the sides of the body.

When the egg hatches, the shell splits lengthwise on the bottom through the space uncovered by the prismatic layer from end to end. The larvæ all hatch at about the same time and crawl around on the surface of the leaf amongst the empty eggshells for several hours before swimming away. The hatching occurs five or six days after the eggs are laid.

The newly hatched larva.—As soon as it is once straightened out the newly hatched larva is from 5 to 5.5 mm. long, and the head, which is the widest part of the body, is 0.75 mm. in diameter. This larva is like the fully matured one, except that the prothorax is as wide as the mesothorax and metathorax, and the first two pairs of lateral gills are plumose like the others.

FIG. 84.—Dorsal view of larva of *Dineutes americanus*. FIG. 85.—Head of same, enlarged. FIG. 86.—Antenna. FIG. 87.—Mandible. FIG. 88.—Maxilla, dorsal view. FIG. 89.—Labium, ventral view. FIGS. 90 and 91.—External and internal hook on last segment of abdomen.

Habits of the larva.—This larva swims with a sinuous motion of the whole body up and down after the manner of a flatworm. There are no swimming fringes on the legs, but instead the eight posterior pairs of lateral gills are heavily fringed on both sides, and thus serve for locomotion as well as for breathing. By lashing them up and down the larva can move either forwards or backwards with great rapidity. On the land it crawls quite rapidly; being unable to lift the posterior part of the abdomen above the ground, it aids locomotion by using the last segment with its hooks like the posterior prolegs of the caterpillar, arching the abdomen upward like the so-called inchworm. It can also jump quite a distance by snapping its body in the same manner as the *Thermonecetes* larva. When two larvæ come together out of the water, the first instinct is self-preservation, and each jumps back as far as it can.

In an aquarium the larva rests nearly always on the bottom and not on the water plants, and the abdomen maintains a constant trembling motion up and down, which is evidently its mode of breathing. Hence, it never needs to come to the surface for an air supply.

It is not very voracious but will defend itself fiercely when attacked and will catch anything that is unfortunate enough to crawl against it. It sometimes attacks and kills small fish as is related on page 250. It shows a preference for the nymphs of damselfleis and mayflies and the larvæ of *Corethra* and *Chironomus*.

Description of the larva.—The larva has the appearance of a small centipede, owing to the presence of lateral gills along the abdominal segments (fig. 84). When full grown it measures 25 to 30 mm. in length and 3 to 3.5 mm. in width. The body is made up of the head, 3 thorax and 10 abdomen segments, and is seven times as long as wide and strongly flattened. The general color is white, lighter on the ventral surface and in the lateral gills, and faintly tinged with yellowish-brown on the dorsal surface. The eyes are black, but the following parts are dark brown—the mandibles, a triangular spot between the bases of the antennæ and the eyes, the neck on both the dorsal and ventral surfaces, the posterior margin of the dorsal plates on the first thorax segment, and a small spot on the dorsal surface of the base of each leg in the shape of an inverted ∇ .

The head is elliptical in outline, one-third longer than wide, flattened dorsoventrally, but with both surfaces convex, almost squarely truncated anteriorly with a small rostrum on the mid line, bordered on either side by a short pointed tooth. The antennæ project from the dorsal surface of the head behind the outer corners of the bases of the mandibles. Each is four-jointed, the three terminal joints filiform and diminishing a little in length and diameter, the basal joint much wider and shorter. The mandibles are alike, each is slender, curved, acute, and suctional, the inner tube opening through a slit near the tip.

The maxillæ are a little longer than the antennæ and are attached to the ventral surface of the head just inside the bases of the mandibles. The basal joint is long and stout, the second joint about half the length but nearly as wide. To its outer corner is attached the four-jointed palp, the three distal joints about the same length, the proximal one about half as long. At the inner corner is a long curved process, emarginate at the tip, representing the lacinia, and between the lacinia and palp is a two-jointed galea, the terminal joint much longer and narrower than the basal, both joints armed with a long seta. There are also two setæ on the dorsal surface opposite the base of the galea, two on the outer margin near the basal joint, and a small curved spine on the inner margin at the base of the lacinia. The labium is peculiar in that the bases of the palps are fused on the mid line; the palps themselves are three-jointed with a small fold or wrinkle between the first and second joints; obviously there is no chance for a ligula.

As in the *Dytiscidæ*, the eyes are 12 in number, a group of 6 just behind the base of each antenna and all visible in dorsal view. Their arrangement may be seen in figure 85, p. 303; the two dorsal eyes are close together with their long axes at right angles to each other. The other eyes are separated a short distance laterally and a much longer distance longitudinally, and their long axes are parallel, respectively, to those of the dorsal pair. All the eyes protude slightly from the surface, and in the space between them a seta is located. Posteriorly the head is narrowed into a short neck, covered with two narrow plates on the dorsal surface, but naked on the ventral surface.

The three thorax segments are about the same length, but the first one is a quarter narrower than the other two and carries a pair of dorsal plates. The other segments and the abdomen are destitute of dorsal plates, since this is not a burrowing larva.

The 10 abdominal segments are represented in length by the numbers 11, 15, 18, 18, 19, 19, 20, 20, 15, 10, and in width by the numbers 28, 31, 33, 35, 34, 34, 33, 30, 21, 8. From the posterior corners of

each segment is given off a pair of narrow, conical gills, 10 times as long as wide, contracted at the base and tapered to an acuminate point. The ninth segment carries two on either side instead of one, and the tenth segment has none. Each gill contains a narrow central tracheole, and the eight posterior pairs are heavily fringed with hairs, although the first two pairs are naked. The tenth segment is naked, a little longer than wide, and armed at its posterior end with four sickle-shaped hooks, the inner one on either side considerably larger than the outer one. Miall (1895, p. 36) said of these hooks in the *Gyrinus* larva that they "are believed to be of use in climbing." They are also used during the construction of the pupa case, holding the posterior end of the larva securely in place while it gathers the materials for making the case.

Pupation.—When the larva is full grown, it crawls out of the water and up the bank, and its lateral gills shrivel up and fall off, except the last double pair and the single pair just in front of them, which are used for locomotion. The distance traveled and the place finally selected appear to depend upon the moisture of the earth, which must be soft enough to be easily worked but not moist enough to be muddy. The larva is quite particular in its choice and often covers a considerable area before finding a location that suits it.

Then there must be a convenient support to which the pupa case may be attached. The under surface of a dead grass or rush stem was usually chosen, since it was near enough to the ground for the larva to reach after building material and at the same time far enough removed to give the space requisite for the completed case. The case is made of pellets of earth stuck together with saliva. The earth apparently is not chewed and thoroughly mixed with the saliva after the manner of the mud wasps; rather, a mouthful of material is seized by the mandibles, wet with saliva, and pressed into place, and there is no smoothing of the outside surface or shaping by the mandibles. The outside of the case is rough, but the curve of the walls is quite regular. Sand grains, small fragments of rock, bits of wood, and pieces of leaves are mixed with the mud pellets in the walls. The larva clings to the grass stem with its posterior hooks and constructs the case around its own body. When the case is finished, except a small orifice at one end, the larva transfers enough material to the inside of the case and completes it from there. The case is 13 to 16 mm. long, 8 to 10 mm. wide, and is usually a fairly regular ellipsoid. The walls are about 1 mm. in thickness, except at the ends, where it is increased to 2 mm. A full-grown larva is about 30 mm. long, and hence its body must be folded inside the case; it assumes the form of the letter C, the ventral surface inside. After resting two or three days the skin splits open along the dorsal mid line from the base of the head to the ninth abdomen segment and flattens out against the inside of the case.

Description of the pupa.—General shape oblong, rather squarely rounded anteriorly, more pointed posteriorly, the head folded down upon the thorax and invisible in dorsal view. Length 10.5 mm., width 4.5 mm. through knees of first legs. Color yellowish-white, turning later into brown on the dorsal surface; eyes black. The eyes are divided as in the adult, each half a hemisphere, the flat surfaces facing each other and connected by a narrow cord. The front of the head reaches well beyond the bases of the first and second legs, and the maxillary palps project diagonally from beneath the upper lip. The basal joints of the legs are at right angles to the body axis and the knees project beyond the lateral margins. The tips of the first legs meet on the mid line, those of the second legs are separated a short distance, and those of the third legs are widely separated. The elytra are considerably shorter than the wings and are squarely truncated at their tips, whereas the wings are bluntly pointed.

On the ventral surface of the pupa there are no setae, except a ragged fringe across the anterior margin of the prothorax and at the posterior end of the abdomen. The dorsal surface is plentifully supplied with setae, as shown in Figure 93. When the pupa case is horizontal, the pupa rests usually upon its back, and when the case is vertical upon the tip of the abdomen.

These pupae can not be preserved like the others in 95 per cent alcohol, nor in a mixture of 95 per cent alcohol and 10 per cent formaldehyde. In either preservative the pupa flattens out completely in a day or two and is absolutely worthless. Carnoy's mixture of glacial acetic acid, absolute alcohol, and chloroform is the only preservative tried that gave satisfactory results.

Wickham (1893a) noted that this pupa is much more quiescent than is usual with the Coleoptera, and he could only detect the faintest movement of the abdomen in the specimens he observed. If the pupa be overturned in its case, however, or be irritated with a needle, it will prove to be lively enough and will wriggle about vigorously.

The duration of the pupal period is seen in the following table:

Entered chamber.	Pupated.	Emerged.	Entered chamber.	Pupated.	Emerged.
1919.			1920.		
July 8.....	July 10.....	Died.	July 20.....	July 23.....	July 28.
July 13.....	July 15.....	July 20.	July 21.....	July 22.....	Do.
July 14.....	July 16.....	July 21.	Do.....	July 23.....	July 29
Do.....	do.....	Do.	July 22.....	Do.....	Do.
			Do.....	July 24.....	Do.
1920.					
July 20.....	July 23.....	July 28.			

Habits of the adult.—This genus includes the largest of the whirligig beetles, and the present species is the most abundant of any found in the fishponds. Although nowhere occurring in such swarms as characterize the closely related genus *Gyrinus*, the aggregate, nevertheless, forms a very respectable percentage of the pond fauna.

The locomotion is peculiar, whirling or spinning around a vertical axis, or circling in companies on the surface of the water; they seem never to move straight away in any direction. They swim with great rapidity and dive like other beetles, but spend most of their time on the surface film, and hence with the upper portion of their bodies in the air. To fit them for this mode of life, the under surface of the body is very flat lengthwise but quite convex transversely, and is hence shaped much like the bottom of a canoe. They skim the surface so rapidly and whirl about with such agility that it is extremely difficult to catch them without a net. They can fly well and frequently fly into the laboratory at night, but they can not rise from the surface of the water; they must climb up a grass or rush stem in order to spread their wings.

The adults are carnivorous like the larvæ, but have rather the habits of scavengers, feeding upon dead animal matter that finds its way into the ponds and floats on the surface. Miall (1895, p. 33) quoted the following observation by W. F. Baker:

I was once watching some Gyrini when a gadfly came flying round my head. I struck at it and knocked it into the water stunned if not dead. Two or three Gyrini seized it and shortly afterwards the whole swarm clustered round. In a short time nothing was left except the wings of the fly, which were allowed to drift away. This is the only occasion on which I have seen anything of the sort. I could never get captive Gyrini to eat dead flies.

That the genus *Dineutes* responds more readily to artificial feeding is manifest from the following: The adult *Dineutes americanus* in pond 2F were fed with freshly killed insects, including two kinds of grasshoppers, two grass moths of different species, two damselflies (*Ischnura verticalis* and *Enallagma hageni*), a dragonfly (*Leucorhinia intacta*), a butterfly (*Phyciodes tharos*), and a mayfly imago (*Hexagenia* sp.), and they ate them all voraciously. As many would seize the insect as could crowd around it, grasping it with their mandibles. Then they would swim off, sometimes going fairly straight away, sometimes whirling around in wild curves and sometimes diving beneath the surface, but always holding on to their prey and tearing out mouthfuls of the insect tissues. When one bit off more than he could swallow at once, he would hurry away with it, pursued by a hungry crowd, each intent on snatching it from him, and he was lucky if he could keep it long enough to finish devouring it.

Another habit became conspicuous during the hot weather of the summer. Ordinarily the adult whirligigs are more or less scattered over the surface of the pond, but on hot days they show a decided preference for the shade. Most of the ponds have a small pier running from the shore to the outlet pipe to facilitate the handling of the latter. This pier is made of short lengths of plank with spaces between and casts a shadow which is either solid or streaked with rays of light according to the time of day. All the adult *Dineutes* in the pond on hot days gathered in this shadow about the middle of the forenoon and remained until late in the afternoon. When the shadow was solid they scattered indiscriminately over it, but when it was crossed with streaks of sunshine they carefully avoided the latter. The accompanying photograph (fig. 4, frontispiece) shows them thus congregated beneath the pier of pond 5D. It was taken about noon by H. W. Clark.

Description of the adult.—General outline an elongated ellipse 11.5 to 12.5 mm. long, 4.5 to 5 mm. wide, thus almost two and a half times as long as wide, the last segment in the female and the last two segments in the male projecting behind the elytra. Both dorsal and ventral surfaces distinctly convex; only the first legs visible in dorsal view, the others folded beneath the body. Above black, the elytra

FIG. 92.—Ventral view of pupa of *Dineutes americanus*. FIG. 93.—Dorsal view of the same. FIG. 94.—Head of adult beetle with old larva head still adhering to it. For some reason the epicranial suture did not open and allow the larva to withdraw its head at the time of pupation. FIG. 95.—Antenna of larva of *Berosus pantherinus*. FIG. 96.—Right mandible of *Berosus striatus*. FIG. 97.—Left mandible of same. FIG. 98.—Left mandible of *B. pantherinus*. FIG. 99.—Maxilla of *striatus*. FIG. 100.—Maxilla of *pantherinus*. FIG. 101.—Labium of *striatus*.

strongly bronzed; beneath black very shining; abdomen tinged with brown; legs brownish-yellow. Elytra of the male feebly sinuate both on the lateral margins and near the tips, the latter separated but little and the angles only slightly produced backwards. In the female both sinuations are more pronounced, the tips are more widely separated, and the angles are more distinctly produced.

The antennæ are peculiar and are very similar to those of *Gyrinus*, which are usually cited by authors as the type of what is known as the irregular form. Each antenna is made up of two parts, a proximal portion of three joints and a distal portion of seven joints. The second proximal joint is produced into a wide wing, which curves up around the base of the distal portion of the antenna. To the inside of this wing is attached the third proximal joint, and the first distal joint is fastened by a minute neck to the dorsal surface of this third joint. The distal portion of the antenna is club-shaped and six-jointed, the first joint apparently made up of three joints fused. Miall (1895, p. 34) said: "The peculiar form of the *Gyrinus* antenna is probably a means of keeping it dry." In this antenna the enveloping wing of the second proximal joint and the long fringes of hairs on the third joint assist in keeping the sensory terminal portion dry.

The mandibles are large and strong but are blunt and approach the herbivorous type more closely than the carnivorous. The maxillæ are sharp and sickle-shaped and typically carnivorous; the palp is five-jointed and somewhat club-shaped. The labium is well developed, with large circular paraglossæ and three-jointed palps.

The fore legs are prehensile, and in the male the tarsal joints are slightly dilated and their ventral surface is covered with rows of suckers that stand out like the pile on velvet. Each sucker is a narrow tube enlarged at the tip into a cup-shaped disk.

Genus *GYRINUS* Geoffroy.

Gyrinus (Linnaeus, 1758, p. 412).

Gyrinus (Geoffroy, 1762, p. 193).

This is a genus whose species are smaller, narrower, and more convex than those of the preceding genus. Each elytron has 11 rows of distinct punctures and when held so as to reflect the light usually shows a yellowish tint. The legs vary from yellow to reddish-brown in color and are relatively longer than in the genus *Dineutes*. The species vary so little that they are hard to distinguish; four have been reported from the fishponds but are not found there regularly. They seem rather to be itinerant visitors from the river and occur most frequently on the ponds that are nearest the river.

Gyrinus ventralis Kirby, 1837, p. 80.

Gyrinus limbatus Say, 1825, p. 109.

Neither of these species breeds in the Fairport fishponds, but the adults are occasionally found there in considerable numbers, and hence the more important facts in their life history will be of interest. These facts are taken from various authors and apply equally to the two species.

Eggs.—The eggs are laid in rows on the leaves or stems of water plants and closely resemble those of the preceding genus in shape, in color, and in time of hatching.

Habits of the larva.—It swims and breathes in the same manner as the larva of *Dineutes* already described. According to Miall (1895, p. 39): "The *Gyrinus* larva feeds upon water insects and possibly upon other aquatic animals. Failing these it will eat the tender parts of submerged plants." According to Needham the larvæ also "feed upon the body fluids of bloodworms and other small animal prey" (1916, p. 221). It is difficult to understand how a larva like this, whose mouth parts are typically carnivorous, and whose mandibles are suction-like like those of the *Dytiscidæ*, can eat vegetable food as stated by Miall.

Description of the larva.—This larva is similar to that of *Dineutes*, except that the first two pairs of lateral gills are fringed with hairs like the other pairs. This larva is only about 14 mm. in length and is widest through the second thoracic segment, which is nearly 2 mm. in width. The abdomen

FIG. 102.—Dorsal view of larva of *Berosus striatus*. FIG. 103.—Head of same enlarged. FIG. 104.—Head of larva of *Berosus pantherinus*. FIG. 105.—Antenna of larva of *B. striatus*. FIG. 106.—Antenna of adult beetle, *striatus*. FIG. 107.—The same, *pantherinus*. FIG. 108.—Maxilla of adult *striatus*. FIG. 109.—Maxilla of adult *pantherinus*.

contains 10 segments, and the last one is armed with two pairs of sharp, curved hooks similar to those on the *Dineutes* larva. The mouth parts are also similar, the mandibles being sharp-pointed, perforated by a slit near the apex, and hence suctional. The lateral gills increase in length backwards and contain tracheoles, which give off smaller branches to the gill walls. The legs are long and slender and destitute of swimming hairs.

Pupation.—According to Miall (1895, p. 39):

The pupa of *Gyrinus* is so well hidden that few naturalists have ever seen it. Modeer, quoted by De Geer, says that about the beginning of August the larva creeps out of the water by climbing up the water-plants, and then spins a grayish cocoon pointed at both ends. Inclosed in this cocoon it changes to a pupa and emerges as a perfect insect towards the end of the same month. Modeer adds that the pupa is very liable to the attacks of *Ichneumon*s.

It hardly seems possible that this larva would depart so far from the custom of the *Dineutes* larva as to spin a cocoon of silk. The *Dineutes* cocoon is grayish and pointed at both ends, but it is certainly made of mud pellets, although it looks oftentimes as if it were made of silk. It seems more probable that the *Gyrinus* cocoon is also made of mud, and the larva would be just as susceptible to the attacks of *Ichneumon* flies while constructing it.

Description of the pupa.—This pupa is similar in all respects to that of *Dineutes* but is much smaller and entirely white in color. The bases of the first swimming legs project similarly beyond the lateral margins and are at right angles to the body axis. The labrum is very distinct, and the head has a large prominence on either side just above the base of the antenna.

Habits of the adult.—These gyrenids prefer gently running water and congregate in swarms on the surface of the river (fig. 5, frontispiece), but careful search has failed to reveal a single larva, pupa, or pupa case around any of the ponds. Hence, except for the food which the adults occasionally furnish to the fish, they do not enter into the ecology of the ponds at all. They fly with ease but like the *Dineutes* adult can not take flight from the surface of the water. Westwood (Miall, 1895, p. 33) said that he found their food to consist of small dead floating insects, and it thus resembles closely that of *Dineutes*. Fowler (Miall, 1895, p. 33) remarked that the broad and blunt mandibles indicated a partially vegetable diet, though the sharp and sickle-shaped maxillæ favored a different conclusion, and Miall himself (1895, p. 33) added that in captivity the adults feed upon water-plants. Miall also adds an interesting item that these adults when handled give off from the joints of the body a milky fluid that has the odor of cockroaches. The male is capable of producing a squeaking noise by rubbing the under side of the elytra against the dorsal surface of the posterior abdomen segments.

Genus *BEROSUS* Leach.

Berosus (Leach, 1817, p. 92).

This is a genus of small, convex, and elongate beetles, usually of a yellowish color with darker spots on the thorax and elytra. They are herbivorous, both the adults and the larvæ feeding on green algæ. The antennæ of the adults have only seven segments, and the posterior tibiæ and tarsi are densely fringed with swimming hairs.

Berosus striatus (Say). Figs. 96, 97, 99, 101-103, 105, 106, 108, 110.

Hydrobius striatus (Say, 1825, p. 108).

Egg cases.—The egg cases are attached to the stem or leaf of some submerged plant. The case and its fag² much resemble one of the old-fashioned long-handled warming pans, in which coals were placed for the purpose of warming up a bed before sleeping in it. The case proper is circular or elliptical in outline, about 2 mm. long, 1.5 mm. wide, and 0.33 mm. high, the length being measured continuous with that of the fag. It is surrounded by a narrow band or margin of silk, which fastens it securely to the support. Both the upper and the under surfaces are quite convex. The fag is ribbon-like, from 4 to 6 mm. long and about 0.2 mm. wide, and it usually clings to the support, running up from the case toward the surface of the water but never quite reaching it. Each case contained from three to five eggs, which apparently require from 8 to 10 days to hatch.

² See p. 332.

The newly hatched larva.—The newly hatched larva is 2 mm. long and 0.35 mm. wide through the metathorax. It is light gray in color, the chitin areas tinged with yellowish-brown, and the entire surface covered with minute setæ. The legs and lateral gills are much longer in proportion to the body than those of the mature larva, and the metathorax is wider than the abdomen, but otherwise it is an almost exact miniature of the mature larva.

Habits of the larva.—These larvæ are very sluggish; they can not swim at all but crawl about slowly over the vegetation, their long tracheal gills standing out rigidly on either side like rods. They cover themselves with green algæ and lie inert for hours at a time, only coming out after food. When disturbed, they curl up slightly and feign death, and it is often difficult to determine whether they are really dead or not. They are the most inactive of all the larvæ here studied but are as persistent crawlers as the *Peltodytes* larvæ. They can not be kept in a mud cell unless the latter is securely sealed. They are also hard to kill and will live for an hour or an hour and a half when placed in 95 per cent alcohol. They breathe entirely through the lateral gills, which contain tracheoles, and hence have no need to come to the surface for air. They eat, as far as could be observed, nothing but algæ, *Chara*, *Nitella*, etc. Two larvæ were kept a long time in an aquarium with an abundance of Entomostraca, snails, and insect larvæ of various kinds. They refused them all and ate only vegetable food.

Description of the larva.—General form spindle-shaped, slightly depressed, widest through the second abdominal segment, much narrowed both anteriorly and posteriorly. Total length on the mid line 10 mm.; greatest width 2.5 mm.; greatest thickness 2 mm.; length of posterior gills 3 mm. Body made up of the head, 3 thorax segments, and 8 abdomen segments. Each of the first seven abdomen segments carries a single pair of tracheal gills, which are cylindrical and threadlike and increase in length from in front backwards. These gills, unlike those of the gyrenid larva, are entirely naked. The last segment has no gills and is very small. Color a grayish-yellow, deepening to brown on the thorax and along the sutures between the joints.

Head quadrangular in outline; antennæ three-jointed, joints diminishing greatly in length and width; first joint with a sensory papilla on the inner margin at the distal end; second joint with a long seta at the distal end on the inner margin and a sensory papilla on the outer margin; third joint minute, armed with three unequal setæ.

Mandibles asymmetrical, the right one with three blunt conical teeth on the inner margin, the distal tooth the largest, the middle one less than half as large, and the proximal one a mere knob. The left mandible also has three teeth, nearer the base, much closer together and about the same size. Just above them and hiding them in dorsal view is a bunch of radiating comblike spines.

The maxilla is five-jointed, the basal joint more than twice the combined length of the other four, with a large seta on its inner margin. The second joint is short and subquadrate and bears on its inner margin a small knob armed with a sensory papilla and a seta. Of the remaining joints the fourth is longer than the third and fifth combined, while the fifth is tipped with four small sensory papillæ. The labial palps are two-jointed, the distal joint twice the length of the basal and tipped with a single seta; there is no ligula.

The eyes are behind the center of the head and are arranged as shown in Figure 103 (opp. p. 309). The first six abdominal segments are each divided into a larger anterior portion bearing the lateral gills and a smaller posterior portion; the last two segments are entire. Each anterior portion is further divided by a transverse groove or wrinkle.

Pupation.—The larva crawls but a short distance from the water's edge and hollows out its pupal chamber in the soft earth $1\frac{1}{2}$ to 2 inches beneath the surface. It occasionally pupates within 24 hours after the completion of the chamber but more often remains several days before transforming.

Mutkowski (1918, p. 414) stated with reference to the family Hydrophilidæ:

Only a single species, *Berosus* sp. (probably *striatus*) Say, is represented in the lake (Mendota), and this species is quite rare. The larva occurs in sandy depths up to 6 meters. I was able to breed the species and discovered that the pupa is aquatic and a water-breather like the larva, but the emerged adult escaped before I had seen it.

If he had seen the emerged adult he would have discovered his mistake, for this pupa is certainly terrestrial like all the others here described.

Description of the pupa.—General form an elongate oval, 6 mm. long and 3.25 mm. wide, the posterior end rather bluntly pointed. The color is white, usually with a decided greenish tinge; the eyes are at first light brown but deepen with age. Just before emergence the white changes to yellow, the

head blackens, the dorsal surface of the prothorax shows the two semilunar black spots, and the wings are darkened.

The antennæ stand out at right angles to the body axis; the long maxillary palps extend back beyond the bases of the second legs. The femora of all three pairs of legs are at right angles to the body axis; the tibiæ of the first pair are folded tightly against the femora; the tarsi are parallel with the body axis and some distance apart. In the other two pairs of legs the tibiæ and tarsi are in line and extend diagonally backwards to the mid line. At the posterior end of the abdomen are two strong cerci, each armed with a single long moniliform spine.

The large styli on the dorsal surface of the body are arranged as follows: 10 along the anterior margin of the pronotum, 8 along the posterior margin, 1 on each lateral margin, and a row of 4 across the center, 24 in all. Schiødte (1872) in his figure of a *Berosus* larva showed 26 pronotal styli, but out of 40 pupæ belonging to this and the following species not one showed more than 24 styli. There is also a similar stylus inside the base of each elytron and wing, two on the first abdominal segment, four on each succeeding segment to and including the seventh, the lateral ones being near the longitudinal center of the segment instead of on the posterior margin, two much smaller ones on the eighth segment and two tiny setæ above the bases of the cerci on the ninth segment. Each stylus has a thickened base that ends in two short teeth and a thread-like terminal portion. The pupa rests a part of the time on these styli with its back downward, but its normal position is the other side up resting upon its cerci and the styli of the head and pronotum, with its body strongly arched. Out of 25 pupæ reared to the adult stage 20 remained in the pupal chamber five days, while the other 5 emerged in four days.

Habits of the adult.—These beetles swim well but rather slowly; on the land they walk with considerable agility and can even run, while their powers of flight are indicated by the fact that they are frequently captured in trap lanterns some distance from the water. They were also among the first beetles to appear in the newly filled ponds described on page 237. None of those under observation ate anything but green algæ, although they had abundant opportunity to take animal food. This species is found in nearly all the ponds and furnishes excellent fish food, while both the larvæ and the adults are too small to injure even the youngest fish.

Description of the adult.—General outline elongate oval 4 to 5 mm. in length, the narrowed end anterior; very convex; thorax as wide as the base of the elytra. Head black, with a bronzed surface, finely and evenly punctate; eyes grayish-brown; thorax greenish-yellow tending to orange, with a semilunar fuscous spot on either side of the mid line; scutellum elongate; elytra greenish-yellow, each with 10 distinct longitudinal striæ of coarse black punctures and 8 to 11 small, remote, indistinct black spots, those along the center paired, the others single. Ventral surface dull brownish-black, legs, palps, and antennæ yellow; bases of the femora brown.

Antennæ clavate, seven-jointed; first joint elongate, semilunar, second and third joints shorter, narrower, and straight, with a long seta on the outer margin of the second joint. Last four joints swollen, increasing in length distally and covered with fine hairs. Mandibles with three rows of large teeth, the outer row with three teeth, the middle row with two, and the inner row with a single tooth. Inside of the latter, along the inner margin, is a row of stout curved spines. Maxillæ of typical form, the stipes with coarse hairs along the outer margin; palp three-jointed and clavate. Labial palps also three-jointed and pilose.

***Berosus pantherinus* Leconte.** Figures 95, 98, 100, 104, 107, 109, 111.

Berosus pantherinus (Leconte, 1855, p. 364).

Egg cases.—The egg cases of this species are similar to those of the preceding species but are not flattened as much, the case proper is not circular in outline, and the fag is shorter and wider. They contain, however, about the same number of eggs, which require the same length of time to hatch.

Habits of the larva.—This larva has the same habits as the preceding one and feigns death in the same way, but it is not as sluggish as *striatus* and does not lie inert for such long periods. It eats nothing but algæ.

Description of the larva.—It is much smaller than *striatus*, being only 6 mm. long and 2 mm. wide. The body is not tapered as much as in *striatus*, especially posteriorly; the lateral gills are flattened instead of being cylindrical and are relatively much longer and narrower, the posterior pair being fully as long as the entire body. Furthermore, these gills are trailed inertly along the sides of the body in-

stead of standing out rigidly. The anterior margin of the prothorax is not reentrant but is cut squarely across. The head is shorter, and the eyes are in front of the center, the anterior ones being opposite the bases of the antennæ. The antennæ and mouth parts are much the same as in the preceding species, but the left mandible instead of having three teeth covered with processes has one large tooth with a row of processes around its broad tip. A deep groove extends along the inner margin of the mandible from this process to the base, and from the bottom of the groove project a row of irregular and unequal teeth. The inner margin in front of the groove is also irregular.

Description of the pupa.—The pupa is similar to that of *striatus* and is armed with the same jointed styli, but the body is much narrowed and shortened posteriorly and is greener in color. The elytra, wings, and legs are lengthened, the tips of the wings reaching the anterior margin of the penultimate abdomen segment and the tips of the third legs projecting beyond the basal joint of the cerci. The latter are much longer, and their terminal portion is more distinctly moniliform. The head is considerably longer and narrower, and the maxillary palps project backwards to the bases of the third legs.

Description of the adult.—This beetle is the same size as the preceding species. The thorax has two black spots instead of the semilunar lines of *striatus*, and each elytron has 10 distinct black spots—2 near the base, 4 in an irregular transverse line in front of the center, 3 in another irregular line behind the center, and 1 near the tip. The basal joint of the antenna is shorter and more strongly curved, and the second joint lacks the spine at its tip. The labium is longer and narrower, and the labial palps are not as heavily armed with setæ. This species is more restricted than the preceding in its distribution among the fishponds, but wherever it is found it furnishes excellent fish food.

***Berosus peregrinus* Herbst.**

Berosus peregrinus (Herbst, 1797, p. 314).

Berosus peregrinus (Richmond, 1920, p. 48; pl. 10).

A life history of this species, lacking the pupal stage, was given by Richmond, and from it the following abstract has been condensed.

Egg case.—Chestnut-shaped, cap end flat, cap continuous with a long narrow ribbon, the opposite end rounded. Length of case 0.32 mm.; width 1.20 mm.; height 1.60 mm. Length of ribbon 4.50 mm. Each case contained from 2 to 4 eggs which hatched in 6 to 8 days.

Description of the larva.—General form similar to that of *striatus*, but the head and prothorax are relatively much wider. Total length 5.60 mm.; greatest width (second abdominal segment) 1.68 mm. Head ovate, a little wider than long; antennæ nearer the lateral margins than in the two preceding species; ocular areas circular and close behind the bases of the antennæ. Prothorax the same width and length as the head, meso and meta thorax slightly widened; body broadest through the second abdominal segment, then rapidly narrowed. The lateral gills are as short as those of *striatus*, are much more slender, and are trailed alongside the body like those of *pantherinus*. Color a uniform yellowish-white, the chitin areas yellowish-brown.

The mandibles are asymmetrical and resemble more closely those of *striatus*; the left one has three larger teeth on the inner margin, covered with smaller ones. The basal joint of the maxilla is not as long as in the other species and is armed along its inner margin with a row of five stout setæ. The labium is small, with two-jointed palps, each tipped with five short setæ and one long one.

Description of the pupa.—Schödte (1872) stated the distinguishing characters of this pupa as follows:

Motory styli of abdominal tergites in fours; abdominal tergites with a small lateral tubercle on either side; spiracles not concealed; abdominal pleurites not distinctly separated from the tergites; styli of pleurites very short and conical; lateral styli of abdominal tergites very long and slender; prothoracic styli also long and slender; cerci elongate, tapering, crooked and distally moniliform.

His figure showed 26 pronotal styli instead of the 24 found in the two preceding species.

Description of the adult.—This species is the same size as the other two. It is distinguished from *striatus* by the facts that the second, third, and fourth abdominal segments in the male have a slight longitudinal keel and that there is only one tooth instead of two in the middle of the notch on the fifth segment of the abdomen. It is distinguished from *pantherinus* by the fact that the spots on the elytra are very indistinct and are more or less fused in couples.

It is much less abundant in the fishponds than the other two species, and only a few specimens were obtained, but both the larvæ and the adults furnish good fish food without being at all destructive.

FIG. 110.—Ventral view of pupa of *Berosus striatus*. FIG. 111.—The same, *B. pantherinus*. FIG. 112.—Egg case of *Enochrus nebulosus*. FIG. 113.—Egg of same. FIG. 114.—Right mandible of newly hatched larva. FIG. 115.—Left mandible. FIG. 116.—Antenna. FIG. 117.—Antenna of *Enochrus diffusus*. FIG. 118.—Labium of *nebulosus*, ventral. FIG. 119.—Labium of *diffusus*.

Genus **HYDROPHILUS** DeGeer.

Hydrophilus (DeGeer, 1774, p. 371).

Hydrocharis (Hope, 1838, p. 125).

This is a genus of medium-sized beetles, in which the prosternum, instead of being grooved where it meets the anterior end of the sternal crest, is entire and is raised into a sharp keel. These are very active beetles, swimming rapidly and running about on land with great agility. The adults appear to feed entirely upon algæ; but the larvæ are as voracious as those of *Hydrous* and *Tropisternus*, and although they have never been observed attacking young fish they are amply large enough to do so. It is hence deemed expedient to include here an abstract of the excellent description given by Wickham (1895) of the only species found in the Fairport fishponds. The adults of this species are well distributed among the ponds, in at least two of which they are very abundant, but careful search every year for the larvæ and pupæ has resulted negatively.

***Hydrophilus obtusatus* Say.**

Hydrophilus obtusatus (Say, 1823, p. 201).

Hydrocharis obtusatus (Bowditch, 1884, p. 1).

Hydrocharis obtusatus (Wickham, 1895, p. 168).

Hydrophilus obtusatus (Richmond, 1920, p. 31; pl. 1, figs. 1-2; pl. 6, figs. 1-10).

Egg case.—The egg case of this species is similar to that of *Hydrous*, but is smaller and is nearly always covered with a dead leaf or something of the sort. The case is white except the tag³ and the base of the cover, which are brown; it is 10 to 12 mm. long, 9 to 10 mm. wide, and 8 to 9 mm. high. The tag is cylindrical and tapers to a sharp point; it is 7 to 10 mm. long and is enlarged at its base into a plate 4 to 5 mm. high. About 40 eggs are deposited in each case, and they hatch in 6 or 7 days.

Habits of the larva.—These larvæ are very similar to those of *Hydrous*, both in structure and habits. They swim in the same manner and come to the surface to breathe, supporting themselves upon the surface film by means of their cerci. When young, they feed readily upon Cyclops and other Entomostraca, and when fully grown they eat tadpoles, insect larvæ, and the larvæ of other beetles. According to Bowditch (1884), they require 30 days to become fully matured, and then they pupate and remain in the pupa state until the following spring. This statement was strongly questioned by Richmond (1920) and seems equally impossible to the writer. If it were true the pupa would certainly be frozen during the winter, and it is not the kind of a pupa to be capable of withstanding such an experience.

Description of the larva.—Color of dorsal surface greenish, head and prothorax chestnut, ventral surface lighter. Form elongate spindle-shaped, broadest at the middle of the abdomen. Length 26 to 28 mm. Width 5 to 6 mm. Head narrower than the prothorax, inclined obliquely upward, the frontal margin lobed at the center, the ventral surface with four long mottled patches more than half the entire length. Antennæ three-jointed, basal joint very long and fringed with short setæ along the inner margin, second and third joints much shorter. Mandibles with two teeth on the inner margin, the distal one much larger than the proximal. Maxillæ with a long basal joint, a short second joint armed at its inner distal corner with a short process, a third joint half as long as the second, and two terminal joints each of which is about as long as the second joint. Labium large, the mentum irregularly hexagonal, with a distinct tooth on either side near the apex; palps two-jointed, the second joint much the longer; ligula more than twice as long as the basal segment of the palps and slightly tapered. Abdominal segments with two dorso-lateral rows of blunt spines on either side, and a row of lateral filamentary appendages, each tipped with two setæ, on the first seven segments. The eighth tergite forms the superior valve of the stigmatic atrium and bears a large chitinated plate; its posterior margin is divided into four lobes, each tipped with several setæ. The first seven tergites each show a transverse row of four tubercles and each tubercle is tipped with a seta. The lateral filamentary appendages are longer than in *Tropisternus* or *Hydrous* but do not function as gills.

³ See p. 332.

Description of the pupa.—This pupa is 15 to 16 mm. long and 8 mm. wide through the thorax; it is clear green in color, becoming brown about the head and appendages as it matures. The general form is elongate-obovate, the posterior end bluntly pointed. The dorsal surface of the head and prothorax is armed with large curved styli similar to those on the Hydrous pupa. These are arranged as follows: 2 above each eye, 3 very long ones at the anterior corners of the pronotum, 3 shorter ones just inside of them on the anterior margin, 3 on each lateral margin, a transverse row of 4 in front of the center, another transverse row of 3 behind the center, and 10 along the posterior margin, making 35 in all on the pronotum. There are two similar styli on the mesothorax and two more on the metathorax, and six on each of the first seven abdominal segments, the lateral ones mounted on small tubercles. The eighth segment has four tubercles on its posterior margin, each armed with a stylus. The ninth segment terminates in two divergent cerci, nearly 3 mm. long and bifid at their tips. The maxillary palps are very long and reach back beyond the bases of the second legs. The wings and elytra are very short and do not reach beyond the fourth abdominal segment.

Description of the adult.—Length 14 to 16 mm. Male longer than the female, the latter very obtuse posteriorly; dorsal surface black and shining; ventral surface dark reddish-brown and pubescent. Each elytron shows four rows of distinct punctures, the outer row being double. The metasternal spine does not project behind the coxæ of the hind legs.

Genus LACCOBIUS Erichson.

Laccobius (Erichson, 1832, p. 20).

This is a genus of minute but very active beetles, whose diminutive size is more than offset by their agility both in the water and on the land. The adults are dark-colored and have the habit of burrowing in the mud or débris on the bottom of the pond and remaining there entirely concealed. They are vegetable eaters and are so small they can do no possible harm, but both the adults and the larvæ make good fish food.

***Laccobius agilis* Randall. Figure 146.**

Laccobius agilis (Randall, 1838, p. 19).

Laccobius agilis (Richmond, 1920, p. 43; pl. 9, figs. 1-11).

This is one of the rarer species in the Fairport fishponds, but a few larvæ and pupæ were obtained in addition to the adults. Since figures of the egg case, the newly hatched larva, and the mature larva have been published by Richmond in the paper cited above (1920), that of the pupa is the only one here presented. No egg cases were found in the fishponds, therefore the description is borrowed from Richmond.

Egg case.—General form nearly spherical, 1.40 to 1.60 mm. in diameter, the tag ⁴ a hollow filament 7 to 10 mm. long; attached to roots or blades of grass at the water's edge, or to stones. Each case contains from 2 to 11 eggs, which hatch in from 7 to 11 days, the larvæ breaking through the side of the case.

Habits of the larva.—These larvæ are poor swimmers, and their usual mode of locomotion is by crawling over the vegetation or along the bottom of the pond. They breathe in the usual manner by means of a stigmatic atrium at the posterior end of the abdomen. When breathing, they usually rest upon the leaf or stem of some convenient water plant, thrust the end of the abdomen above the surface of the water, and then open the atrium. The side of the aquarium was also often used for this purpose. Sometimes the larva swims to the surface head upward and, inverting its body, endeavors to thrust the atrium above the water. This proves difficult, and it may try half a dozen times before succeeding, but once in position, the edges of the opened atrium will support the larva, and it hangs from the surface film. These larvæ are not cannibals and may be confined together without eating one another. The only things they were observed to eat in the aquarium were a few very small snails.

Description of the larva.—General form oblong, four times as long as wide. Length 5.8 mm.; greatest width through second abdominal segment 1.5 mm. Head quadrangular, slightly elevated, often

⁴ See p. 332.

retracted under the prothorax as far as the ocular areas. Thorax a little wider than the head; abdomen a little wider than the thorax, the first seven segments about the same width with scalloped margins, the eighth segment narrower, as wide as long, with a large dorsal sclerite, the ninth and tenth segments rudimentary; there are no cerci except the minute ones connected with the atrium.

Antennæ short and three-jointed, the second joint the same width as the first and much longer, with a long finger process at the outer distal corner; terminal segment not much larger than this finger process, tipped with three long setæ and several sense cones. Mandibles asymmetrical, curved, and acuminate, the right one with three inner teeth decreasing in size proximally, the left one with two toothed areas, each pectinated dorsally. Maxillæ five-jointed, the basal joint (stipes) swollen and longer than the rest of the appendage, its inner margin with five stout setæ, the second joint (palpifer) a little wider than long with a short finger process on its inner margin. Labium small, palpiger widened distally, palps two-jointed, the terminal joint four times the length of the basal and tipped with many sense cones. Ocular areas outside the bases of the antennæ; eyes in two nearly parallel rows. Color dirty-white to grayish-brown.

Pupation.—Richmond (1920) reported that of two larvæ placed in a terrarium one pupated on the surface of the earth and the other burrowed just beneath the surface. All the pupæ found by the writer were beneath the surface and 2 to 3 feet from the water's edge. This larva seems to select drier mud than some of the others, and its pupal chamber is about 4 mm. in diameter, slightly longer than wide. When the chamber is completed, the larva transforms almost at once and remains in the pupa stage four or five days.

Description of the pupa.—The most striking characters of this pupa are its exceptional width and the great length of all three pairs of legs. It is 3.70 mm. in length, including the cerci, and has a width of 2.25 mm. through the thorax. It thus has the shape of a short and very wide spindle, which is sharply tapered both anteriorly and posteriorly. When first formed it is bright sea-green in color, but soon becomes white with black eyes. As development proceeds the legs, wings, and elytra become tinged with brown.

There are two styli above each eye, situated about half way between the eye and the mid line. The anterior and posterior margins of the pronotum each carry 10 styli, and there is a transverse row of 4 across the center of the segment. The meso and meta notum each have two styli, and there is a transverse row of 4 across each of the first 7 abdominal segments, the lateral one on either side mounted on a small tubercle. The eighth segment has two small dorsal processes close to the mid line, and the ninth segment ends in two cerci armed with long moniliform spines.

The antennæ are carried outward nearly at right angles to the body axis; the femora of all three pairs of legs also extend in the same direction, while the tibiæ and tarsi are curved inward to the mid line. The tarsi are all tipped with spines; the first pair reach the first abdominal segment, the second pair reach the center of the seventh abdominal segment, and the third pair extend well beyond the body to the center of the cercal spines. The spurs at the tips of the tibiæ on the hind legs are fairly prominent but are concealed by the tarsi of the second legs.

Description of the adult.—General form short and stout, nearly as wide as long and strongly convex. Length 2 to 3 mm. Head and prothorax blackish-iridescent with a broad yellow margin on the thorax. Elytra pale with dark striæ; undersurface black, legs and palpi pale. Head covered with fine wrinkles, the margin in front of the eyes yellow; thorax three times as wide as long, as wide at the base as the elytra and sparsely covered with fine punctures. On the elytra the punctures are very small and are set close together in distinct and regular rows.

Genus ENOCHRUS Thomson.

Enochrus (Thomson, 1859, p. 18).

Philydrus (Solier, 1835, p. 315).

This is a genus of small beetles, oval or elliptical in outline, blackish or brownish-yellow in color, and covered with fine punctures regularly arranged. Each elytron has also four rows of coarser punctures. These beetles are not as agile as *Laccobius* and do not hide as persistently, but they swim fairly well and can run quite fast. They frequent the smaller ponds and are found either at the water's edge or close

FIG. 120.—Dorsal view of larva of *Enochrus nebulosus*. FIG. 121.—Head of larva of *E. diffusus*. FIG. 122.—Maxilla of *nebulosus*. FIG. 123.—Maxilla of *diffusus*. FIG. 124.—Right mandible of *diffusus*. FIG. 125.—Left mandible. FIG. 126.—Ventral view of pupa of *nebulosus*. FIG. 127.—Mandible of adult beetle, *nebulosus*, dorsal view.

to it in the *Spirogyra* and *Mougeotia*. Apparently they feed entirely upon these algæ. They are not abundant anywhere in the Fairport fishponds, but both the adults and the larvæ make excellent fish food.

***Enochrus nebulosus* (Say).** Figures 112-116, 118, 120, 122, 126, 127.

Hydrobius nebulosus (Say, 1825, Supplement vol. 2, p. 277).

Philydrus nebulosus (Richmond, 1920, p. 69, pl. 1, fig. 9).

Egg case.—The egg case of this species is 3 mm. long, 2.50 mm. wide, and 2 mm. high at the center of the cap end. The side next to the support is flattened and fastened rather securely. The cap is semi-circular and slightly concave, the hinge margin straight, the free edge evenly rounded. The fag⁵ is in the form of a flat ribbon, a little narrower than the case itself, and uneven in width, but in general tapering toward the free end. It is 8 to 12 mm. long and 1 to 1.70 mm. wide and is fastened to the support so that it does not float in the water. Eight cases were found in pond 13B upon the undersurface of the leaves of *Potamogeton illinoensis*. Each contained from 12 to 20 eggs, and they all hatched together six days after being brought into the laboratory. Compare with this Richmond's record (1920, p. 66):

Ten egg cases were made by a single specimen of *Philydrus nebulosus* during February (indoors) and some of them were placed below the surface of the water. The time required for hatching is from six to nine days.

The eggs are regular ellipsoids 0.56 mm. long and 0.25 mm. wide, with a small triangular projection at the end which is fastened to the wall of the case.

Habits of the larva.—These larvæ are very sluggish and crawl about slowly over the vegetation or on the bottom close to the water's edge. They burrow in the mud or even crawl out of the water and may be found under stones or débris close to the water, where it is always moist. When kept in a glass dish indoors, they crawl up the sides of the dish above the surface of the water but never far enough to become dry. In walking they use the large tubercles on the ventral surface of the abdomen just as a caterpillar uses its prolegs, and the end of the abdomen functions like the posterior prolegs of the caterpillar. As Richmond has stated (1920) the true legs move first, then the prolegs, and finally the end of the abdomen, the whole motion being rhythmic. On a leaf or on the side of a glass dish they frequently cling to the surface with their prolegs and the end of the abdomen and raise the head and thorax into the air, reaching about in different directions. They can also move backwards in the same manner as the *Tropisternus* larva, but with much less speed and agility. They can not, or at least they do not, swim. When thrown into the water they immediately rise to the surface in consequence of the large amount of air in their tracheæ. They then float about with the posterior end of the abdomen above the surface film until they strike some object upon which they can crawl.

They showed no tendency to eat others of their own kind, as is the custom with most of the hydrophilid larvæ, but fed upon the minute Entomostraca, Bryozoans, etc., in the aquarium. A *Potamogeton* leaf with egg cases attached was floated upon the water, and the larvæ after emerging browsed around upon this leaf and apparently found enough to eat.

Description of the newly hatched larva.—Length, including the maxillæ, 2 mm.; width through the metathorax 0.35 mm. Color gray with black eyes and the chitinized portions of the body and appendages brown. General form elongate but rather thickset, the abdomen not much narrowed posteriorly and rather bluntly rounded. Head quadrangular, wider than long, slightly elevated, with almost straight sides. Frontal margin sinuate; frons elongate, campanulate, reaching the entire length of the head and practically obliterating the epicranial suture. Eyes fairly close to the bases of the antennæ, all six visible in dorsal view, the first (anterior) one enlarged, the sixth reduced in size, removed from the others, and twisted so that its axis is nearly horizontal.

The antennæ are short, the tip of the second joint not quite reaching the palpiger of the maxillæ, the two basal joints of the same width, the first one a third shorter than the second, the third a fourth of the length and a third of the width of the second. The second joint bears on its inner margin, a little distal to the center, a sense cone tipped with a seta, and a long seta ventral to the base of the cone. On its outer margin at the distal end, on a level with the base of the third joint, is a finger process, nearly as long as the third joint, and outside of its base two sense cones. The third joint is tipped with several long sense cones and a few setæ.

⁵ See p. 332.

The mandibles are asymmetrical, the left one with a single large tooth on the inner margin, the right one with two. The distal portions of the two mandibles are about the same size and curvature, and each has a row of well-defined teeth extending from its base nearly to the tip. The large tooth on the left mandible has two minute spines on its proximal margin, while the same margin of the distal tooth on the right mandible has a row of four saw teeth. The proximal tooth on the right mandible is much smaller than the distal one and is unarmed. By comparing the figures here given of the mandibles with those published by Richmond (1920) of the mandibles of *perplexus* it will be seen that the former are much more prominently toothed and that the proximal tooth on the right mandible is much nearer to the distal one, as Richmond (1920) himself stated.

The maxillæ are long and stout. When the tips of the mandibles just touch each other in front of the head, the antennæ, the mandibles, and the labial palps all reach the same level, which is about the center of the palpiger of the maxillæ. Thus, the distal half of the palpiger and the whole of the palps project beyond the other appendages. The cardo is fused with the stipes, and the junction of the two is indicated by constrictions on the lateral margins. The stipes is large and stout and not much narrowed distally; it is one-half longer than the palpiger and palpus together, with two large setæ on the outer margin just beyond the center. The palpiger is about half the diameter of the stipes, its length to its width as 9 to 14. At its inner distal corner is a club-shaped process as long as the first joint of the palpus and tipped with two setæ. The palpus is three-jointed, the joints increasing in length distally in the proportion of 5, 7, and 9. The basal joint has a single seta on its dorsal surface near the outer margin, the second joint has one on the inner margin, and the terminal joint is tipped with two setæ and three sense cones.

The labium is proportionally large, with a pentagonal gula one-half wider than long; its postero-lateral margins are four times the length of the antero-lateral ones. The submentum is small; the mentum is barrel-shaped, about as long as wide. The palpiger is dome-shaped and three-fifths as long as the mentum; the ligula is a little longer than the basal joint of the palps and slightly enlarged at its tip. The labial palps are two-jointed, the terminal joint three times as long as the basal and tipped with setæ and sense cones, but without any setæ at its base.

The prothorax is as long as the head and one-fourth wider, with strongly convex sides; the mesothorax and metathorax diminish in length, but are as wide as the prothorax. The abdomen is slightly narrower than the thorax, the first seven segments distinct and similar, slightly narrowing posteriorly, the eighth and ninth segments rudimentary, representing, respectively, the superior and inferior valves of the stigmatic atrium. Spiracles present on the mesothorax, metathorax and the first seven segments of the abdomen. These abdominal segments also bear laterally one large and two small tubercles on either side and a row of four across the dorsal surface, all armed with long setæ. On the ventral surface each segment from the third to the seventh inclusive carries near each lateral margin a prominent tubercle, which is armed with recurved spines instead of setæ and serves as a proleg.

The mature larva.—When mature, the larva is 6.40 mm. long and 1.35 mm. wide at the first three abdominal segments. The head, the thorax, and the anterior abdomen are light brown, the posterior abdomen is gray. The head is 0.45 mm. long and 0.55 mm. wide; the first joint of the antenna is nearly as long as the second; the serrate flap of the labrum is retained and becomes a little more prominent on the right side, and thereby asymmetrical. The serrations on the terminal blades of the mandibles are completely retained, but those on the proximal margin of the median teeth have entirely disappeared. Neither the maxillæ nor the labium have changed.

This larva crawls fully as far from the water's edge as the much larger *Tropisternus* larva and locates its pupal chamber in rather dry mud, pupation taking place almost as soon as the pupal chamber is completed.

Description of the pupa.—General form elongate-ovate, 4.50 mm. long, exclusive of the cerci, and 1.90 mm. wide through the prothorax, the abdomen much narrowed posteriorly. Entirely white except the eyes, which are dark brown, almost black, and the cerci and styli, which are light brown.

Head smooth with two supraorbital styli on either side, but no tubercles near the vertical margin. Pronotum somewhat three-lobed anteriorly, its posterior margin straight but not indented in front of the elytra. Twenty-four styli, 10 on the lateral and anterior margins, the 2 on the median lobe much longer than any of the others, 8 on the posterior margin, 2 on the median lobe posterior and outside of the long anterior ones, and 4 in a curved transverse row behind them. Mesonotum and

metanotum with a single stylus on either side near the elytron and wing; scutellum prominent in the center of the mesonotum.

Antennæ inclined backward at an angle of 45° with the body axis, mandibles, and maxillæ very prominent, the maxillary palps extending beyond the tips of the first legs. Basal joints of all three pairs of legs nearly at right angles to the body axis, tibiæ of the first two pairs flexed back against them, tibiæ of the third legs curved inward at an angle of 45°. Tarsi of the first legs flexed sharply backward, of the other two pairs nearly continuous with the tibiæ; tibial spines prominent on the second and third legs. Tergite of first abdominal segment with four styli; tergites of the second to seventh abdominal segments inclusive with six styli; eighth and ninth tergites with two each. Eighth sternite with a pair of appendages on its posterior margin, touching each other on the median line and extending backwards over the ventral surface of the ninth segment to the bases of the cerci. Posterior outer corners of the ninth sternite prominent and acute; cerci two-jointed, fleshy, tapering, 1 mm. in length.

The duration of the pupal stage in 2 beetles whose larvæ were brought into the laboratory and placed in artificial pupal chambers was 4 and 5 days, respectively. On first emerging, the entire beetle is dark gray, the antennæ and mouth parts white, and the legs reddish-brown. The color darkens rapidly, the eyes first becoming black, then the elytra dark brown, and finally the thorax and head dark brown also.

Habits of the adult.—The adults live wholly in the floating *Edogonium*, *Hydrodictyon*, and *Spirogyra* and have never been taken in a net while sweeping other parts of the ponds. They seem, however, to prefer the undersurface of the leaves of *Potamogeton* as a support for their egg cases, and only two of the latter were found among the algæ. These beetles swim well and crawl about among the algæ rapidly, but they can not jump or run. They feed apparently entirely upon the algæ, and being common in several ponds and entirely harmless they furnish excellent fish food.

Description of the adult.—This species is distinguished from others of the genus chiefly by the fact that the prosternum is distinctly carinated. The general form is elliptical, 4 to 4.50 mm. long and 1.60 mm. wide. All the specimens obtained in the Fairport ponds were dark yellowish-brown, a little paler toward the margins, with the entire undersurface black.

Antennæ nine-jointed, the three terminal joints much enlarged, almost spherical and densely covered with fine hairs. The ninth joint is much larger than the eighth and the eighth larger than the seventh. The sixth joint is three times as wide as long, with a tuft of hairs on its outer distal corner; the first joint is sharply bent near the base. Mandibles short and stout, the tip at right angles to the basal portion; a secondary tooth ventral to the tip and on the inner margin a distal tuft of coarse straight spines and a proximal row of stout curved setae. In the maxillæ the palps are very long, nearly twice the length of the body of the appendage, and the galea is armed with rows of curved blunt spines. The labial palps are very short and do not appear at all in the pupa, being concealed by the other mouth parts.

Enochrus diffusus. (Leconte.) Figures 117, 119, 121, 123–125.

Philydrus diffusus (Leconte, 1855, p. 371).

Two egg cases were obtained from the same pond, 13B, as those of the preceding species and also from the leaves of *Potamogeton illinoensis*. They hatched in seven days, and the young larvæ were reared to a length of 4 mm.; but they could not be carried further, and no pupæ were obtained. The identity of the larva, therefore, is not absolutely proved, but since only two species of this genus have ever been found in the pond after repeated search it is reasonable to refer the present specimens to the second species.

Egg case.—The egg cases are considerably smaller than those of *nebulosus* and quite different in structure. Apparently a flat strip of silk 2.50 mm. long and 2 mm. wide is first spun and securely fastened to the undersurface of the leaf. Upon this 10 or 12 eggs are placed in a single layer and secured by strands of loose silk. Then another strip of silk is spun over the eggs and fastened around the edges to the first strip. And finally a short and wide bag ⁶ 5 mm. in length is added. This is as wide as the

⁶ See p. 332.

first strip where it joins the latter, but tapers toward the free end. The case thus has no cap and is very strongly flattened, so much so in fact that the first one found was taken for a simple piece of ribbon, but in pulling it from the leaf it was torn open and revealed the eggs inside. These eggs appeared freshly laid and hatched in seven days after being taken into the laboratory.

Habits of the larva.—The habits of these larvæ are very similar to those of the preceding species. They have the same method of locomotion by means of the prolegs and the end of the abdomen and spend most of their time above the surface of the water. Apparently they never swim but crawl about slowly over the vegetation and along the sides of the aquarium. They feed readily upon the chironomids and entomostracans in the aquarium and do not show any tendency to fight with one another. Those under observation also ate a batch of snail's eggs that happened to be upon the same leaf as their own egg case.

Description of the newly hatched larva.—Length 2.35 mm.; width through the metathorax 0.32 mm. Color gray, the eyes black, the head and thorax dark brown. The general structure of the body is the same as that of the preceding species, with the following differences. The antennæ are shorter and much stouter, but the armature is very similar. The mandibles are longer and more slender, with differences in the teeth, which are shown in the figures. The maxillæ are considerably stouter, and the stipes is armed with four or five large and strong spines on the ventral surface near the inner margin. The labium is also stouter, the palpiger bears five large setæ; the basal joints of the palps almost fuse on the mid line beneath the ligula, and each is armed with five setæ on its dorsal surface. The head is much wider than long and is covered with scattered setæ on its dorsal surface. The labro-clypeus is also more heavily armed with spines and setæ. The large spines at the sides show up prominently in dorsal view, and the whole dorsal surface is more or less corrugated.

***Enochrus perplexus* (Leconte).**

Philydrus perplexus (Leconte, 1855, p. 371).

Philydrus perplexus (Richmond, 1920, p. 67; pl. 14, figs. 1-10).

Richmond (1920) succeeded in securing the complete life history of this species, which he presented in the reference given above, together with excellent pictures of the larva in different stages of development and of the egg case. He also gave a very short (three and a half lines) description of the newly hatched larva of *Enochrus* (*Philydrus*) *ochraceus* (p. 70), with a figure of the egg case, and another brief description of the newly hatched larva of *Enochrus* (*Philydrus*) *hamiltoni* (p. 71).

Genus TROPISTERNUS Solier.

Tropisternus (Solier, 1835, p. 308).

This is a genus of medium-sized beetles of an oval or elliptical form, smooth and shining black in color, with the dorsal surface strongly convex. They are by far the most common beetles in the fishponds and are so abundant that they play an important part in the economy of fish culture. They are all of them excellent swimmers and are agile upon land, walking and running well, but not jumping at all. They feed largely upon *Anabæna* and *Clathrocystis*, which float upon the surface of most of the ponds during the summer months. Neither the adults nor the larvæ molest young fish, while they themselves furnish excellent fish food.

***Tropisternus lateralis* (Fabricius). Figures 128-136, 139.**

Hydrophilus lateralis (Fabricius, 1775, p. 228).

*Tropisternus nimbatu*s (Say, 1825, p. 205).

Tropisternus lateralis (Blatchley, 1919, p. 318).

The egg case and the eggs.—The female of this species attaches her silken egg case to some convenient water plant, the stem or the leaf of grass growing in the water, the leaf of *Convolvulus* grown in from the edge of the pond, or the stem of *Sagittaria*. Failing these, any other water plant may be chosen or the case may be attached to floating débris. Often several cases will be found upon the same support, and as many as 12 have been seen upon one grass leaf. The actual spinning of the case was witnessed several times and may be described as follows: Taking a position back downward upon a floating support, or head upward on an erect stem, the female holds herself in position with her front and middle legs. She

then moves her spinneret rapidly from side to side, guiding the thread with her hind legs. Where the silk comes in contact with the support it is flattened for a short distance and pressed against the surface, to which it adheres firmly. In this way is formed a little bag with a rounded bottom, one side being flattened against the support and the mouth of the bag left open. These bags are from 6 to 10 mm. long and from 4 to 5 mm. in diameter, and it takes a female about 20 minutes to complete one. The work is interrupted only by the necessity of obtaining fresh air, which happens about twice during the entire period.

When the bag is completed, the eggs are deposited in it. Each egg is wrapped in silk, leaving the larger end loosely inclosed, while the silk about the smaller end is gathered into a narrow strand which is securely fastened to the side of the case that is flattened against the support. The egg does not stand perpendicular to this side of the case but is inclined a little toward the open end. Each is fastened to the others that come in contact with it, as well as to the side of the case. The number of eggs in a case varies greatly; sometimes there are only 6, and again the number may rise to 20 or even 24. The eggs in 31 cases were counted in August, 1919, with the following results: Two contained 6 eggs, nine contained 7 eggs, seven contained 8 eggs, three contained 9 eggs, two contained 10 eggs, one contained 11 eggs, three contained 12 eggs, two contained 14 eggs, one contained 17 eggs, and one contained 24 eggs. The fastening of the eggs in place occupies three to five minutes according to the number of eggs laid. After completing the bag and before depositing the eggs the female usually takes a short rest of about five minutes.

As soon as the eggs are deposited she spins a cover for the open end of the case, which is fastened to the side of the case next to the support, but elsewhere is left free. It is pushed into the case a little and is made somewhat larger than the opening, so that the margin is held in place by friction. The open end of the case is then prolonged 0.5 mm or more beyond the cover, and the side next to the support is spun into a narrow flattened ribbon, 20 to 60 mm. in length, which gradually tapers toward the tip, and which is not attached but floats freely in the water. As soon as the ribbon is long enough the beetle transfers her hold from the support to the ribbon, and as she spins rises gradually away from the support. The spinning of the cover and the ribbon occupies about 10 minutes, and the female remains beneath the water the entire time.

During the spinning of the case, the deposition of the eggs, and the spinning of the cover and ribbon, the female is attended by the male, who clings to her back just behind the head, thus leaving the posterior end of the body free. He can not, or at least does not, remain beneath the water as long as the female, but leaves her and rises to the surface frequently for fresh air, returning to her immediately. His function seems to be one of protection against disturbance, particularly from other males of the same species, which he drives away whenever they appear. When the case is finally completed, the male and female separate and rest for a long time. The same pair construct at least several cases, but just how many could not be determined. The eggs hatch in about three days.

Richmond (1920, p. 31) gave as the first characteristic of the Hydrophilidae, to which the present genus belongs, the following: "Egg cases characterized by their horny mast and comparatively larger size." Although that statement is correct in general, there are just enough exceptions to prove the rule, and the present species is one of those exceptions. Out of several hundred egg cases not one was found with a "mast," but every one had a long narrow ribbon as just described. This is the more noteworthy since both the species that follow finished their cases with a mast.

The egg case of the present species may be characterized as follows: The case proper one-and-a-half to two times as long as wide, considerably flattened and fastened lengthwise to the support, with a tag⁷ in the shape of a narrow ribbon three to six times as long as the case itself and of the same color and texture as the latter. It is flexible, never fastened to the support but sometimes clinging to it, and usually floats freely in the water.

Habits of the larva.—This larva swims rapidly, not only using the swimming setae on its legs, but also utilizing the tufts of hairs along the sides of the abdomen by means of a vertical undulatory motion. This latter movement enables it to swim backward as well as forward, and so great is its agility that it can dart forward to capture its prey and then shoot backward to avoid danger. When out of the water, it can also move either backward or forward quite rapidly by means of similar undulations or can even lift its body free from the ground like the larva of *Laccophilus* or *Coptotomus*.

⁷ See p. 332.

FIG. 128.—Egg of *Tropisternus lateralis*. FIG. 129.—Dorsal view of larva of same. FIG. 130.—Head enlarged, showing color pattern. FIG. 131.—Side view of posterior end of abdomen. FIG. 132.—Dorsal view of same. FIG. 133.—Antenna. FIG. 134.—Mandible. FIG. 135.—Maxilla. FIG. 136.—Labium, ventral view.

On coming to the surface to breathe it swims upward, tail first, then reverses its body and thrusts its abdomen above the surface film, but having no cerci it can not cling to this film for any length of time. Its usual procedure is to cling to some support with its legs while breathing. Its exertions when eating demand a constant air supply, and it usually seizes its prey and swims to the nearest water plant. It then backs up the stem, dragging its prey after it until it can thrust its abdomen above the surface. It can thus eat and breathe at the same time, and it is engaged in doing both nearly all the time. There is nothing in its makeup which sanctions an eight-hour day or one day of rest in seven. It works constantly from the earliest streak of dawn until the last rays of twilight disappear and keeps this up until it is fully matured. It is the very personification of voracity and gluttony and will eat any kind of an insect adult or larva that it can overpower. Like the Hydrous larva it partakes freely of its own kind, even of its brothers and sisters, and of those hatched in any egg case only one or two survive, and they have eaten all the others. This wholesale cannibalism is the salvation of the other smaller denizens of the ponds; without it they would speedily disappear, but with it they obtain a chance to live. In the ponds the favorite food of these larvæ is mayfly larvæ and damselfly nymphs; they also eat *Pelocaris femorata*, a bug of very questionable reputation, and the nymphs of back swimmers and water boatmen, both of which are very harmful to young fish.

This is one of the larvæ mentioned by Comstock (1912) that swim with their prey to a leaf or stem near the surface. Resting on this support it raises its head out of the water and, holding it vertically upward, crushes its prey to pulp between its powerful jaws, letting the juices run down its open throat. It is never content with the juices alone, however, as is the dystiscid larva, but always swallows the pulp.

Description of the newly hatched larva.—This larva is 3.85 mm. long, including the mouth parts, and 0.7 mm. wide. Head trapezoidal, considerably narrowed posteriorly; frontal sutures straight; epicranial suture longer than in the *glaber* larva and shorter than in the *mixtus* larva; frons flat and narrow triangular, the base of the triangle (anterior side) a fourth shorter than the sides, the apex acute. Anterior margin of head not concave but approximately straight; teeth of labro-clypeus small, the two outside ones the largest, the two next to them much smaller and the same size as the one in the center, the remaining two mere points, sometimes wholly lacking. There are two spines near the center of the frons set well back from the frontal margin and six others in a transverse row just behind the frontal margin, and a single spine on each lateral margin in front of the center. There are no spines on the lateral expansions of the epistoma except at the outer frontal corners, where there are two, one behind the other.

The first eye (farthest anterior) is the largest; outside of its posterior end is a seta, another stands behind the fourth eye, and a third behind the sixth eye, and there are two more widely separated near the fronto-antennal suture. The colored area on either side of the head behind the eyes carries three setæ.

The basal joint of the antenna is two-thirds as long again as the two terminal joints, and the tip of the latter nearly reaches the point of the mandible. The fingerlike appendage at the end of the terminal joint has only a single segment. The mandibles are the most slender of the three *Tropisternus* species here described, are curved but little, and are very acuminate. The distal tooth on the inner margin is also the most slender, its bifid tip is the most acuminate, and the teeth on its inner margin are the longest and sharpest in the three species. The middle tooth on the left mandible is long, slender, and acuminate; it is not double but is inserted in the groove nearer its ventral margin. The proximal tooth is minute, triangular, acute, and single; it is inserted on the ventral margin of the groove, and its edge is not produced transversely. On the right mandible there are two small proximal teeth, side by side, one on either margin of the groove, and a trifle larger than the proximal tooth of the left mandible. The maxilla is more slender than in the other two species, but otherwise similar to them. The labium also is slender but short, and the tips of its palps only reach the distal third of the maxillary stipes. The mentum has nearly straight sides, its anterior angles are produced but little, and are rather bluntly rounded. The ligula is conical, considerably tapered, and apparently jointed near the tip. The terminal joint of the palpus is nearly five times as long as the basal and ends in the usual armature of sense cones and setæ.

The mature larva.—General form spindle-shaped and considerably depressed, with tufts of silky hairs along the sides of the abdomen and other smaller ones scattered sparsely over the body. When fully grown the larva has a length of 10 to 12 mm. and a width across the third abdominal segment of 3 to 3.5 mm. Each of the abdominal segments is divided into a narrower anterior and a wider posterior

portion, and along each lateral margin is a fold of skin that is raised into a papilla near the center of the posterior portion of each segment. There are similar folds on the dorsal and ventral surfaces close to the lateral fold, and they also are raised into papillæ opposite the lateral papillæ. Between the dorsal and lateral papillæ and a little in front of them lie the spiracles, which remain closed until the time of pupation.

The color is yellow, tending to orange on the head and thorax, lighter and grayish on the abdomen. The eyes are black, and the following markings are cinnamon brown: The tips and teeth of the mandibles; a stripe through the center of the head lengthwise, containing a herringbone figure of deeper brown; a spotted area on either side behind the eyes; four longitudinal stripes on the ventral surface of the head; irregular markings on the dorsal surface of the thorax and abdomen, as shown in Figure 129 (p. 323). The ventral surface of the thorax and abdomen is dull yellow. In general, the brown markings increase with age, and when the larva enters the pupal chamber the entire dorsal surface is dark brown, almost black.

The antennæ are even more slender than in the newly hatched larva; the basal joint is more curved and becomes sparsely fringed with long hairs on its inner margin. The base of each antenna is about half-way between the lateral margin and the mid line. The mandibles also remain slender, but become blunter with age; the proximal tooth on the inner margin of the left mandible becomes smaller and often entirely disappears. The maxillæ are practically unchanged, except that the palpifer has increased slightly in relative length. The labium now has a transverse row of large spines across its dorsal surface near the base; the palps are two-jointed, the terminal joint four times as long as the basal and tipped with one long seta and several short ones.

Each of the longitudinal tracheæ is enlarged in the last two abdominal segments and acts as a reservoir for air. The two open into the bottom of a transverse pocket just beneath the dorsal surface at the posterior margin of the last segment. The overhanging dorsal surface is rounded into four narrow lobes and forms the roof of the pocket or atrium. The floor is formed by the ventral surface, which is divided into three lobes, the median one much longer and wider than the lateral ones, and all projecting considerably beyond the dorsal surface. Each lateral lobe carries on its posterior margin a claw that curves upward and assists in keeping the atrium closed while the larva is beneath the water. On the floor in front of the opening of each trachea is a large finger process, projecting upward and tipped with long hairs. Nearer the median line and farther back is another pair of much smaller processes, also projecting upward and tipped with a single long hair. The breathing apparatus thus resembles very closely that described by Miall (1895, p. 91) for *Hydrobius fuscipes*.

Pupation.—When fully grown, the larva crawls quite a distance from the water's edge and hollows out a pupal chamber from 2 to 2½ inches beneath the surface, in which it remains two or three days before pupating. It continues to breathe through the atrium, and the spiracles do not function until after its transformation.

Description of the pupa.—General outline elongate-obovate; greatest width 4 mm. through the bases of the wings; total length, including the cerci, 9 mm. Color at first a pale greenish-white, becoming snow-white in preservatives, except the eyes, which are reddish-brown. On the dorsal surface the styli are arranged as follows: 10 along the anterior margin of the pronotum longer than the others; 4 smaller ones near the mid line and removed a little from the margin; 2 posterior to the center of the segment; 1 on each lateral margin and 8 across the posterior margin; 1 either side of the scutellum on the mesonotum; 2 on the metanotum; 4 on the first abdominal segment; 6 on each of the following six segments, the two lateral ones close together and mounted on small tubercles; 2 much smaller ones on the posterior margin of the eighth segment at the tips of small and indistinct lobes. Each of these styli have a thickened, fleshy, and moniliform base, tipped with a corkscrew seta. There are no supraorbital styli. The ninth segment terminates in two fleshy and superficially annulate cerci, which are stout and divergent at the base and then curve like parenthesis marks. Each is bifid at the tip, the two points ending in stout spines, and there is another stout spine on the outer margin near the center.

The antennæ extend outward at right angles to the body axis; the maxillary palps reach back to the bases of the third legs, and the labial palps do not quite reach the posterior margin of the second legs. The femora of all the legs stand at right angles to the body axis; the tibiæ of the first legs are folded tightly against the femora; the tarsi are turned backward parallel with the body axis and widely separated. The tibiæ and tarsi of the second and third legs are in line with each other, and their tips

meet on the mid line of the body; each has separate pockets for the spines at the distal ends of the tibiae. The large metasternal spine does not quite reach the tips of the second legs.

Inside the pupal chamber the pupa rests upon the large spines of the prothorax and the posterior cerci, the dorsal surface uppermost and strongly arched. Of 10 pupæ reared in 1919, 4 remained three days in the pupa stage, 4 remained four days, and 2 remained five days. Of 10 pupæ reared in 1920, 6 remained only three days in the pupa stage, while the other 4 remained four days. The pupæ reared in 1920 emerged two weeks earlier in July than those in 1919, which may have had some influence on the length of the pupal period.

Habits of the adult.—When first emerging from the pupa stage, this beetle is yellowish in color with black eyes, but with no other pigment visible. After emerging it remains about three days in the pupal chamber before coming out into the light, gradually turning a reddish-yellow, and finally black with yellow margins on the thorax and elytra. If taken from the chamber during this time and thrown into the water, it floats lightly on the surface like a whirligig beetle and swims for the shore or the nearest vegetation. Evidently it can not submerge itself and manage its air supply at that stage. When fully matured, it is an excellent swimmer and is also agile upon land, walking and running easily but not jumping. It feeds largely upon *Anabæna* and *Clathrocystis*, which float upon the surface of most of the ponds during the summer. Turning bottom upward and clinging to the surface film with its legs, the beetle scoops in the floating algæ with its labial and maxillary palps. Sometimes it clings to floating objects and reaches the algæ from that foothold.

Description of the adult.—General form elongate-ovate, with evenly rounded outlines, the abdomen often projecting a little from beneath the elytra. Total length 8 to 10 mm.; greatest width (through the thorax) 3 to 3.50 mm. Dorsal surface olive-black, shining; the head, thorax, and elytra with a narrow margin of pale yellow, and sparsely covered with fine silky hairs, longer on the margins, especially toward the posterior end of the elytra. Ventral surface black, the antennæ, maxillæ, legs, and wide margins on the thorax and elytra yellow. Bases of the femora and outer margins of the tarsi black, eyes pale lavender.

The antennæ are nine-jointed, the last four joints enlarged into a densely pilose club. Mandibles with a long and acute terminal tooth and a squarely truncated secondary tooth, the truncated edge cut into smaller teeth. From the posterior margin of the second tooth two divergent series of small comb teeth extend toward the base of the mandible. The maxillæ are typical in form, the palps elongate, four-jointed, the last joint nearly one-third longer than the preceding one. The labial palps are three-jointed, short, and pilose.

This beetle is easily recognized by the yellow borders of the thorax and elytra, which stand out sharply in contrast with the shiny black of the dorsal surface. It is decidedly the most abundant species around the fishponds; it is present and breeding in every one of them except the small 6D, and it is probably found there at times. Although the larvæ are such ferocious little cannibals, they are not large enough to menace young fish, but, on the other hand, their exceptional abundance makes them an important factor in fish food.

***Tropisternus glaber* (Herbst).** Figures 137, 140, 142, 143, 145.

Hydrophilus glaber (Herbst, 1797, p. 398).

Tropisternus glaber (Wickham, 1893a, p. 340).

Tropisternus glaber (Richmond, 1920, p. 35, pl. 7, figs. 1-9).

Eggs and egg case.—This beetle also spins a silken egg case similar to that of the preceding species but a little larger, and nearly always with a spike instead of a ribbon for a fag.⁸ These cases are 6 to 9 mm. long, 8 to 12 mm. wide, and 4 to 5 mm. high at the mouth. The number of eggs in a case varies greatly but averages about 10 or 12. Three or four days intervene between the laying and the hatching of the eggs. About 100 egg cases of this species were found in 1921 in pond 9D, in little patches of *Edogonium* floating at the surface of the water. Under these conditions they were somewhat different from those described by Richmond (1920) and may be characterized as follows: Nearly spherical, about the same length and width, not flattened at all but fastened at various places to the algal strands, so that the case lies horizontally in the water. The cap is circular in outline, stands vertically upright, and is prolonged into a cylindrical fag⁸ which tapers to a sharp point and which is always darker in color and coarser in texture than the white case and cap.

⁸ See p. 332.

FIG. 137.—Head of larva of *T. glaber*. FIG. 138.—Head of larva of *T. mixtus*. FIG. 139.—Ventral view of pupa of *lateralis*. FIG. 140.—The same, *glaber*. FIG. 141.—The same, *mixtus*. FIG. 142.—Fag of egg case of *mixtus*.

Comstock in Manual of the Study of Insects (1912, p. 527, fig. 636) gave a picture of one of these cases. Referring to it in the text he stated: "Some species deposit as many as a hundred eggs in one of these waterproof packages (fig. 636)." The cases are waterproof only in the sense that water does not injure them and not in the sense that water can not enter them, since they are left open to allow the exit of the larvæ. Again, the large floating cases of Hydrous and not the one figured by Comstock are the ones that contain 100 eggs.

Description of the newly hatched larva.—Length 4.5 mm., and width of the thorax 0.8 mm.; color light brown. Head trapezoidal, about the same length and width, slightly narrowed posteriorly; fronto-clypeal sutures indistinct; frontal sutures straight, converging and uniting to form an epicranial suture less than one-twelfth of their own length. Frons flat and broadly triangular, the three sides of the triangle about equal. Anterior margin of head somewhat concave, the lateral expansions of the epistoma projecting in front of the labro-clypeus. The teeth of the latter are large and include a conical tooth at the center larger than any of the others and, on either side of it, two smaller teeth close together and a larger one removed a little distance. The sinuses on either side of the central tooth, between the two teeth and the distant one, and on the outside of the latter, each carry a short and stout spine. The frontal margin of the epistoma has no spines except two at each outer corner, side by side, about the same size as those on the labro-clypeus. Near the anterior margin of the frons is a transverse row of four small setæ nearly in a straight line; a fourth of the distance behind them are two more, one on either side of the mid line. There is a seta outside the sixth eye, another outside the fifth eye, and a row of three behind the ocular area. The first (anterior) eye is only a little larger than any of the others.

The basal joint of the antenna is only a third longer than the other two joints together, but the terminal joint projects beyond the tips of the mandibles. The fingerlike appendage on this joint is apparently two-segmented. These antennæ are much stouter than those of the *lateralis* larva, especially the second and third joints. The mandibles are the stoutest and most strongly curved of the three species here described, and their tips are comparatively blunt. The distal tooth on the inner margin is also stouter, its bifid tip is more bluntly rounded, and the teeth on its inner margin are shorter and coarser. The middle tooth on the left mandible is broadly triangular and not double but stands apparently in the center of the groove. The proximal tooth is minute and on the ventral margin of the groove, but its proximal edge runs across the groove nearly to the dorsal margin. On the right mandible there are two small proximal teeth, side by side, one on either margin of the groove. The maxillæ are stouter than those of *lateralis* but otherwise similar to them. The labium is also stout and shorter than in *lateralis*, the tips of its palps reaching just beyond the center of the maxillary stipes. The mentum has convex sides, and its anterior corners are produced into blunt spines; the ligula is cylindrical and only slightly tapered; the terminal joint of the palpus is four times the length of the basal joint.

The mature larva.—When fully grown the larva is 12 to 15 mm. long and 3 to 4 mm. wide. This larva is very similar to that of *lateralis* but is somewhat larger, darker in color, and more densely clothed with hairs. The papillæ on the abdomen are longer, more numerous, and carry larger tufts of hairs; the mandibles are stouter, shorter, and not as acuminate; the maxillæ are shorter and stouter, and the upper lip of the stigmatic atrium is evenly rounded instead of being cut into narrow lobes. Figure 130 shows the upper surface of the head of a mature *lateralis* larva, while that of the mature *glaber* larva is shown in Figure 137, and the two larvæ can be distinguished by the color patterns. The yellow on the dorsal surface of the head and the five yellow stripes on the ventral surface are much more pronounced in the present species. Sometimes this larva has a brown streak through the head along the mid line of the dorsal surface, but even then the color pattern is distinctly visible. This larva, like the preceding species, undergoes changes with age; the antennæ and maxillæ become more slender, and their basal joints increase in relative length. The mandibles are less acuminate, but the proximal teeth on their inner margins remain broader, blunter, and closer to the distal teeth than in the *lateralis* larva. The labium broadens, and the mentum acquires a formidable set of short spines on its dorsal surface. When fully matured, the larva becomes almost black and is densely covered with papillæ and hairs.

The habits and food are the same as those of the *lateralis* larva; Richmond (1920, p. 35) said that the *glaber* larvæ he reared in an aquarium "fed readily on entomostracans and small tadpoles."

Description of the pupa.—The pupa is like that of the preceding species, with the following differences. It is slightly longer (9.5 mm.) but not wider the labrum and the distance between the eyes

is wider; the maxillary and labial palps are shorter and stouter; the wings are about the same length; the metasternal spine is longer and not as stout; the cerci are longer and more slender; the third legs reach the penultimate abdominal segment; the eyes are not as red and are considerably lighter in color.

Of 10 larvæ reared in 1919, 6 remained in the pupa state four days, 2 remained five days, and 2 six days. Of 10 larvæ reared in 1920, 2 remained in the pupa state three days, 6 remained four days, and 2 remained five days. Wickham (1894), in endeavoring to rear the larva of a bombardier beetle which had infested the pupa of *Dineutes americanus*, substituted in place of the gyrinid food a pupa of the present species and it was accepted by the parasite. Another *glaber* pupa was infested with the maggots of a species of *Phora*, one of the Diptera. These two instances would indicate that the pupæ of the present species are susceptible to the attacks of parasites of this sort.

The adult beetle.—The adults are larger than those of either of the other two species here described, attaining a length of 9.50 to 11 mm., and rarely reaching 12 mm. The form is a much broader oval, and the punctures of the elytra are larger and more distinct. The head, thorax, and elytra are entirely black on the dorsal surface and more or less bronzed, with no yellow stripe or silky hairs along the lateral margins. Ventral surface also entirely black, dull on the body, but shiny on the legs and sternal crest, the five basal joints of the antennæ, the laciniae and palps of the maxillæ, and the labium yellow. Basal joint of the antenna considerably longer than in the preceding species and more strongly curved. Terminal tooth of mandibles shorter and secondary tooth longer; labial palps shorter, the setæ at the tips subterminal.

This species has never been seen feeding on *Anabæna* or *Clathrocystis* but stays beneath the surface and eats *Chara*, *Nitella*, etc. While this species is not as abundant as the preceding it is still found in every pond but two, and it breeds as prolifically. For this reason it becomes an important item in the food of the young fish.

***Tropisternus mixtus* (Leconte).** Figures 138, 141, 144.

Hydrophilus mixtus (Leconte, 1855, p. 368).

Egg case and eggs.—The egg case is from one and a quarter to two times as wide as long, strongly flattened and fastened to the support transversely, the mouth usually projecting slightly beyond the edge of the support. The bag⁹ is in the shape of a slender cylinder made of twisted strands which stands rigidly upright in the water, is the same diameter throughout, and is usually frayed at the tip (fig. 142, p. 327). When the mouth of the case does not reach the edge of the support, the side next to the support is prolonged to the edge as a broad ribbon, securely fastened, and the bag is attached to this ribbon. The bag is always darker in color and coarser in texture than the case, the cap, and the broad ribbon. Case 6 to 8 mm. long, 7 to 10 mm. wide, and 4 to 6 mm. high at the mouth; bag 8 to 12 mm. long.

The egg is much shorter and broader than that of *lateralis*; the latter is three times as long as wide, but the egg of the present species is less than two and a half times as long as wide. From 8 to 12 eggs are laid in a single case, and they hatch in four or five days.

Habits of the larva.—The habits of these larvæ are very similar to those of the other two species but differ in one marked particular. The larvæ of the other two species begin their cannibalistic ravages inside the case as soon as they get out of the egg. Many of the larvæ are eaten by their brothers and sisters before they emerge from the egg case, and sometimes out of an entire brood only one will be left to crawl forth eventually. The present larvæ, however, act in a radically different manner. Thirty cases were brought into the laboratory and placed in a small aquarium and allowed to hatch. A few larvæ appeared at about the right time and then disappeared overnight. At first it was supposed that they had crawled out of the aquarium in some way, and a cover was placed over it to prevent this. No more larvæ appeared, however, and after a day or two the cases were taken out and opened separately. Two-thirds of them were entirely empty, containing neither eggs nor larvæ. The other third were packed full of active vigorous larvæ, each case containing from 25 to 35 and one 42 larvæ. They were packed very closely inside these cases but were not tangled, for the moment the case was opened they separated and swam away in different directions. As the cases contained only 10 or 12 eggs apiece, the larvæ must have crawled from two cases into a third one and bunched with the larvæ of the latter until it was as full as it would hold. Moreover, they seemed to be living in perfect harmony; there was no evidence either then or subsequently that they were at all cannibalistic. In no instance was one of them seen to attack

⁹ See p. 332.

FIG. 143.—Dorsal view of larva of *T. glaber*. FIG. 144.—The same, newly hatched *mixtus*. FIG. 145.—Ventral view of head of *glaber*. FIG. 146.—Ventral view of pupa of *Laccobius agilis*. FIG. 147.—Frons of *Thermonectes ornatocollis*. FIG. 148.—A single laciniate spine of the same, enlarged.

and kill another, even though food was scarce. The simple fact that they do thus herd together in such numbers shows an entirely different disposition from that of the other two species. In the ponds they fed readily upon snails, entomostracans, damselfly nymphs, mayfly larvæ, and small tadpoles. In all other respects their habits were identical with those of the two preceding species.

Description of the newly hatched larva.—This larva is 4 mm. long, including the mouth parts, and 0.75 mm. wide. Head nearly quadrate, not appreciably narrowed posteriorly; fronto-clypeal suture distinct; antennal sutures wavy rather than straight, converging posteriorly into the shortest epicranial suture of the three species here described, only one-twentieth the length of the antennal suture. Frons triangular, the anterior side or base one-fifth shorter than the other two sides, the apex or posterior angle broadly rounded. Anterior margin of the head only slightly concave, the lateral expansions of the epistoma barely protruding beyond the clypeus. The latter has rather small teeth, larger than those of *lateralis* but not as large as those of *glaber*. The central one and the two outside ones are the same size and larger than the other four. The transverse row of six small spines are all about the same size and equally distant from the margin. The frontal margin of the epistoma also carries on either side a row of 10 or 11 small spines, increasing in size outwardly, the largest one at the outer corner.

The first (anterior) eye is larger than any of the others; behind the sixth eye stands a seta, and there is a row of four along each lateral margin of the head behind the eye area. The basal joint of the antenna is shorter than in the other two species and is only three-fifths longer than the other two joints together. The terminal joint is a little shorter than the second joint and less than half its diameter; the fingerlike appendage at its tip has apparently two segments.

The mandibles are stouter than those of *lateralis* but not as stout as those of *glaber*. The distal tooth on the inner margin is like that in the preceding species, its bifid tip bluntly pointed, the teeth on its inner margin quite distinct. The middle tooth is not double, but is short, broadly triangular, and acuminate, and stands in the center of the groove. The proximal tooth is minute and stands on the ventral margin of the groove, its proximal edge running across to about the center of the groove. The two proximal teeth on the right mandible stand side by side, one on each margin of the groove. The maxillæ are stouter than in the two preceding species but otherwise similar to them. The labium is relatively longer, the terminal setæ of its palps reaching the distal end of the maxillary stipes. The mentum has convex sides, and its anterior corners are produced into short and acute spines.

The mature larva.—When fully matured, the larva is 11 to 13 mm. long, 3.25 to 3.75 mm. wide. This larva may be recognized at once by the color pattern; along the median line of the dorsal surface of the head and curving backward from the eye areas on either side are broad stripes of orange-yellow, narrowed posteriorly. Between these on each side is a wide stripe of dark, cinnamon-brown, running from the base of each antenna back to the prothorax, and another wide brown stripe on either lateral margin behind the eyes. These stripes are all uniform in color and not spotted. On the prothorax in place of the longitudinal dashes of the other species there is a three-sided parallelogram on either side of the mid line, the anterior end lacking. The mesothorax and metathorax have dark brown sclerites like those of the other species but differing somewhat in shape. The abdomen is light brown dorsally, the margins of each segment slightly darkened, but without other markings. The lateral tracheæ show through as a wide dark line along either side.

This larva has a larger number of papillæ along the sides of the abdomen and is more densely covered with hairs than either of the others. The basal joints of the antennæ remain less than twice the length of the other two joints together, and are comparatively stout. The labium is narrow but elongate, and the tips of the labial palps reach well beyond the distal tooth on the inner margin of the mandibles.

Description of the pupa.—Total length, including the cerci, 6.50 mm., greatest width, through the bases of the second legs, 3.35 mm. Length of metatarsal spine, including the wide base, 1.75 mm. In the *lateralis* pupa this spine is 2.40 mm. long, and in the *glaber* pupa it is 3 mm. long. Length of cerci 1 mm. This pupa differs from the two preceding ones in the following particulars: The space between the eyes is wider; the labial palps are longer; the metasternal spine is actually shorter, but its tip reaches the middle of the fifth abdominal segment; the tarsi of the second legs and the tips of the wings reach the middle of the sixth segment; and the tips of the third legs reach the anterior margin of the last segment. The cerci are as slender as those of *glaber* but lack the spines on the outer margins. The mesotibial and metatibial spines are less distinct. The duration of the pupa stage is four or five days, as in the other species.

Habits of the adult.—The habits of the adult are the same as those of the other two species, and the food is the same as that of the preceding species. This beetle is not as agile as *lateralis* but is rather clumsy when out of the water.

Description of the adult.—The adult is from 8.5 to 9 mm. long. This species is distinguished from *lateralis* by the lack of the yellow margins on the thorax and elytra and from *glaber* by the fact that the elytral punctures are of quite different sizes intermingled with one another, and the beetle is considerably smaller. The anterior portion of the sternal crest and the apical halves of the femora and tibiae are brownish-yellow instead of black. The species is only found in a few of the ponds and then not abundantly, but it furnishes as good fish food as the others and is harmless.

Genus HYDROUS Leach.

Hydrous (Leach, 1817, p. 165).

The only representative of this genus found in the Fairport fishponds is *Hydrous triangularis* (Say), which has already been fully described and figured by the writer in this Bulletin, Vol. XXXIX, pages 9 to 38; 23 text figures.

Genus DONACIA Fabricius.

Donacia (Fabricius, 1775, p. 195).

This genus is represented in the Fairport fishponds by the single species *Donacia æqualis* Say. The complete life history of this species with description and figures of the larva, pupa, imago, and cocoon is given by A. D. MacGillivray (1903, p. 321).

CAP ATTACHMENT ON EGG CASE.

The name and the function of the attachment to the cap of the egg case has provoked considerable discussion amongst the various investigators who have studied the water beetles, but without any satisfactory results. It has been designated by many as a "mast," but this is open to several objections. Whatever name is selected should be one that will apply to the egg cases of all hydrophilids indiscriminately. A mast is tall, upright, rigid, and more or less cylindrical, but in some hydrophilids (*Tropisternus*, *Enochrus*, *Berosus*) this attachment is flat, ribbonlike, and floats pliantly in the water. In others (*Laccobius*, *Helophorus*) it forms a hollow tube for the exit of the larvæ, and in one genus (*Hydrobius*) it forms a wide collar or cape around the cap end of the case. The term mast is an evident misnomer for anything in the shape of a ribbon or collar.

This cap attachment has also been called a "balancer" or "equipoise," but either of these names implies that it maintains or at least helps to maintain equilibrium. Since the great majority of the egg cases are fastened securely to some support, it is manifestly impossible for anything of this sort to affect their equilibrium. The only cases to which such a term would be applicable are those of *Hydrous* and *Hydrophilus*, and other genera certainly have an equal claim to recognition.

In striving to interpret the function of this cap attachment it has usually been taken for granted that it was in some way necessary to the development of the eggs. The investigator has thus been prejudiced in his observations, and all his efforts have been directed toward discovering in what way such an attachment could benefit the eggs, rather than toward finding its real function. The first and most obvious suggestion has been that this cap attachment contributed in some way to

the aeration of the eggs. Unfortunately in the only instances where this would be possible from a physical standpoint, the attachment proves to be solid and covered on the outside with a glazing impervious to air. In the great majority of cases the eggs are wholly immersed in water and the only method of aeration is through the water itself.

There are several genera (*Ochthebius*, *Hydroscapha*, *Cymbiodyta*, etc.) that do not construct any case at all but deposit their eggs either singly or in a mass in or near the water. Evidently, therefore, eggs can be developed without the help of this cap attachment. Why not infer that the eggs of all the genera can be thus developed and seek some other explanation for the attachment? In order to test whether the attachment is essential to egg development in genera whose egg cases possess it, 30 egg cases of *Tropisternus glaber* were brought into the laboratory and their attachments were cut off, taking care not to injure the cases themselves. These cases were in various stages of development, some just completed, others from one to three days old. They were gathered and the attachments removed on July 18, the larvæ began to hatch on July 22, and the last of them appeared on July 27. From these 30 cases were obtained 363 larvæ, an average of 12 for each case, and on examining the cases at the close of the experiment it was found that only four eggs had failed to hatch. This certainly is up to the normal percentage of hatching and proves conclusively that the cap attachment is not essential to the development of the eggs. What then is the attachment and what reason can be given for its existence?

In the great majority of cases the attachment is different in color and texture from the rest of the case. Miger claimed that in *Hydrous* (*Hydrophilus*) there were three secretions—one the normal secretion for the construction of the case, another for spinning the loose covering which surrounds the eggs, and the third for making the cap attachment. There is a similar difference in the egg cases of *Tropisternus glaber* and *T. mixtus*, but in the case of *T. lateralis* there are only two kinds of silk, that which forms the cap and its attachment ribbon not being distinguishable from that which forms the case itself. According to Richmond (1920) this last is true of many other hydrophilids.

These facts seem to indicate that the true explanation of this cap attachment is the one originally given by Lyonet, but apparently not appreciated by any entomologist since his day. In speaking of the "mast" of the egg case of the European species *Hydrous piceus*, Lyonet said: "I do not know the use of this little mast. Perhaps it enables the insect to get rid of an excess of silky matter" (1832, p. 135). In the account here given of the spinning of the egg case of *Tropisternus lateralis* it is shown that the case is spun first out of the normal silk secretion, then the eggs are laid and fastened in place inside the case with the loose silk, and finally the cap and its attachment are made. The normal silk secretion is white in color and fine in texture, and it forms the body of the case. During the laying of the eggs some of the contents of the oviducts may come out with the eggs and mingle with the silk secretion, making it thinner and looser in texture, thus forming the loose fibers used for covering the individual eggs. When the egg-laying ceases, the silk secretion returns to its normal texture and is used to

form the cap and in many genera the cap attachment, both of which are then like the case itself. In other genera, however, the dregs of the contents of the silk glands are different in color and texture, and so the cap attachment and sometimes the cap itself differs in these particulars. The attachment is simply the result of the efforts of the beetle to completely empty its silk glands of their contents and has no relation whatever to the development of the eggs. If this be the explanation of the construction of this attachment, the name "fag" is suggested for it, signifying the end or loose end, the latter or meaner part, of the weaving.

In *Tropisternus*, furthermore, the tip often unravels and forms a sort of fringe, which carries the same idea a little farther. In *Hydrous* and *Hydrophilus* the last of the contents of the silk glands is gummy or mucilaginous and dries in the air, because the egg cases of these genera float on the surface of the water. In consequence the surface of the fag and at least the basal half of the cap are smooth and more or less shiny. The fag also is much stiffer than in other genera. It is possible, however, that a similar result would be obtained if the fag of the egg cases of other genera were dried in the air instead of under water.

BIBLIOGRAPHY.

AGASSIZ, LOUIS.

1850. Lake Superior, its physical character, vegetation, and animals, compared with those of other and similar regions, with a narrative of the tour, by J. Elliot Cabot, and contributions by other scientific gentlemen. 8°, 428 pp., 8 pls. Boston. [The Coleoptera were by J. L. Leconte and included water beetles, some of which were new species.]

ALT, WILLY.

1912. Ueber das Respirationssystem von *Dytiscus marginalis* L. Ein Beitrag zur Morphologie des Insektenkorpers. Zeitschrift für wissenschaftliche Zoologie, Bd. 99, pp. 357-413, 34 figg. Leipzig.
- 1912a. Ueber das Respirationssystem der Larva von *Dytiscus marginalis*. *Ibid.*, pp. 414-443, 15 figg. [These two papers give detailed descriptions and excellent figures.]

ASHMEAD, W. H.

1894. Descriptions of two new hymenopterous parasites from water beetles. The Canadian Entomologist, vol. 26, pp. 24-26. London, Canada. [The parasites were *Ichneumon* flies, *Gausocentrus gyrini* from a *Gyrinus* pupa and *Cyrtogaster dineutis* from a *Dineutes* pupa.]

AUBÉ, CHARLES.

1838. Species générales des Coléoptères de la collection de M. le Comte Déjean. Vol. 6. Paris. [This volume contains the water beetles.]

BAKER, FRANK C.

1916. The relation of mollusks to fish in Oneida Lake. Technical Publication No. 4, New York State College of Forestry, Syracuse University, vol. 16, No. 21, pp. 8-366. [Included a list of plants and animals found associated with the mollusks, among which were two dytiscids, one halipid, three gyrinids, and two hydrophilids.]

BAKER, W. F.

1894. *Hydrobius fuscipes*: Notes on its life-history, larval anatomy, etc. The Naturalist, pp. 327-333. London.

BALFOUR-BROWNE, FRANK.

1908. On the British species of the genus *Philydrus* Solier. Entomological Record, vol. 20, pp. 25-29. London.
1910. On the life-history of *Hydrobius fuscipes* L. Transactions, Royal Society of Edinburgh, Vol. XLVII, Part II (1909-10), pp. 317-340, Pls. I-III. Edinburgh.
1913. The life-history of a water beetle. Nature, Vol. XCII, pp. 20-24. London.

BAUER, ALBERT.

1910. Die Muskulatur von *Dytiscus marginalis*. Ein Beitrag zur Morphologie des Insektenkörpers. Zeitschrift für wissenschaftliche Zoologie, Bd. 95, Viertes Heft, pp. 594-646, 19 figg. Leipzig.

BERLESE, ANTONIO.

1909. Gli Insetti: loro organizzazione, sviluppo, abitudini e rapporti con l'uomo. 1. Embriologia e Morfologia. X+1044 pp. con 1292 fig. e 10 tav. Milano Società editrice libraria. [*Hydrobius fuscipes*, *Hydrophilus piceus*, *Berosus spinosus*, pp. 55, 832, 875.]

BEUTENMÜLLER, WM.

1891. Bibliographical catalogue of the described transformations of North American Coleoptera. Journal, New York Microscopical Society, Vol. VII, pp. 1-52. New York.

BLATCHLEY, WILLIS STANLEY.

1910. On the Coleoptera or beetles known to occur in Indiana. Indiana Department of Geology and Natural Resources, Bulletin No. 1, 1386 pp., 590 figs. Indianapolis.
1919. Insects of Florida. 5a. Supplementary notes on the water beetles. Bulletin, American Museum of Natural History, Vol. XLI, pp. 305-322. New York. [Made *Thermonectes ornaticollis* a distinct species, p. 314; made *Tropisternus nimbatus* (Say) a synonym of *T. lateralis* (Fabricius), p. 319.]

BLUNCK, HANS.

1911. Zur Kenntniss der Natur und Herkunft des "milchigen Secrets" am Prothorax des *Dytiscus marginalis* L. Zoologischer Anzeiger, Bd. XXXVII, pp. 112-113. Leipzig.
1912. Beitrag zur Kenntniss der Morphologie und Physiologie der Haftscheiben von *Dytiscus marginalis* L. Zeitschrift für wissenschaftliche Zoologie, Bd. 100, pp. 459-492, 11 figg. Leipzig. [A detailed description of the structure and working of the disks on the front tarsi of the male.]
- 1912a. Das Geschlechtsleben des *Dytiscus marginalis* L. 1. Teil. Die Begattung. *Ibid.*, Bd. 102, pp. 169-248, 44 figg.
1913. *Idem*. 2. Teil. Die Eiblage. *Ibid.*, Bd. 104, pp. 157-179, 2 figg.
- 1913a. Kleine Beiträge zur Kenntniss des Geschlechtsleben und der Metamorphose der *Dytisciden*. 1. Teil. *Colymbetes fuscus* L. und *Agabus undulatus* Schrank. Zoologischer Anzeiger, Bd. XLI, pp. 534-546, 5 figg. Leipzig. [Described the sex apparatus.]
- 1913b. *Idem*. 2. Teil. *Acilius sulcatus* L. *Ibid.*, pp. 586-597, 4 figg. [Described the sex apparatus.]
1916. Recherches sur la respiration des insectes aquatiques adultes. Archives de Zoologie expérimentale et générale, T. XLIV, pp. 58-73, 3 figg. Paris.
1917. Die Entwicklung des *Dytiscus marginalis* Linn. vom Ei bis zur Imago. Zeitschrift für wissenschaftliche Zoologie, Bd. 117, pp. 1-129, 57 figg. Leipzig.
- 1917a. Die Schreckdrüsen des *Dytiscus* und ihr Secret; Zweiter und letzter Teil. *Ibid.*, Heft 2, pp. 205-256, 3 figg., 4 tables.

BÖVING, ADAM GIEDE.

1914. On the abdominal structure of certain beetle larvæ of the campodeiform type. A study of the relation between the structure of the integument and the muscles. Proceedings, Entomological Society of Washington, vol. 16, pp. 55-63, Pls. III and IV. Washington.
- 1914a. Notes on the larva of *Hydroscapha* and some other aquatic larvæ from Arizona. *Ibid.*, pp. 169-174, Pls. XVII and XVIII.

BOWDITCH, F. C.

1884. *Hydrocharis obtusatus*. Journal, Boston Zoological Society, Vol. III, pp. 1-6.

BROCHER, FRANK.

1910. Les phénomènes capillaires. Leur importance dans la biologie aquatique. Annales, Biologie Lacustre, T. 4, pp. 89-138. Bruxelles. [Explained when and why a surface attracts water and when it does not and applied this to animals living in the water.]
1911. Observations biologiques sur quelques insectes aquatiques. *Ibid.*, pp. 367-379. [Described the eggs and larvæ of *Berosus sericeus*.]
- 1911a. Recherches sur la respiration des insectes aquatiques adultes. Les Dyticidés. *Ibid.*, pp. 383-398, 5 figs.

BROCHER, FRANK—Continued.

1912. Recherches sur la respiration des insectes aquatiques adultes. Les Elmidés. *Ibid.*, T. 5, pp. 136-179, 23 figs. [Stated on p. 178 that *Haliphus*, after having inhaled through the posterior abdominal spiracles, exhaled beneath the coxal plate, the reverse of the explanation given by Matheson.]
- 1912a. L'appareil stridulatoire de l'*Hydrophilus piceus* et celui du *Berosus ariceps*. *Ibid.*, pp. 215-217, 3 figs. [In stridulating the lateral margin of the second abdominal segment is rubbed against a roughened spot on the linear surface of the elytron.]
- 1912b. Recherches sur la respiration des insectes aquatiques adultes. Le Cybister. *Ibid.*, pp. 218-219. [The two posterior pairs of abdominal spiracles are supplied by a special tubular trachea of large diameter, which runs forward to the metathorax alongside the regular trachea, the two being united opposite each spiracle by a short branch.]
- 1912c. Recherches sur la respiration des insectes aquatiques adultes. L'*Hydrophile*. Étude physiologique et anatomique. *Ibid.*, pp. 220-258, 22 figs. [The spiracles located between the prothorax and mesothorax are the only ones used for inspiration when the beetle is in the water, and they communicate by means of the antennæ with the film of air that covers the ventral surface of the body.]
- 1912d. Recherches sur la respiration des insectes aquatiques (imago). Nèpe. *Hydrophile*. Notonecte. Dyticidés. *Hæmonia*. Elmidés. *Societas entomologica*, vol. 27, No. 21, pp. 91-93; No. 22, pp. 102-103. Stuttgart.
1913. Recherches sur la respiration des insectes aquatiques. Étude anatomique et physiologique du système respiratoire chez les larves du genre *Dytiscus*. *Annales, Biologie Lacustre*, T. 6, pp. 120-147, 11 figs. Bruxelles. [Gave a detailed description of the spiracles of the last segment and explained how they are opened and closed by the movements of the cerci.]
1914. Observations biologiques sur les Dyticidés. *Ibid.*, pp. 303-313, 4 figs. [An attempt to answer the questions: Can the elytra be wet? Of what use are the channels in the elytra? What is the function of the opalescent white skin secretion?]
- 1914a. Recherches sur la respiration des insectes aquatiques adultes. Les Dyticidés (second article), suivi d'une notice sur les mouvements respiratoires de l'*Hydrophile*. *Ibid.*, T. 7, pp. 5-39, 12 figs. [A detailed description of the anatomy of the respiratory system and the physiology of respiration in two species of *Dytiscus*.]

BUHK, F.

1910. Lebensweise und Entwicklung von *Spercheus emarginatus* Schall. *Entomologische Rundschau*, Bd. 27, pp. 127-128; 134-136. Stuttgart.

BURGESS, EDWARD.

1881. The structure of the mouth in the larva of *Dytiscus*. *Proceedings, Boston Society of Natural History*, Vol. XXI, 1880-1882 (1883), pp. 223-228, 4 figs. [Showed that the *Dytiscus* larva has a wide and well-developed mouth, although its lips are locked together by a dove-tailed joint developed for that purpose.]

CALWER, C. G.

1858. Käferbuch. Allgemeine und specielle Naturgeschichte der Käfer Europa's. 8°, 738 pp. Stuttgart.

CASPER, ALOIS.

1913. Die Körperdecke und die Drüsen von *Dytiscus marginalis* L. Ein Beitrag zum feinerem Bau des Insektenkörpers. *Zeitschrift für wissenschaftliche Zoologie*, Bd. 107, pp. 387-508, 44 figs. Leipzig. [Divided the glands into offensive, pseudoacinous, and pygidial, the first of which are for repelling larger enemies, possibly fish.]

CHEAVIN, W. HAROLD S.

1914. The water beetle (*Dytiscus marginalis*). *Knowledge*, vol. 37, pp. 222-225, 270-271, 14 figs. London. [Most of the figures are excellent photographs illustrating the structure and life history of *Dytiscus marginalis*.]

CLAIRVILLE, J. DE.

1798. Entomologie helvétique, ou catalogue des insectes (Coléoptères) de la Suisse, rangés d'après une nouvelle méthode avec descriptions et figures. Vol. 1. Rhyncophora. Zürich.
1806. *Idem*. Vol. 2. Adephaga.

COMSTOCK, JOHN HENRY.

1912. A manual of the study of insects. 10th ed. xi+701 pp., 797 figs. Comstock Publishing Co., Ithaca, N. Y.

COOKE, A. H.

1895. Molluscs. 459 pp. Cambridge Natural History Series. MacMillan & Co., London and New York.

CROTCH, G. R.

1873. Revision of the Dytiscidae of the United States. Transactions, American Entomological Society, vol. 4, pp. 383-424. Philadelphia.

CURTIS, JOHN.

1827. British entomology; being illustrations and descriptions of the genera of insects found in Great Britain and Ireland. Vol. 5. London. [Established the new genus *Cybister*, p. 151.]

CUSSAC, ÉMILE.

1852. Mœurs et métamorphoses du *Spercheus emarginatus* et de l'*Helochares lividus*. Annales Société Entomologique de France, T. 10, pp. 617-627, Pl. 13, figs. 8-26. Paris.

DALE, J. C.

1832. Brief notice of the habits and transformations of the dragonfly; compiled in explanation of the accompanying cut. The magazine of Natural History and Journal of Zoology, Botany, Mineralogy, Geology, and Meteorology, Vol. V, pp. 517-520, Fig. 98. London.

1832a. Small fishes are destroyed by other insects, besides the larvæ of dragonflies as instanced p. 519. *Ibid.*, p. 668. [Among other insects mentioned are water beetles.]

DEEGENER, P.

1913. Respirationsorgane. Handbuch der Entomologie, Bd. I, Cp. 5, pp. 316-382, figs. 213-274. Jena. [Included the respiration organs of both adults and larvæ.]

DE GEER, CHARLES.

1774. Mémoires pour servir à l'histoire des insectes. Vol. 4. Stockholm. [Contained the water beetles.]

DIMMOCK, GEORGE.

1886. Belostomidae and some other fish-destroying bugs. Bulletin, U. S. Bureau of Fisheries, Vol. VI, 1886, pp. 353-359, 1 fig. Washington. [See p. 251.]

DIMMOCK, GEORGE, and FREDERICK KNAB.

1904. Early stages of Carabidae. Bulletin No. 1, Springfield (Mass.) Museum of Natural History, 55 pp., 4 pls., 1 fig. [Found a hymenopterous parasite (*Spilocryptus incertus*), and the larva of a bombardier beetle (*Brachinus janthinipennis*), feeding upon pupæ of *Dineutes americanus*.]

DONCKIER DE DONCEEL, H.

1879. Sur les mœurs de *Colymbetes fuscus*. Annales, Société Entomologique de Belgique, T. 22. Comptes-rendus des Seances de la Société Entomologique de Belgique, Année 1879, pp. CLV-CLVI. Bruxelles.

DONISTHORPE, HORACE.

1900. Notes on the copulation of *Hydrophilus piceus* L. The Entomologist's Record and Journal of Variation, Vol. XII, pp. 291-292. London, Berlin, and New York.

DRAKE, CARL J.

1914. The food of *Rana pipiens* Shreber. Ohio Naturalist, vol. 14, pp. 257-269. Columbus Ohio. [Beetles formed an important item of this food.]

DUGÈS, EUG.

1884. Métamorphoses du *Tropisternus lateralis* Fabricius. Annales, Société Entomologique de Belgique, T. 28, pp. 7-11, Pl. I, figs. 1-17. Bruxelles.

1885. Métamorphoses du *Cybister fimbriolatus* Say. *Ibid.*, T. 29, pp. 26-31, Pl. II, figs. 1-15.

ELLES, J.

1830. The water beetle. The Magazine of Natural History and Journal of Zoology, Botany, Mineralogy, Geology, and Meteorology, Vol. III, pp. 148-149. London. [Quoted in full on p. 251.]

ERICHSON, WILHELM FERDINAND.

1832. *Genera Dytyceorum*. Inaugural-Dissertation. 48 pp. Berlin.

EVERMAN, BARTON WARREN, and H. WALTON CLARK.

1920. *Lake Maxinkuckee: A physical and biological survey*. Vols. I and II. Vol. I, 660 pp., illus. Vol. II, 512 pp., illus. Indianapolis.

FABRICIUS.

1775. *Systema entomologiæ sistens Insectorum Classes, Ordines, Genera, Species, adjectis synonymis, locis, descriptionibus, observationibus*. Fleusburgi et Lipsiæ.

1801. *Systema Eleutheratorum*. Hafniæ.

FALL, H. C.

1901. List of the Coleoptera of southern California, with notes on habits and distribution and descriptions of new species. *Occasional Papers, California Academy of Science*, VIII, 282 pp. San Francisco. [The water beetles are enumerated on pp. 51-58.]

1917. *New Dytiscidæ*. *Journal, New York Entomological Society*, vol. 25, pp. 163-182. New York.

FOLSOM, J. W.

1906. *Entomology with special reference to its biological and economic aspects*. vii+485 pp., illus. Philadelphia. [Adaptations of aquatic insects, pp. 184-192.]

FORBES, S. A.

1880. The food of fishes. *Bulletin, Illinois State Laboratory of Natural History*, Vol. I, No. 3, pp. 18-65. Peoria, Ill. [Reprint, 1903, pp. 1-70.]

1888. On the food relations of fresh-water fishes: A summary and discussion. *Ibid.*, Vol. II, pp. 475-538.

FRICKEN, W. VON.

1887. Ueber Entwicklung, Atmung, and Lebensweise der Gattung *Hydrophilus*. *Tageblatt der LX Versammlung deutscher Naturforscher und Aertste*, pp. 114-115. Wiesbaden.

FRISCH, JOHANN LEONHARD.

1721. Beschreibung von allerley Insekten in Deutschland nebst nützlichen Anmerkungen und nöthigen Abbildungen von diesem kriechenden und fliegenden inländischen Gewürme. Bd. 6. Berlin. [Contained the water beetles.]

GAHAN, CHARLES J.

1900. Stridulating organs in Coleoptera. *Transactions, Entomological Society of London*, pp. 433-452, Pl. VII. London.

GANGLBAUER, LUDWIG.

1899. Die Käfer von Mitteleuropa. *Hydroscaphidæ*, Bd. 3, pp. 332-335. Wien.

1904. *Idem*. *Hydrophilidæ*, Bd. 4, pp. 141-286.

GARMAN, W. H.

1881. The egg-case and larva of *Hydrophilus triangularis* Say. *The American Naturalist*, Vol. XV, pp. 660-663, 3 figs. Philadelphia. [Abstract in *Annals and Magazine of Natural History*, vol. 15, 1881, p. 66.]

1890. A preliminary report on the animals of the Mississippi bottoms near Quincy, Ill., in August, 1888. Part 1. *Bulletin, Illinois State Laboratory of Natural History*, Vol. III (1887-1895), pp. 123-184. Peoria, Ill.

GEMMINGER, MAX, and EDGAR VON HAROLD.

1868. *Catalogus Coleopterorum hucusque descriptorum synonymicus et systematicus*. Vol. 2. Munich. [Contained the water beetles.]

GEOFFROY, ETIENNE ST. HILAIRE.

1762. *Histoire des Insectes*. 2 vols. Paris.

GERMAR, ERNST FRIEDRICH.

1824. *Insectorum species novæ, aut minus cognitæ, descriptionibus illustratæ*. 624 pp., 2 pls. Halæ.

HALIDAY, ALEXIS H.

1855. Entomological remarks. *Natural history Review*, vol. 2, p. 116, pl. 3. Dublin. *Ochthebius punctatus*.

1856. Description of the larvæ of *Ochthebius punctatus* and *Diglossa marsa*. *Ibid.*, vol. 3, p. 20.

HALL, C. A.

1914. Common British beetles. viii+88 pp., 23 pls. London. [The adult and larva of *Dytiscus marginalis* were well described and finely figured.]

HANKINSON, THOS. L.

1907. A biological survey of Walnut Lake, Mich. Michigan State Biological Survey Report for 1907, pp. 156-288, 75 pls. Lansing. [Contained notes on aquatic insects by J. G. Needham, pp. 252-271.]

HARRIS, THADDEUS WILLIAM.

1828. Contributions to entomology; Dytiscidæ. New England Farmer, vol. 7, No. 5, p. 156 and No. 6, p. 164. Boston.

HAUPT, H.

1907. Was mich eine Hydrophilus (Hydrous) Larve lehrte. Wochenschrift für Aquarienkunde, Bd. 4, pp. 326-328. Braunschweig.
1909. Zur Biologie der Hydrous (Hydrophilus) Larve. Zeitschrift für Naturwissenschaften, Bd. 81, pp. 301-304. Leipzig.

HENNEGUY, L. FÉLIX.

1904. Les insectes: Morphologie, reproduction, embryogénie. xviii+804 pp., 622 figs., IV col. pls. Paris. [Hydrophili types of development, pp. 320-322, Figs. 306-307.]

HENSHAW, SAMUEL.

1885. List of the Coleoptera of America north of Mexico. 161 pp. Published by American Entomological Society, Philadelphia.

HENTSCHEL, ERNST.

1909. Das Leben des Süßwassers. Eine gemeinverständliche Biologie. IV+336 pp., 299 figg. 17 Taf. München. [Included water beetles.]

HERBST, JOHANN FRIEDRICH WILHELM.

1797. Natursystem. * * *. Käfer. Bd. 7. Berlin. [Included water beetles.]

HOLSTE, G.

1910. Das Nervensystem von *Dytiscus marginalis*. Ein Beitrag zur Morphologie des Insektenkörpers. Zeitschrift für naturwissenschaftliche Zoologie, Bd. 96, pp. 419-476. Leipzig.
1913. Das Nervus proctodæo-genitalis des *Dytiscus marginalis* L. Zoologischer Anzeiger, Bd. XLI, pp. 150-156, 2 figg. Leipzig.

HOPE, FREDERIC WILLIAM.

1838. The coleopterists' manual. Vol. 2. London. [Proposed the genus *Hydrocharis*, p. 125, which becomes a synonym of *Hydrophilus*.]

HORN, GEORGE H.

1883. Miscellaneous notes and short studies of North American Coleoptera. Transactions, American Entomological Society and Proceedings, Entomological Section of the Academy of Natural Sciences, Vol. X, pp. 269-312, Pl. IX. Philadelphia.

1883a. [Maxillæ of Gyrinidæ.] *Ibid.* (Proceedings), p. xvi.

1885. A note on some Hydrophilidæ. The Canadian Entomologist, Vol. XVII, pp. 137-139. London, Canada.

1890. Notes on the species of Ochthebius of Boreal America. Transactions, American Entomological Society, Vol. XVII, pp. 17-26, Pl. II. Philadelphia.

1890a. Notes on some Hydrobiini of Boreal America. *Ibid.*, pp. 237-278, Pls. III and IV.

1890b. A revision of the Sphæridiini inhabiting Boreal America. *Ibid.*, pp. 279-314, Pl. IX.

JACQUELINE-DUVAL, PIERRE NICHOLAS CAMILLE.

1856. Manuel entomologique. Genera des Coleopteres d'Europe. * * *. Tome 1, cah. 3. Paris. [Contains dytiscids and gyrinids.]

JUDAY, CHANCEY.

1907. A study of Twin Lakes, Colo., with especial consideration of the food of the trouts. Bulletin, U. S. Bureau of Fisheries, Vol. XXXVI, 1906 (1907), pp. 147-178, Pl. III, 6 text figs., 11 tables. Washington.

KELLOGG, VERNON L.

1908. American insects. xiv+694 pp., 812 figs. Henry Holt & Co., New York.

KIRBY,

1837. Fauna borealis americana. [Established, Vol. IV, p. 78, a new species (*Dineutes assimilis*), now regarded by the best authorities as a synonym of *Dineutes americanus* Say.]

LACORDAIRE, TH.

1854. Histoire naturelle des insectes. Tome 1. Paris. [Beetle genera, pp. 443-475.]

LAKER, ABBOTT.

1881. The cocoons of *Hydrophilus piceus* and *Hydrobius fuscipes*. The Entomologist, vol. 14, pp. 82-84. London.

LAMEERE, A.

1899. Discours sur la raison d'être des métamorphoses chez les insectes. Annales, Société Entomologique de Belgique, T. 43, pp. 619-636. Bruxelles.
 1900. Notes pour la classification des Coléoptères. *Ibid.*, T. 44, pp. 365-366.
 1903. Nouvelles notes pour la classification des Coléoptères. *Ibid.*, T. 47, pp. 155-165.

LAMPERT, KURT.

1910. Das Leben der Binnengewässer. Berlin. [Included the water beetles.]

LATREILLE, PIERRE ANDRÉ.

1802. Histoire naturelle, générale et particulière des Crustacés et des insectes. Tome 11. Paris. [Contained the water beetles.]

LEACH, WILLIAM ELFORD.

- 1814-1817. The Zoological Miscellany. 3 vols. London. [Contains the classification of insects.]

LECONTE, JOHN L.

1855. Synopsis of the Hydrophilidæ of the United States. Proceedings, Academy of Natural Sciences, Philadelphia, Vol. VII, 1854, 1855 (1856), pp. 356-375. Philadelphia.
 1861. Classification of the Coleoptera of North America, Part I. Smithsonian Miscellaneous Collections, Vol. III, xxv+208 pp. Washington.
 1862. *Idem. Ibid.*, pp. 209-286.
 1863. New species of North American Coleoptera, Part I. *Ibid.*, Vol. VI (1867), No. 167, 86 pp.

LECONTE, JOHN L., and GEORGE H. HORN.

1883. Classification of the Coleoptera of North America. Smithsonian Miscellaneous Collections, Vol. XXVI, No. 507, xxxviii+567 pp. Washington.

LENG, CHARLES W.

1888. Water beetles of Staten Island. Proceedings, Staten Island Association, April 14, 1888. New York.
 1889. Hydrophilus of Staten Island. *Ibid.*, January, 1889.
 1913. Aquatic Coleoptera. Journal, New York Entomological Society, Vol. XXI, pp. 32-42. New York. [Discussed modifications of structure and vestiture by which water beetles are adapted to their aquatic life.]
 1913a. Dytiscus flying in January. *Ibid.*, p. 160.

LENG, CHARLES W., and ANDREW J. MUTCHLER.

1918. Insects of Florida. V. The water beetles. Bulletin, American Museum of Natural History, Vol. XXXVIII, pp. 73-116, 2 figs. New York. [Regarded *Thermonectes ornaticollis* as a variety of *T. basilaris* and not as a separate species.]

LINNÉ, C. VON.

1758. Caroli Linnæi. * * *. Systema naturæ. * * *. 10th ed. Tome I. Holmiæ.
 1759. *Idem.* Tome II.

LINTNER, J. A.

1878. Report on the insects and other animal forms of Caledonia Creek, N. Y. Appendix, Tenth Annual Report, Commissioners of Fisheries of the State of New York for 1877 (1878), pp. 12-36. [Included water beetles.]

LOWNE, B. T.

1871. On the so-called suckers of Dytiscus and the pulvilli of insects. The Monthly Microscopical Journal: Transactions, Royal Microscopical Society, Vol. V, pp. 267-271, Pl. LXXXIX. London. [Gave a detailed account of the structure of the anterior tarsus of the male Dytiscus and called attention to the viscid secretion discharged by the cupules, which greatly increases their adhesion.]

LYONET, PIERRE.

1832. Recherches sur l'anatomie et les métamorphoses de différentes espèces d'insectes, ouvrage posthume by Pierre Lyonet. Publié par M. W. De Haan. Accompagnées de 54 planches. iv + 580 pp. Paris. [Water beetles described p. 128-151 and figured pl. 13, figs. 47-50.]

MABBOTT, DOUGLAS C.

1920. Food habits of seven species of American shoal-water ducks. U. S. Department of Agriculture, Bulletin No. 862, 70 pp., VII pls. Washington.

MACGILLIVRAY, A. D.

1903. Aquatic Chrysomelidæ and a table of the families of coleopterous larvæ. Bulletin No. 68, New York State Museum, pp. 288-327, pls. XXI-XXXI. Albany. [Useful for identifying water-beetle larvæ.]

MACLEAY, WILLIAM SHARP.

1825. Annulosa Javanica, or an attempt to illustrate the natural affinities and analogies of the insects collected in Java by Thomas Horsfield and deposited by him in the museum of the honorable East India Co. London.

MATHESON, ROBERT.

1912. The Halipidæ of North America, north of Mexico. Journal, New York Entomological Society, Vol. XX, pp. 156-193, Pls. X-XV, text figs. A-C. New York. [An excellent systematic list of all species, an explanation of the mode of respiration, and the life histories of two species of Peltodytes and one of Halipilus.]

1914. Life-history of a dytiscid beetle (*Hydroporus septentrionalis*). The Canadian Entomologist, Vol. XLVI, pp. 37-40, unnumb. pl. London, Canada.

- 1914a. Notes on *Hydrophilus triangularis* Say. *Ibid.*, pp. 337-343, pl. 22, figs. 29-31.

MCATEE, W. L.

1913. Food habits of the mallard ducks of the United States. U. S. Department of Agriculture, Bulletin No. 720, 36 pp., Pl. I. Washington.

MCATEE, W. L., and F. E. L. BEAL.

1912. Some common game, aquatic, and rapacious birds in relation to man. U. S. Department of Agriculture, Farmers Bulletin No. 497, 30 pp., 14 figs. Washington.

MEGUSAR, FRANZ.

1906. Einfluss abnormaler Gravitationswirkung auf die Embryonalentwicklung bei *Hydrophilus aterrimus* Eschscholtz. Archiv für Entwicklungsmechanik der Organismen, Bd. 22, pp. 141-148, 3 figs. Leipzig.

1907. Die Regeneration der Coleopteren. *Ibid.*, Bd. 25, pp. 148-234, Pls. V-VIII.

1909. Lebensgeschichte der Hydrophiliden. Verhandlungen der k. k. Zoologischbotanischen Gesellschaft in Wien, Bd. LIX, pp. 278-287. Wien.

MEINERT, F.

- 1879-1880. Om mundens Bygning hos Larverne af Myrmeleontiderne, Hemerobierne, og Dytiscerne. Videnskabelige Meddelelser fra den naturhistoriske Forening, series 4, vol. 1, pp. 69-72. Kjøbenhavn. [First discovered that the mouth of the Dytiscus larva is open and not closed, as had been believed up to his time.]

1901. Vandkalvelarverne (larvæ Dytiscidarum). Det Kongelige Danske Videnskabernes Selskabs Skrifter, series 6, Vol. IX, pp. 337-340, pl. 1-6. [Very useful for comparison with American species.]

MENTZSCHEFAHL, A. VON.

- 1778-1779. Nachricht von einigen Wasser-insecten an den bartsch, nach welchen sich die Fischer bei ihren winterfischereyen richten. Oekonomische Nachschriften der Gesellschaft in Schlesien. Vol. VI (1778), pp. 393-394; Vol. VII (1779), pp. 2-5. [Mentioned two species of dytiscids as insects which attacked the European perch.]

MIALL, L. C.

1895. The natural history of aquatic insects. ix+395 pp., 116 figs. Macmillan & Co., London and New York. [Aquatic beetles, pp. 30-96, 21 figs.]

MIGER, FÉLIX, et LANCRET.

1804. Sur les larves Hydrophiles et Dytiques. Bulletin, Paris Société Philomatique, T. 3, pp. 229-231.

MIGER, FÉLIX, et LANCRET—Continued.

1809. Mémoires sur les larves d'insectes Coléoptères aquatiques. 1. Mémoire sur le grand Hydrophile. Annales, Museum nationale d'histoire naturelle, T. 14, pp. 441-459, Pl. 28, 9 figs. Paris.

MOORE, EMMELINE.

1920. Some plants of importance in pondfish culture. Appendix IV, Report of the U. S. Commissioner of Fisheries for 1919. Bureau of Fisheries Document No. 881, 20 pp., 1 map, 7 tables. Washington.

MULSANT, É.

1844. Histoire naturelle des Coléoptères de France. Vol. 3, Palpicornes, 196 pp., 1 pl. Paris et Lyon.

MULSANT, É., et CL. REY.

1861. Description d'une espece nouvelle d'Ochthebius [lejolissi] et de la larve de cet insect. Mémoires, Société Imperiale des Sciences Naturelles de Cherbourg, T. VIII, pp. 181-189, 1 pl.

MUTTKOWSKI, RICHARD ANTHONY.

1918. The fauna of Lake Mendota. A qualitative and quantitative survey with special reference to the insects. Transactions, Wisconsin Academy of Sciences, Arts, and Letters, Vol. XIX, Part I, pp. 374-482, 9 tables. Madison.

NEEDHAM, JAMES G.

1904. Beetle drift on Lake Michigan. The Canadian Entomologist, Vol. XXXVI, pp. 294-296. London, Canada.

1907. Notes on aquatic insects of Walnut Lake. See Hankinson, 1907.

1917. The insect drift of lake shores. The Canadian Entomologist, Vol. XLIX, pp. 129-137. London, Canada.

1918. Aquatic insects. In Fresh-water biology, by Henry B. Ward and George C. Whipple, Ch. XXVII, pp. 876-946, Figs. 1354-1392. John Wiley & Sons (Inc.). New York and London.

NEEDHAM, JAMES G., and J. T. LLOYD.

1916. The life of inland waters. 8°, 438 pp., 244 text figs. Ithaca, N. Y.

NEEDHAM, JAMES G., and HELEN V. WILLIAMSON.

1907. Observations on the natural history of diving beetles. The American Naturalist, Vol. XLI, pp. 477-494, 8 figs. Boston. [A list of Dytiscidae found in the "Gym Pond" at Lake Forest, with notes on their habits and life histories.]

ORCHYMONT, A. D'.

1913. Contribution à l'étude des larves hydrophilides. Annales de Biologie Lacustre, T. 6, pp. 173-214, 23 figs. Bruxelles. [Described and figured the larvæ of several European genera and gave a classification of genera according to their known larvæ.]

PAGANETTI-HUMMLER, G.

1899. Coleopterologische Liebesszenen der Ochtheben. Zeitschrift für Entomologie, Dritte Reihe, Bd. 4, p. 107. Breslau.

PEARSE, A. S.

1918. The food of the shore fishes of certain Wisconsin Lakes. Bulletin, U. S. Bureau of Fisheries, Vol. XXXV, 1915-16 (1918), pp. 215-292. Bureau of Fisheries Document No. 856. Washington.

PERRIS, ÉDOUARD.

1876. Nouvelles promenades entomologiques. Annales, Société Entomologique de France, Série 5, T. VI, pp. 171-244. Paris. [*Helophorus rugosus*, pp. 183-185.]

PLANET, LOUIS.

1891. Développement de l'Hydrophile brun (*Hydrophilus piceus*). *Hydrophilus piceus*. Métamorphoses. Le Naturaliste, 2^e Série, 13^e Année, pp. 259-260. Paris.

PLATEAU, FÉLIX.

1872. Un mot sur le mode d'adhérence des mâles de Dytiscides aux femelles pendant l'acte de l'accouplement. Annales, Société Entomologique de Belgique, T. 15, 1871-72, pp. 205-242. Bruxelles. [Proved by experiment that a freshly killed *Dytiscus marginalis*, when its suckers were applied to a glass cylinder, could support more than 13 times its own weight.

1876. Note sur une sécrétion propre aux Coléoptères Dytiscides. *Ibid.*, T. 19, pp. 1-10.

PLATT, EMILIE LOUISE.

1915. The population of the "blanket-algae" of fresh-water pools. The American Naturalist, Vol. XLIX, pp. 752-762, 1 map. The Science Press, New York. [In this blanket were found undetermined dytiscid larvæ, the larva of the haliplid genus *Peltodytes*, and adults of two genera of hydrophilids.]

PORTIER, P.

1911. Recherches physiologiques sur les insectes aquatiques. Archives de Zoologie expérimentale et générale, Série 5, T. 8, pp. 89-379. Paris.

POUJADE, G. A.

1901. Sur l'*Hydrophilus piceus* (Linn.). Bulletin, Société Entomologique de France, Année 1901, pp. 229-230. Paris.

PUTNAM, J. D.

1876. List of Coleoptera found in the vicinity of Davenport, Iowa. Proceedings, Davenport Academy of Natural Sciences, Vol. I, 1867-1876 (1876), pp. 169-173. Davenport.
 1876a. List of Coleoptera collected in the Rocky Mountains of Colorado in 1872. *Ibid.*, pp. 177-182.
 1876b. Report on the insects collected by Captain Jones' expedition to northwestern Wyoming in 1873. *Ibid.*, pp. 187-192.
 1876c. Report on the insects collected in the vicinity of Spring Lake Villa, Utah Co., Utah, during the summer of 1875. *Ibid.*, pp. 193-205.

RANDALL, J. W.

1839. Descriptions of new species of coleopterous insects inhabiting the State of Maine. Boston Journal of Natural History, Vol. II, pp. 1-33. Boston. [*Hydrophilus agilis* (*Laccobius agilis*), p. 19.]

REEKER, H.

1891. Die Tonapparate der Dytiscidæ. Archiv für Naturgeschichte, Bd. LVII, pp. 105-112, Pl. VI. Berlin.

RÉGIMBART, M.

1878. Étude sur la classification des Dytiscidæ. Annales, Société Entomologique de France, Série 5, T. 8, pp. 447-466, Pl. 10. Paris.

REITTER, EDMUND.

1909. Coleoptera. In Die Süßwasserfauna Deutschlands, hrsg. von A. Brauer. iv+235 pp. Jena.

RENGEL, C.

1901. Zur Biologie des *Hydrophilus piceus*. Biologisches Centralblatt, Bd. 21, pp. 173-182, 209-220. Berlin.

REY, CL.

1887. Essai d'études sur certaines larves de Coléoptères. Annales, Société Linnéenne de Lyon Nouvelle série, T. 33, pp. 131-259, Pls. I and II. [*Ochthebius* (*Calobius*) *quadricollis* Muls., p. 141.]

RICHMOND, E. AVERY.

1920. Studies on the biology of the aquatic Hydrophilidæ. Bulletin, American Museum of Natural History, Vol. XLII, pp. 1-94, Pls. I-XVI. New York. [Gave the complete life histories of 9 species and described the eggs and larvæ of 13 other species, with good figures of all.]

RILEY, C. V.

1881. Notes on *Hydrophilus triangularis* [Say]. The American Naturalist, Vol. XV, pp. 814-817, 2 figs. Philadelphia.
 1885. Water-beetles destroying carp. Bulletin, U. S. Bureau of Fisheries, Vol. V, 1885, p. 311. Washington. [Quoted in full on page 251.]

ROBERTS, C. H.

1889. Notes on water beetles. Entomologica Americana, Vol. V, p. 82. Brooklyn, N. Y.
 1895. The species of Dineutes of America, north of Mexico. Transactions, American Entomological Society, Vol. XXII, pp. 279-288, Pls. V and VI. Philadelphia. [Does not include either food or habits.]
 1905. The distinctive characters of the eastern species of the genera *Dytiscus* and *Cybister*. Journal, New York Entomological Society, Vol. XIII, pp. 103-107. New York. [These characters are all anatomic.]
 1913. Critical notes on the species of Haliplidæ of America, north of Mexico, with descriptions of new species. *Ibid.*, Vol. XXI, pp. 91-123.

RUPERTSBERGER, MATHIAS.

1880. *Biologia der Käfer Europas*. Eine Uebersicht der biologischen Literatur gegeben in einem alphabetischem Personen- und systematischen Sach-Register nebst einem Larven Cataloge. 295 pp. Linz. [Included the water beetles, pp. 112-115.]
1894. *Die biologische Literatur über die Käfer Europas von 1860 an*. Mit Nachträgen aus früherer Zeit und einen Larven-Cataloge. 308 pp. Linz.

SAUNDERS, WILLIAM.

1879. *Hydrophilus triangularis*: Habits and transformations popularly noticed. The Canadian Entomologist, Vol. XI, p. 223, fig. 14. Montreal.

SAY, THOMAS.

- 1823-1824. Description of coleopterous insects collected in the late expedition to the Rocky Mountains under the command of Major Long. Philadelphia Journal Academy Natural Sciences, Vol. III, 1823, pp. 139-216; 238-282; 298-331; 403-462. Vol. IV, 1824, pp. 83-99.
1825. Descriptions of insects of the families of Carabici and Hydrocanthari of Latreille, inhabiting North America. Transactions, American Philosophical Society, Vol. II, N. S., pp. 1-109. Philadelphia. [*Dytiscus fimbriolatus* established as a new species, p. 91.]
1834. Descriptions of new North American insects, and observations on some already described. Transactions, American Philosophical Society, Vol. IV, pp. 409-470.

SCHAUM, H., und E. A. H. VON KISSENWETTER.

1868. *Naturgeschichte der Insekten Deutschlands*. Bd. 1, Hälfte 2, 144 pp. Berlin. [Discusses Dytiscidae and Gyrinidae.]

SCHAUPP, F. G.

1879. List of the described coleopterous larvæ of the United States, with some remarks on their classification. Bulletin, Brooklyn Entomological Society, Vol. II, pp. 1, 13-14, 21-22, 29-30. [Under the Dytiscidae, Gyrinidae, and Hydrophilidae it was stated that no larva of a North American species had been described up to that date.]

SCHJØDTE, JØRGEN MATTHIAS CHRISTIAN.

- 1861-1872. De matamorfoosi eleutheratorum observationes; bidrag til insekternes udviklingshistorie. Naturhistorisk Tidsskrift, series 3, Bd. 1, 1861-2, pp. 193-232; pl. 3-10. Bd. 3, 1864-5, pp. 131-224; pl. 1-12. Bd. 8, 1872, pp. 211-221; pl. 9. Kjøbenhavn.

SCHLICK, WILL.

1887. Yngleforhold hos *Spercheus emarginatus*. [Rearing conditions with *Spercheus emarginatus*] Entomologiske Meddelelser, Bd. 1 (1887-88), pp. 26-27. Kjøbenhavn.

SCHWARZ, E. A.

1914. Aquatic beetles, especially Hydrosapha, in hot springs, in Arizona. Proceedings, Entomological Society of Washington, vol. 16, pp. 163-168. Washington.

SCOTT, HUGH.

1913. Coleoptera, Hydrophilidae, Histeridae [of the Seychelles]. Transactions, Linnean Society of London, vol. 16, pp. 193-234, Pl. XIV.

SHARP, DAVID.

1875. On three new species of Hydrophilidae. The Entomologist's Monthly Magazine, Vol. XI, pp. 247-250. London.
1880. Insecta. Coleoptera. Biologia Centrali-Americana. Vol. 1, Part 2, xv+824 pp., 19 col. pls.
1882. On aquatic carnivorous Coleoptera or Dytiscidae. Transactions, Royal Dublin Society, Vol. II (Series II), pp. 179-1003, Pls. VII-XVIII. Dublin.
1883. Revision of the species included in the genus Tropisternus (fam. Hydrophilidae). Transactions, Royal Entomological Society of London, pp. 91-117. London.

SHERMAN, JOHN D., JR.

1913. Some habits of the Dytiscidae. Journal, New York Entomological Society, Vol. XXL, pp. 43-54. New York. [Excluded large bodies of water as unfavorable for beetles and divided the others into meadow ponds, ponds, and pools of the forests, running water, and springs, giving the species found in each and their habits.]

SOLIER, A. J. J.

1835. Essai sur les Collaptérides. Annales, Société Entomologique de France, T. 4, pp. 249-420, Pls. V-IX. Paris. [Genus Philodrus established on p. 315.]

STEIN, FRIEDRICH.

1847. Vergleichende Anatomie und Physiologie der Insekten. Erste Monographie. Ueber die Geschlechts-Organen und den Bau des Hinterleibes bei den weiblichen Käfern. 8+139 pp. Berlin.

THOMSON, CHARLES GUSTAV.

1859. Skandinaviens Coleoptera, Synoptiskt Bearbetade. Vol. 1. Lund. [Enochrus established, p. 18.]

WARD, JOHN J.

1914. Some new discoveries in natural history. A tool-using insect. Strand Magazine, vol. 48, pp. 523-525, 5 figs. London and New York.

WESENBERG-LUND, C.

1913. Biologische Studien über Dytisciden. International Review der gesamten Hydrobiologie und Hydrographie, ser. 5, No. 1, 129 pp., 9 pls., 5 figs. Leipzig.

WICKHAM, H. F.

1893. Studies on the male tarsus in some adepagous Coleoptera. Bulletin, Laboratories of Natural History, State University of Iowa, Vol. II, No. 4, pp. 322-329, Pls. V-VIII. Iowa City. [Described the dilated tarsi of three species of Cybister, one of Thermonectes, one of Acilius, five of Dytiscus, and one of Colymbetes.]
- 1893a. Description of the early stages of several North American Coleoptera. *Ibid.*, pp. 330-344, Pl. IX. [Included *Gyrinus picipes* Aube, *Dineutes americanus* Say, *Tropisternus glaber* Herbst, and *Brachinus janthinipennis*.]
1894. On some aquatic larvæ, with notice of their parasites. The Canadian Entomologist, Vol. XXVI, pp. 39-41. London, Canada. [Included a bombardier beetle and a hymenopter on the pupa of *Dineutes americanus*, and an ichneumon on the pupa of a species of *Gyrinus*, while a pupa of *Tropisternus glaber* was infested with the maggots of a species of *Phora*, one of the Diptera.]
1895. On the larvæ of *Hydrocharis obtusatus* and *Silpha surinamensis*. Entomological News, Vol. VI, pp. 168-171, Pl. VI. Philadelphia. [An abstract given on page 314.]
- 1895a. The Coleoptera of Canada. - The Canadian Entomologist, Vol. XXVII, pp. 69-76, 117-122, 149-153, 181-186, 213-216. London, Canada.
1911. A list of the Coleoptera of Iowa. Bulletin, Laboratoris of Natural History, State University of Iowa, Vol. VI, No. 2, pp. 1-40, Iowa City.

WILSON, CHARLES BRANCH.

1923. Life history of the scavenger water beetle (*Hydrous (Hydrophilus) triangularis*) and its economic relation to fish breeding. Bulletin, U. S. Bureau of Fisheries, Vol. XXXIX, 1923-24, pp. 9-38, 22 figs. Washington.

WINTERSTEINER, FRED.

1913. Environment of Hydrophilidæ. Journal, New York Entomological Society, Vol. XXI, pp. 54-55. New York. [All the Hydrophilidæ except the Sphæridini are aquatic, yet only four genera, *Hydrous*, *Tropisternus*, *Hydrophilus*, and *Berosus*, can swim. The rest crawl about on submerged vegetation.]

WRIGHT, A. H.

1920. Frogs: Their natural history and utilization. Appendix VI, Report of the U. S. Commissioner of Fisheries for 1919, Bureau of Fisheries Document No. 888, 44 pp., 22 pls., 2 figs. Washington. [See quotation on page 248.]

XAMBEU, V.

1894. Mœurs et métamorphoses d'insectes [Hydrophilides]. Annales, Société Linnéenne de Lyon, N. S., T. 41, pp. 132-135.
1895. *Idem*. *Ibid.*, T. 42, pp. 25-42.

ZAITZEV, PH.

1908. Catalogue des Coléoptères aquatiques des familles des * * * Hydrophilidæ. Horæ Societatis Entomologicæ Rossicæ, vol. 38, pp. 324-418. St. Pétersbourg.

DEPARTMENT OF COMMERCE.
HERBERT HOOVER, Secretary of Commerce.

BUREAU OF FISHERIES.

[HENRY O'MALLEY, Commissioner.]

Chief functions.—Propagation of useful food fishes, including lobsters, oysters, and other shellfish, and their distribution to suitable waters.

Investigations relating to fish culture, fish diseases, conservation of fishery resources, and development of commercial fisheries.

Study of methods of fisheries and fishery industries and utilization of fishery products.

Collection of statistics of fisheries.

Administration of Alaska salmon fisheries, Pribilof Islands fur-seal herd, and law for protection of sponges off Florida coast.

BUREAU OF NAVIGATION.

[D. B. CARSON, Commissioner.]

Chief functions.—General superintendence of commercial marine and merchant seamen.

Supervision of registration, licensing, numbering, etc., of vessels under the United States flag and annual publication of list of such vessels.

Enforcement of navigation and steamboat inspection laws and laws governing radio communication, as well as duties connected with fees, refunds, taxes, fines, etc., originating under such laws.

COAST AND GEODETIC SURVEY.

[E. LESTER JONES, Director.]

Chief functions.—Survey of coasts of United States and Territories and publication of charts. Among other things, this includes base measure, triangulation, topography, and hydrography; deep-sea soundings, temperature, and current observations; magnetic observations and researches; gravity researches, etc.

Publication of results of this work in annual reports and special publications, including charts of coasts and harbors. Tide tables are published annually in advance, as well as other information of use to navigators.

BUREAU OF THE CENSUS.

[WILLIAM M. STEUART, Director.]

Chief functions.—Decennial census covering population, agriculture, manufactures, mines and quarries, and forest products. Decennial report on wealth, public debt, and taxation.

Decennial statistics relating to inmates of institutions, including paupers, insane, prisoners, and juvenile delinquents.

Census of agriculture in each mid-decennial year, a biennial census of manufactures, quinquennial census of electrical public utilities, statistics of marriage and divorce.

Annual financial statistics of State and municipal governments.

Annual statistics of births, deaths, causes of death, etc., in the registration area of the United States.

Quarterly statistics of leaf-tobacco stocks and of production, stocks, and consumption of fats and oils.

Monthly or semi-monthly statistics of cotton ginning, cotton stocks and consumption, the production, stocks and consumption of hides and leather, the production of shoes, and of active textile machinery.

Compilation and publication, in Survey of Current Business, of monthly commercial and industrial statistics.

BUREAU OF STANDARDS.

[GEORGE K. BURGESS, Director.]

Chief functions.—Custody of standards adopted or recognized by the Government.

Construction of standards when necessary. Testing and calibration of apparatus and comparison of standards used by scientific or other institutions with those in custody of bureau.

Determination of physical constants and properties of materials.

Testing of materials and establishment of standards and processes in cooperation with commercial firms or organizations.

Collection and dissemination of information showing approved methods in building, planning, and construction, including building materials and codes and such other matters as may encourage, improve, and cheapen construction and housing.

Studies on simplified commercial practices and their establishment through cooperative business organizations.

BUREAU OF LIGHTHOUSES.

[GEORGE R. PUTNAM, Commissioner.]

Chief functions.—Establishment and maintenance of light-houses, lightships, buoys, and other aids to navigation on sea and lake coasts and on rivers of the United States, including Alaska, Hawaiian Islands, and Porto Rico.

Publication of Light Lists, Buoy Lists, and Notices to Mariners, including information regarding all aids to navigation maintained by Lighthouse Service.

STEAMBOAT INSPECTION SERVICE.

[GEORGE UHLER, Supervising Inspector General.]

Chief functions.—Inspection of vessels, licensing of officers of vessels, and administration of laws relating to such vessels and their officers. Certification of able seamen who form crews of merchant vessels.

Inspection of vessels, including hulls, life-saving equipment, and types of boilers; testing of all materials subject to tensile strain in marine boilers.

BUREAU OF FOREIGN AND DOMESTIC COMMERCE.

[JULIUS KLEIN, Director.]

Chief functions.—Compilation of timely information on world market conditions and openings for American products in foreign countries secured through commercial attachés and trade commissioners of Department of Commerce and foreign service of Department of State.

Distribution of such information to American business through weekly Commerce Reports, special bulletins, confidential circulars, and the news and trade press.

Maintenance of commodity, technical, and geographical divisions in Washington to afford special service to American export industries.

Compilation and distribution of names of possible buyers and agents for American products in all parts of the world and publication of weekly lists of specific sales opportunities abroad.

Maintenance of 33 district and cooperative offices in 33 cities in the United States to expedite delivery of market information to business men and to keep departments advised as to more urgent requirements of American trades and industries.

Publication of official statistics on imports and exports of the United States.

19,
FAUNA OF PENIKESE ISLAND, 1923.

(EDITED BY R. E. COKER.)

Reprinted from BIOLOGICAL BULLETIN, Vol. L, No. 1, January, 1926.

1945
CARP

FAUNA OF PENIKESE ISLAND, 1923.

(EDITED BY R. E. COKER.)

INTRODUCTION.

On the occasion of the fiftieth anniversary of the founding of the Agassiz laboratory on Penikese, a biological reconnaissance of the island was undertaken jointly by botanists and zoölogists from the Marine Biological Laboratory and the Fisheries Biological Station of the United States Bureau of Fisheries at Woods Hole, Mass. The studies of the flora have been published under the editorship of Professor I. F. Lewis in *Rhodora*, Vol. 26, Nos. 310, 311 and 312, 1924. The zoölogical collections and studies were made by the workers to be named hereafter, while the arrangement of the report for publication has been entrusted to the present editor.

With regard to the fauna, as well as to the flora, the collections were made by large parties, but chiefly on one day in each case. Practical considerations made it necessary for the zoölogists to restrict attention to the larger animals existing above the tide line, that is to say, to the non-microscopic animals living on the land or in the small freshwater and brackish ponds that are described by Miss Shaw in the report on Flora. Notwithstanding the number of collectors and the varied interests and experiences represented by them, the time spent on Penikese imposed an obvious limit to the exhaustiveness of the collections, especially since the fauna of the island is comprised largely in the group of Arthropods, so many of which are seasonal in appearance.

In the following list are the names of the persons comprising the zoölogical collecting expedition to Penikese Island, August 7, 1923, with the names of the respective institutions with which they were permanently engaged. The abbreviation "M.B.L." for Marine Biological Laboratory or "U.S.F.L." for United States Fisheries Laboratory, is used to denote the local laboratory to which each was temporarily attached during the summer of 1923.

- F. E. Chidester, West Virginia University. U.S.F.L.
R. E. Coker, University of North Carolina. U.S.F.L.
Arch E. Cole, Northwestern University. M.B.L.
Manton Copeland, Bowdoin College. M.B.L.
J. A. Dawson, Dalhousie University. M.B.L.
S. R. Detwiler, Harvard University. M.B.L.
Samuel W. Geiser, Washington University. M.B.L.
Robert A. Goffin, U. S. Bureau of Fisheries.
Benjamin Grave, Wabash College. M.B.L.
Caswell Grave, Washington University. M.B.L.
George M. Gray, Marine Biological Laboratory.
Walter N. Hess, De Parmo University. M.B.L.
Hoyt S. Hopkins, Baylor Medical College. M.B.L.
Ondess L. Inman, Antioch College. M.B.L.
Ivey F. Lewis, University of Virginia. M.B.L.
Edwin Linton, Washington and Jefferson College and University
of Georgia Medical Dept. U.S.F.L.
S. O. Mast, Johns Hopkins University. M.B.L.
C. E. McClung, University of Pennsylvania. M.B.L.
Everett C. Myers, Johns Hopkins University. M.B.L.
James T. Penney, University of North Carolina. U.S.F.L.
Albert M. Reese, West Virginia University. U.S.F.L.
A. H. Sturtevant, Carnegie Institute of Washington. M.B.L.
Henry C. Tracy, University of Kansas. U.S.F.L.
Arthur D. Whedon, North Dakota Agricultural College. M.B.L.
H. L. Wieman, University of Cincinnati. M.B.L.
Charles B. Wilson, Massachusetts State Normal School, West-
field. U.S.F.L.
John E. Wilson, Student Harvard Law School. U.S.F.L.
F. E. Wood, Illinois Wesleyan University. M.B.L.
Lorande Loss Woodruff, Yale University. M.B.L.
Donnell B. Young, Carleton College. M.B.L.

The following junior members of the expedition rendered helpful service in collecting:

Robert E. Coker, Jr.
Frederick C. Copeland.
Preston S. Copeland.

The party was conveyed from the Fisheries Laboratory at Woods Hole to Penikese Island by the U. S. Fisheries Steamer *Pharalope*. Collecting apparatus of every character as available was taken; there were seines, townets, dipnets, butterfly nets, sweeping nets, spade, rakes, gun, dipper, spoon, rat traps, mouse traps, etc., with necessary reagent for killing and preserving, and containers of various sorts, besides maps, labels, salinometers and cameras. The methods employed may be inferred from the apparatus taken.

It was originally contemplated to report the collections by station and habitat, but the character of the fauna of the island to which reference is made on page 25 below, made it evident that no particularly useful purpose would be served by adhering to a plan that would have both complicated the study and greatly extended the report.

Penikese Island. Northwest part, looking north from Pond 2-B.
(See footnote to p. 27.)

The study and identification of material was done in part by certain members of the collecting party, and in part by specialists associated with the United States National Museum and the Boston Society of Natural History; cordial acknowledgments are due to those institutions for the assistance that was so freely rendered. Appropriate credit to individuals is given in connection with the lists of species beginning on page 26, but in this place particular mention should be made of the following persons as the virtual authors of the systematic portion

of this report: Messrs. C. W. Johnson (insects of several orders), A. H. Sturtevant (Diptera), C. B. Wilson (Odonata, aquatic Hemiptera, and aquatic Coleoptera), C. E. McClung (Orthoptera), Manton Copeland (Lepidoptera—butterflies), J. H. Emerton (Arachnida), Ondess L. Inman and Everett C. Myers (Birds).

Pond 1-D. (See footnote to p. 27.)

The general character of the island and its ecological features as regards the vegetation have been described by Lewis and Miss Shaw in the report previously mentioned. While the vegetational environments are of interest in connection with the consideration of the fauna, it would be superfluous to restate here the data to be found in that publication, especially in the section on "Ecology of Penikese" by Miss Margaret F. Shaw. It is necessary to give only a single quotation from Lewis (below) and to say that the small rocky island is practically devoid of trees, and, except where denuded of all vegetation in some of the nesting grounds of terns, is given over to grasses and other small plants, with rarely a low growing shrub or willow.

"The island Penikese is a remnant of the terminal moraine now seen in the Elizabeth Islands. It is about two thirds of a mile long and half as broad, with a broadly spatulate point for convenience of reference called Tub Point, extending further to the east for another third of a mile. Its contour is dominated by low hills on the main body of the island, with depressions here and there which may be ponds of a rather temporary character (map).

"The original vegetation, like that of neighboring islands, is said by Jordan to have been of a forest type, with pitch pine red cedar, red maple, shagbark, shadbush, poplar birch, horn-beam, and two or three species of sumac. In 1873 there was 'no trace left save the rotten roots of a solitary beech stump and a few branches of red cedar and red maple (?) found buried in the muck of a small swamp.' Cutting of the original timber had been followed by the introduction of sheep, which remained on the island until about 1910. From 1905 to 1921 Penikese was used by the State of Massachusetts as the site of a leprosarium. After the removal of the lepers in 1921 the island has been uninhabited except for the caretaker and his wife.

Pond 2-D. (See footnote to p. 27.)

"Jordan says that his 'list may have a special interest to future students, and also a general interest to botanists, as showing which plants survive a prolonged struggle for existence against grass and sheep.' If the State retains possession of Penikese and establishes a bird sanctuary there, the continued history of the development and succession of plants and animals cannot fail to be of interest and importance. Surveys at stated intervals will give precise information about natural succession under the prevailing climatic and edaphic conditions, and will furnish data on the means of dispersal of species in this region."¹

A physical feature of little interest to the botanists but offering

¹ Lewis, I. F., "The Flora of Penikese, Fifty Years After," *Rhodora*, Vol. 26, No. 310, pp. 182-4, October, 1924.

a relatively important habitat for animals consists in the low stone fences that have been built in somewhat rambling fashion over the hills of the main island. Though now falling down in places, these walls harbor numbers of spiders, isopods and insects. The old houses and sheds are likewise inhabited by many insects and spiders.

EARLIER COLLECTING ON PENIKESE.

Although Penikese Island has been visited by naturalists from time to time during the past fifty years, only one paper has been encountered that deals with the fauna above the tide line. It may readily be understood why the pioneers of Agassiz's school had little time for study of the land fauna, engrossed, as they then were, with the revelations of marine life. Yet it seems worth while to quote in full the following communications from members of the original laboratory written fifty years after.

"I do not think that any one at Penikese listed the land snails, insects or other land animals except birds. We were busy with the novelties of the sea. C. O. Whitman gave most of his time to the birds, and I think had a list. F. H. Snow knew birds also. I made no formal list of the fishes, though I began my studies on them there. I could give an approximate record now. I listed also the Algæ, as well as the land plants. Walter Faxon recorded the marine Crustacea, and I made a list of the mollusks. Whether it is in existence now, I do not know. Time works havoc with manuscripts.

"Very sincerely yours,

"DAVID STARR JORDAN."

"I do indeed thank you for the pictures of Penikese and the laboratory at Woods Hole. I regret exceedingly that I cannot help you in the matter of Flora and Fauna of that Island. I was too busy with my lecture work to do more than that. The terns' nests with eggs were very abundant and a little work was done on its embryology.

"Faithfully yours,

"EDW. S. MORSE."

Information of similar purport has been given me by Professor Cornelia M. Clapp, and Mr. Samuel E. Cassino, others who worked in the old laboratory on Penikese.

It is of particular interest that the only species described from Penikese (of which record has been found) is one of those relatively rare forms of crustacea, the branchiopods, that it should bear the name of the great teacher, and that the description should have been published in the second and final year of the original laboratory. The species is *Eulimnadia agassizii* Packard (1874);¹ it seems never to have been collected elsewhere.

In later years the island has been visited at various times by collectors and specimens have been deposited in several museums; but such collecting was done incidentally or in course of trips to various islands, and, almost invariably, without special publication. An exception is found in the paper by A. P. Morse entitled "Notes on the Orthoptera of Penikese and Cuttyhunk," appearing in *Psyche*, Vol. 7, p. 179, December, 1894.²

Among other naturalists who have submitted specimens from Penikese to various museums are J. P. Moore, Manton Copeland, Alexander Forbes, and J. T. Nichols. The following notes are quoted from a letter of Dr. Moore to the editor; "In 1892 and again in 1895, I collected in a small pond on Penikese two species of leeches, *Helobdella stagnalis*, and *Erpobdella punctata*. A few years later I again visited the island and think that I found leeches, but cannot find the record. Leeches are so easily carried by the aquatic birds that introduction is readily accomplished and one may expect to find other species. Even if all of the leeches should be destroyed by a prolonged period of drying of the small pools, the same or other species could be

¹ Packard, A. S. In Sixth Annual Report of the Peabody Academy of Science, Salem, Mass., 54, 1874.

In a later publication Packard says:

"About 100 females, mostly with eggs, occurred in a small pool of fresh water on Penikese Island, Buzzard's Bay, Aug. 27, 1873, collected by Mr. Walter Faxon. Upon examining the pool the following July or August (1874), the young, about a line in length, were found, but the pool subsequently dried up." (Quoted from "A Monograph of the Phyllopod Crustacea of North America, with remarks on the Order Phyllocarida," 12th Annual Report of the U. S. Geological and Geographical Survey of the Territories (for 1878), pages 295-590; Washington, 1883.

² I am indebted to Mr. C. W. Johnson for reference to the paper on Orthoptera. The species collected on Penikese are listed in another place. Editor.

quickly reestablished. . . . There are probably other species of Oligochæta in addition to the three named in your list. I know that I found *Enchytræus albidus* (= *Halodrilus littoralis*) on the strand and one of the small Naiidæ in fresh water but these records also are not available just at present."

DISCUSSION OF RESULTS.

As will later be shown in detail, animals of 216 species were taken and subsequently identified, and these, grouped by phyla and lesser subdivisions, are distributed as follows:

NUMBER OF SPECIES OF ANIMALS COLLECTED FROM PENIKESE ISLAND, AUGUST, 1923.			
Annelids.....	3	species	
Mollusks.....	1	"	1
Arthropods:			
Crustacea.....	2	"	
Myriapods.....	1	"	
Insects.....	162	"	
Arachnids.....	15	"	
Vertebrates:			
Amphibia.....	1	"	
Reptiles.....	1	"	
Birds (actually resting on the island).....	29	"	
Mammals.....	1	"	
Total.....	216	"	
Insects by Orders:			
Odonata.....	3		
Orthoptera.....	8		
Hemiptera (terrestrial 20, aquatic 6).....	26		
Neuroptera.....	2		
Lepidoptera.....	13		
Diptera.....	47		
Coleoptera (terrestrial 30, aquatic 24).....	54		
Hymenoptera.....	9		
Total number of species of insects.....	162		

It is worth while to allude to certain groups that are not represented in the list. Although a thorough search was made for fish in the brackish and freshwater ponds, none were found. Since isolation is not usually sufficient to account for the want of small fish in ponds, even such as may occasionally become

¹ An aquatic gastropod lost before identification.

nearly dry, the absence of such forms is doubtless to be attributed to the abundance of fish-eating birds on the island. It is notable in this connection that the amphibia were represented by a single species, the common toad, the least attractive member of the class to carnivorous animals. Among reptiles, too, turtles and water snakes must be extremely rare, if present at all, the only reptile taken being the common garter snake, of which several specimens were obtained both by the botanists on July 24, and by the zoölogists on August 7. Toads were also taken on both days. It appears that previous collectors interested in the herpetology of the island have found only the toad and the garter snake. It is surprising that aquatic crustacea were not found. Not even were copepods encountered in net collections from the small ponds. Perhaps in this respect, as in others, the results would have been different at another season.

Viewing the fauna of the island, as a whole, we observe that it is largely arthropodan—insect, arachnid and myriapod. Exclusive of arthropods and birds, we found but 4 species of invertebrates (3 earthworms and 1 gastropod) and 3 of vertebrates (an amphibian, a reptile, and a mammal). The invertebrate fauna would have been greatly extended by giving consideration to minute forms of animal life; but the vertebrate fauna was doubtless fully covered, except as to birds, which are migratory and seasonal. The apparent relative poverty of the island in nearly all forms of animal life (as regards number of species) may be attributed in great part to the very limited variety of environments, as afforded by plants and physical conditions.

An outstanding feature of the fauna of Penikese Island is its composition (almost entirely) of forms of very general distribution for the latitude. This, of course, is to be expected, since there are no known conditions upon the island to suggest the probability of the occurrence of unusual forms of life. In such a place we must seek not to find a fauna of special types, but rather to ascertain which of the common types of animal life encounter there the conditions favorable or requisite for their existence. Nevertheless, Penikese happens to be the place of collection of at least one specific type. (See p. 23 above.)

It is hoped that, quite apart from any interest which might

attach to this survey from its relation to the historical place and occasion, it will serve a useful scientific purpose as a basis of comparison with future conditions. It would be desirable for collections to be made at all seasons, under various weather conditions and in different years. Penikese Island has recently been set aside by the State of Massachusetts as a Bird Sanctuary, and placed under the Board of Conservation who are interested in fostering both the birds and the insect life of the island. The entire aspect of the insect fauna of the island may change materially at any time in consequence either of the invasion of new species adapted to present conditions but not yet arrived, or as a result of changing conditions of vegetation upon the island, such, for example, as would follow upon renewal of grazing or upon natural or artificial reforestation. In event of such change it will fortunately be possible, to some extent, to compare new and old conditions with respect to both plants and animals, and thus to study problems of coördination between the two kingdoms. We have, therefore, thought it a proper function of the introductory part of this report to direct attention to the forms that appear to be lacking, as well as to those that were found. Needless to say, future comparisons must not omit from consideration the season of the year and the precedent meteorological conditions such as are of record elsewhere than in this paper.

ANIMALS OF LAND AND PONDS,
PENIKESSE ISLAND, AUGUST, 1923.

ANNELIDS.

(Identification by U. S. National Museum.)

Lumbricus terrestris Linnaeus.

One adult and one apparently immature example taken near red house.

Helodrilus caliginosus trapezoides (Savigny).

One example taken at same place.

Helodrilus tenuis (Eisen).

Two examples taken with preceding species and one in southern part of island.

MOLLUSCS.

(Gastropod from pond not identified.)

ARTHROPODS.

Crustacea.

(Identification by U. S. National Museum.)

Oniscus asellus Linnæus.

Porcellio rathkei Brandt. Abundant under boards and logs and in stone fences.

Myriapods.

(Identification by R. V. Chamberlain, Museum of Comparative Zoölogy, Cambridge, Mass., through U. S. National Museum.)

Lithobius forficatus Linnæus.

*Insects.*Odonata.¹

(Identification by C. B. and J. E. Wilson.)

Anax junius (Drury). Pond 1-B; three nymphs.

Pond 2-B; four nymphs.

Pond 1-D; seven nymphs.

Celithemis eponina (Drury); seen flying about in two places.

Ischnura verticalis (Say); Pond 2; two adults.

Pond 2; four adults.

Orthoptera.

(Identification by C. E. McClung.)

Gryllidæ.

Gryllus assimilis.

Nemobius vittatus Harr.

¹ In reports on aquatic insects (Odonata, Hemiptera, Coleoptera) the several small ponds are distinguished by letters and numbers, as follows: The two small water-holes near the northwest corner of the island are designated 1-B and 2-B, 1 being southwestward of 2; 1-C (Cattail Pond) is on the eastward side of the island near the keeper's house; near the southerly tip of the eastward extension of the island (Tub Point) are two small ponds, 1-D and 2-D, 1 being northeastward of 2. The largest pond, that near the southerly point of the main island, known to the collectors as South Pond (A) was decidedly brackish and yielded only one aquatic insect. The specific gravities (uncorrected for temperature) and the temperatures of the waters of these ponds were as follows: South Pond, 1.015 (20° C.); 1-B and 2-B, 0.99 (21° C.); 1-C, 0.99 (20° C.); 1-D, 1.0018 (23° C.); 2-D, 1.005 (22° C.).—EDITOR.

Locustidæ.

Conocephalus fasciatus De G.*Orchelimum vulgare* Harr.

Acrididæ.

Melanoplus femur-rubrum De G.*Melanoplus atlanis* Riley.*Chorthippus maculipennis* Scudd.*Dissosteira carolina* Linn.

Generally distributed, localized only by distribution of food plants.

The following list of Orthoptera appeared under the title "Notes on the Orthoptera of Penikese and Cuttyhunk," by A. P. Morse. (*Psyche*, Vol. 7, p. 179. Dec. 1894.)¹

SPECIES COLLECTED ON PENIKESE.

Acrididæ.

Stenobothrus æqualis Scudd. Common.*Stenobothrus maculipennis* Scudd. Common.*Chortophaga viridifasciata* De G. Scarce.*Dissosteira carolina* Linn. Common.*Psinidia fenestralis* Serv. Scarce.*Melanoplus atlanis* Riley. Scarce.

Locustidæ.

Xiphidium (Conocephalus) fasciatum De G. Common.

Gryllidæ.

Nemobius vittatus Harris. Common.

Hemiptera (Heteroptera).

(Identification by C. W. Johnson, Boston Society of Natural History.) (See also "Aquatic Hemiptera" below.)

Pentatomidæ.

Cænis delius Say.

Coreidæ.

Harmostes reflexulus Say.

Lygæidæ.

Cymus luridus Stål.

¹ Note by courtesy of C. W. Johnson.

Nabidæ.

Pagasa fusca Stein.*Nabis propinquus* Reut.*Nabis fesus* Linn.

Miridæ.

Teratocoris discolor Uhl.*Pæciloscytus basalis* Reut.*Lygus pratensis* Linn.*Onychumenus decolor* Fall.

Saldidæ.

Saldula interstitialis Say.

Hemiptera (Homoptera).

(Identification by C. W. Johnson, Boston Society
of Natural History.)

Cercopidæ.

Philænus leucophthalmus Linn. var. *ustulatus* Fall.*Philænus lineatus* Linn.

Cicadellidæ.

Helochara communis Fitch.*Dræculacephala mollipes* Say.*Dræculacephala minor* Walk.*Acucephalus albifrons* Linn.*Deltocephalus simplex* Van D.

Fulgoridæ.

Liburnia pellucida Fabr.*Liburnia campestris* Van D.Aquatic Hemiptera.¹

(Identification by C. B. and J. E. Wilson.)

Arctocoris interrupta (Say); Ponds 1-D and 2-B; three specimens in all.

Belostoma flumineum Say; Pond 1-B; one nymph, identification doubtful.

Corixa verticalis Fieber; Pond 2-D; twenty-two specimens.

Pond 1-D; twenty specimens.

Pond 1-B; one specimen.

Pond 2-B; twenty specimens.

South pond; one specimen.

¹ See footnote to page 27.

- Buenoa margaritacea* Bueno; Pond 1-D; one doubtful nymph.
Gerris marginatus Say; Pond 1-B; ten specimens; Pond 1-D;
 one nymph.
Microvelia borealis Bueno; Pond 2-B; one specimen.

Neuroptera.

(Identification by C. W. Johnson, Boston Society
 of Natural History.)

Hemerobiidæ.

Hemerobius stigmaterus Fitch.

Chrysopidæ.

Chrysopa oculata Say.

Lepidoptera—Butterflies.¹

(Identification by Manton Copeland, Preston S. Copeland and
 Frederick C. Copeland.)

- Pieris rapae* Linnæus (9).
Euvanesa antiopa Linnæus (1).
Vanessa atalanta Linnæus (1).
Vanessa huntera Fabricius (1).
Junonia cænia Hübner (4).
Heodes hypophlæas Boisduval (5).

Lepidoptera—Moths.

(Identification by C. W. Johnson through Mr. Copeland.)

- Hadena lignicolor* Guenée (1).
Drasteria erechtea Cramer (3).
Drasteria crassiuscula Haworth (7).
Pyrausta fissalis Grote (1).
Crambus hortuellus Hübner (18).
Argyria nivalis Drury (1).
Ancylis Hübner sp? (1).

Diptera.

(Identification by A. H. Sturtevant, whose report is transmitted
 with the letter that is quoted immediately following.)

"I am enclosing the list of Penikese Diptera. There are 47
 species on it—and these are all that I am able to identify with

¹ Figures in parentheses denote numbers of examples taken.

certainty. I should judge that there are about 30 additional species in the material, including the most conspicuous Dipteran encountered on the island, the mosquito, which apparently belongs in the genus *Aedes*, but which I have not included because the species remains very uncertain.

"There is one record that seems never to have been published as American, though the insect is so common that I suspect several people must have identified it correctly before—I have myself had the necessary information for two years now. One or two of the other records are of some interest from the point of view of geographical distribution, and that of *Muscina pascuorum* is apparently the only one for 1923 as early as August. Since the species appears to have been introduced from Europe only within the past few years any such data about it are of value, I think."

Asilidæ.

Asilus paropus Walker (Determined by C. W. Johnson).

Dolichopodidæ.

Dolichopus albicoxa Aldrich.

D. bifractus Loew.

D. pugil Loew.

D. splendidus Loew.

Lonchopteridæ.

Lonchoptera fuscata Fallen.

Syrphidæ.

Allograpta obliqua Say.

Eristalis tenax Linne.¹

Helophilus latus Loew.

Platychirus quadratus Say.

Toxomerus marginatus Say.

Muscinæ.

Muscina pascuorum Meigen.

Stomoxyinæ.

Stomoxyys calcitrans Linne.

Calliphorinæ.

Calliphora erythrocephala Meigen.

¹ Larvæ of this, or a very similar species were very common in samples of mud taken from the bottom of freshwater ponds.—R. E. C.

Lucilia cæsar Linne.

Lucilia sylvarum Meigen.

Pollenia rudis Fabricius.

Ortalinæ.

Chætopsis fulvifrons Macquart.

C. massyla Walker. These two species were taken in large numbers in the salt marshes, but no specimens were obtained of *C. ænea* Wiedemann and *C. apicalis* Johnson, which are the common salt marsh species of the mainland and of Naushon.

Trypaneinæ.

Euaresta bella Loew.

Trypanea abstersa Loew.

T. daphne Wiedemann.

Agromyzinæ.

Cerodonta dorsalis Loew.

Sepsinæ.

Sepsis violacea Meigen.

Themira minor Haliday.

Ochthiphilinæ.

Ochthiphila polystigma Meigen.

Chloropinæ.

Botanobia coxendix Fitch.

B. frit pusilla Meigen.

Chloropisca glabra Meigen.

Elachiptera costata Loew.

Melanochæta longula Loew.

Drosophilinæ.

Drosophila quinaria Loew.

Scaptomyza adusta Loew.

Ephydrinæ.

Dichaeta caudata Fallen.

Dimecænia spinosa Loew.

Ephydra subopaca Loew.

Notiphila scalaris Loew.

Ochthera mantis DeGeer.

Pelina truncatula Loew.

Psilopa atrimana Coquillett.

P. flavida Coquillett.

Scatella dichæta Loew.

Borborinæ.

Leptocera atra Adams. Common and widespread.

Leptocera brachystoma Stenhammar. This species does not seem to have been recorded as American. It is common under eel-grass at high tide level at least throughout the Woods Hole region. I have compared my specimens with British material determined by J. E. Collin, Esq.

Leptocera lutosa Stenhammar. Common and widespread.

Borborus geniculatus Macquart.

Phycodrominæ.

Cælopa parvula Haliday.

Coleoptera.

(Identification by C. W. Johnson, Boston Society
of Natural History.)

Carabidæ.

Galerita janus Fabr.

Chlænius pennsylvanicus Say.

Harpalus caliginosus Fabr.

Harpalus compar Lec.

Harpalus pennsylvanicus DeGeer.

Harpalus herbivagus Say.

Staphylinidæ.

Ocyopus ater Grav.

Silphidæ.

Necrophorus americanus Oliv.

Necrophorus marginatus Fabr.

Silpha lapponica Hbst.

Histeridæ.

Saprinus sp.

Cantharidæ.

Silis bidentatus Say.

Mordellidæ.

Mordellistena pustulata Melsh.

Elateridæ.

Melanotus fissilis Say.

Also a number of larvæ.

Melanotus communis Gyllenhal (Identified by U. S. National Museum).

Dermestidæ.

Dermestes vulpinus Fabr.

Nitidulidæ.

Conotelus obscurus Er.

Phalacridæ.

Stilbus apicalis Melsh.

Coccinellidæ.

Hippodamia parenthesis Say.

Coccinella novemnotata Hbst.

Tenebrionidæ.

Blapstinus mæstus Melsh.

Tenebrio obscurus Fabr.

Scarabæidæ.

Aphodius fimetarius Linn.

Xyloryctes satyrus Fabr.

Phyllophaga? sp.? (larvæ).

Chrysomellidæ.

Calligrapha elegans Oliv.

Galerucella notata Fabr.

Diabrotica duodecimpunctata Fabr.

Phyllotreta sinuata Steph.

Curculionidæ.

Brachyshynchus ovatus Linn.

Aquatic Coleoptera.¹

(Identification by C. B. and J. E. Wilson.)

Acilius semisulcatus (Aubé); Pond 1-D; two specimens.

Agabus disintegratus Crotch; Pond 1-B; three specimens.

Berosus striatus (Say); Pond 1-B; two specimens.

Celambus impressopunctatus (Schall.); Pond 1-D; nine specimens.

¹ See footnote to p. 27.

Cælambus inæqualis Fabricius; Pond 1-B; six specimens.
Deronectes depressus Fabricius; Pond 1-B; ten specimens.
Dytiscus fasciventris Say; Pond 1-C; two specimens.
Hydrophilus obtusatus (Say); Pond 1-B; one specimen.
Haliplus ruficollis DeGeer; Pond 2-B; eighteen specimens.
Hydroporus americanus Aubé; Pond 1-B; three specimens.
Hydroporus modestus Aubé; Pond 2-B; twelve specimens.
Hydroporus niger Say; Pond 1-B; fourteen specimens.
Hydroporus proximus Aubé; Pond 1-B; two specimens.
Hydroporus stagnalis G. & H.; Pond 1-B; seventeen specimens.
Hydroporus tenebrosus Lecepède; Pond 1-B; one specimen.
Hydroporus undulatus Say; Pond 1-B; twenty specimens.
Octhebius foveicollis Lecepède; Pond 2-D; two specimens.
Philhydrus cinctus Say; Pond 2-D; fifty specimens.
Philhydrus nebulosus Say; Pond 1-D; one specimen.
Rhantus binotatus Harris; Pond 1-D; two specimens.
Rhantus bistriatus Bergst.; Pond 1-B; one specimen.
Thermonectes basilaris Harris; Pond 1-D; two specimens.
Tropisternus glaber Herbst; Pond 2-B; six specimens.
Tropisternus nimbatus Say; Pond 1-C; one specimen.

Hymenoptera.

(Identification by C. W. Johnson, Boston Society
of Natural History.)

Ichneumonidæ.

Therion morio Fabr.

Formididæ.¹

Myrmica scabrinodis Nyl. subsp. *schlenki* Emery var. *emeryana*
Forel.

Lasius niger Linn. var. *americanus* Emery.

Lasius (*Chthonolasius*) *brevicornis* Emery.

Halictidæ.

Halictus provancheri Cress?

Megachilidæ.

Osmia lignaria Say.

Apidæ.

Bombus fervidus Fabr.

¹ Identified for the Boston Society of Natural History by Dr. W. M. Wheeler.

Bombus americanorum Fabr.

Bombus bimaculatus Cress.

Arachnids.

(Identification by J. H. Emerton, through U. S.
National Museum.)

Enoplognatha marmorata Hentz.

Epeira trivittata Keys. Many specimens.

Epeira pratensis Hentz. Immature.

Epeira stellata Hentz. Immature.

Argiope trifaciata Forskal. Young, several specimens.

Tetragnatha laboriosa Hentz.

Agalena naevia Walck. All young, half grown.

Dolomedes sexpunctatus Hentz. Young.

Lycosa helluo Walck. With egg cocoon.

Pardosa nigripalpis Em.

Pardosa glacialis Th.

Pardosa lapidicina Em.

Zelotes ater Hentz. Adult male and young.

Ariadne bicolor Hentz.

Phidippus multiformis Em.

Xysticus gulosus Keys.¹

Birds.

Observed and identified by Ondess L. Inman and Everett C.
Myers. (With confirmatory observations by others.)

Song Sparrow—*Melospiza melodia melodia*. Most common land
bird.

Chipping Sparrow—*Spizella passerina passerina*. Few.

Seaside Sparrow—*Passerherbulus maritimus maritimus*. Com-
mon.

Sharp tailed Sparrow—*Passerherbulus caudacutus*.

English Sparrow—*Passer domesticus*. Fairly common about
buildings.

Field Sparrow—*Spizella pusilla pusilla*. Few.

Vesper Sparrow—*Poocætes gramineus gramineus*.

Common Tern—*Sterna hirundo*. Most common.

¹ Specimens identified by J. H. Emerton through Boston Society of Natural
History.

- Roseate Tern—*Sterna dougallii*. Fairly common.
Least Tern—*Sterna antillarum*. Rare.
Cory Shearwater—*Puffinus borealis*. Rare.
Herring Gull—*Larus argentatus*. Rare.
Laughing Gull—*Larus atricilla*. Rare.
Meadow Lark—*Sturnella magna*. Few (6).
Yellow Warbler—*Dendroica æstiva æstiva*. One pair.
Upland Plover—*Bartramia longicanda*.
Semipalmate Sandpiper—*Ereunetes pusillus*. Very common.
Little Green Heron—*Butorides virescens*.
Ruddy Turnstone—*Arenaria interpres morinella*. Two.
Red-wing Blackbird—*Agelaius phæniceus*. Common.
Spotted Sandpiper—*Actitis macularia*.
Least Sandpiper—*Pisobia minutilla*.
Killdeer—*Oxyechus vociferus*.
Yellow legs—*Totanus* sp.? Rare.
Woodcock—*Philohela minor*.¹ One.
Virginia Rail—*Rallus virginianus*.
Curlew—*Numenius* sp.?
Eve Swallow?—
Ringneck Plover—*Aegialitis semipalmata* (Semipalmate Plover).

Other Vertebrates.

- Bufo fowleri*—Common toad. 4 examples.
(Identified by Miss Doris M. Cochran, U. S. National Museum.)
Thamnophis sirtalis sirtalis—Common garter snake. 6 examples.
(Identified by Miss Doris M. Cochran, U. S. National Museum.)
Peromyscus leucopus noveboracensis (Fischer). Field mouse. One example taken in one of the traps left on the island. Specimen preserved by the kindness of the State caretaker on Penikese; identified by F. E. Wood.

¹ Reported by D. B. Young.

SMITHSONIAN INSTITUTION LIBRARIES

3 9088 00049 1357