ECOLOGY OF AN OCEANIC FRESH-WATER LAKE, ANDROS ISLAND, BAHAMAS, WITH SPECIAL REFERENCE TO ITS FISHES

By C. M. Breder, Jr.

(Figs. 26–35 incl.)

Introduction

Andros Island, the largest of the Bahama group, represents a certain ecological condition that should be of particular interest to biologists. It is the purpose of the present paper to call attention to this, and discuss the inferences that have been suggested by two short expeditions into the interior of the island. Although it is the closest to the mainland of the larger Bahama Islands, it is also, interiorly, the least known. This apparent paradox is exaggerated by the fact that it is also the only one supporting any considerable amount of fresh water. In spite of this attraction, its human inhabitants are few and mostly Negro, living a very primitive sort of life. One of the chief reasons for this sparseness of population on Andros Island is doubtless the lack of really good harbors for any but very small craft. The Bahamas generally, are not remarkable for excellent harbors, but even among them this large island is noted for its inhospitable coast.

The expeditions, of which this paper is the chief report,[1] were made possible through the generosity and scientific interest of Mr. Daniel Bacon. At considerable effort and expense he arranged for practically everything, leaving the writer largely free for his field studies. The visits to Andros Island extended from January 20 to January 30, 1932, and from January 20 to January 27, 1933. We are greatly indebted to Mr. E. Forsyth, Commissioner of Andros Island, who is one of the few white residents, living at Mangrove Cay, for his excellent advice and service in supplying us with an exceptionally able, native guide. Mr. Lawrence D. Huntington accompanied the party in 1932. His untiring efforts were invaluable to the success of the trip.

[1] See Breder, 1933a, for a general account of these trips.

The itinerary of the first expedition, after the east side of the island was reached, by way of the Middle Bight, follows. The launch *Escape* which brought our party from Nassau, New Providence, was anchored off Wide Opening. This body was entered by skiff and dory powered by an outboard motor. The first camp was pitched in an attractive grove of mahogany trees on the River Lees. Ducks and other water fowl were abundant at this place. The roots of the mangroves were found to be populated largely by *Lutianus griseus* and *Spheroides testudineus*. Small *Anolis* were not uncommon, and a single *Hyla septentrionalis* was found here. Behind the camp were found numerous small ponds of fresh water, which probably accounts for the presence of frogs so near salt water. The trip was continued out into Turner Sound. On entering this body, numerous large *Tarpon atlanticus* were seen disporting themselves. Milk River was found to be closely overgrown, necessitating the use of machettes to allow passage of the boats. This dense growth was only along the immediate shore line, rapidly falling away on either side to a prairie-like country. The entrance into the fresh water of Lake Forsyth, which, judged by the current of Milk River, must be considerably higher than Turner Sound, brought the party into a distinctly different type of country of a particularly desolate aspect. Birds were practically negligible. A single Maryland yellow-throat was seen, and what was thought to be a night heron was heard one night. Otherwise, the only evident birds were two very attentive buzzards that perched on a dead tree at the camp, or followed the party on seining excursions. On full moonlight nights, the eerie quiet was emphasized by the long shadows cast by the jagged, eroded, old coral snags, and the three patiently waiting buzzards silhouetted against the moon. Other details of this environment are given in the body of the paper.

The return was made by way of Goose River. This stream, considerably wider than the River Lees was found to be populated by large *Ginglymostoma cirratum* (Gmelin) and various *Dasyatis*. As soon as Turner Sound was entered, various birds began to reappear, the Lake Forsyth region being distinctly separated from the salt water environment of this island.

The itinerary of the second expedition, which did not go through to the east side of Andros, follows. After a short stop at Mangrove Cay the South Bight was penetrated to a nearly dry creek which was reported to drain a fresh water pond during the rainy season. A skiff took us up this about a mile. Here it was necessary to abandon it and walk the remaining distance to the lake, about a mile, although the creek was not completely dry and had a fair flow. In South Bight and in the salt parts of the creek the following species of fish were noted: *Ginglymostoma cirratum, Cyprinodon baconi, Tylosurus* sp., *Lutianus griseus* and *Abudefduf marginatus* (Bloch). A young hawksbill turtle was also seen. The South Bight lake region was found to be essentially similar to the Lake Forsyth area. The details of this will be discussed further on.

Returning to South Bight, Grassy Creek, near the southern end of Andros, was next visited. This was entirely marine as far up as penetrated. At the farthest point inland that we visited, a deep hole of indigo blue was found to be filled with a variety of haemulids and lutianids. *Haemulon sciurus* (Shaw), *Lutianus griseus* and *apodus,* at least could be definitely identified. Other fishes, seen or collected in Grassy Creek, were: *Ginglymostoma cirratum, Hypopryon brevirostris* Poey, *Albula vulpes* (Linnaeus), *Cyprinodon baconi, Hemiramphus brasiliensis* (Linnaeus) (at the mouth), *Sphyraena barracuda* (Walbaum), *Epinephelus striatus* (Bloch), *Eucinostomus californiensis, Calamus banjanado* (Bloch and Schneider), *Lutianus griseus, Ocyurus chrysurus* (Bloch), *Haemulon sciurus, Haemulon album* Cuvier and Valenciennes, *Pomacentrus leucostictus* (Muller and Troschel), *Scarus* sp., *Echeneis naucrates* Linnaeus, *Spheroides testudineus.* On the reef, immediately off Fresh Creek, were caught: *Lutianus analis, Haemulon album, Balistes vetula* Linnaeus and *Calamus banjanado.* This region is much more broken and irregular than northern Andros.

A tide pool yielded the following: *Eucinostomus californiensis, Lutianus apodus, Haemulon* sp., *Pomacentrus leucostictus, Abudefduf marginatus, Abudefduf analogous* (Gill),[2] *Halichoeres bivittatus* (Bloch) *Gobius soporator* Cuvier and Valenciennes, and *Auchenopterus* sp.

Deep Creek, a little to the north, was next entered for a very short distance. At this place the following species were seen or collected. *Sardinella macropthalmus* (Ranzani), *Lactophrys bicaudalis* (Linnaeus), and *Echeneis naucrates.*

Mangrove Cay was then returned to and a small fresh water pool seined, in which *Tarpon atlanticus* (Cuvier and Valenciennes)

[2] A new distributional record. See Breder, 1933c.

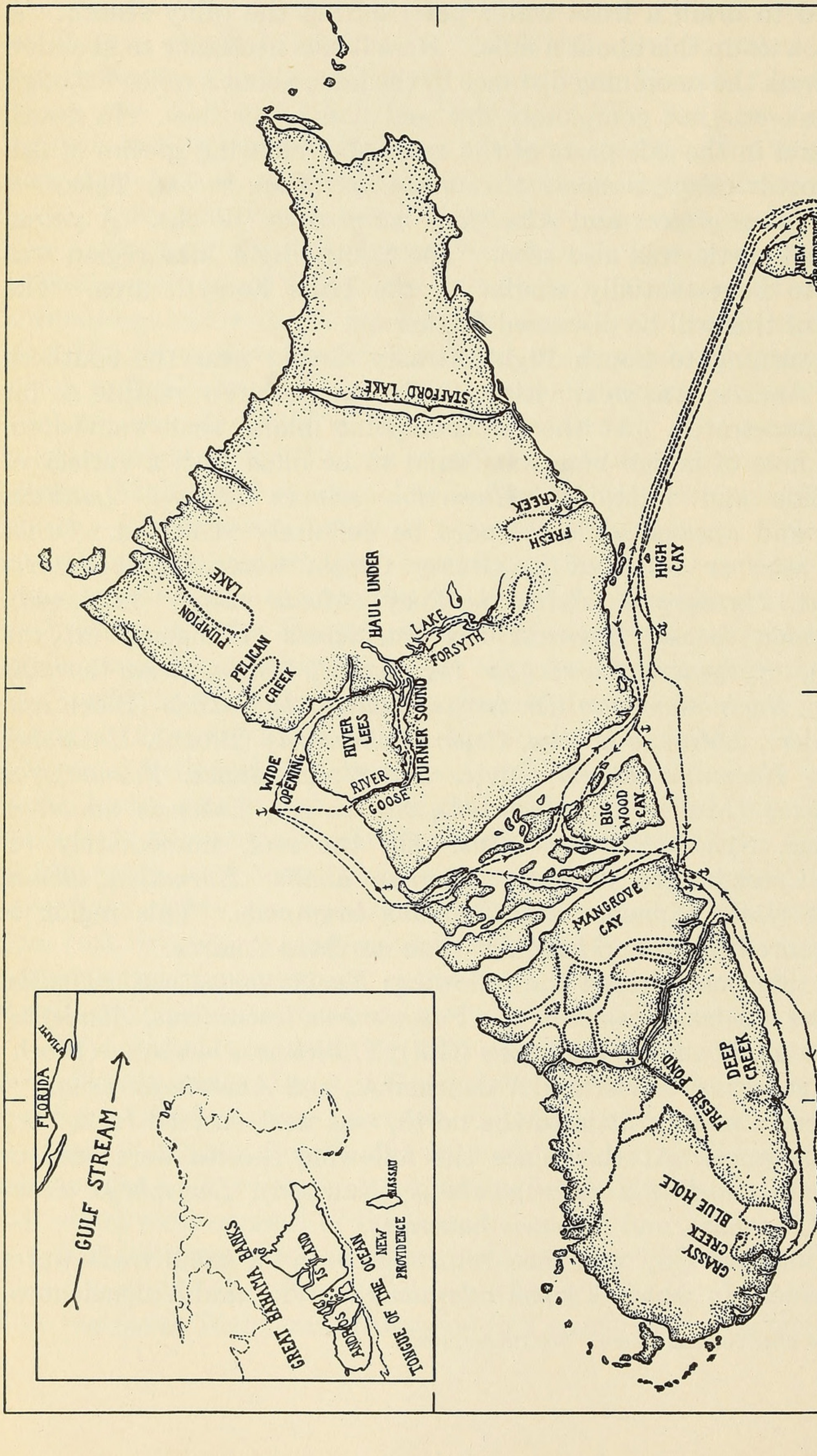

Fig. 26. Chart of Andros Island showing known and reported fresh waters. The latter are indicated by dotted lines, excepting on Mangrove Cay where they indicate the extensive dissection of the island. Actually, there are many other bodies of water, the reports of which were too vague to permit indicating on a chart. Drawn by T. Schewe.

were taken. This place is fully discussed by Breder, 1933a and 1933b. The full itinerary is indicated in Fig. 26.

THE HABITAT

A more complete description of Andros Island, than that given in the introduction, is necessary to understand the biological relationships. This island, which is truly oceanic and of old coral reef formation, is separated from the mainland by the Straits of Florida through which the Gulf Stream sweeps northward. At its narrowest part this represents a stretch of open ocean of about one hundred and twenty miles. The island, actually, is in the nature of an archipelago at the present time, but evidently existed as a single land mass sometime ago. Roughly, it is about as long as Long Island, N. Y., and about twice as wide. It is dissected into three main islands of considerable size, and a host of smaller ones grading down to tiny rocks just awash. On the eastern shore it slopes down abruptly to the very considerable depths of the Tongue of the Ocean which separates it from New Providence and the other more eastern islands. This coast is protected by a well developed, fringing reef, which has few good passes. Inside the reef, navigation is not particularly easy because of the irregular bottom and the general abundance of scarcely submerged coral heads. The western slope is vastly different, grading off gradually in a great marl flat that extends for miles to sea, making a close approach possible, even in small boats, only at a few localities. The exposed portion of the island is composed entirely of eroded coral rock, except where it is covered with marl either desiccated or in a pasty condition. The greatest height of this low island, about one hundred feet, is close to the eastern shore, and most of the drainage is to the westward. The coast line is well known to both naturalists and others, but the interior is inadequately charted and but one body of fresh water is indicated on present day maps. Actually, there are large amounts of fresh water, as well as salt and brackish inlets. If a full survey were made it might actually show nearly one-third the area to be covered with water. Such an impression is obtained when the island is viewed from the seaplane connecting Nassau with Miami. Besides the bodies of water we visited, known as Lake Forsyth and South Bight Lake, another has been indicated by Pilsbry and Black, 1930, (Lake Stafford), and a third was visited by Mr. Bacon some

Fig. 27. The densest stand of trees encountered in the Lake Forsyth region.

years ago, entering by way of Fresh Creek. In addition to these, questioning of the natives revealed consistent answers of other fresh water bodies. These are indicated in Figure 26. In addition, many of the smaller islands are groups much dissected by inlets of the sea.

Dr. Maurice Black, in a personal communication, stated that he did "not see how the land surface of the Great Bahaman Bank can be older than the early Pleistocene, since the fresh water and terrestrial deposits of Andros and the other islands on that part of the Bank all appear to lie with a nonsequence on hard limestone without any Pleistocene species amongst their fossils." He further remarks that according to his studies "the land area on the Great Bahama Bank has, quite recently, been vastly more extensive than it is at present, and that the distribution of the land molluscs is related to this 'greater Andros,' rather than to the present configuration of the island." Also, "that the mollusc fauna of Lake Forsyth includes a large proportion of endemic species which must mean that there have been bodies of fresh water continuously present on the Bank for much longer than has been generally supposed." This water, which is truly fresh but naturally very "hard," being bedded on either old coral rock or marl mud, is not unpleasant as drinking water. Lake Forsyth is exceedingly turbid because of the great amount of fine marl mud in suspension.

The Lake Forsyth region, as noted in the introduction, is distinctly different from the seacoast. Stands of pine are not uncommon but they are rather dismal groves of small dimension for most part, and show the unmistakable ravages of numerous hurricanes. The densest stand encountered is illustrated by Fig. 27 but this is quite exceptional. A more typical grove is shown in Fig. 28 which well illustrates much of the shore line of Lake Forsyth. One of the waiting buzzards, already alluded to, is here seen circling ahead of the party as it was returning to camp from a seining trip. Where the shore line was not as rugged as at the camp site, it was covered with a thick layer of partially dried marl, such as shown in Fig. 29. This was found to be treacherous in spots and must be of a very considerable thickness, in some places at least. These areas represent the greater extent of the lake during times of high water. The stream, Milk River, that connects this lake with the sea, is excessively turbid with marl, from which fact it derives its

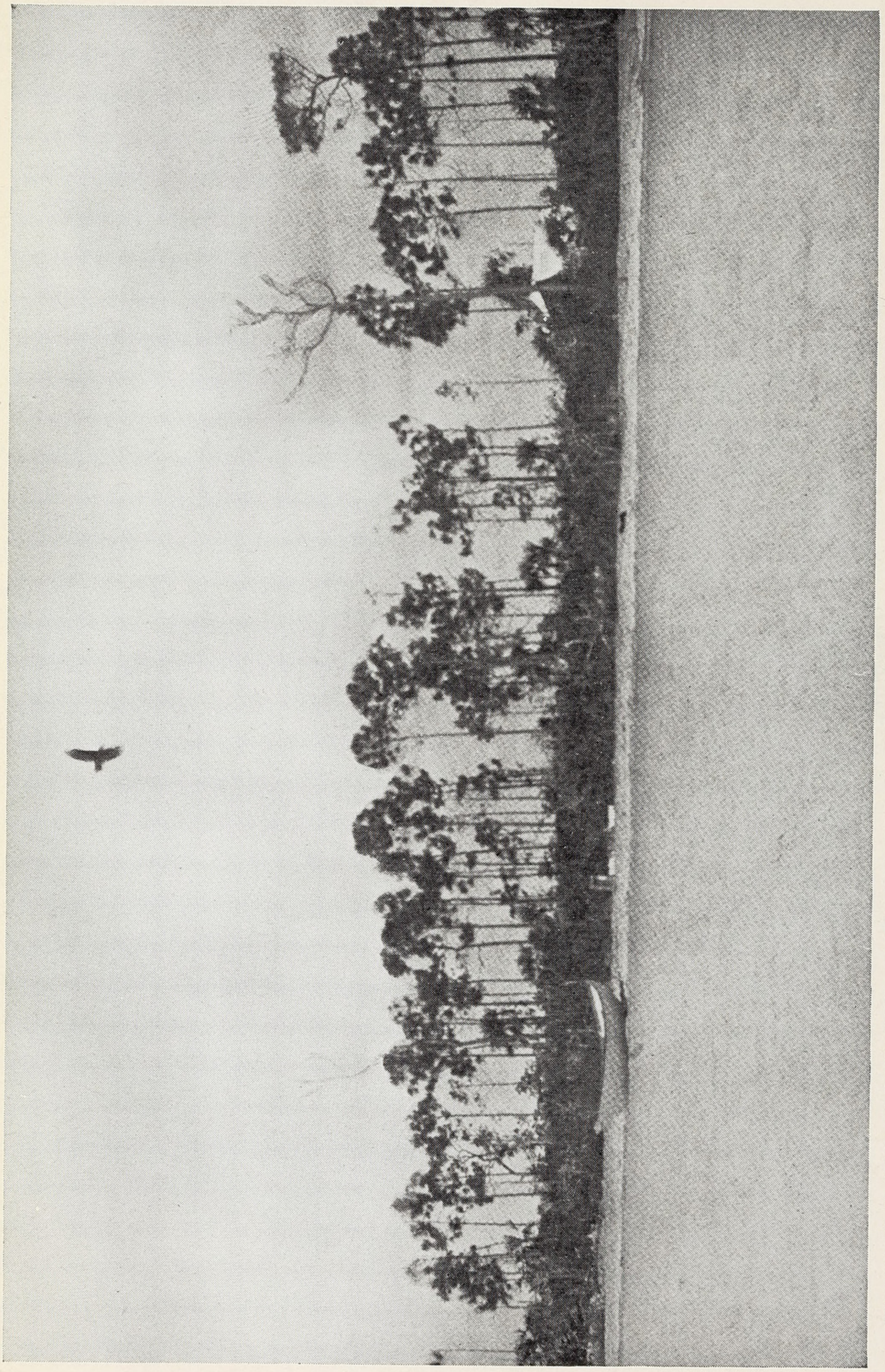

Fig. 28. Lake Forsyth, showing a typical stretch of shore line, including the expedition's camp, as well as one of the constantly attending buzzards.

local name. This turbidity is accounted for by the rather rapid movement of the water through it. One of the wider parts of this stream is illustrated by Breder, 1933a.

The lake, approached via the South Bight, is essentially similar to Lake Forsyth, but appears to be considerably larger. The general form of it is indicated on the chart, Figure 26. Reports have it that there is another drainage into the lagoon near Grassy Creek, and a third to the west side of the island. The shore line and vegetation is reminiscent of Lake Forsyth but does not seem quite so dismal. This is probably accounted for by its greater proximity to the sea, although actually there is more evidence of recent hurricane damage here than at the former locality.

The Invertebrate Fauna

While it is not the purpose of the present communication to discuss the invertebrate fauna of the region under consideration, there are certain features of it that are of considerable importance to the ecology of the vertebrates.

Insects of the camp-pest type were pleasingly absent. Mosquitoes and flies were rare. A few wood roaches were uncovered in preparing camp and gathering firewood. Some butterflies and dragon-flies were constantly about. Spiders were scarce. A single scorpion was seen. It was a matter of some wonderment just what the lizards and frogs managed to find to support life. A few large land crabs and some terrestrial hermits were present but not numerous. Land snails, both Cerions and other genera, were decidedly common. See Pilsbry and Black, 1930.

Aquatic invertebrates of macroscopic size likewise were scarce. Probably the most common were the nymphs of the dragon-flies, usually found half buried in the soft marl. A few dytiscids and red aquatic arachnids were seen. A few small crabs hid in rock holes. The only mollusks encountered were the empty shells of *Physa*. Regarding the aquatic species, it is especially to be borne in mind that all, except possibly the few crabs, are distinctly fresh water forms. This condition will be referred to later as these represent the only invasion of organisms that can be properly thought of as marking a fresh water environment. There has thus been little, if any, successful attempt of the abundant and nearby sea invertebrates to occupy this environment. The reasons therefor

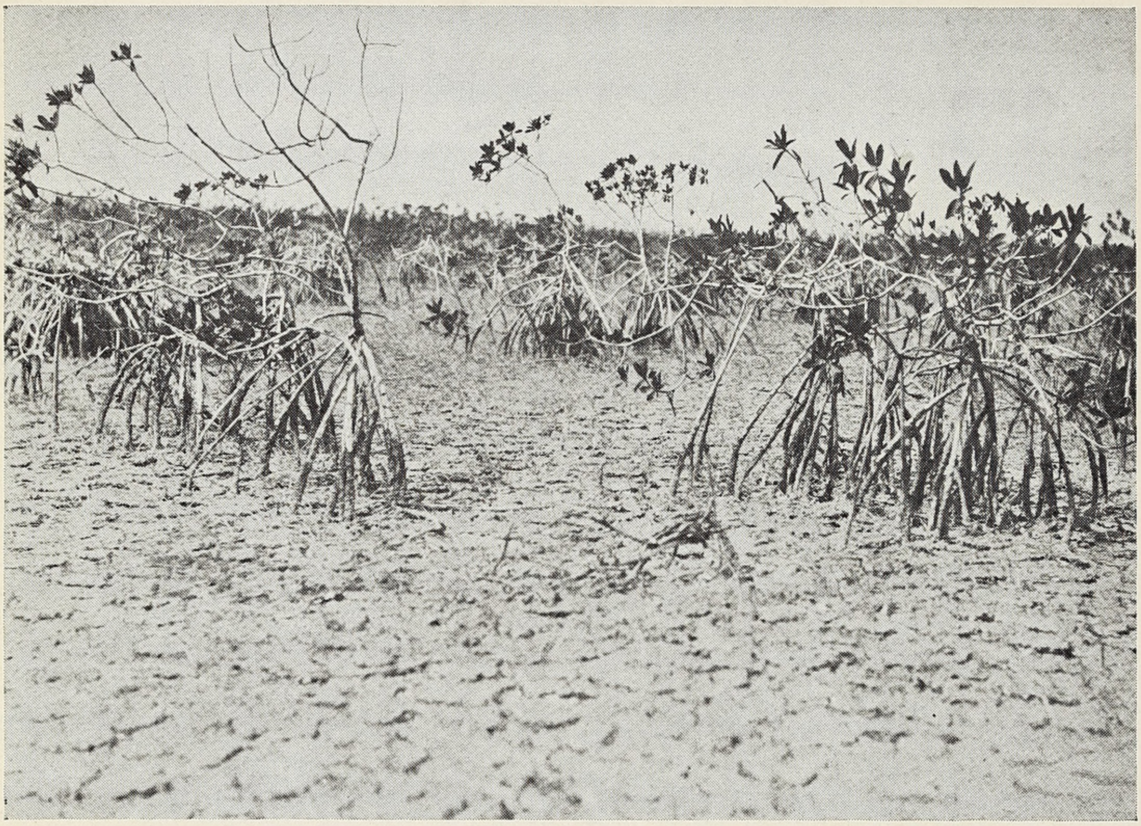

Fig. 29. Flats of partially dried marl, studded with straggling mangroves, are not uncommon about Lake Forsyth and represent the extent of the enlarged lake during times of high water.

will appear subsequently. It may be mentioned in this connection that a fresh-water plant, *Utricularia* has been reported from Andros. None whatever could be discovered in the territories visited, although the peculiar brackish-water algae, *Batophora,* was abundant.

Reptiles

The lizards were naturally more in evidence than frogs, giving what probably is only an appearance of greater abundance. However, they could not be considered as common, as the lizards found in such places go. Such forms as were collected near Lake Forsyth have been identified by Dr. Noble of the American Museum of Natural History. They are *Leiocephalus carinatus* Gray, *Anolis distichoides* Rosen, and *Anolis brunneus* Cope. Most of these were found not more than fifty or seventy-five feet back from shore on broken aeolian rock which made collecting them difficult if not actually hazardous, to one's lower extremities at least.

It was noted that the specimens of *Leiocephalus* at no time were seen to curl their tails. According to the natives, a form living along the seacoast persistently carries its tail curled up tightly, which they distinguish from ordinary lizards by the descriptive appellation, "curly-tailed lizards." None of these was seen or collected, but on another trip with Mr. Bacon to the Berry Islands (1930), where, because of their small size no great distance can be reached from the sea, this type of lizard was abundant and no straight-tailed *Leiocephalus* was encountered. A typical example of *Leiocephalus carinatus* at Lake Forsyth is illustrated by Breder, 1933a, as well as a Berry Island *Leiocephalus*. Even those with regenerating tail-stubs at the Berry Islands, consistently showed this tendency. Furthermore, at no time were these Berry Island lizards seen to completely unwind their tails. When frightened, or interested in an insect, they would alternately tighten and relax this spiral, much after the fashion of the hairspring of a watch, but not quite so rapidly.

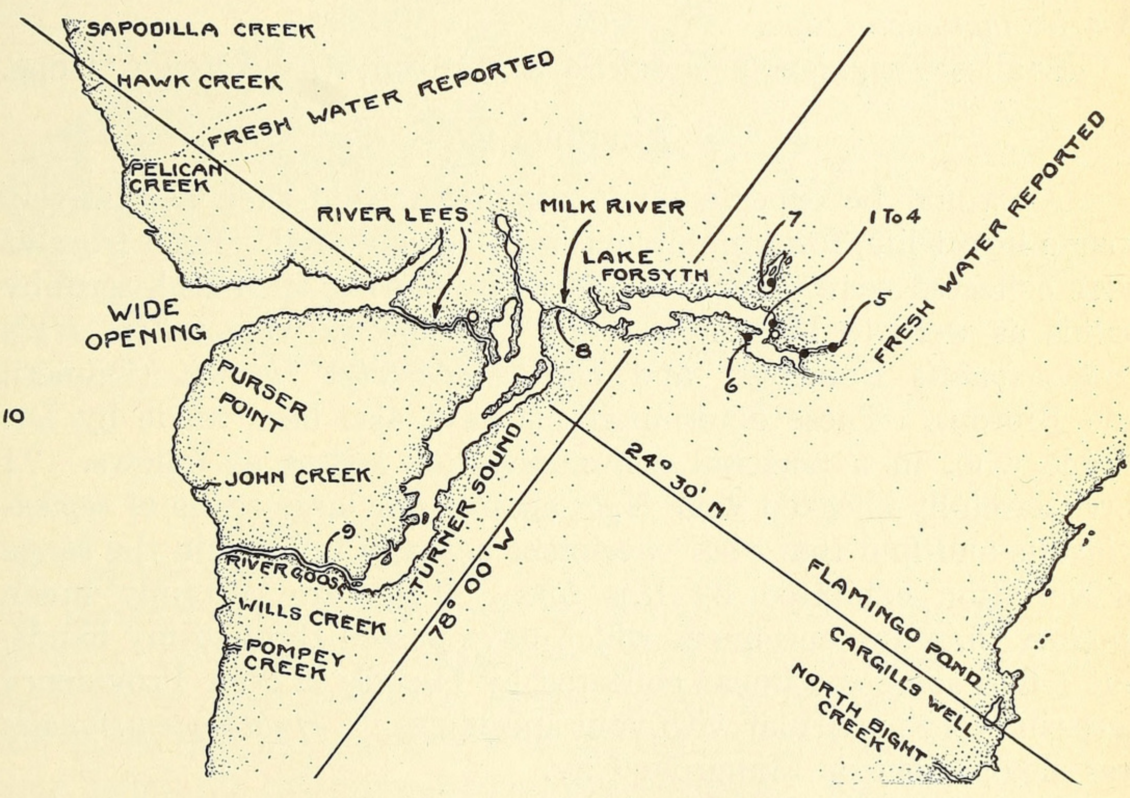

Fig. 30. The Lake Forsyth region. Light circles indicate camp sites. Black circles indicate seining sites. Numerals indicate localities of water samples similarly numbered in Table II. Milk River marks the separation of the fresh water of Lake Forsyth and the sea water of Turner Sound.

On the southern part of Andros, there occurs *Cyclura baealopha* Cope. The natives know of this larger lizard and run it down with dogs, but apparently it is not sufficiently numerous to enter into their food economy to any extent at the present time. None was seen on our visits.

Contrariwise, one of the buzzards that persisted in watching us at Lake Forsyth was seen to catch a live lizard (*Leiocephalus ?*). This act, unusual for such a bird, may be taken as indicative of the paucity of the larger forms of animal life in this region.

A number of objects, thought to be lizard eggs, were found on the leaves and stems of the stunted mangrove bushes. On opening, these were seen to be the pupae of moths. The species, identified by Dr. C. H. Curran, is *Alaradia slossoniae* Packard. One of these is illustrated by Breder, 1933a.

By obtaining the aid of small boys on Mangrove Cay, a considerable series of reptiles was secured on the second expedition.

Lizards: *Anolis distichoides* Rosén; *Anolis brunneus* Cope; *Ameiva thoracica* Cope.

Snakes: *Tropidophis pardalis androsi* Stull; *Alsophis vudii*[3] Cope.

Amphibians

As would be expected in a region showing such a relatively sparse insect life, few amphibians were encountered. Such frogs as were collected were taken at night or by tearing open such scrubby palms as were to be found. Only two species were taken, *Hyla septentrionalis* Boulenger and *Eleutherodactylus ricordii* (Dumeril and Bibron). These determinations have also been made by Dr. Noble who, in a personal communication, writes as follows. "I have carefully checked your *Hyla* against our large series of *septentrionalis* and find that your specimens actually fall within the range of variation exhibited by this form. They are certainly much rougher than any specimens which have passed through my hands, but I find some specimens collected by Nichols in New Providence agree in every particular with your specimens." *Hyla septentrionalis* was also present on Mangrove Cay.

Conversation with numerous natives uniformly revealed that in early May all of the small pools of Andros are exceedingly noisy with the calls of frogs. Those boys more given to prowling around

[3] Apparently a new record from Andros.

inland were most emphatic. Consequently, it may well be that frogs are actually more common than the season of our visit would indicate. On the other hand it does not take many individuals to make up a chorus of an impressive volume on such silent nights as those encountered on inland Andros.

Fishes

The fishes collected in Lake Forsyth have already been listed, Breder, 1932, and discussed from the taxonomic standpoint. The fishes are the only vertebrate group that can be considered abundant in this environment, at least in the season of our visit. The following data were not considered in the purely taxonomic list above mentioned. The information concerning size and number is relegated to Table I. Collecting sites are indicated in Fig. 30.

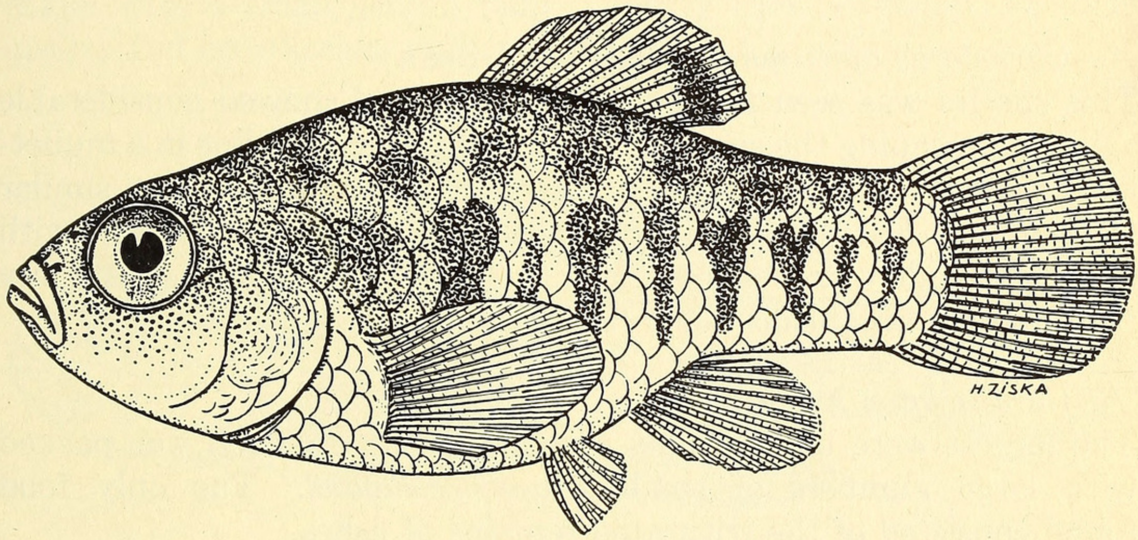

Fig. 31. *Cyprinodon baconi* Breder.

1. *Cyprinodon baconi* Breder
All specimens examined were uniformly packed with *Batophora* generally broken down to little more than a brown paste. In quiet pools males could frequently be seen pursuing females, in a manner not unlike that of *C. variegatus* in the latitude of New York, a short time before the full nuptial colors are assumed. Fig. 31.

2. *Gambusia manni* Hubbs
Food in this species was essentially similar to that of the preceding. Courtship activity could be frequently observed.

3. *Strongylura notata forsythia* Breder
Undeveloped sexually. The intestinal contents consisted of fish remains, and one dragon-fly nymph. Fig. 32.

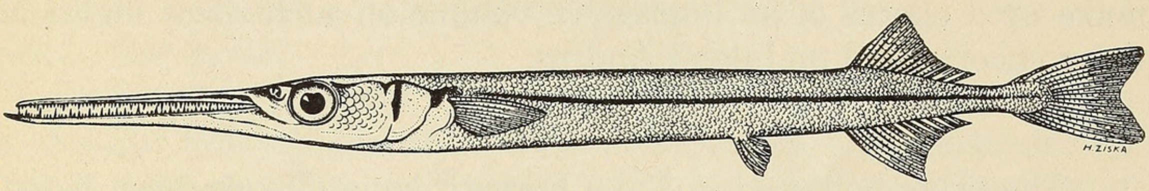

Fig. 32. *Strongylura notata forsythia* Breder.

4. *Strongylura timucu* (Walbaum)
The single specimen of this species, a female of 290 mm. s. l., was approaching ripeness. The intestinal contents consisted of the badly macerated remains of some small fish, (*Gambusia* or *Cyprinodon ?*). The body cavity held two *Filaria* (?).

5. *Chriodorus atherinoides* Goode and Bean
This species was seen to leap on occasion and showed considerable agility in escaping the seine by passing over the cork line in a mullet-like fashion. The gonads were nearly ripe. The food was similar to that of *Eucinostomus. Batophora* either breaks down with extreme rapidity or else most of it is "mouthed" and rejected, only the adherent organisms being retained.

6. *Caranx latus* Agassiz
The largest were undeveloped sexually. The stomach was packed with large numbers of small *Acanthocephalans.* The only food found consisted of the triturated remains of fishes.

7. *Lutianus griseus* (Linnaeus)
Both specimens (175 and 124 mm. s. l.) were undeveloped sexually. The body cavity contained numerous nematodes. The digestive tract contained the mangled remains of fishes and one dragon-fly nymph.

8. *Eucinostomus californiensis* (Gill)
None of these fishes appeared to be mature. The intestinal tracts were packed for most part with fragments of *Batophora,* diatoms, and to a lesser extent the remains of associated animal organisms, mostly small crustaceans.

9. *Eucinostomus gula* (Cuvier and Valenciennes)
On detailed examination of the large series of this genus (587), about fifty proved to be the present form. As their stomach contents was identical with that of *E. californiensis,* and their range of sizes not nearly so great, these two related species are considered together in Table I.

10. *Spheroides testudineus* (Linnaeus)
The single specimen of 155 mm. s. l. was a male approaching ripeness. There was no food in the digestive tract.

11. *Gobiomorus dormitor* Lacepede
Remains of very small fish. Nematodes in body cavity. Sexually undeveloped.

12. *Lophogobius androsensis* Breder
Males with a small genital palp. Nearly ripe. Remains of small insects and crustaceans in digestive tract. Fig. 33.

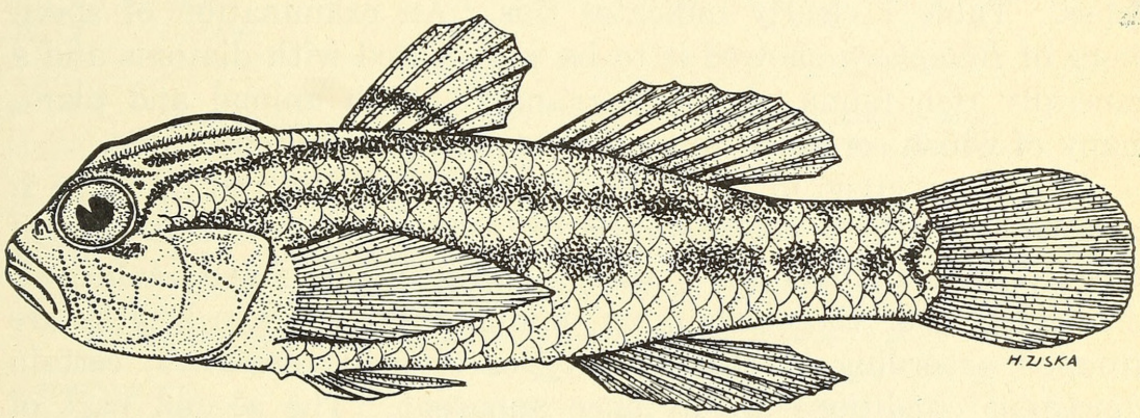

Fig. 33. *Lophogobius androsensis* Breder.

Two very striking peculiarities about these fishes are apparent. The one is their very presence in such large quantities in a lake of fresh water, since they are typically marine or at least brackish-water forms. The other is the problem of the basic food supply, in a region relatively barren of objects which could form such a basis, as is indicated under the previous heading. Insects or other life falling into the water could not possibly support the evidently well fed and numerous fishes, some of which are strictly predacious. Stomach examination reveals the source at once, however, for at least five of the species feed directly on the mat of *Batophora* flooring the bottom of this lake, even to the deepest parts sounded (about six feet). Breder, 1933a, illustrates this plant. The species subsisting on this vegetation include both the smallest and the most numerous. *Gambusia manni, Cyprinodon baconi, Chriodorus atherinoides* and *Eucinostomus californiensis* and *gula,* were all found to be well filled with this plant. The first two were not found near larger forms, keeping for most part to shallow water or in pools cut off from the main lake, and consequently do probably not form an important source of food for piscivorous species. *Chriodorus,* while freely ranging and occasionally seen to leap as if pursued by other fishes, are probably not numerous enough to be of any particular importance. *Eucinostomus,* however, is ubiquitous and a great variety of sizes is available, specimens having been collected that ranged from 27 to 127 mm. in standard length. This species clearly forms the connecting link in the food chain between vegetation and the purely predacious forms, such as *Caranx, Lutianus* and *Strongylura* either directly or through the intermediary of other predacious fishes. Table I clearly indicates this. An examination of specimens of *Batophora* showed it to be well coated with diatoms and a generally rich fauna of micro-organisms, both animal and plant, many of which certainly go to enhance the general food value.

The data given in the foregoing annotated list and in Table I, form the basis for a consideration of the food chain in this isolated lake. If the number of species, number of specimens collected; their weight, or their maximum, minimum or average lengths are grouped according to the three types of food consumed, certain consistent conditions are at once apparent. The second part of Table I shows these relationships, and the remainder gives them calculated from a proportional viewpoint. The data need hardly be elaborated upon. While the collection is not sufficiently extensive to assume any great degree of accuracy for the figures as standing, they certainly represent a numerical approach to the proportions of the various elements in the food chain. That is to say, the number of specimens and the total weight of the vegetable eaters are greater than that of the piscivorous, while the average weight and maximum, minimum and average lengths are all greater in the latter. This is the expected relationship between predators and their food. If those few forms which feed on invertebrates are considered included as food objects for the fish-eating species,

TABLE I. THE FISH POPULATION AND ITS FOOD

No.	Species	No. of Specimens	Weight in Grams		Standard length in mm.			
			Total	Average	Max.	Min.	Mode	Average
1	*Cyprinodon baconi*	47	13.8	0.3	33.5	12.0	17.5	17.1
2	*Gambusia manni*	15	3.4	0.2	25.0	15.0	18.5	17.9
3	*Strongylura notata*	22	316.7	14.4	245.0	105.0	180.0	188.6
4	*Strongylura timucu*	1	32.0	32.0	—	—	290.0	—
5	*Chriodorus atherinoides*	5	26.8	5.4	105.0	77.0	—	89.8
6	*Caranx latus*	23	1246.0	54.2	180.0	92.0	130.0	131.3
7	*Lutianus griseus*	2	163.9	81.9	175.0	124.0	—	139.5
8	*Eucinostomus californiensis*	587 (8 and 9)	2231.1	3.6	127.0	27.0	65.0	83.2
9	*E. gula*							
10	*Sphoeroides testudineus*	1	955.7	955.0	—	—	155.0	—
11	*Gobiomorus dormitor*	3	23.6	7.8	110.0	87.0	—	59.0
12	*Lophogobius androsensis*	4	9.6	2.4	43.0	29.0	—	38.2

Nos.	Food	No. of species							
1, 2, 5, 8, 9,	Vegetation	5	654	2265.1	3.5	127.0	12.0	—	52.0
3, 4, 6, 7, 11	Fishes	5	51	1782.2	34.9	290.0	87.0	—	161.7
10, 12	Invertebrates	2	5	965.3	193.0	155.0	29.0	—	86.6

Proportional calculations with invertebrate feeders reduced to unity

Food								
Vegetation	2.5	130.8	2.3+	0.0+	0.8+	0.4+	—	0.6+
Fishes	2.5	10.2	1.7+	0.2−	1.8+	2.9+	—	1.8+
Invertebrates	1.0	1.0	1.0	1.0	1.0	1.0	—	1.0

Proportional calculations with fish feeders reduced to unity

Vegetation and Invertebrates	1.4	12.9+	1.8+	5.6+	0.9+	0.5−	—	0.9−
Fish	1.0	1.0	1.0	1.0	1.0	1.0	—	1.0

which they doubtless are, the differences become still more marked. However, mollusk and insect eaters are few, as indeed they must be in such an environment, and their importance is relatively slight. Very likely the food requirements determine to a considerable measure just what fishes may successfully establish themselves in such a lake. First, with the establishment of a dense vegetative growth, the plant-eating forms should appear, to be followed by the predacious species. As the marine invertebrates do not enter, for reasons to be subsequently discussed, those fishes which feed on them must be held off until such a time when fresh water substitutes can establish themselves. Although the data derived from the examination of stomach contents of the specimens collected can hardly be considered as sufficient to warrant such conclusions, the foods of the types represented—in some cases the exact species—are well known. It is thus evident that the fishes of Lake Forsyth, in the final analysis, are almost entirely supported by the dense beds of *Batophora* and the microscopic and nearly microscopic organisms dwelling in its fronds. The fishes in the lake at South Bight were similar to the Forsyth fishes.

Cyprinodon baconi Breder. Fairly common but none as large as the type specimen. In the nearly salt water this species was also present, probably due to the short creek connecting this lake with the sea. The marine localities are noted in the introduction.

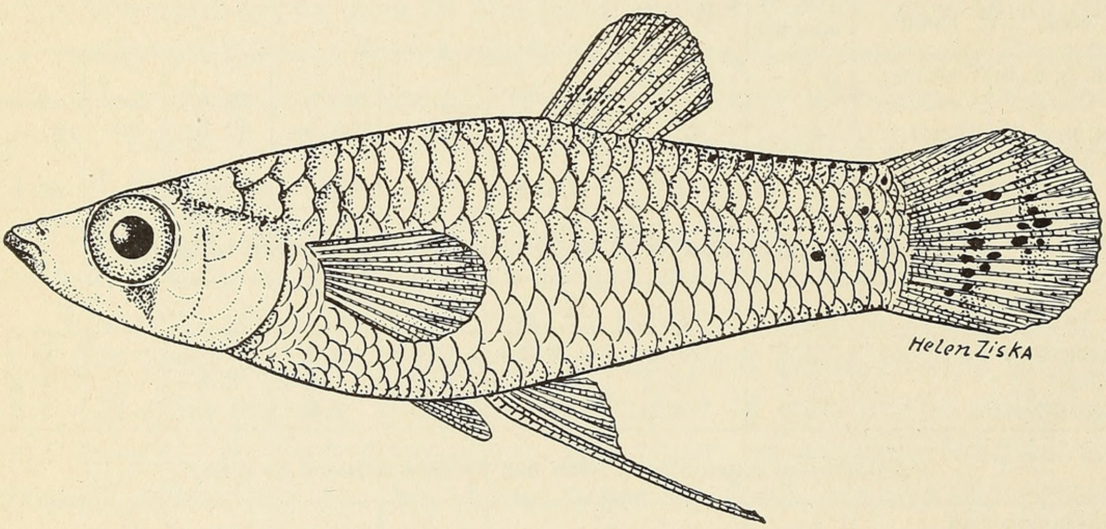

Fig. 34. *Gambusia hubbsi* Breder.

Gambusia hubbsi Breder. Common at one spot only. As noted in the original description (Breder, 1934), this species presented a much different appearance in the field than its close relative *G. manni* seen in Lake Forsyth and in Lake Killarney on New Providence. They were tinted with a definite steel blue and were decidedly larger. Aside from this their behavior was notably different. *G. manni,* as seen by us, was a very timid fish, whereas *G. hubbsi* was comparatively very tame. Fig. 34.

Strongylura notatus forsythia Breder. Four examples were all entirely within the range of variation, marking this race. It is noteworthy that no *S. notatus* were seen on Andros in either year excepting these in fresh water.

Eucinostomus californiensis (Gill). Common wherever seining was carried on.

Lutianus griseus (Linnaeus). Much more common and larger than in Lake Forsyth. As there is probably a similar food chain in this body of water it seems likely that the presence of these larger and more numerous snappers may account for the relative paucity of the other species.

The fishes of a small pool on Mangrove Cay are fully discussed by Breder, 1933b. They consisted solely of small *Tarpon atlanticus*. In the stomach of some were found fragments of *Cyprinodon baconi?* This pool differed from the other fresh water localities encountered, in that it was foul and turbid with dark colored detritus and agreed with other West Indian localities harboring young tarpon. For a discussion of this specialized and restricted type of environment, the paper above mentioned should be referred to.

Chemical Nature of Lake Forsyth

The most striking feature of the fish fauna of Lake Forsyth is that bearing on the chemical nature of these peculiar waters. The analytical data are given in Tables II and III, from which it is at once apparent that the water is "fresh" in the ordinary sense of the term. The freezing point and specific gravity alone are enough to establish the small amount of salts in solution. Comparisons with various municipal waters of the continental United States (Clarke, 1924) shows, however, that although the amounts of material in solution are not very evident by the two above mentioned methods, there is still considerably more in solution than in most fresh waters of North America. There are, however, several river waters with a considerably greater amount of dissolved material (*e. g.* Arkansas, Pecos and Santa Maria Rivers). They are all in the middle or southwestern sections of the continent. The Atlantic coast drainage is very definitely lower. Waters of closed basins and mineral springs are mostly higher, and in many cases very much higher.

Furthermore, a study of the table shows the substances in solution to be substantially in the relative proportion that they occur in the sea, with the notable exceptions of chloride and the

TABLE II. CHEMICAL ANALYSIS*

No.†	Date	Locality	Δ	pH	Cl ‡ (mM per liter)	SO_4	Σ A^-	CO_2 § H_2CO_3	K	Na	Ca	Mg	Σ B^+	Fixed residue
1	Jan. 24	Lake Forsyth, surface	– .04	7.6	12.995	4.00	20.995	2.0407	1.452	18.037	.998	0.057	21.599	—
2	Jan. 25	" " "	– .05	7.6	12.995	3.75	20.495	2.1457	1.089	18.037	.998	0.055	21.232	—
3	Jan. 25	" " bottom	– .05	7.5	12.995	4.00	20.995	2.1607	1.452	20.993	1.248	0.094	25.129	—
4	Jan. 25	" " "	– .05	7.5	13.91	3.50	20.910	2.1607	1.634	20.993	.998	0.082	24.787	—
5	Jan. 25	" " farthest east	– .10	7.6	19.40	3.50	26.900	2.3032	1.634	22.572	1.123	0.128	26.708	—
6	Jan. 27	" " Old Camp	– .05	7.6	13.60	3.00	19.600	2.2507	1.634	20.537	1.497	0.095	25.355	—
7	Jan. 27	Land-locked Pool	– .04	7.3	9.33	2.50	14.330	1.9291	1.271	13.527	.874	0.032	16.610	—
8	Jan. 28	Milk River	– .07	7.7	13.60	4.00	21.600	2.1000	2.179	15.560	1.248	0.102	20.439	—
9	Jan. 28	Goose River	–2.08	8.1	545.70	28.80	603.300	2.3778	8.030	517.000	10.444	40.517	625.9	—
10	Jan. 28	Off Purser's Point	–2.16	8.0	561.00	30.40	621.800	1.9357	10.130	521.500	13.476	40.517	639.6	—
11	Feb. 2	Lake Killarney	–0.39	8.2	123.74	3.50	130.735	2.1457	2.179	107.770	1.996	3.843	121.627	—
			atm.	Sp.‖ Gravity	Parts per thousand									
1	——	——	0.482	1.0015	.460	.384	.844	.089	.056	.414	.039	.0014	.510	.95
2	——	——	0.603	1.0015	.460	.360	.820	.094	.042	.414	.039	.0014	.496	.902
3	——	——	0.603	1.0025	.460	.384	.864	.095	.056	.481	.050	.0022	.589	1.02
4	——	——	0.603	1.0025	.493	.336	.829	.095	.064	.481	.039	.0020	.586	1.02
5	——	——	1.206	1.0015	.687	.336	1.023	.101	.064	.519	.044	.0031	.597	1.43
6	——	——	0.603	1.0010	.482	.288	.770	.099	.064	.472	.059	.0023	.597	1.06
7	——	——	0.482	1.0010	.342	.240	.582	.084	.049	.311	.035	.0025	.397	.836
8	——	——	0.844	1.0010	.482	.360	.842	.092	.084	.357	.050	.0025	.493	1.05
9	——	——	24.99	1.0290	19.348	2.764	22.012	.104	.313	11.891	.417	.985	13.606	39.71
10	——	——	25.95	1.0300	19.891	2.918	22.809	.085	.395	11.994	.539	.985	13.913	40.312
11	——	——	4.7	1.0046	4.387	.336	4.723	.094	.084	2.478	.079	.093	2.734	8.69

* Determinations made by J. Hanache. † These numbers refer to localities shown in Figure 10, excepting No. 11 which is on New Providence.
‡ Cl –0.35 for Br_2 and I_2 gives slightly lower values. § Includes traces of $'NO_2$, and $'NO_3$, and 0.2 mM of PO_4. ‖ Reduced to 15° C.

sulphate radical, the former of which plays such an important role in the ocean. This comparison is more forcefully brought out in Table III, which gives the same data reduced to terms of percent. While there is always a considerably greater amount of chlorine than sodium detectable in ocean water, indicating the presence of other chlorides,[4] the excess is very slight in water from Lake Forsyth. In ocean water less than three-fifths of the Cl can be opposed to the Na, necessitating that other chlorides must account for the rest. In Lake Forsyth the Cl in excess of the Na is exceedingly slight, something less than one-tenth of the total Cl not being opposed by Na. The sulphate radical, on the other hand, is about

TABLE III. CHEMICAL PROPORTIONS OF LAKE FORSYTH*

	Ocean † Average	Logger-head ‡ Key	Ocean Nos. 9–10 Average	Lake Killarney No. 11	Milk River No. 8	Lake Forsyth Nos. 1–7 Average
Cl	55.29	55.24	54.03	58.08	33.77	33.16
Br	0.19	.17	———	———	———	———
SO_4	7.69	7.54	7.82	4.45	25.22	22.91
CO_3	0.21	.34	.26	1.24	6.44	6.47
Na	30.59	30.80	32.89	32.83	25.01	30.43
K	1.11	1.10	.98	1.12	5.89	3.89
Ca	1.20	1.22	1.32	1.05	3.50	3.00
Mg	3.72	3.59	2.70	1.23	0.17	0.14
	100.00	100.00	100.00	100.00	100.00	100.00
Salinity p.p.m.	33,010.0 to 37,370.0	35,490.0	36,313.0	7,551.0	1,427.5	1,451.8

* Calculated by J. Hanache. † Mean of 77 samples. From Clarke, 1924, after Dittmar, 1884. ‡ Sample off Loggerhead Key, Fla. From Clarke, 1924, after Steiger, 1910.

three times as great in Lake Forsyth as in the ocean. The carbonate radical shows an even greater discrepancy, being over twelve times as large. The other items are also larger except magnesium which is exceptionally low.

These remarks obviously refer to the relative amounts as expressed in Table III. The quantities of salts in Lake Forsyth are of course all much less than in the ocean, as is indicated in the expression of salinity. This is likewise indicated in Table II in terms of absolute quantity excepting the comparatively uniform

[4] This is true even after a deduction has been made for other halogens which in the analysis have not been separated.

carbonate radical which is only relatively increased in Table III. It is clear that this water is then deficient in chlorides, as compared with the sea, and high in sulphates and carbonates which give the lake a decidedly different chemical constitution.

Despite the low concentration of salts in this lake, a variety of marine fishes was found to inhabit it, as already mentioned. In order to better understand these conditions, certain laboratory experiments were carried on which are discussed in a latter section.

In addition to the foregoing chemical peculiarities of this body of fresh water, a rather striking phenomenon could be seen almost at any time in any cove into which the wind happened to be blowing. A thick layer of white scum would rapidly accumulate under such conditions, generally proportional to the strength of the wind and the consequent wave action as well as the duration of its prevalence from one quarter. A typical cove so clogged is illustrated by Breder, 1933a. With a continued wind this froth would pile up on the shore, in places to the depth of two feet. As it dried, great chunks of it would be torn away in the breeze and be carried further inland, the small masses caught by an erratic gust sometimes lodging far up in the pine trees.

When piled up on the shore, the new froth when still white greatly resembled a well-made meringue. Breder, 1933a, shows an example of this formation. Due to the accumulation of dust on the sticky surface, the mass soon takes on a grayish tinge. This and the desiccating effect of the dry air causes a firm crust to form, somewhat protecting the interior. In time the material does thoroughly dry, due to cracking of the crust, and there remains a soft cake-like material. This substance is smooth and slippery, distinctly giving the impression of soap fragments.

Analysis yielded no fatty acids or other saponified or saponifiable substances. Although the samples were inadequate for a complete analysis, it is safe to infer that much of the material was $CaCO_3$ (marl). $CaCO_3$ and $NaHCO_3$ in a test tube will produce a froth not dissimilar in appearance and with the same soap-like feeling. No matter what may be the exact nature of the material, it represents a peculiar return of substances direct from a body of water to the land. Commonly, the run-off of the soil is thought of in its effect in supplying materials to the aquatic environment. Here, contrariwise, is a case where material is spread out on the shore directly from the water. The rain in turn dissolves or dislodges the material and eventually carries it back to the lake.

There has been considerable discussion as to the manner of formation of the extensive marine marl beds on the west side of Andros Island and elsewhere. The present data on Lake Forsyth are suggestive, in connection with these large deposits of $CaCO_3$. Harvey, 1929, and Clarke, 1924, both discuss such views at some length. The current ideas concerning the origin of these flats may be summarized as follows.

Origin	Process		Result
Organic			
Bacterial activity Albumen of animals	Releases Ammonium Carbonates	Precipitates $CaCO_3$	Marl Aragonite (unstable and largely dissappears)
Remains of $CaCO_3$ shells, etc.	Ground up by wave action		
Inorganic			
Streams entering the sea carry	$CaCO_3$ in suspension Ca in heavy solution which precipitates $CaCO_3$ when added to sea water		

Possibly all of them contribute, as none seems to be mutually exclusive. Since the highest land is close to the eastern shore and the drainage mostly to the west, practically all of the run-off drains in that direction. Since, as above noted, this island at some earlier date was larger than it now is, and as an abysmal depth occurs to the east—Tongue of the Ocean—it follows that the island's extent must have been largely to the westward, probably giving even more drainage in that direction. This, together with the indications of a larger amount of fresh water than has been generally credited, which is necessarily charged heavily with lime, would suggest that such in itself might be a sufficient causation. Additional $CaCO_3$ is taken into solution with every rainfall and precipitated, as evaporation progresses, between rains. Both that in solution and suspension is continually urged seaward into a medium already saturated in respect to Ca. Wave action remains to account for its spreading evenly over this relatively shoal area.

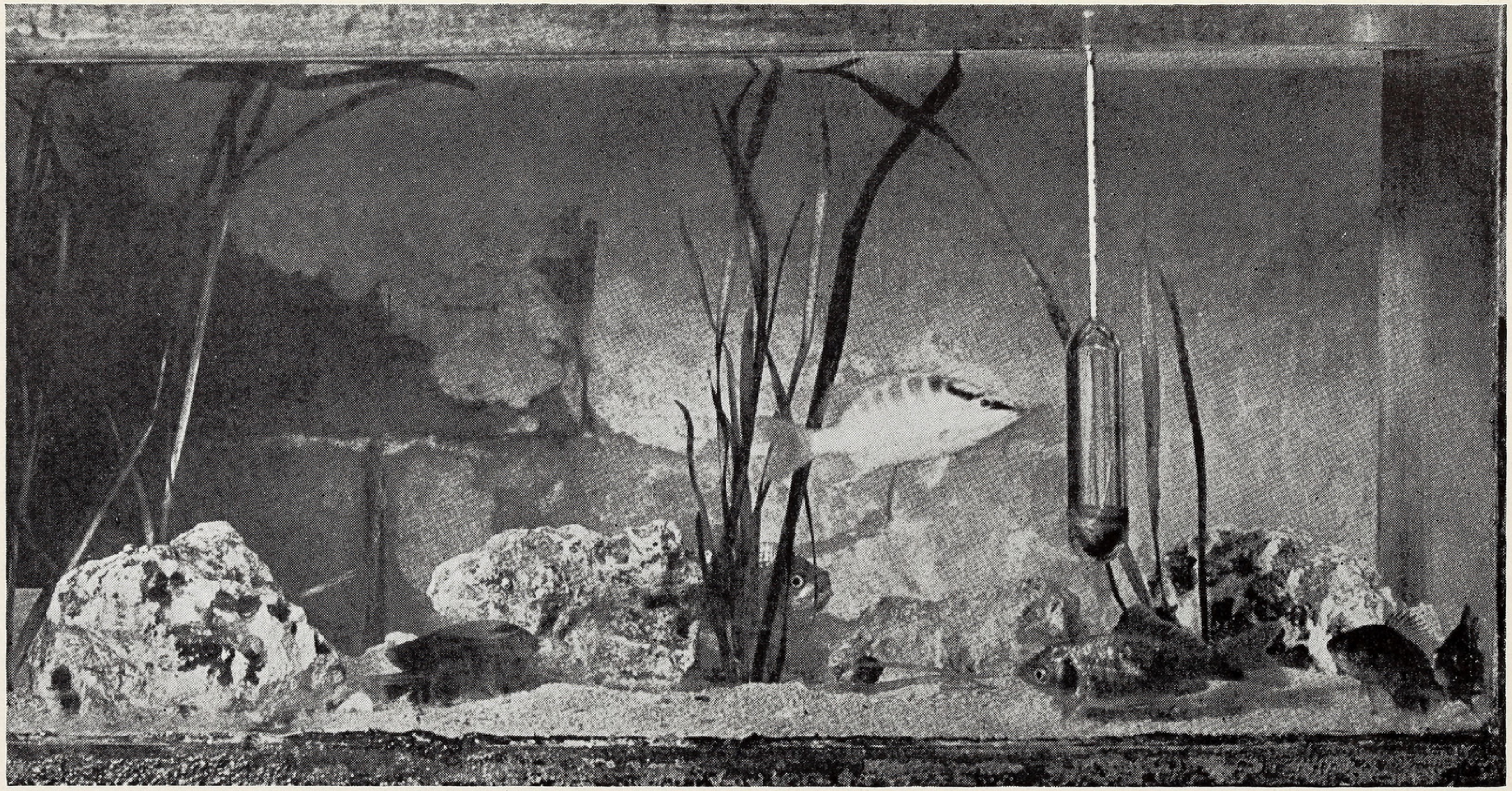

Fig. 35. Aquarium set up to simulate the Lake Forsyth water condition. The hydrometer may be seen resting at the top of its scale at 1.000 sp.g. The lowest mark on the scale, just above the bulb, reads 1.030. The density of the water from which the marine fishes were taken was a little less than this, about 1.028. The marine fishes had been living in this water for twelve days when this photograph was taken. They are as follows. *Pomacentrus leucostictus*, to left of center at the bottom; *Lutianus apodus*, to left of hydrometer in midwater. The fresh water fishes living with them are located as follows. *Carassius auratis*, under hydrometer and under tail of *Lutianus; Eupomotis gibbosus*, two in extreme lower righthand corner. Photograph by S. C. Dunton.

Experimental Data

Since it has been shown that Lake Forsyth is not a body of salt water and that it does harbor a variety of truly marine fishes, it remains to explain this anomalous condition. Although there are numerous fishes capable of dwelling in either fresh or salt water, the majority of marine fishes expire shortly if transferred to fresh water even if the transfer is gradual. As Lake Forsyth is bedded in coral rock and contains much calcareous marl in suspension, one would naturally look to this as a possible reason for the conditions earlier described. In order to test this hypothesis a number of experiments were undertaken at the New York Aquarium, Breder (1933c). While it is hardly necessary to describe them all in full detail at this place, the following abridgment may serve to clarify the point. Water was approximately synthesized according to the following formula.

NaCL	0.795	gms. per liter
$CaCO_3$	0.1099	
$CaSO_4$	0.3376	
K_2SO_4	0.1265	
$MgSO_4$	0.0094	

Other water was made up by placing in New York City tap water a considerable excess of calcium carbonate and calcium sulphate. This and the more carefully compounded solution gave indistinguishable results. This is to say, that the presence of calcium is enough to account for such effects. Fishes transferred immediately from sea water to this type of fresh water died in a very short time; in fact, nearly as short a time as when immersed in "soft" fresh water. Transfer consuming about three days was found to be adequate to accommodate the following species:

Hippocampus hudsonius
Centropristes striatus
Stenotomus chrysops
Lutianus synagris
Lutianus apodus
Anisotremus virginicus
Bathystoma striatum
Angelichthys ciliaris
Pomacentrus leucostictus
Abudefduf saxatilis

The experimental set-up was not entirely satisfactory and it is felt that much greater success could have been obtained if a more elaborate arrangement had been made, but for the present purposes the demonstration is adequate. The fish that gave the greatest satisfaction was the single specimen of *Lutianus apodus*. This fish lived for twenty days after accommodation to fresh water. At that time the experiment was terminated unintentionally, due to an accident in the water supply. A photograph of this fish is shown in Fig. 35, together with other species both fresh and salt. The hydrometer serves to indicate the lack of density of the water. The water used for the experiment was "hardened" simply by placing coral sand on the bottom, together with lumps of plaster of paris. It may be noted in passing that the fresh water fishes *Carassius auritus* and *Eupomotis gibbosus* were introduced directly from New York City water and thrived exceedingly well. Other investigators, such as Keys, 1931, transferred fishes from salt to fresh water, but the species used in the case cited, *Fundulus*, are all unusually adaptable and frequently endure indifferently well in either; so much so that it may almost be considered a generic characteristic. Such is not the case, however, with the species used in the present experiments, especially such as *Pomacentrus*, *Angelichthys*, et cetera. It thus appears to be clear, from the investigations of others and the present field and laboratory studies, that a large variety of marine fishes are able to exist in fresh water saturated with respect to calcium, while the "soft" fresh waters are quickly disastrous.

This view calls attention to a controversy between students at the Plymouth Aquarium and those associated with the New York Aquarium. The former institution uses quicklime for the correction of stored sea water, while the latter uses sodium bicarbonate. See Atkins, 1931; Breder and Howley, 1931; Breder and Smith, 1932, and Cooper 1932. While agreement has been reached in these contributions concerning the theoretical validity of the use of $NaHCO_3$, the data presented herewith support the use of calcium as a practical means if so desired. Certainly if sea fishes can be made to exist in fresh water by its presence, the partial replacement of sodium by it in sea water could hardly be expected to have serious consequences except after long periods, if at all.

It appears, however, on further consideration, that the matter is not quite as simple as the above would indicate, for it so happens that an abundance of lime salts was always present in the New York Aquarium circulation. The tanks themselves are for most part concrete, lined with tufa rock and bedded with coral sand. Calcium is also added to the system by way of the foods.[5] Consequently it is inferred that the improvement in general health and longevity, noted by Breder and Howley, 1931, is a measure of the difference between the calcium and sodium treatments rather than a measure of the difference between sodium and no treatment at all. It is doubtful, to the writer, if an aquarium such as the New York institution, could endure for any length of time if it were not for this unintentional introduction of Ca.

The behavior of the fishes transferred to fresh water merits some consideration in this connection. Although they were active and ate normally, their peculiar reaction to shock was entirely unexpected. Most of the deaths were actually seen taking place by one or another observer. On quiet approach to the tank all would appear to be well with the fishes, but a smart blow on the tank would invariably cause one or more to go into a convulsion. This consisted of disorganized swimming movements in which the equilibrium would be upset alternating with rapid quivering of the entire fish. The mouth would open spasmodically to its full extent and seem to lock in that position. Recovery would usually take place within an hour or death would ensue in a few minutes. It would seem that this effect was most likely induced indirectly by the great dilution of the body fluids coupled with the relatively high, but absolutely low, concentration of calcium. A study of this is out of the present province but the physiological processes involved should be of interest.

Although in the field nothing peculiar about the seined fishes was noted, it is unlikely that under such conditions, with the catches half buried in soft mud, anything of this sort would have been observed. Also it may be that the behavior is only a passing condition of newly introduced specimens. It may be pointed out, however, that for laboratory purposes this fact works against any practical application in which the use of lime might be involved.

As the saturation point of Ca is lower in fresh than in sea water, it follows that the experimental fishes were actually suffering from a calcium deficiency. The behavior on shock was consequently not unlike that described for higher animals.

[5] It may be noted in this connection that in all "balanced" fresh water aquaria so far examined there is a distinct increase in the calcium content with age.

Discussion

The data concerning the conditions obtaining in Lake Forsyth suggest items in the establishment of fresh water environment. Starting with coral formations projecting through the surface of a tropical sea and entirely disconnected with any continental or other land, the fauna, as well as the flora, establishing itself must necessarily come from either of two sources. Species may be transported over the intervening ocean or may be evolved from intruding marine forms.

Considering the Bahamas generally, it is clear that the herpetological fauna has been established by the chance oversea transport of relatively few species that since gave rise to a considerable number of slightly differentiated endemic forms. This view is given by Dunn, 1932, in a consideration of the origin of the Greater Antilles fauna, and certainly a similar condition is apparent in the Lesser. The mammals present an essentially similar picture and the birds, with their ready means of self transportation, a normal condition for them. This may likewise be argued, with the appropriate variations, for all of the terrestrial invertebrates as well as the flora. The aquatic forms of life adjacent to these shores are of course all marine and typically West Indian.

With these two conditions it appears that the terrestrial fauna and flora are established to about their present limit of abundance, on such an alkaline soil. As pointed out earlier, most of the Bahamas are too small to support any considerable amount of fresh water for a number of reasons. They are low and not infrequently flooded by storms; the surface drainage is small although rainfall is abundant, and the lack of a deep soil does not encourage the collection of pools. For this reason, so far as known, waters are all salt or at best brackish, on even such large islands as Great Inagua and Great Abaco. In Table II, sample 11 serves as an example of one of the lakes on New Providence. The invasion of such waters by sea fishes is not remarkable and occurs regularly when there are no obstacles of other kinds. A similar invasion occurs even when the water is distinctly fresh, as on Andros Island, which is possible because of its large calcium content. Marine invertebrates in general do not share this adaptability with the fishes. Broadly considered the macroscopic marine invertebrates are peculiarly susceptible to slight chemical changes in sea water, as anyone associated with an aquarium operated on a closed circulation can testify. Consequently it is not surprising to find the invertebrates in Lake Forsyth to be chiefly insects with considerable powers of flight such as dragon-flies, and fresh water snails such as *Physa* (See Pilsbry, 1930). This condition is likewise true of the aquatic plants, no strictly marine forms being encountered. Only the peculiar brackish and hardwater *Batophora* was found by the writer. *Utricularia* and *Sagittaria* have been reported from other islands in brackish water (Coker, 1905). It is evident that the fishes, for most part, invaded directly from the sea. This is excepting the cyprinodonts and the gobies, whose distribution throughout the West Indies follows fairly closely the brackish shores of all islands, extending well into both salt and fresh water when the latter is present at all. Most of these fishes are notoriously resistant to even rapid changes from fresh to salt, or vice versa.

While it is a fact that sea fishes on occasion will enter rivers for a greater or lesser distance, there is not ordinarily any such influx, on the seaboard of the United States at least, to a point where the salinity is as low as that of Lake Forsyth. For rather extensive data on this, see Hildebrand and Schroeder, 1928. Another locality that has an extensive invasion of marine fishes is the Tuyra basin of eastern Panama, with which the writer is familiar. This drainage to a large extent runs through limestone. No studies were made of its water chemistry but there certainly must be a considerable amount of calcium present, although of course not nearly as great as in the Bahamas. In regard to this, in describing the habitat, Breder, 1927, states: "The upper reaches, above the effect of tide, are bottomed chiefly by a soft, decomposing, calcareous rock." All other streams that have been examined in their lower reaches by the writer show a practically negligible calcium content. Sea fishes do not enter to a notable degree and then only for brief excursions. This is making allowance for the frequently disregarded overriding of fresh water on a bottom layer of salt at extreme high tide which may extend a considerable distance inland.

An examination of the rivers of the world, considering the intrusion of marine fishes with regard to their calcium content, should be illuminating. The present studies suggest that the amount of invasion of this sort may vary directly with the quantity of Ca present.

The conditions on Andros Island are suggestive of the next step in the development of an insular fauna. To further such establishment a slow rising of the land with the consequent increase both in area and altitude would go far to the development of a fresh water habitat. A detailed comparison with a similar but comparatively high oceanic island should be highly instructive.

Summary

1. The Lake Forsyth region of Andros Island supports only a relatively poor fauna of terrestrial vertebrates.

2. The lake itself, which is fresh water, supports a considerable fish fauna (12 species), all of which are marine types.

3. The main food chain traces back clearly to the heavy flooring of the algae *Batophora.*

4. Marine invertebrates have not invaded this fresh water to any extent, the few invertebrates present being mostly fresh water types.

5. The presence of marine fishes may be accounted for by their ability to withstand fresh water in which a sufficient amount of calcium is present.

6. Lake Forsyth may be considered as representing a "new" fresh water environment in which invading forms are just commencing to establish themselves.

7. Various gradations from this condition backward to purely marine conditions are represented in other Bahama Islands, Andros Island representing the most advanced position chiefly because of its greater drainage area.

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