LABORATORY OBSERVATIONS ON CERTAIN MOSQUITO LARVAL PREDATORS

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Introduction. Studies on the role of mosquito predators have been undertaken by a number of workers. Baldwin *et al.*, (1955) pointed out that many of the investigations were confined to studies in laboratory aquaria and he was rather critical because "these environments create conditions such as crowding, absence of prey shelter, and lack of alternative prey, which prevent an analysis of predation in terms of field conditions."

The purpose of the present experiments was not to correlate the laboratory findings with what is actually going on in nature, but to observe the feeding behavior of several kinds of predators under laboratory conditions.

Materials and Methods. Egg rafts of *Culiseta incidens* Thomson were collected in Alum Rock Park in San Jose, California, and reared in the laboratories of San Jose State College. The method of larval rearing introduced by McLintock (1952) was adapted. Larvae and pupae thus reared were used in most of the experiments, but specimens collected in the field were also utilized occasionally.

For laboratory observation and experimentation the larvae were kept in round finger-bowls 7 inches in diameter and 2½ inches deep, filled with 500 milliliters of tap water. Each bowl was covered with a piece of window glass so that pellicle formation would be at a minimum.

Into each bowl a "potential predator" collected in the field was placed with a known number of mosquito larvae or pupae, and observations were made every day at the same hour. The number of mosquito larvae or pupae consumed by each predator was recorded daily and, in addition, detailed observations of the behavior of the predators were recorded.

No control was needed for these experiments, for specimens were either eaten or not, and obviously in a "control" bowl none would be eaten. The mosquito larvae or pupae that disappeared, or were torn apart, during each test period were assumed to have been consumed or attacked by the predators. Dead larvae or pupae that were not mutilated were not tabulated because it is likely that death might have been due to other factors.

An attempt was also made to see whether in the absence of light the predators would be equally capable of catching their prey. This was done simply by placing the bowls in a completely dark environment (i.e., covered with a black plastic sheet).

The experiments were conducted at room temperature (70° to 81° F.), from March to May of 1965 and from April to May, 1966.

Observations and Discussion. The behavior and effectiveness of each experimental predator was noted carefully, and each is discussed separately in the following paragraphs. The data are summarized in Tables 1 to 3.

California Newts (*Taricha torosa* Rathke). The immature California newt has been reported to feed on many aquatic insects, including mosquito larvae (Stebbins, 1951). In the present study, it was found to be a very efficient predator. It devoured all the animals that were available to it, including mosquito larvae and pupae, damselfly naiads, tadpoles and even smaller members of its own species. The number of mosquito larvae destroyed, however, seemed to depend upon the size of both the predator and the prey, the

TABLE 1.—Feeding efficiency of various predators based on observations made in 1965. (Roman numerals indicate mosquito larval instars)

Predators *	No. Days Observed	No. Larvae or Pupae Put in	No. Larvae or Pupae Consumed
Taricha torosa	33	25 I	25 I
		50 II	50 II
		156 III	123 III
		209 IV	134 IV
		23 pupae	15 pupae
T. torosa	62 (died)	50 I	49 I
		25 II	25 II
		10 III	10 III
		44 IV	34 IV
		8 pupae	6 pupae
		1 damselfly naiad	1 damselfly naiad
		1 *T. torosa* (smaller)	1 *T. torosa*
		3 tadpoles	3 tadpoles
Dytiscus marginicollis (large larva; 4.8 cm. long)	14 (died)	21 IV	12 IV
		11 pupae	3 pupae
D. marginicollis (large larva; 4.7 cm. long)	11 (died)	21 IV	12 IV
		5 pupae	5 pupae
Rhantus sp.	15 (died)	30 III	22 III
		33 IV	6 IV
		5 pupae	0 pupae
Rhantus sp.	4	21 II	12 II
		17 pupae	8 pupae
Rhantus sp. (2 specimens)	4 (died)	50 II	43 II
		47 III	4 III
Tramea lacerata	12 (died)	15 III	10 III
		80 IV	47 IV
T. lacerata	5	45 III	29 III
		30 IV	21 IV
T. lacerata	5	39 III	20 III
		36 IV	14 IV
Anax junius	29 (died)	25 I	13 I
		40 II	30 II
		5 III	5 III
		12 IV	12 IV
		20 pupae	13 pupae
		1 damselfly naiad	1 damselfly naiad
		1 small newt larva	1 small newt larva
Libellula comanche	15 (died)	33 IV	15 IV
		14 pupae	8 pupae
Notonecta shooterii	40 (died)	19 IV	17 IV
		35 pupae	32 pupae
N. undulata	8	142 IV	130 IV
N. undulata	8	93 III	62 III
		65 IV	46 IV
N. undulata	26	25 II	18 II
		91 III	79 III
		270 IV	201 IV
		21 pupae	15 pupae
Abedus indentatus	56	73 III	73 III
		125 IV	122 IV
		10 pupae	10 pupae

* Common names: *Taricha torosa*, California newt. *Dytiscus*, *Rhantus*, diving beetles. *Tramea*, *Anax*, *Libellula*, dragonflies. *Notonecta*, backswimmer. *Abedus*, giant waterbug.

abundance of the prey, and the state of hunger of the predator.

Analysis of data obtained in 1966 seemed to indicate that as the larvae increase in size, more of them are consumed by the newt (see Table 2). One of these predators after 24 hours of starvation devoured five 4th instar larvae in 8 minutes. Usually, the newt did not search for prey, but waited until some unfortunate smaller animal came near its mouth, then it slightly jerked its head and suddenly snapped at the victim. While swimming around in the bowl the predator quite often bumped into objects. If it thus contacted either a live mosquito larva or some non-living particle resembling a larva, its reaction followed the same snapping pattern. When the newt made a "strike" it rarely missed the target. It was interesting to find that the feeding activity of these predators is not significantly altered by darkness.

DYTISCID BEETLES—IMMATURE. Dytiscid beetles, both larvae and adults, are known to be predaceous (James, 1961, 1965). In the present study the larvae of *Dytiscus marginicollis* LeConte and *Rhantus* sp. were observed. An interesting observation was made concerning the vicious nature of these dytiscid larvae. When two larvae of *D. marginicollis* were placed together, one attacked and killed the other in a few minutes. In another instance, after one larva killed another, the victor also soon died. This was possibly due to the poisonous nature of dytiscid saliva (Lorenz, 1952). This same phenomenon was observed with larvae of *Rhantus*. The feeding behavior of dytiscid larvae was excellently described by Lorenz (1952), who said: "The animal lies in ambush. . . .; suddenly it shoots at lightning speed towards its prey, darts underneath it, then quickly jerks its head and grabs the victim in its jaws." The observations made by the present writer correspond remarkably well with those of that famous naturalist.

D. marginicollis larvae are considerably larger than those of *Rhantus*. The former appeared to be more efficient in catching the third and fourth instar mosquito larvae than in catching the first and second instars, while the latter seemed quite successful in capturing all instars. As the data in Table 2 show, large larvae of *D. marginicollis* failed to catch any of the early instar larvae, but the medium-sized one did somewhat better. It is possible that the larger the mandibles of the predator, the more difficult it is to catch early instar mosquito larvae.

Darkness apparently had no effect on the feeding habits of these predaceous diving beetle larvae.

DRAGONFLIES—IMMATURE. Three different species of dragonfly naiads, *Anax junius* Drury, *Libellula comanche* Calvert and *Tramea lacerata* Hagen, were studied. Two main types of predatory behavior of dragonfly naiads have been described by Walker (1953) and by Pritchard (1965), namely, the "climbers" and the "sprawlers." Climbers actively pursue their prey. They "perceive the movements of animals much smaller than themselves at a distance of several inches, and stalk their prey with stealthy, cat-like motion, stopping whenever the movement ceases, and thus advancing gradually until within striking distance." Sprawlers, on the other hand, "are much more sluggish, and even when hungry will make no attempt to strike at their prey until it comes within reach of the extended labium." As Pritchard pointed out, the climbers detect their prey by sight while the sprawlers rely upon tactile stimulation. Careful observations made by the present author indicate that *Anax junius* may fit the "climber" category, while *Libellula comanche* and *Tramea lacerata* seem to be "sprawlers."

It was observed that *Anax* naiads often devour their prey very rapidly, but *Libellula comanche* and *Tramea lacerata* only open their mouths after mosquito larvae or pupae have accidentally bumped into their head or labium. A small damselfly naiad was eaten by one *Anax junius* within a minute and later five 4th instar

TABLE 2.—Feeding efficiency of various predators based on observations made in 1966.

Predators	No. Days Observed	No. Larvae or Pupae Put in	No. Larvae or Pupae Consumed
Taricha torosa	41	80 I	15 I
		40 II	15 II
		160 III	119 III
		499 IV	314 IV
		34 pupae	0 pupae
Dytiscus marginicollis (large larva, 5.2 cm. long)	10 (died)	40 I	0 I
		80 II	80 II
		100 III	14 III
		70 IV	42 IV
D. marginicollis (medium larva, 3.7 cm. long)	21 (died)	60 I	3 I
		60 II	9 II
		120 III	60 III
		175 IV	101 IV
		25 pupae	5 pupae
Tramea lacerata	14 (died)	60 I	36 I
		60 II	53 II
		80 III	29 III
		80 IV	14 IV
Lestes * *congener*	17 (died)	55 I	44 I
		65 II	62 II
		130 III	82 III
		74 IV	30 IV
		30 pupae	1 pupa
Notonecta shooterii	46	60 I	48 I
		60 II	56 II
		289 III	249 III
		581 IV	464 IV
		7 pupae	2 pupae
N. shooterii (with some green algae in the bowl)	46	60 I	7 I
		60 II	20 II
		222 III	152 III
		515 IV	152 IV
		25 pupae	0 pupae

* *Lestes*, damselfly.

mosquito larvae were consumed in 8 minutes (the first one was eaten in about 9 seconds!). When three pupae were offered to the same naiad, they were all devoured within 30 seconds. A California newt was placed in the bowl and it was eaten by the naiad on the next day.

It was found that *Tramea lacerata* captured prey in complete darkness, but it has not yet been determined if *Anax junius* and *Libellula comanche* naiads will feed in the absence of light.

DAMSELFLIES—IMMATURE. Damselfly naiads have been previously reported to prey upon mosquito larvae and pupae (Hinman, 1934). In the present study, *Lestes congener* Hagen was observed. Its predatory behavior was very similar to the "climber" category of dragonfly naiads. However, while the damselfly naiads seem proficient in catching the first, second, and third instar mosquito larvae, they are less proficient in catching fourth instars and pupae. Since the fourth instar is the final mosquito larval stage and is larger than any other instars, it is reasonable to assume that fewer of them are needed to satiate the appetite of a predator. The mosquito pupae, by virtue of their violent and rapid tumbling action, may frequently be able to escape capture by damselfly naiads.

BACKSWIMMERS—NYMPHS AND ADULTS. Backswimmers have also been known to prey on mosquito larvae and pupae, as well as many other small insects (Hinman, 1934). In the present study, two species were observed as predators of mosquito larvae. Members of the species *Notonecta shooterii* Uhler and *N. undulata* Say made strikes with amazing accuracy and tremendous speed whenever they "sighted" the prey. Since the bugs possess sucking mouth parts, they feed only by sucking out the body fluids of the mosquito larvae, leaving the head capsules and exoskeletons behind.

Carthy (1965), reported that the vibrations caused in the water by swimming insects attract *Notonecta* to its victim, "which it locates by means of sensory hairs on its outstretched oar-like legs. Orientating itself to receive equal stimulation on the two sides the bug swims directly to the prey."

The results obtained in the present research indicated that the backswimmers, both adults and nymphs, were able to catch some of the first instar mosquito larvae, but the rate of capture increased when older instars of mosquito larvae were available (Table 2).

It was interesting to note that a single backswimmer (*N. shooterii*) in a bowl by itself showed a greater prey-consuming rate than did any of those in another bowl where three backswimmers were placed at the same time. It might have been expected that, as the abundance of predators increased there would be a corresponding increase in the number of mosquito larvae destroyed. The observations, however, showed the contrary to be true, and this requires an explanation. It was often noticed that when two or three backswimmers were put together they tended to cling to one another, more or less assuming a "mating" position. It is possible that in the presence of two or more backswimmers, particularly when one is a female, there are behavioral changes directed toward sexual preoccupation rather than feeding activities.

It was also noticed that the number of mosquito larvae consumed by a backswimmer nymph was reduced considerably during the molting period of the predator. However, the predation was resumed as soon as the molting process was completed.

As compared with other predators, backswimmers appeared to be exceptionally successful in catching mosquito pupae. It is very likely that their lightning speed of attack is largely responsible for this success.

It should be mentioned also that adding algae to the bowl appeared to provide considerable protection to the mosquito larvae (see Tables 2 and 3). It was also observed that as more and more pieces of algae were removed from the bowl the number of mosquito larvae devoured seemed to increase steadily.

Placing the backswimmers and their potential prey in total darkness seemed to have no effect at all on the feeding rate.

Giant Water Bugs—Adults and Nymphs. Giant water bugs are known to be the masters of their immediate environment. They have been reported to feed on a variety of insects as well as on tadpoles and fish (Usinger, 1956). In the present study, *Abedus indentatus* Haldeman was found to be an exceptionally efficient predator. The manner of feeding on mosquito larvae is somewhat similar to that of the backswimmers, since both kinds of predators possess sucking mouth parts. However, since giant water bugs are relatively large insects, it is no surprise that they eat more. Usually 10 to 20 immature mosquitoes (third or fourth instar larvae) were destroyed within 24 hours. Because of its enormous size, the movement of this predator is usually somewhat sluggish. However, whenever it makes a strike at a victim, its accuracy was comparable to that of the backswimmers.

Conclusions. The number of immature mosquitoes consumed by predators depends upon several factors, including the following: the kind of predators; the size of the predators; the size of the prey; the state of hunger and the activity of the predators; and probably many other factors.

It is difficult to conduct this sort of ex-

TABLE 3.—Feeding efficiency in normal laboratory condition compared with that in dark condition (1966).

Predators	Normal Illumination: No. Larvae Put in	Normal Illumination: No. Larvae Consumed	Total Darkness: No. Larvae Put in	Total Darkness: No. Larvae Consumed
T. torosa	20 II	6 II	20 II	11 II
	40 III	30 III	40 III	17 III
D. marginicollis (medium larvae)	40 III	23 III	40 III	17 III
D. marginicollis (large larvae)	20 II	0 II	20 II	0 II
	20 IV	15 IV	20 IV	17 IV
T. lacerata	20 II	18 II	20 II	19 II
	40 III	2 III	40 III	27 III
L. congener	20 II	19 II	20 II	16 II
	40 III	39 III	40 III	27 III
N. shooterii	20 II	18 II	20 II	20 II
	60 III	60 III	60 III	59 III
N. shooterii (with some algae in the bowl)	40 II	17 II	20 II	9 II
	50 III	40 III	40 III	27 III

periment over an extended period of time, due to the fact that certain predators such as immature dragonflies, damselflies and dytiscid beetles cannot survive in the laboratory very well as they are approaching pupation or maturity, for in nature these insects require certain environmental conditions in order to complete their growth. Dragonfly and damselfly naiads normally climb upon standing aquatic plants, rocks, logs or tree trunks in order to secure a position some distance from water before they emerge (Walker, 1953). Dytiscid mature larvae crawl up the shore and burrow in a suitable spot to form a pupal chamber, or tunnel into the mud near the water line (Usinger, 1956). Certain other predators, such as immature California newts, backswimmers and giant water bugs, seemed to be able to survive in the laboratory condition for one or more months.

Predators such as immature California newts, the diving beetle *Rhantus* larvae, dragonfly and damselfly naiads, backswimmers and giant water bugs appeared to feed on all instars of mosquito larvae. Large larvae of *D. marginicollis,* however seemed to prefer later instars as their source of food, and this is probably related to the size of the mandibles of the predators.

Mosquito pupae are less likely than larvae to be devoured by predators because of their rapid tumbling action when startled.

Darkness did not significantly affect the feeding activity of the predators that were observed. The exact mechanism for detection of prey by the predators under this condition was not determined. However, tactile stimulation may assume an important role.

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SEASONAL VARIATIONS IN THE SUSCEPTIBILITY OF *CULEX PIPIENS PIPIENS* L. TO DDT AND DIELDRIN

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Resistance to DDT in mosquitoes was first discovered in the *Culex pipiens* complex (Mosna, 1947; Missiroli, 1947), but although several workers have investigated the susceptibilities of the larvae to various insecticides (Brown, Armstrong and Peterson, 1954; Burbutis and Davis, 1955; Hamon, Grjebine, Coz, Klein and Michel, 1959) very little information exists on the insecticide susceptibility of adult *C. pipiens pipiens* L. Apart from the work of Kuhlow and Garms (1964), there have been no investigations into any possible seasonal variations in the susceptibility of this species, although Lachmajer (1962) considered hibernating adults in Poland to be DDT resistant.

Davidson (1964) concluded that the normal susceptibility of *C. pipiens* var. *molestus* Forsk. and various strains of *C. p. fatigans* Wied. to DDT and dieldrin was similar, and Busvine (1965) considered that both these forms and *C. p. pipiens* have approximately the same susceptibilities. Furthermore, a comparison of the susceptibility of *C. p.* var. *pallens* Coquillett to DDT and dieldrin (Yasutomi, 1962) with published results for the above three forms, suggests that this species can also be included in this category. It is therefore appropriate to compare the susceptibilities of these species with those found for *C. p. pipiens* in the present investigations.

METHODS. Hibernating adults of *C. p. pipiens* used in the trials were collected monthly from September 1964 to March 1965 from a variety of dark and damp brick-work shelters on Brownsea Island, which is situated in Poole Harbour, Dorset, southern England. Adults were

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