MOSQUITO LARVAL DEVELOPMENT IN CONTAINER HABITATS: THE ROLE OF ROTTING *SCIRPUS CALIFORNICUS*

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Larvae of *Culex tarsalis* Coquillett and *Culiseta inornata* Williston are abundant in duck ponds within the San Joaquin freshwater marsh. *Culex tarsalis* are found year-round and *Culiseta inornata* are found during the winter months. Each duck pond has an area of open water ringed with emergent *Scirpus californicus* (bulrush) and *Typha latifolia* and *Typha angustifolia* (cattails). Low densities of larvae are found in the areas of emergent vegetation, with species composition changing with season. The ponds dry seasonally and the emergent vegetation lodges and forms rafts of decaying vegetation when the ponds are reflooded. In these rafts, larval densities can be quite high.

Rafts of decaying *Scirpus* are common in the leeward corners of the duck ponds and provide good larval habitats, with larval densities reaching 40 per dip with a mean value of 12 per dip (n = 17 sites) (Bradley et al. 1986). In manipulative field experiments, we were able to increase larval densities of unproductive corners of two duck ponds by introducing rafts of decaying *Scirpus*.

Our ponds are stocked with *Gambusia affinis*, which reproduce and build up sizeable populations in summer and fall. The high densities of mosquito larvae found in the rotting *Scirpus* mats may reflect a failure of mosquitofish to achieve control in this microhabitat. An analogous effect of abundant aquatic vegetation on control by *Gambusia* has been observed for *Anopheles occidentalis* Dyar and Knab larvae by sago pondweed (*Potamogeton*) (Collins et al. 1983, Collins and Resh 1984, Feminella and Resh 1986). Schaefer and Miura (1985), found high densities of *Culex spp.* and *Aedes melanimon* Dyar in a habitat similar to our duck ponds, i.e., ponds containing lodged *Typha*.

This study examined the reasons mosquito larvae are found in greater abundance in decaying *Scirpus* mats than in open water. Previous work in similar habitats, as well as our own observations, suggests that *Scirpus* mats provide a refuge from mosquitofish predation. This is a difficult hypothesis to test by field observations. We designed an experiment using containerized field habitats to specifically test this hypothesis.

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An alternate explanation for larval success in the decaying *Scirpus* is that it provides a source of nutrients for the developing mosquito larvae. The experimental design also allowed us to test this second hypothesis.

Replicate experimental units were produced by placing six wooden palettes in the water at the inner edge of the border of emergent *Scirpus* in one of the duck ponds. Four clear, plastic five-gallon (18.9-liter) drums were placed on each palette. Each drum was filled with sieved pond water. Since the clear drums were partially immersed in the ponds among the emergent vegetation, the containers resembled the pond habitat with respect to temperature and light levels. A layer of rinsed, decaying *Scirpus* was introduced into two of the four containers per palette. Fifty field-captured 3rd and 4th instar mosquito larvae (*Culex tarsalis* and *Culiseta inornata* in naturally occurring proportions) were then introduced into each container. Finally, *Gambusia* were introduced into half of the drums (4 per container). The result was that each palette held a random array of four treatments: (1) control—mosquito larvae only; (2) plants—mosquito larvae and *Scirpus*; (3) plants and fish—mosquito larvae with *Scirpus* and *Gambusia*; and (4) fish—mosquito larvae with *Gambusia* only.

Each container was covered with a net mounted on a conical frame to trap emerging adults. Successfully emerged adults were counted and removed four times a week. The experiment was conducted with six palettes in October 1986, and repeated in late November using five palettes, giving a total of 11 replicates. To eliminate the effect of palette location and time of year on mosquito emergence, data were analyzed by within palette comparisons using a nonparametric test.

Emergence success was selected as an indicator of habitat suitability. In the October experiment (Fig. 1A), no mosquitoes emerged from containers with fish in the absence of plants. In the containers with plants, fish failed to consume all of the mosquito larvae, indicating that rotting *Scirpus* affords some protection from mosquitofish predation. This protection is incomplete as can be seen by comparing the number of adults emerging from containers with fish and plants with the number emerging from control containers. Control containers had only mosquito larvae and repeatedly produced more

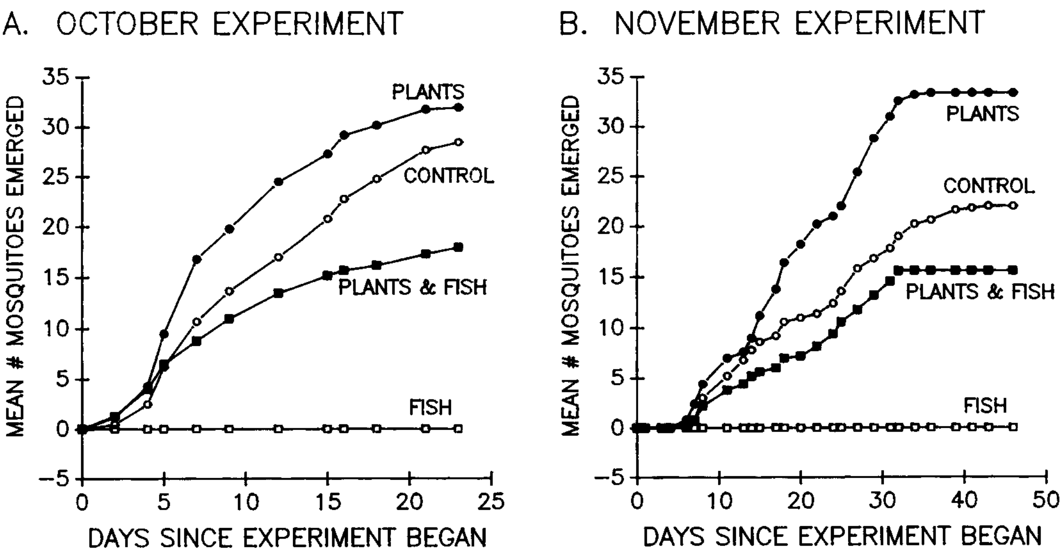

Fig. 1. The influence of decaying *Scirpus californicus* and *Gambusia affinis* on mosquito emergence success. Fig. 1A reports mean values for 6 replicates per treatment; Fig. 1B means are for 5 replicates per treatment. The mean number of mosquitoes emerging is based on a maximum possible of 50.

adult mosquitoes than did containers with *Gambusia* and *Scirpus*. In addition to interfering with fish predation, *Scirpus* mats contribute some other factor which enhances emergence success as evidenced by plant treatment containers, which produced more adult mosquitoes than did control containers. When the experiment was repeated in November, the pattern among treatments was identical with that in the first trial (Fig. 1B). We subjected our data to statistical analysis using pairwise tests to compare treatments within palettes for all 11 palettes. These were tested for significance using the Wilcoxon matched-pairs signed-ranks tests (Siegel 1956). Emergence success with plants alone was greater than success in both the control treatment ($P < 0.025$) and the plants and fish treatment ($P < 0.01$). Emergence success in containers where fish were present without plants was less than in containers with neither fish nor plants (control, $P < 0.001$) and less than in containers with both fish and plants ($P < 0.001$).

A second indication of habitat suitability is development time. The mean time to emergence was measured for each treatment on each palette (Fig. 2). Palettes 1–6 were run in October, palettes 7–11 in November. The effects of cooler temperatures in November are clearly evident in the extended development times of the mosquitoes. Within treatment dates, it took larvae in the absence of plants one to two days longer to emerge than in the presence of plants. This difference was significant both in the presence and absence of fish. Larvae in the plant and fish treatment took the same length of time to

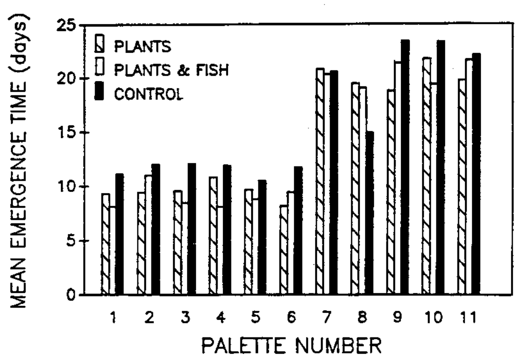

Fig. 2. The influence of decaying *Scirpus californicus* and *Gambusia affinis* on time to emergence for 3rd and 4th instar larvae. Palettes 1–6 were from the October experiment, palettes 7–11 were from November.

emerge as did those with plants only. Sign tests (Siegel 1956) were used to test the significance of the following comparisons of mean emergence times:

1. plants < control — $P = 0.03$
2. plants & fish < control — $P = 0.07$
3. plants = plants & fish — $P = 0.55$

These experiments allow us to conclude several things about the role of rotting *Scirpus* in mosquito larval development and its interaction with mosquitofish predation in our container habitats.

In the absence of plants as a prey refuge, mosquitofish predation was 100% effective. The four mosquitofish present quickly eliminated all of the mosquito larvae. In the presence of a floating *Scirpus* layer, predation was less effective than in the absence of *Scirpus*. When fish and plants were both present, emergence success was significantly less (approximately half) than with plants alone, indicating some predation occurred in the presence of vegetation although it was far from complete. Presumably, the plants physically interfered with fish predation.

Decaying *Scirpus* resulted in a significantly higher percentage of larvae emerging even in the absence of fish predation. This effect, which is independent of the effect of vegetation on fish predation, may be due to enhanced nutrition for developing larvae or to some factor linked to the physical structure provided by the *Scirpus*, e.g. by providing a platform for adult emergence (Marshall and Staley 1932). In a field enclosure experiment examining the effect of pondweed on *Anopheles occidentalis* larvae, Orr and Resh (1987) found that larval survival was greater with pondweed than without, even when there were no *Gambusia* in the enclosures. They attribute this result to pondweed as either a source of nutrients or as a refuge from adverse effects of physical disturbance.

Both in the presence and absence of *Gambusia*, mosquito development is faster with *Scirpus* than without. One explanation for our results is that the decaying *Scirpus* may provide nutrients to the developing larvae, thus speeding up the development process. Another possible explanation is that decaying *Scirpus* may raise water temperature; this would also speed up development. In our experiments, the presence or absence of fish does not appear to affect development rate. Nayar (1967, 1968) showed that improved nutrition speeds development in fourth instar larvae and pupae of *Aedes taeniorhynchus* Wiedemann and in pupae of *Culex nigropalpus* Theobald.

In summary, decaying *Scirpus* appears to enhance mosquito larval survival, development and emergence success. It directly increases survival by interfering with fish predation. Its effects on development rate and emergence success may be due to nutrients and/or physical structure it affords mosquito larvae and emerging adults. These hypotheses require further testing. Our results have important implications for control of mosquito larvae in field situations. Integrated pest management of mosquitoes in similar habitats should include removal of dead and lodged vegetation.

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