AN EVALUATION OF THE MOSQUITOFISH, GAMBUSIA AFFinis, AND THE INLAND SILVERSIDE, MENIDIA BERRYLLINA, AS MOSQUITO CONTROL AGENTS IN CALIFORNIA WILD RICE FIELDS

VICKI L. KRAMER,1 RICHARD GARCIA1 AND ARTHUR E. COLWELL2

ABSTRACT. The mosquitofish, Gambusia affinis, and the inland silverside, Menidia beryllina, were evaluated in experimental, one-hectare wild rice plots in Lake County, California, for their impact on densities of Culex tarsalis, Anopheles freeborni and Anopheles franciscanus. Gambusia affinis were tested at 0.6 and 1.7 kg/ha and the silversides at ca. 0.9 kg/ha. The silversides did not survive well in the rice field system and none of the silverside guts examined contained mosquito larvae. The mosquitofish increased steadily throughout the season and mosquito larvae were found in 9% of the fish dissected. Analysis of variance did not reveal significant differences among the mosquito populations in the 3 fish treatments and controls on any sampling date. More than 40 species of aquatic insects were collected and population densities of selected aquatic insects were similar in the 4 treatments.

INTRODUCTION

Lake County, California, is a relatively new rice growing region; wild rice (Zizania palustris Linn.) was first cultivated in 1981 and acreage has expanded from 160 to more than 300 hectares in 1986 (Tomkins 1987). Wild rice is grown from May through October, providing a breeding habitat for mosquitoes during the warm summer months. Since the onset of wild rice cultivation in Lake County, populations of Culex tarsalis Coquillett, Anopheles freeborni Atkken and Anopheles franciscanus McCracken have increased (Colwell, unpublished data).

Gambusia affinis (Baird and Girard), the mosquitofish, has been shown by several researchers (Craven and Steelman 1968, Hoy and Reed 1970, 1971; Hoy et al. 1971) to be an effective mosquito control agent in white rice (Oryza sativa Linn.) fields, but little is known about the effectiveness of G. affinis in wild rice fields. Wild and white rice plants have several differences that could affect the control potential of G. affinis. In California, for instance, wild rice requires 90 days to mature whereas white rice requires approximately 150; thus an additional 60 days are available for the fish population to increase in the white rice. The rice plants also differ physically; wild rice reaches a height of up to 3 meters and has a much fuller canopy than the shorter white rice, which grows to approximately 1 meter. Herbicides and insecticides are rarely used in wild rice fields, whereas in white rice both herbicides and insecticides are applied, generally at the beginning of the growing season.

Besides G. affinis, another fish common to Lake County is the inland silverside, Menidia beryllina (Cope). The inland silverside has been shown to effectively control mosquito larvae in laboratory and small, semi-natural field trials in Florida (Middaugh et al. 1985). However, silversides have never been tested in a rice habitat where conditions such as light intensity, vegetation and water depth may differ from previously studied lentic habitats.

This study was designed to evaluate the mosquito control efficacy of G. affinis and M. beryllina in Lake County wild rice fields. Since wild rice is a relatively new habitat in Lake County, a survey of the aquatic insect fauna was necessary. An additional objective of the study was to evaluate the impact of the fish on the major aquatic insect groups.

MATERIALS AND METHODS

In 1986 the Lake County Mosquito Abatement District (MAD) constructed 18 one-hectare (quarter-acre) rice plots approximately 3 km south of Upper Lake, California. The study site was adjacent to commercial wild rice farms and shared with them a common water source from Clear Lake. These first-year experimental rice plots had separate inflow valves and outlet boxes to prevent the mixing of water among fields. A series of screens at the main water inlet to the pump and cloth bags (0.5 mm mesh) on the inflow pipes served as barriers to unwanted fish. The plots were seeded on June 13 using a seed broadcaster attached to an all-terrain vehicle.

Fields were randomly assigned one of 4 treatments: no fish, 0.6 or 1.7 kg/ha (0.5 or 1.0 lbs/acre) of G. affinis, or ca. 0.9 kg/ha (0.5 lbs/acre) of silversides. (These mosquitofish release rates are substantially greater than the 0.2 lbs/acre commonly used by the mosquito abatement districts in the Sacramento Valley for mosquito control in white rice fields [Combs 1986]). There were 5 replicates of each of the first 3 treatments and 3 silverside replicates.

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GAMBUSIA AFFINIS IN WILD RICE FIELDS

DECEMBER 1987

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METHODS

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The rice plots had an average water depth of
15 cm. The average minimum water temperature
during the rice-growing season was 21°C and the
maximum, 30°C. Maximum plant height was
approximately 2.8 m. These measurements ap-
proximate those found in commercial wild rice
fields in Lake County.

Although high rates of silverside reproduction
have been noted in nearby Clear Lake (Moyle
1976), conditions in the wild rice fields ap-
parently were not suitable for survival and repro-
duction. After a small, initial increase, the sil-
verside population dropped to a count of only
0.5 fish per trap at preharvest (Fig. 1).

The G. affinis increased steadily throughout
the season to a maximum of 20 fish/trap in the
0.6 kg/ha fields and 76 fish/trap at 1.7 kg/ha
(Fig. 1). Mosquitofish caught in the minnow
traps ranged from 15 to 52 mm standard length.
Migration from the fields was minimal with an
average of less than 2 fish/day recovered from
the outflow bag of each field. The water from
one 1.7 kg/ha field was drained just prior to
harvest and approximately 7,600 mosquitofish
(ca. 32 kg/ha) were recovered, a density of 10
fish per square meter. In this field, an average
of 143 G. affinis were caught per trap when eight
traps were set just prior to drainage. The number
of fish caught per trap therefore represented
about 2% of the total fish population in the field
(approximately 2,400 fish, including fry, males,
and mature females, equaled 1 kilogram).

Throughout most of the growing season, the
immature mosquito population levels were ap-
parently very similar in both the control and G.
affinis treated fields (Fig. 2). The greatest diver-
gence between treatments was on the final sam-
ing date with mosquito populations of 2.7, 2.3,
and 1.3 larvae/dip in the control, 0.6 and 1.7 kg/
ha fields respectively. However, these sampling
points, as well as all others throughout the sea-
son, were not significantly different (P > 0.05).

The age structure and species composition of
the mosquito populations were also similar be-
 tween the treatments.

Mean number of larvae/dip on July 24, August
6, and August 26 equaled 2.8, 2.7 and 5.9 (range

![Fig. 1. Gambusia affinis and Menidia beryllina populations in wild rice fields, Lake County, California, 1986.](image-url)
of field means: 0.6-4.5, 0.7-5.4, 1.8-8.9). The within group variances of the immature mosquito populations (field interior dips, average of all fields combined) on these dates were 5.58, 7.18, and 13.53 respectively. Mosquito larvae showed a clumped distribution in the rice field interiors since population variances greatly exceeded the means (Pielou 1977).

A variety of organisms was found in the 110 mosquitofish guts examined. Zooplankton only were found in 55% of the fish guts, zooplankton and insects (or snails) in 27%, insects only in 1%, and 17% of the mosquitofish had empty guts. Cladocerans (primarily Ceriodaphnia, Chydorus and Bosmina) were the most abundant zooplankton; ostracods and copepods were also found. Larval mosquitoes were found in 10 (9%) of the fish (standard fish length ranged from 17 to 35 mm and included 9 female and 1 male fish). Twenty-three anophelines (3 first, 7 second, 6 third, and 4 fourth instar) and 7 culicines (5 first, 1 second, 1 third, and 0 fourth instar) were identified. The proportion of culicines to anophelines found in the fish guts (23:77) was similar to that found in the fields by dipping (13:87) in mid-August. Five of the fish had ingested just one mosquito larva; the rest ingested either 2, 4, 5, 6 or 8 larvae. All of the fish guts containing mosquito larvae had zooplankton and 6 contained other insects. Prey size selection was not correlated with fish size; first instar larvae were found in the guts of fish ranging from 21 to 35 mm (standard length) and fourth instars in fish 17 to 32 mm. Other studies have, however, found a positive correlation between prey size selection and fish size (Farley 1980, Wurtsbaugh et al. 1980). Chironomids were found in 19 mosquitofish (range of 1-4 per fish, mean of 1.5 per fish, total ingested = 29). Gut contents also included 13 hydrophilids, 9 phyid snails, 4 homopterans, 3 odonates, 3 ephemeropters and 1 hydricarinia.

No mosquito larvae were found in the guts of the 18 silversides dissected. They fed primarily on cladocerans and ostracods. Two chironomids, one hydrophilid and one corixid were also found in the silverside guts.

The Cx. tarsalis larvae showed an initial population peak in mid-July and a second smaller peak at the end of August (Fig. 3). The late stage (third and fourth) culicines however were more abundant in late August than mid-July. The larval anopheline population was composed of approximately 60% An. freeborni and 40% An. franciscanus. The peak anopheline count was at the end of August. Larval populations in the interior of the fields were overall somewhat greater than the perimeter dip counts, although...
Table 1. Aquatic insects collected from Lake County, California wild rice fields.

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Genus and species</th>
<th>Life stage collected¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diptera</td>
<td>Ephydridae</td>
<td>Brachydeutera argenteata (Walker)</td>
<td>L, P</td>
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<tr>
<td></td>
<td>Tabanidae</td>
<td>unidentified</td>
<td>L</td>
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<td></td>
<td>Stratomyiidae</td>
<td>Odontomyia or Hedriociclus sp.</td>
<td>L, P</td>
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<td></td>
<td>Culicidae</td>
<td>Anopheles freeborni Aitken</td>
<td>L, P, A (reared)</td>
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<td></td>
<td></td>
<td>Anopheles franciscanus McCracken</td>
<td>L, P, A (reared)</td>
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<td></td>
<td></td>
<td>Culex tarsalis Coquillet</td>
<td>L, P, A (reared)</td>
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<td></td>
<td></td>
<td>Culex peus Speiser</td>
<td>L, P, A (reared)</td>
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<td></td>
<td></td>
<td>Chironomus sp.</td>
<td>L</td>
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<tr>
<td></td>
<td></td>
<td>several unidentified species</td>
<td>L</td>
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<tr>
<td>Coleoptera</td>
<td>Ceratopogonidae</td>
<td>Dasyhelea sp.</td>
<td>L, P, A (reared)</td>
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<td></td>
<td>Tipulidae</td>
<td>Tipula sp.</td>
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<td></td>
<td>Elmidae</td>
<td>Zaitzevia parvula Horn</td>
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<td></td>
<td>Hydrophilidae</td>
<td>Tropisternus lateralis (Fabricius)</td>
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<td>Tropisternus ellipticus (Le Conte)</td>
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<td>Hydrophilus triangularis Say</td>
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<td></td>
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<td>Berosus punctatissimus Le Conte</td>
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<td>Paracyamus subexpexus (Say)</td>
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<td></td>
<td></td>
<td>Enochrus sp.</td>
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<td></td>
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<td>Laccobius sp.</td>
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<td></td>
<td></td>
<td>Helophorus sp.</td>
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<td></td>
<td>Dytiscidae</td>
<td>Laccophilus decipiens Le Conte</td>
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<td>Laccophilus atristernalis Crotch</td>
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<td></td>
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<td>Liodessus affinis (Say)</td>
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<td></td>
<td></td>
<td>Thermonectes basilaris (Harris)</td>
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<td>Rhantus hoppingi (Wallis)</td>
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<td>Agabus approximatus Fall</td>
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<td>Deronectes striatellus (Le Conte)</td>
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<td>Deronectes exigius (Motschusky)</td>
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<td>Trichoptera</td>
<td>Halipdidae</td>
<td>Laccophilus decipiens Le Conte</td>
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<td>Hydropsychidae</td>
<td>Hydropsyche sp.</td>
<td>L, P</td>
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<td>Mesoveliidae</td>
<td>Mesovelia fulvani White</td>
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<td></td>
<td>Hebrididae</td>
<td>Merragata hebroids White</td>
<td>N, A</td>
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<td></td>
<td>Gerridae</td>
<td>Limnopus notabilis Drake &amp; Hottes</td>
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<td>Gelastocoridae</td>
<td>Gerra incognitus Drake &amp; Hottes</td>
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<td>Belostomatidae</td>
<td>Gelastocoris oculatus (Fabricius)</td>
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<td>Notonectidae</td>
<td>Gelastocoris oculatus (Fabricius)</td>
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<td></td>
<td>Notonecta undulata Say</td>
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<td></td>
<td>Buena scimitra Bare</td>
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<td>Cordisidae</td>
<td>Corisella decor Uhler</td>
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<td>Odonata</td>
<td>Aeshnidae</td>
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<td>Aeshnidae</td>
<td>Anax junius (Drury)</td>
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<td>Libellulidae</td>
<td>Pantala hynemenae (Say)</td>
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<td></td>
<td>Coenagrionida</td>
<td>Sympetrum corruptum (Hagen)</td>
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<td>Ephemeroptera</td>
<td>Enallagma carunculatum Morse</td>
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<td>Baetidae</td>
<td>Ischnura sp.</td>
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<td></td>
<td>Siphlonuridae</td>
<td>Calilaetus sp.</td>
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</table>

¹List includes specimens from commercial wild rice farms and the experimental plots. Specimens identified by Dave Woodward, Lake County MAD.

²N = nymph, L = larva, P = pupa, A = adult.

The differences were not significant (Student's t-test, P > 0.05).

The seasonal abundance of female mosquitoes in the light trap collections appears in Figure 4. The Cx. tarsalis light trap collection showed two peaks; the July peak (118 females/trap night) was about half the August peak (210 females/trap night). The An. franciscanus collection peak (150 females/trap night) was in early August, 2 weeks prior to the An. freeborni peak (285 females/trap night). In white rice fields in the Sacramento Valley, An. franciscanus also emerges earlier and in lower numbers than An. freeborni (Bohart and Washino 1978). The num-
ber of males of each species was usually low (<10% of the total catch) except in late August, when the Cx. tarsalis males increased sharply and briefly, outnumbering the females collected. Other species collected by the light trap included Culiseta inornata (Williston), Cs. incidunt (Thomson), Aedes melanimon (Dyar) and Cx. erythrothorax (Dyar). Nearby breeding sources, such as commercial wild rice fields and irrigation ditches, undoubtedly contributed to the light trap counts.

More than 40 species of aquatic insects were collected from the wild rice fields by trapping and by dipping (Table 1). The most numerous insects collected by the minnow traps were notonectids, hydrophilid adults and dytiscid adults (Fig. 6). Hydrophilid larvae, dytiscid larvae, damselflies, mayflies and corixids were more effectively sampled by dipping than minnow trapping (Fig. 6). Belostomatids and dragonflies were collected in low numbers by both trapping systems. No significant differences were found during the course of the growing season between any aquatic insect population density in G. affinis-treated and control fields (Figs. 5 and 6).

Other studies (Farley and Younce 1977, Miura et al. 1984) have found that G. affinis (0.2-0.25 lbs/acre) significantly reduced populations of notonectids, damselflies and mayflies, in white rice fields. Although fish were stocked at higher rates in the wild rice fields than in the white rice field studies, the shorter growing season for wild versus white rice may not have allowed the fish population to build up enough significantly affect the aquatic insect populations.

In conclusion, we do not recommend M. beryllina as a mosquito control agent for wild rice fields because this fish did not survive well in the rice field system. Gambusia affinis thrived in the Lake County wild rice fields but did not substantially affect mosquito populations under the conditions of this study. This may have been due in part to the omnivorous feeding nature of G. affinis as demonstrated by our gut analysis data and other studies (Miura et al. 1979, Farley 1980), and the large availability of alternative prey in the wild rice fields. The physical structure of the wild rice plant (large basal stem and extensive tillering near base) may also have impeded the movement of the fish and provided refuge for the mosquito larvae. Finally, the short growing season may not have allowed the fish population to become great enough to have an impact on the mosquito larval population. The divergence of the mosquito populations among the G. affinis-treated and control fields, at the end of the growing season, although not significant statistically, perhaps indicated the beginning of an effect. In California white rice fields, where G. affinis has been shown to effectively control mosquito larvae (Hoy and Reed 1970, 1971), mosquito densities are typically much lower (Lemenger and Kaufman 1986) than in Lake County wild rice fields. Thus, higher release rates of G. affinis, although impractical for many mosquito control agencies, may be necessary for mosquito control in wild rice fields.

Fig. 5. Population densities of (A) notonectids, (B) hydrophilid adults and (C) dytiscid adults (number per minnow trap) in Gambusia affinis-treated and control wild rice fields, Lake County, California (control — 0.6 kg/ha G. affinis — — — — — — — 1.7 kg/ha G. affinis — — — — — — —).

Fig. 6. Population (B) corixids (number per 200 dips) — California (control — — — — — — —)

ACKNOW

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Fig. 6. Population densities of (a) hydrophilid larvae, (b) dytiscid larvae, (c) damselflies, (d) mayflies and (e) corixids (number per 200 dips) in Gambusia affinis-treated and control wild rice fields, Lake County, California (control —, 0.6 kg/ha G. affinis — —, 1.7 kg/ha G. affinis — —).


The research active effort between Experiment Station, Mississippi a USDA, CSRS, Soil Biology, Ecology of Rice in the South USDA, ARS, Rice Research Laboratory 33604.

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