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

VICKI L. KRAMER,[1] RICHARD GARCIA[1] AND ARTHUR E. COLWELL[2]

ABSTRACT. The mosquitofish, *Gambusia affinis*, and the inland silverside, *Menidia beryllina*, were evaluated in experimental, one-tenth 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 among 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 (Tompkins 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tarsalis* Coquillett, *Anopheles freeborni* Aitken and *Anopheles franciscanus* McCracken have increased (Colwell, unpublished data).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 abut 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 is 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-tenth 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 1.5 lbs/acre) of *G. affinis*, or ca. 0.9 kg/ha (0.8 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.

---

[1] Division of Biological Control, University of California, Berkeley, CA 94706.

[2] Lake County Mosquito Abatement District, 410 Esplanade, Lakeport, CA 95453.

Gambusia affinis were collected from the Lake County MAD fish ponds, weighed and released into the selected plots on July 3. Silversides are easily killed if not handled carefully (Moyle 1976). Therefore, the fish were seined from Clear Lake, from early to mid-July, in the early morning to avoid heat stress, transported in aerated containers, and counted during release into the fields, all within 30 minutes. A portion of the fish in each field was retained in live cars to determine survivorship after 24 hours. Approximately 700-1,000 fish (0.7-1.0 kg/ha) survived the release in each rice field (23% mortality).

The larval mosquitoes and other aquatic insects were monitored on a weekly basis by taking 5 standard (400 ml) dips at each of 8 stations positioned around the perimeter of each plot (40 dips/plot). Twenty dips were taken along a transect through the interior of each plot every second week. Dip samples were concentrated in a fine mesh (0.5 mm) net and the contents identified and counted in the laboratory. Once in July and twice in August, the individual dip counts from the interior of the field were recorded before the mosquito larvae were concentrated, to provide information on variation among dips. Adult mosquito densities were monitored with a New Jersey light trap (Mulhern 1942).

Three minnow traps (3.2 mm mesh) were set overnight in each field on a biweekly basis to monitor the fish and invertebrate predator populations. On one occasion, just prior to harvest (September 20), eight traps were set per field. The fish, insects, and other organisms from all minnow traps were counted, identified, and returned to their original trapping location. On August 14, a subsample of the mosquitofish (110) and all of the silversides (18) trapped from each fish-treated plot were frozen for later gut analyses. Large (2 m^3) bags (1.3 mm mesh) were fastened to the outlet boxes to monitor fish migration from the fields. Water temperature, water depth, and plant height were measured throughout the season.

One-way analysis of variance and Tukey's test (for pairwise comparisons, $P = 0.05$) were used to detect differences in the immature mosquito and other aquatic insect populations among the 4 treatments.

RESULTS AND DISCUSSION

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 approximate 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 apparently were not suitable for survival and reproduction. After a small, initial increase, the silverside 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 apparently very similar in both the control and *G. affinis* treated fields (Fig. 2). The greatest divergence between treatments was on the final sampling date with mosquito populations of 2.7, 2.3, and 1.8 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 season, were not significantly different ($P > 0.05$). The age structure and species composition of the mosquito populations were also similar between the treatments.

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

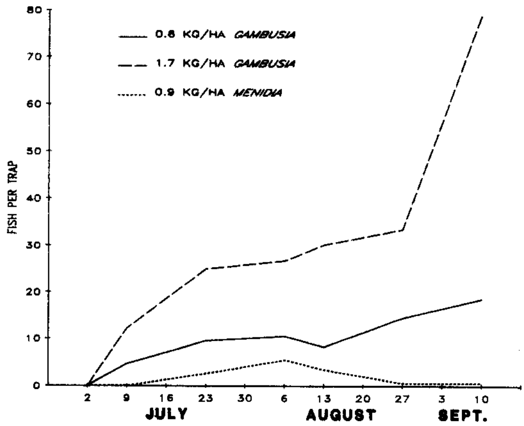

Fig. 1. *Gambusia affinis* and *Menidia beryllina* populations in wild rice fields, Lake County, California, 1986.

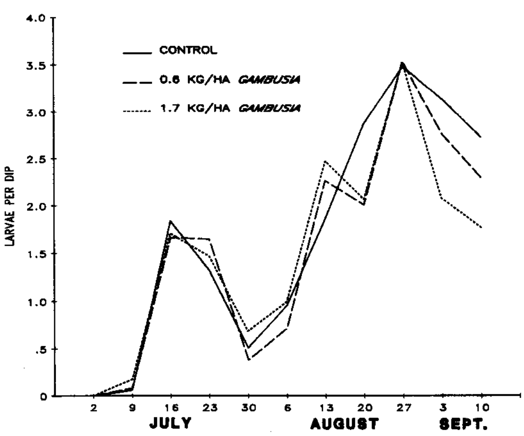

Fig. 2. Mosquito larval populations in *Gambusia affinis*-treated and control wild rice fields, Lake County, California, 1986.

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 13.52 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 physid snails, 4 homopterans, 3 odonates, 3 ephemeropterans and 1 hydracarina.

No mosquito larvae were found in the gut contents 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

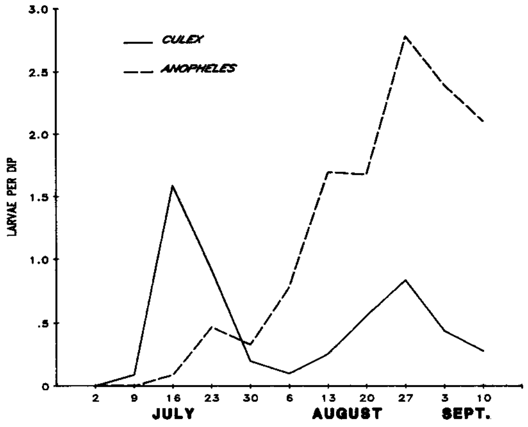

Fig. 3. Larval populations of *Culex* and *Anopheles* in wild rice fields, Lake County, California, 1986 (data are for all fields combined).

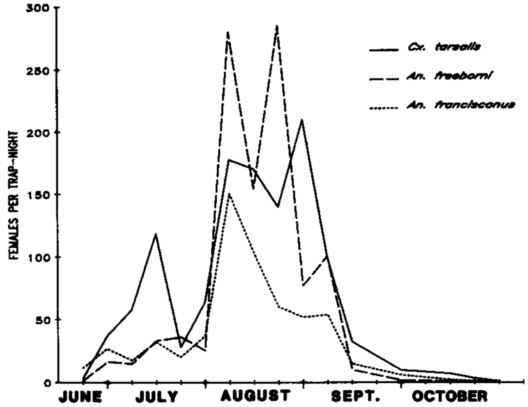

Fig. 4. Light trap counts of *Culex tarsalis, Anopheles freeborni* and *An. franciscanus* females adjacent to wild rice fields, Lake County, California, 1986 (fields drained September 15).

Table 1. Aquatic insects collected from Lake County, California wild rice fields.[1]

Order	Family	Genus and species	Life stage collected[2]
Diptera	Ephydridae	*Brachydeutera argentata* (Walker)	L, P
	Tabanidae	unidentified	L
	Stratiomyidae	*Odontomyia* or *Hedriodiscus* sp.	L, P
	Culicidae	*Anopheles freeborni* Aitken	L, P, A (reared)
		Anopheles franciscanus McCracken	L, P, A (reared)
		Culex tarsalis Coquillett	L, P, A (reared)
		Culex peus Speiser	L, P, A (reared)
	Chironomidae	*Chironomus* sp.	L
		several unidentified species	L
	Ceratopogonidae	*Dasyhelea* sp.	L, P, A (reared)
	Tipulidae	*Tipula* sp.	L
Coleoptera	Elmidae	*Zaitzevia parvula* Horn	A
	Hydrophilidae	*Tropisternus lateralis* (Fabricius)	L, A
		Tropisternus ellipticus (Le Conte)	A
		Hydrophilus triangularis Say	L, A
		Berosus punctatissimus Le Conte	A
		Paracymus subcupreus (Say)	A
		Enochrus sp.	A
		Laccobius sp.	A
		Helophorus sp.	A
	Dytiscidae	*Laccophilus decipiens* Le Conte	A
		Laccophilus atristernalis Crotch	A
		Liodessus affinis (Say)	A
		Thermonectes bassilaris (Harris)	A
		Rhantus hoppingi (Wallis)	A
		Agabus approximatus Fall	A
		Deronectes striatellus (Le Conte)	A
		Deronectes eximius (Motschulsky)	A
	Haliplidae	*Peltodytes callosus* (Le Conte)	A
Trichoptera	Hydropsychidae	*Hydropsyche* sp.	L, P
Hemiptera	Mesoveliidae	*Mesovelia mulsanti* White	N, A
	Hebridae	*Merragata hebroides* White	N, A
	Gerridae	*Limnoporus notabilis* Drake & Hottes	A
		Gerris incognitus Drake & Hottes	A, N
		Gerris incurvatus Drake & Hottes	A, N
	Gelastocoridae	*Gelastocoris oculatus* (Fabricius)	A
	Belostomatidae	*Belostoma flumineum* Say	N, A
	Notonectidae	*Notonecta unifasciata* Guerin	N, A
		Notonecta undulata Say	N, A
		Buenoa scimitra Bare	N, A
	Corixidae	*Corisella decolor* Uhler	N, A
		Hesperocorixa laevigata (Uhler)	N, A
Odonata	Aeshnidae	*Anax junius* (Drury)	N
	Libellulidae	*Pantala hymenaea* (Say)	N
		Sympetrum corruptum (Hagen)	N
	Coenagrionidae	*Enallagma carunculatum* Morse	N
		Ischnura sp.	N
Ephemeroptera	Baetidae	*Callibaetis* sp.	N
	Siphlonuridae	*Siphlonuris spectabilis* Traver	N

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

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

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 number 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. incidens* (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. 5). 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 refugia 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 (Lemenager 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.

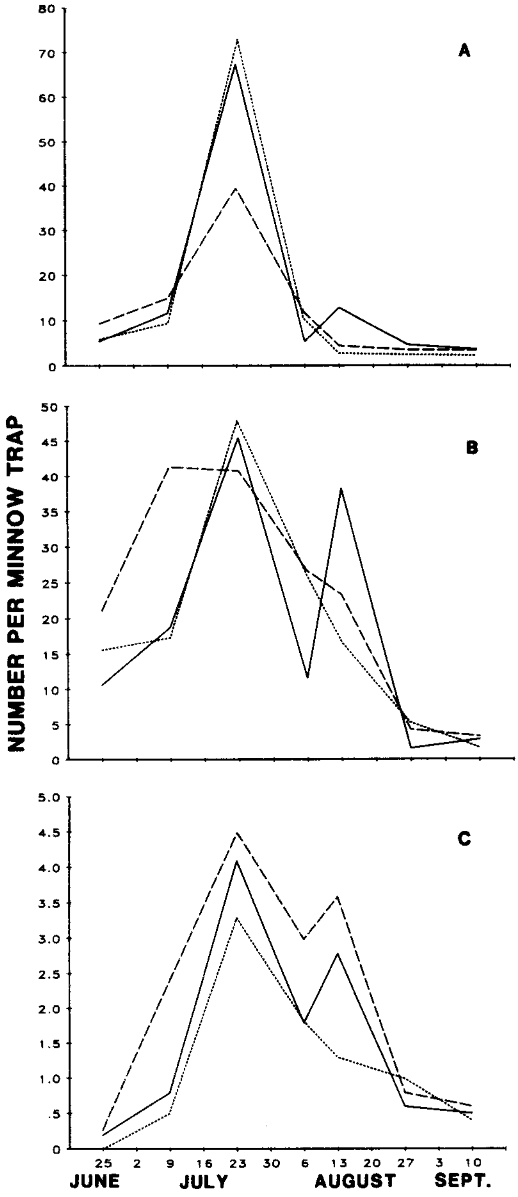

Fig. 5. Population densities of (A) notonectids, (B) hydrophilid adults and (C) dytiscid adults (number per minnow trap) in *Gambusia affinis*-treated and control wild rice fields, Lake County, California (control ——, 0.6 kg/ha *G. affinis* – – –, 1.7 kg/ha *G. affinis* · · · ·).

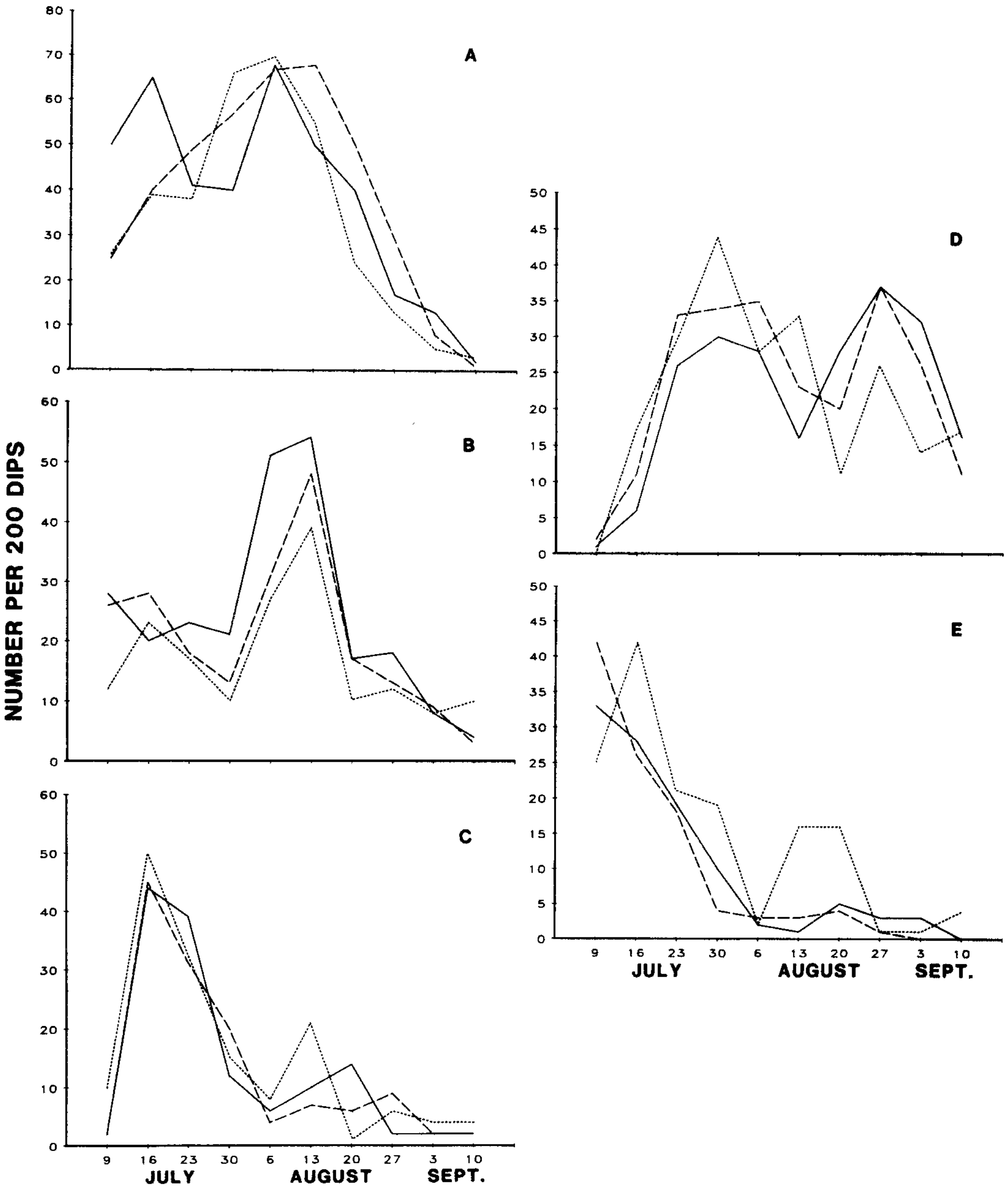

Fig. 6. Population densities of (A) hydrophilid larvae, (B) dytiscid larvae, (C) damselflies, (D) mayflies and (E) corixids (number per 200 dips) in *Gambusia affinis*-treated and control wild rice fields, Lake County, California (control ——, 0.6 kg/ha *G. affinis* - - -, 1.7 kg/ha *G. affinis* · · · ·).

ACKNOWLEDGMENTS

This study was supported in part by special state funds for mosquito research in California. We thank David Woodward, Norman Anderson, Bill Davidson, Therese Nelson, Anthony Arroyo and William Voigt for their assistance and cooperation.

REFERENCES CITED

Bohart, R. M. and R. K. Washino. 1978. Mosquitoes of California, Univ. of Calif. Press, Publ. 4084, 153 pp.

Combs, J. C. (Ed.). 1986. California Mosquito and Vector Control Association Yearbook. CMVCA Press, pp. 32–33.

Craven, B. R. and C. S. Steelman. 1968. Studies on a biological and chemical method of controlling the dark rice field mosquito in Louisiana. J. Econ. Entomol. 61:1333–1336.

Farley, D. G. 1980. Prey selection by the mosquitofish *Gambusia affinis* in Fresno County rice fields. Proc. Calif. Mosq. and Vector Control Assoc. 48:51–54.

Farley, D. G. and L. C. Younce. 1977. Effects of *Gambusia affinis* (Baird and Girard) on selected non-target organisms in Fresno County rice fields. Proc. Calif. Mosq. and Vector Control Assoc. 45: 87–94.

Hoy, J. B. and D. E. Reed. 1970. Biological control of *Culex tarsalis* in a California rice field. Mosq. News 30:222–230.

Hoy, J. B. and D. E. Reed. 1971. The efficacy of mosquitofish for control of *Culex tarsalis* in California rice fields. Mosq. News 31:567–572.

Hoy, J. B., A. G. O'Berg and E. E. Kaufman. 1971. The mosquitofish as a biological control agent against *Culex tarsalis* and *Anopheles freeborni* in Sacramento Valley rice fields. Mosq. News 31:146–152.

Lemenager, D. C. and E. E. Kaufman. 1986. Abundance and distribution of immature *Culex tarsalis* and *Anopheles freeborni* in rice fields of the Sutter-Yuba M.A.D.: Follow-up sampling to detect similarities in larval distribution, 1984 vs. 1985. Proc. Calif. Mosq. Vector Control Assoc. 54:123–128.

Middaugh, D. P., P. G. Hester, M. V. Meisch and P. M. Stark. 1985. Preliminary data on use of the inland silverside, *Menidia beryllina*, to control mosquito larvae. J. Am. Mosq. Control Assoc. 1:435–441.

Miura, T., R. M. Takashi and R. J. Stewart. 1979. Habitat and food selection by the mosquitofish *Gambusia affinis*. Proc. Calif. Mosq. Vector Control Assoc. 47:46–50.

Miura, T., R. M. Takahashi and W. H. Wilder. 1984. Impact of the mosquitofish (*Gambusia affinis*) on a rice field ecosystem when used as a mosquito control agent. Mosq. News 44:510–517.

Moyle, P. B. 1976. Inland fishes of California. Univ. of Calif. Press, Berkeley. 405 pp.

Mulhern, T. D. 1942. New Jersey mechanical trap for mosquito surveys. New Jersey Agric. Exp. Stn. Circ. 421:1–8.

Pielou, E. C. 1977. Mathematical ecology. John Wiley and Sons, Inc., NY. 385 pp.

Tompkins, D. 1987. Lake County Agricultural Crop Report. Depart. Food and Agriculture, Lakeport. 5 pp.

Wurtsbaugh, W., J. J. Cech, Jr. and J. Compton. 1980. Effect of fish size on prey selection on *Gambusia affinis*. Proc. Calif. Mosq. Vector Control Assoc. 48:48–51.