THE INFLUENCE OF VEGETATION AND MOSQUITOFISH ON *CULEX TARSALIS* ABUNDANCE IN DUCK CLUB PONDS IN SOUTHERN CALIFORNIA

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ABSTRACT

The effectiveness of current mosquito abatement measures using mosquitofish was evaluated in two 1.8 ha duck club ponds in the Coachella Valley of southern California. The effects of *Gambusia* stocked at current operational densities (1.4 kg/ha), vegetation, and their interaction, were studied in 16 m^2 enclosures. As compared to non-vegetated plots, *Culex tarsalis* larval populations were considerably larger in plots that contained dense vegetative growth only along the pond perimeter, or both perimeter vegetation and dense stands of emergent vegetation in the pond interior. Mosquitofish stocked during the late summer and early autumn at 1.4 kg/ha did not significantly reduce mosquito larval populations in duck club plots. Concurrent studies in 36 m^2 ponds yielded equivalent results. *Culex tarsalis* larval abundance in ponds without fish did not differ significantly from that in ponds where *Gambusia* was stocked at 1 kg/ha. However, larval abundance in ponds containing mosquitofish stocked at the extremely high density of 4 kg/ha differed significantly from those in the control (without fish) and 1 kg/ha *Gambusia* treatments.

The interactions among the chronology of pond inundation, seasonal reproduction cycles of mosquitofish, natural sources of mosquitofish mortality, varying degrees of vegetation and water management, and reduced access of MAD personnel to mosquito developmental sites, complicate mosquito control efforts in duck club ponds. Mosquitofish populations in typical duck club ponds are subject to factors (predacious birds, thermally-stressful conditions, and, probably, low food abundance) that reduce survivorship and recruitment.

Introduction.

Duck club ponds in southern California have been identified as important developmental sites for *Culex tarsalis* Coquillett (Durso and Burguin 1988) and several other mosquito species. In the Coachella Valley, several thousand acres bordering on the northern end of the Salton Sea are flooded annually for recreational duck hunting. U.S. Fish and Wildlife regulations currently permit California duck clubs to provide supplemental forage to migrating waterfowl. Under these regulations, duck club managers stock small, peripheral ponds with additional forage and maintain large expanses of relatively open water on which ducks alight after foraging.

The duck ponds are disked in mid-summer and flooded during late August. Water is pumped into the ponds from wells, enters each pond via dropboxes, and flooding is completed after four to six weeks. If supplemental forage is provided, regulations stipulate that ponds must be kept full of water through approximately mid-January. In most ponds, water persists through mid-March.

Vegetation management practices differ among the duck clubs. Whereas the pond interiors are typically disked, the vegetation along the perimeter dikes is either removed or cut. When cut, the cuttings are left in place and inundated as the ponds are flooded. In those duck clubs where the perimeter vegetation is not removed, or where thick emergent vegetation develops (usually in the first pond flooded) ponds support large populations of mosquito larvae .

The prevailing method of mosquito abatement is to stock the ponds with the mosquitofish, *Gambusia affinis* (Baird and Girard), at initial densities approximating 1.4 kg/ha. Additional control measures utilizing insecticides are sometimes necessary, but are often difficult to carry out because access to the ponds is restricted during duck hunting season.

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Despite the stocking of mosquitofish, large numbers of adult mosquitoes are trapped in the vicinity of duck clubs (Durso and Burguin 1988). The effectiveness of current mosquito abatement measures using mosquitofish was studied during 1988 by examining the effects of *Gambusia* stocked at current operational densities (1.4 kg/ha), vegetation control, and the interaction between these two factors on mosquito larval populations inhabiting duck club ponds.

Materials and Methods.

The effects of vegetation and *Gambusia* on *Cx. tarsalis* larval abundance were studied in 16 m^2 enclosures. As flooding began during mid-August, three enclosures were positioned in each of two 1.8 ha ponds at the Adohr Valley Farms Duck Club in Mecca, California. Each enclosure was divided into four plots with partitions constructed of fiberglass window screening (approximately 7 openings/cm), buried in the bottom sediment, and supported by wooden stakes. Four treatments were randomized within three blocks (enclosures) in each pond: vegetation alone (V), non-vegetated alone (N), vegetation and *Gambusia* (FV), and non-vegetated and *Gambusia* (FN).

Interior vegetation in the N and FN plots was removed by hand and shoreline vegetation was removed with a shovel. A small amount of vegetation (approximately 0.5 m^2) was left along the partitions in the FN plots as a refuge for the fish, and in the N plots as a control for the FN vegetation. *Gambusia* adults were captured from a local pond after one week, weighed, and added to the appropriate plots.

The vegetation cover differed in the two ponds. One-quarter of the surface of Pond 1 was not disked and it supported a dense cover of grasses that was dominated by bearded sprangletop (*Leptochloa fascicularis* (Lam.)). The perimeter vegetation was primarily spikerush (*Eleocharis macrostachya* Britt.), with a thick growth of Bermuda (*Cynodon dactylon* (L.)), and saltgrass (*Distichlis spicata* (L.)). The enclosures in Pond 1 were situated within the dense vegetation. Pond 2 was typical of the remaining ponds in the duck club; the pond interior lacked emergent vegetation and the perimeter was surrounded by a dense growth of Bermuda and saltgrasses.

Mosquitoes, macroinvertebrates, and zooplankton were sampled with a 350 ml dipper. A stratified sampling procedure was followed in which three dips were taken (1) along the shore and (2) 3 m from the shore in each plot and in the pond adjacent to each block. The thick vegetation in Pond 1 precluded sampling by net. The enclosures were sampled weekly from late August through the start of duck hunting season in mid-October. The ponds were sampled once in late October after the enclosures had been removed. The contents of each set of 3 dips was combined, preserved in alcohol, identified and enumerated in the laboratory under a dissecting microscope. Mosquitofish in each plot were sampled every other week using a baited minnow trap that had been lined with window-screening. Water temperature was monitored with minimum-maximum thermometers.

The effects of fish, vegetation, and experimental manipulation (plots vs. pond) were compared for the Pond 1 data by a repeated measures ANOVA and linear contrasts. Because samples from plots through time were presumably autocorrelated, the effect of time (sample date) was removed from the main effects. Tests of this factor violate the assumptions of the ANOVA and are not reported here. To satisfy the assumptions of the ANOVA, counts from 1 m and 3 m strata were combined, log-transformed (count + 1), and analyzed for the entire larval population (1st though 4th instars). Because larvae were not captured in non-vegetated plots on 19 September, analyses were repeated after deleting this date from the data set (29 August through 10 October). The results reported did not change.

The mean and the variance of larval counts in the non-vegetated plots of Pond 2 were zero for most sampling dates, and parametric statistical analysis of these data was inappropriate. We compared the ranks of larval abundance in Pond 2 plots using Wilcoxon's Signed-Ranks tests. Larval counts in vegetated and nonvegetated plots were analyzed separately for each block and combined across blocks. Nominal values are provided in the discussion.

Results and Discussion.

Vegetation. The presence of emergent vegetation in the pond interiors and perimeter vegetation along the pond dikes significantly increased *Cx. tarsalis* larval populations as compared to non-vegetated plots. In Pond 1, mosquito larvae in vegetated plots were initially very abundant and declined between four and six weeks after the pond was flooded (Fig. 1a). This trend was similar to that observed for *Cx. tarsalis* larvae in ponds at the Aquatic and Vector Control Research Facility (Oasis, California) located approximately 3 km northwest of Adohr Valley Farms (Mulla 1986, 1989). The abundance of mosquito larvae in non-vegetated plots in Pond 1 was significantly lower than that in vegetated plots ($F_{1,8}$ = 24.85, p = 0.001).

The phenology of the larval population differed in Pond 2. As compared to vegetated plots in Pond 1, *Cx. tarsalis* larvae were less abundant from 29 August through 19 September (Fig. 1b). Larval abundance increased markedly between 19 and 26 September. After the enclosures were placed into the ponds, approximately two-thirds of the water entering the ponds during mid-August was diverted elsewhere. Whereas water levels in Pond 1 were reduced very little, water levels in Pond 2 declined to a point where the shoreline vegetation was barely inundated. On about 19 September, the majority of water was diverted again into Ponds 1 and 2 and the shoreline vegetation in Pond 2 was reinundated to pre-diversion levels. Rising water levels, which reinundated the shoreline vegetation, and the vegetation that developed during the 5-6 weeks since manipulations were made, increased the available larval habitat and, perhaps, preferred mosquito oviposition sites.

Culex tarsalis larvae were considerably more abundant in vegetated plots than in non-vegetated plots of Pond 2 (Blocks combined: T_S = 0, $p < 0.01$). Unlike the blocks in Pond 1, larval populations in the blocks of Pond 2 were markedly heterogeneous. Very few larvae were captured in the plots of one block (Block A). Larval counts in vegetated plots did not differ significantly from those in nonvegetated plots (Block A: T_S = 5.5, $p > 0.05$). However, in the other two blocks (Block B and C), *Cx. tarsalis* larvae were significantly more abundant in vegetated plots than in the non-vegetated plots (Block B: T_S = 0, $p < 0.01$; Block C: T_S = 0, $p < 0.01$).

The differences of vegetation cover among the blocks were congruous with the effects reported above. By 26 September, vegetation extended approximately 1.5 m from the shoreline into the vegetated plots in blocks B and C . As compared to the vegetated plots in blocks B and C, the vegetation in the V and FV plots of block A was less extensive and did not differ noticeably from adjacent non-vegetated plots.

<u>*Gambusia affinis.*</u> Mosquitofish stocked at 1.4 kg/ha did not significantly reduce *Cx. tarsalis* larval populations as compared to plots that lacked fish. For reasons given below, the effect of mosquitofish was tested only for plots in Pond 1. The effect of *Gambusia* was not significant ($F_{1,8}$ = 2.63, $p > 0.14$). Also, the fish by vegetation interaction ($F_{1,8}$ = 0.05, $p > 0.8$) and pond versus plot comparison ($F_{1,8}$ = 0.42, $p > 0.53$) were not significant.

Concurrent studies conducted at our Aquatic and Vector Control Research Facility, in which we examined the effects of mosquitofish stocking density (0, 1, and 4 kg/ha) on *Cx. tarsalis* yielded equivalent results (Walton and Mulla, unpublished data). During late August and September, mosquito larval abundance in mesocosms stocked with 1 kg/ha *G. affinis* did not differ significantly from that in mesocosms without fish. However, mosquito larval populations were reduced significantly when *Gambusia* was stocked at the extremely high density of 4 kg/ha. Interestingly, a similar study during the spring provided different results. As compared to non-fish controls, mosquito larval populations were reduced markedly and equally by mosquitofish stocked at 1 and 4 kg/ha (Walton et al. unpublished data).

We were unable to assess the effect of *Gambusia* in Pond 2 because the fish were eliminated from all plots. Mosquitofish probably were eliminated by predation and thermal stress. Ardeids (herons and egrets) were observed in large flocks in and around duck club ponds undergoing inundation. Prior to moving to newly flooded habitats, these predators were observed foraging in the enclosures and throughout both ponds. In addition to predation, the shallow water depths, reduced interior vegetation, and hot desert temperatures created thermally-stressful conditions for *Gambusia* (Fig. 2a). Maximum water temperatures during the period from 29 August through 12 September exceeded *Gambusia*'s thermal maximum (Castleberry and Cech, unpublished data). The denser vegetation cover and lower water temperatures in Pond 1 permitted some fish to survive and reproduce in all plots containing fish (Fig. 2b).

<u>General Discussion:</u> Current mosquito abatement methods using mosquitofish in duck clubs of the Coachella Valley are, at times, ineffec-

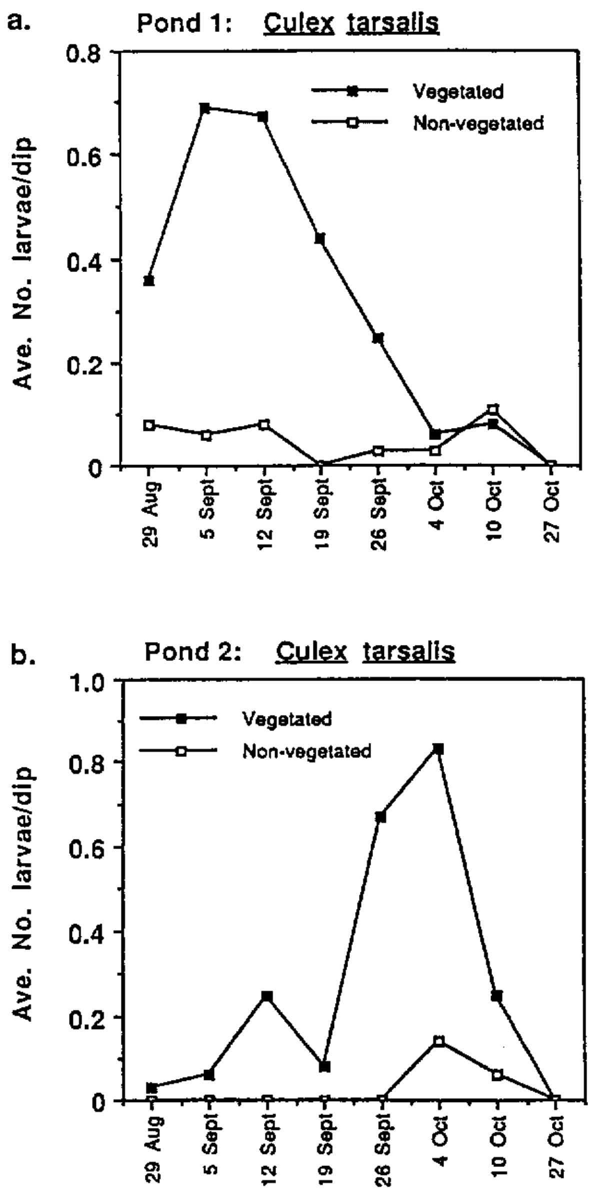

Figure 1.-Average abundances of *Cx. tarsalis* larvae in vegetated and non-vegetated plots in (a) Pond 1 and (b) Pond 2. Averages were computed after combining data from V and FV plots (vegetated) or N and F plots (non-vegetated).

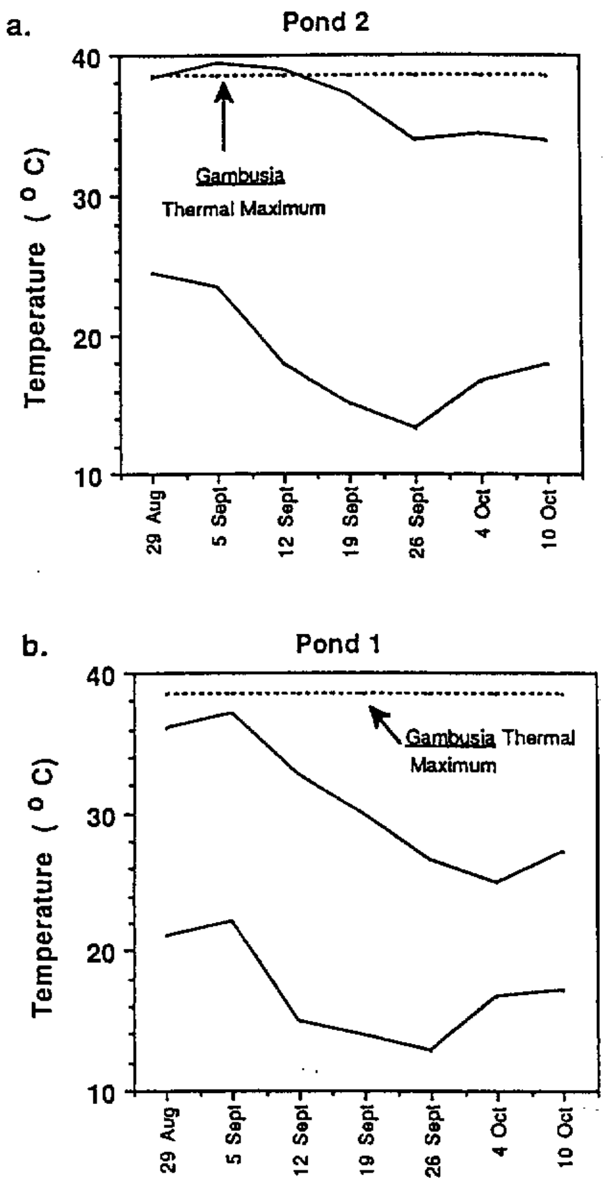

Figure 2.-The maximum and minimum water temperatures recorded in (a) Pond 2 and (b) Pond 1 during 1988. The broken line is the thermal maximum for *G. affinis* (Castleberry and Cech, unpublished data).

Table 1.-Percent of *Gambusia affinis* digestive tracts containing terrestrial or molluscan prey in three studies during 1988. n = sample size.

Study	Terrestrial	Snails	
U.C.R. Ponds (Spring):	3	0	(n=35)
U.C.R. Ponds (Fall):	36	0	(n=22)
Adohr Valley Farms:	62	35	(n=52)

tive or, at the least, complex. The interactions among the chronology of pond inundation, seasonal reproduction cycles of mosquitofish, natural sources of mosquitofish mortality, varying degrees of vegetation and water management, and reduced access of MAD personnel to mosquito developmental sites, complicate mosquito control efforts in duck club ponds.

Several factors reduce recruitment and survival of *Gambusia*. First, mosquitofish undergo a photoperiodically-induced reproductive decline during the autumn (Sawara 1974, Milton and Arthington 1983). This decline coincides with or precedes the time at which *Gambusia* are stocked into duck club ponds. Studies conducted at our Aquatic and Vector Control Research Facility in the Coachella Valley confirm that, during the fall, *Gambusia* stocking densities must be greater than would be required to achieve a comparable level of mosquito control during the spring or early summer.

Second, mosquitofish mortality is high in typical duck club ponds because of reduced vegetative cover and shallow water depth (approximately 22 to 30 cm). *Gambusia* succumb to predation by birds and to thermal stress where water temperatures approach 40°C. High water temperatures additionally must reduce mosquitofish reproduction (Coykendall 1980), and restrict fish to cooler microhabitats such as small stands of emergent vegetation or dense shoreline vegetation. In Pond 2, predation, thermal stress, and water diversions restricted the small, resident mosquitofish population to the dense emergent vegetation in one corner of the pond.

Third, aquatic macroinvertebrate abundance in duck club ponds, as compared to the 36 m^2 ponds at our Coachella Valley facility, is relatively low. Given the proximity of the duck club ponds to the Salton Sea and the salinity of the soil in the Coachella Valley, the macroinvertebrate fauna was dominated by halophilic and, presumably, more euryhaline species. Aquatic macroinvertebrate abundance in Pond 1 was 2 to 5 times lower than that observed in our Oasis ponds (Fig. 3a). In more typical duck club ponds, such as Pond 2, aquatic macroinvertebrates were even less abundant (Fig. 3b). Total aquatic macroinvertebrate abundance in Pond 2 was 10 to 18 times lower than that observed in the Oasis ponds.

Although aquatic macroinvertebrate abundance in duck club ponds was lower than that recorded in the Oasis ponds, zooplankton populations (cladocerans and ostracods) in the duck club ponds were larger than those in the Oasis ponds (Figs. 4a and 4b). During the four to five weeks after flooding, duck club zooplankton could differ from that in the Oasis ponds by more than an order of magnitude.

Whereas small-sized *Gambusia* were observed to feed primarily on zooplankton and chironomid midges, larger-sized *Gambusia* (> 1.5 cm standard length) in duck club ponds were incorporating terrestrial and molluscan (snails) prey into their diets. The proportion of *Gambusia* digestive tracts containing terrestrial or molluscan prey was

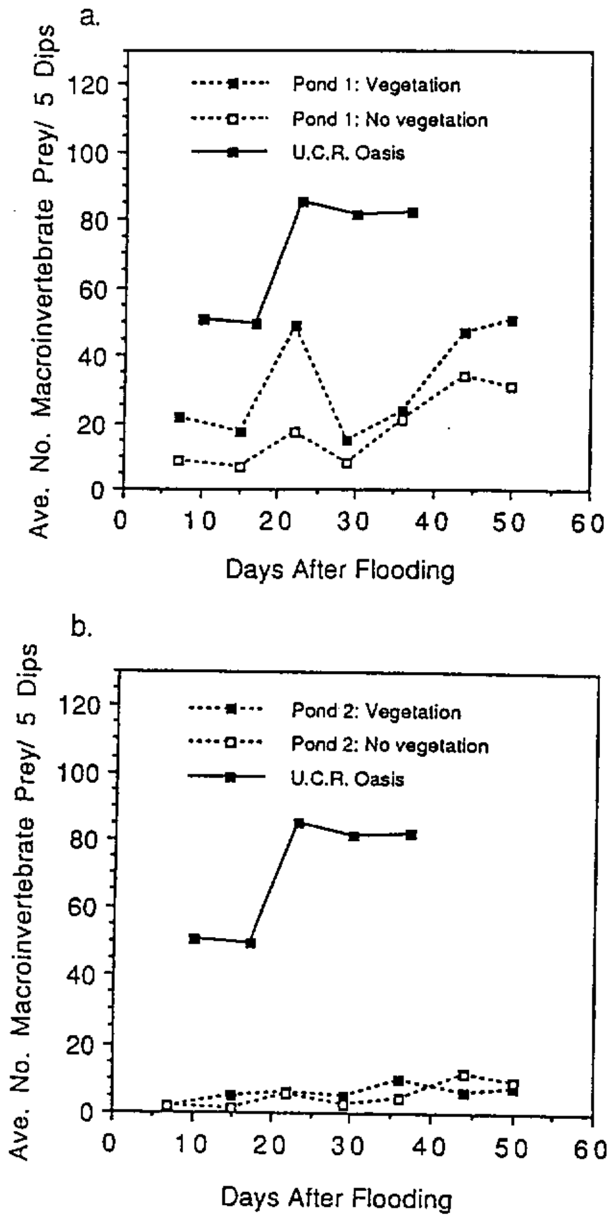

Figure 3.-The average number of aquatic macroinvertebrate in prey five 350 ml dipper samples from duck club plots and 36 m^2 ponds at the U. C. R. Aquatic and Vector Control Research Facility (Oasis, California) during the late summer and early autumn 1988. a. Comparison of macroinvertebrate abundance in plots of Pond 1 and the Oasis ponds; b. Comparison of macroinvertebrate abundance in plots of Pond 2 and the Oasis ponds.

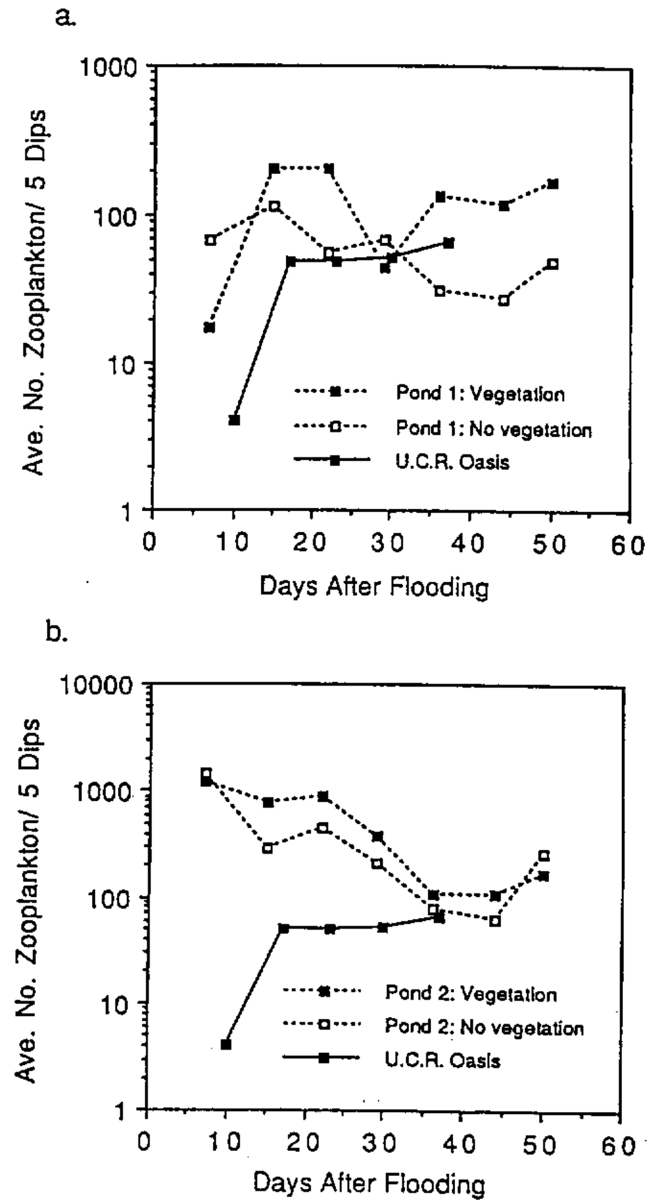

Figure 4.-The average number of zooplankton (cladocerans and ostracods) in five 350 ml dipper samples from duck club plots and 36 m^2 ponds at the U. C. R. Aquatic and Vector Control Research Facility (Oasis, California) during the late summer and early autumn 1988. a. Comparison of zooplankton abundance in plots of Pond 1 and the Oasis ponds; b. Comparison of zooplankton abundance in plots of Pond 2 and the Oasis ponds.

greater for mosquitofish in duck club ponds than for mosquitofish in the Oasis ponds (Table 1). Although snails were present in the Oasis ponds, *Gambusia* did not feed on them when alternate prey were abundant. Norland and Bowman (1976) suggested that food supply was an important determinant of mosquitofish population size. It is not known at the present time whether adult *Gambusia* in duck club ponds, by preying on more sclerous terrestrial prey or more heavily armored molluscan prey, meet their metabolic demands or suffer further [illegible]

[illegible] fishes, *Gambusia* never cracked the shells of *Physa* sp. or *Gyraulus* sp..

The late stocking date, reduced food abundance, and reduced interior vegetation decreased mosquitofish reproduction and survival in Coachella Valley duck club habitats. Mosquitofish populations in typical duck club ponds, which lack interior vegetation, are reduced by predation and thermal stress. Although increased vegetative cover might reduce the natural mortality factors operating in duck club ponds, studies in a variety of habitats have shown that emergent vegetation decreased mosquitofish effectiveness as a biological control agent (Craven and Steelman 1968, Meisch 1985, Orr and Resh 1987, Morton et al. 1988).

Vegetation and water management practices in California duck clubs will change if the proposed amendments to U.S. Fish and Wildlife Service regulations are enacted in 1991. If the supplemental forage practice is discontinued, the flooded acreage will likely increase to accommodate the need to [illegible]

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