EFFICACY OF A MICROBIAL INSECTICIDE AND LARVIVOROUS FISH AGAINST *CULEX TARSALIS* IN DUCK CLUB PONDS IN SOUTHERN CALIFORNIA.

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ABSTRACT

The efficacy of *Bacillus thuringiensis* var. *israelensis* (*Bti*) against *Culex tarsalis* was evaluated in 1.8 ha duck hunting club ponds in the Coachella Valley of southern California. Duck loafing ponds were nearly devoid of interior vegetation and *Cx. tarsalis* larvae were concentrated in the vegetation along the perimeter dikes. Therefore, the inundated perimeter vegetation and 3.1 m of the water surface in from each dike were treated with an aqueous suspension of *Bti* (Vectobac 12AS). The aqueous suspension applied at a per pond rate of 1.2 L/ha reduced mosquito larval populations (3rd-4th instars) by 96-100% those in ponds which were stocked with *Gambusia affinis* at a rate of 1.4 kg/ha. The aqueous suspension applied at a per pond rate of 0.12 L/ha (rate based on the area treated: 1.2 L/ha) was ineffective against *Cx. tarsalis*. Mosquitofish stocked at the current operational rate of 1.4 kg/ha did not significantly reduce *Cx. tarsalis* larval populations. The appropriateness of integrated control and environmental control strategies for *Cx. tarsalis* larval populations in duck club ponds are discussed.

Introduction.

Duck hunting club ponds located on the northern shore of the Salton Sea (in Riverside and Imperial Counties in southern California) are important developmental sites of *Culex tarsalis* Coquillett and pose and a significant vector control problem. In the Coachella Valley, several thousand acres are flooded annually for duck hunting. Large numbers of adult *Cx. tarsalis* (>1,000 individuals/trap-night) are captured in CO_2-baited CDC traps during the spring and autumn (Durso and Burguin 1988) and arbovirus activity is prevalent in the vicinity of duck hunting clubs (Durso and Burguin 1988, Emmons et al. 1988).

Current control methodologies for larval mosquito populations inhabiting duck club habitats consist of stocking ponds with larvivorous fish and spot-treating problem areas with larvicides. Inundation of duck club ponds in the Coachella Valley usually begins in late August-early September and flooding is completed after approximately four to six weeks. As the ponds fill with water, mosquitofish (*Gambusia affinis* (Baird and Girard)) are seined from other sources and stocked into duck club ponds at a rate of 1.4 kg/ha. Abatement measures with fish are often supplemented by treating individual ponds which contain dense larval mosquito populations with larvicides such as Golden Bear 1111 Larviciding Oil (Witco Chemical Co., Oildale, CA).

Mosquito abatement districts are replacing conventional chemical control agents with biological agents (Eldridge 1988). Because it is often necessary to treat many duck club ponds with larvicides, a suitable biological larvicide is needed. A mosquito-specific larvicide such as *Bacillus thuringiensis* var. *israelensis* (*Bti*) used in conjunction with larvivorous fish and naturally-occurring predators may provide cost-effective control of mosquito larvae in duck club ponds.

Previous studies in mesocosms have shown that *Cx. tarsalis* populations declined naturally 2-3 weeks after inundation (Mulla 1990, Walton et al. 1990) and, as compared to either treatment alone, an integrated control strategy which combined mosquito-specific bacterial larvicides with

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mosquitofish was most efficacious against *Cx. tarsalis* (Walton and Mulla 1990b). Duck club ponds differ from the mesocosms in size, extent of vegetation cover, and several physical-chemical factors which influence the effectiveness of microbial and biological control agents (Mulla 1990, Walton and Mulla 1990a). Additionally, duck club ponds can be categorized into two general types: ponds that contain vegetation throughout the interior (foraging ponds) and ponds that lack interior vegetation (loafing ponds).

Bacillus thuringiensis var. *israelensis* reduced *Cx. tarsalis* immature populations by 93-100% of pretreatment levels in unreplicated studies of a Fresno County, California wetland field and a Kern County, California duck club (Mulligan and Schaefer 1981). However, the efficacy of bacterial larvicides against *Cx. tarsalis* has not been examined in the Coachella Valley duck club ponds. In 1989, we studied the effectiveness of *Bti* against *Cx. tarsalis* in loafing ponds in a Coachella Valley duck club and compared the levels of control by *Bti* to that by current mosquito abatement practices using mosquitofish alone.

Materials and Methods.

The effectiveness of *Bti* against *Cx. tarsalis* larvae was studied in six 1.8 ha (4.4 acres) ponds at the Adohr Valley Farms Duck Club, Mecca, California. Water was supplied to the duck club via a single well located on the northwest corner of the duck club (Pond 1; Fig. 1). The predominant directions of water flow through the duck club were to the east and south. With the exception of a few stands of tamarisk (*Tamarix ramosissma*), the interiors of the six ponds were devoid of emergent vegetation. The timing of flooding and the perimeter vegetation were similar for pairs of ponds in each row; therefore, the ponds were grouped by row. The ponds in each row were assigned to two treatments; *Bti* or control. To prevent contamination of the control ponds by *Bti*, ponds assigned to *Bti* treatment (Ponds 4, 8 and 11) were located to the east of the control ponds (Ponds 3, 7 and 10).

Two application rates of *Bti* were tested against *Cx. tarsalis*. An aqueous suspension of Vectobac 12AS (Abbott Laboratories: 1200 ITU/mg) applied to ponds with a pressurized sprayer per label directions. The *Bti* suspension was continuously agitated. Because mosquito larval populations were concentrated in the vegetation along the dikes, the inundated perimeter vegetation and 3.1 m (10 ft) of the water surface from each dike were treated at a rate of 1.2 L/ha (1 pt/acre) on October 18. The area treated was equal to 0.2

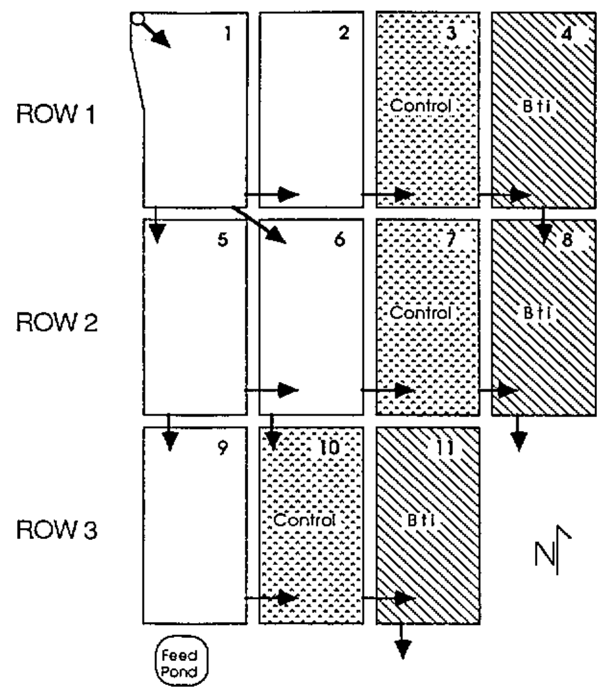

Figure 1. Experimental design in Adohr Valley Farms during 1989. Arrows indicate waterflow directions.

ha; therefore, based on total surface area of the pond, *Bti* was applied at a per pond rate of 0.12 L/ha. This rate was ineffective against *Cx. tarsalis*; hence, on October 25 and November 1, the perimeter vegetation and 3.1 m of the water surface from the dikes were treated at a per pond rate of 1.2 L/ha. Water temperature was measured weekly in Pond 8 with a maximum-minimum recording thermometer.

Mosquito larvae were sampled weekly with a 350 ml dipper at 30 stations in each pond. At each station, five dips were taken along a 2 m region in the perimeter vegetation, combined and preserved in 95% ethanol. The ponds in each row were sampled initially after both ponds had filled with water. The first samples were taken on September 25 (Row 1; Ponds 3, 4), October 2 (Row 2; Ponds 7, 8) and October 10 (Row 3; Ponds 10, 11).

Because these duck club ponds are typically stocked with mosquitofish, we compared mosquito larval abundance in the *Bti*-treated ponds to that in ponds containing *Gambusia affinis*. The rationale for using the current abatement method, instead of a fishless control, is: (1) Stocking mosquitofish into the duck club ponds is common practice; whereas, leaving ponds unmanipulated is not done routinely. (2) If mosquitofish eventually reduced mosquito larval populations, then we could determine how many bacterial larvicide applications were necessary before fish provided significant levels of control. (3) Both types of controls, with and without mosquitofish, were not possible. Although a fishless control is less preferable than one using mosquitofish for the question which we posed, replicate experimental units (ponds) were not available for a fishless control because the other ponds in the duck club (Ponds 1, 2, 5, 6 and 9) were not disked in 1989, had vegetation throughout the pond interiors and differed markedly from the ponds used in our study.

Mosquitofish were stocked into Ponds 3, 7 and 10 at a rate of 1.4 kg/ha (1.25 lbs/acre) on October 5. *Gambusia* were seined from local ponds, weighed, and a mixture of adult and immature fish were stocked into the control ponds.

Mosquitofish were excluded from the *Bti*-treated ponds by surrounding the dropboxes with doubled-over fiberglass window screen (about seven openings/cm). Because the first pond flooded often develops dense stands of emergent vegetation and contains large numbers of mosquitofish which migrate into other ponds, the dropboxes between the control ponds and ponds not used in this study (Ponds 2, 6 and 9) were not screened.

Mosquitofish populations were sampled weekly with Gee minnow traps (Cuba Specialty Mfg. Co., Fillmore, NY) that were lined with fiberglass window screen. Minnow traps were baited with dog food and placed in the corners of each control pond for 24 hours. To determine the effectiveness of the screens, minnow traps were placed in the *Bti*-treated ponds for a 24 hr period on November 13-14.

Statistical analyses. The efficacy of *Bti* and *G. affinis* against *Cx. tarsalis* larvae were tested statistically by making pairwise comparisons of larval abundance (3rd and 4th instars) in ponds within a row for two of the three rows. Late instar larvae were not collected in dip samples from Pond 4; therefore, this pond was not treated with *Bti*. Our data were not directly amenable to statistical testing by a randomized block analysis of variance because one row (block) was not treated with *Bti*, the movement of water through Adohr Valley Farms duck club precluded randomization of treatments in each row and mosquito larvae either were not collected in some pretreatment samples (Ponds 3 and 4) or were eliminated from the ponds by *Bti* treatments (zero mean and variance for a treatment on some dates).

The effect of each *Bti* treatment on *Cx. tarsalis* larval abundance was tested statistically by a Mann-Whitney U test. Whereas 3rd-4th instar larvae were absent in samples taken five days after the ponds had been treated with *Bti* at a pond rate of 1.2 L/ha, the large numbers of 1st-2nd instar larvae in these samples indicated that the effects of the bacterial larvicide lasted less than one week. Also, at the ambient water temperatures, 3rd and 4th instar larvae in a previous sample would have emerged as adults before the next sample was taken. Therefore, separate comparisons (by date) of 3rd-4th instar larval abundance for each *Bti* treatment are appropriate. For the pair of ponds in each row, the numbers of larvae collected at each station were ranked and the U statistic was corrected for ties. Because this procedure is analogous to making multiple t-tests, we adjusted the probability of Type I error to 0.025.

As do parametric statistics, the Mann-Whitney U test also requires that the treatments are randomized among experimental units. Because we could not randomize the two treatments within each row and larval abundance was determined from combined, random samples at fixed stations, the significance levels of the statistical comparisons are, at best, approximations.

Similar tests were used to examine the efficacy of mosquitofish. However, we set the probability of Type I error to 0.01. Because *G. affinis* was stocked only once, a repeated-measures analysis of variance is more appropriate. Yet, unforseen difficulties in one row (3rd-4th instar larvae were not collected from Ponds 3 and 4) precluded this analysis.

Results and Discussion.

Efficacy of *Bti*. *Bti* applied at a per pond rate of 1.2 L/ha significantly reduced *Cx. tarsalis* abundance (3rd-4th instars) by 96 and 100% relative to those observed in the control ponds (Table 1). *Bti* applied at a per pond rate of 0.12 L/ha was ineffective against *Cx. tarsalis* (Fig. 2). At five days after treatment, the numbers of larvae collected in dip samples from *Bti*-treated ponds did not differ significantly from those of the control ponds.

The aqueous suspension, when applied at a per pond rate of 1.2 L/ha, was effective for nearly one week. Whereas the numbers of 3rd and 4th instar larvae in Ponds 8 and 11 were very low on the last two sampling dates (Fig. 2), 1st and 2nd instar larvae were present in both ponds (Fig. 3).

Efficacy of mosquitofish. Mosquitofish stocked at 1.4 kg/ha did not appreciably reduce *Cx. tarsalis* abundance (Figs. 2 and 3). Mosquito larval abundance in two of the control ponds were greatest on October 10 (total number of larvae/150 dips: Pond 7=538, Pond 10=1141). After October

Table 1. Efficacy of *Bacillus thuringiensis* (Vectobac 12AS) at five days post treatment against *Culex tarsalis* (3rd and 4th instar larvae) in Adohr Valley Farms duck club during 1989. For each comparison, n_1 and n_2 in the Mann-Whitney U test equal 30.

Per pond rate (L/ha)	Date	Water Temp. (° C)	Comparison (ponds)	U	|Z|	P(Z)[a]	Reduction[b] (%)
0.12	October 23	14-29	7 vs 8	438	0.212	ns	0
			10 vs 11	340	1.701	ns	0
1.2	October 30	9-28	7 vs 8	315	3.215	**	100
			10 vs 11	284.5	3.225	**	96
1.2	November 6	9-19	7 vs 8	270	3.812	***	100
			10 vs 11	285	3.617	***	100

[a] ns = P(Z) > 0.025; ** = P(Z) ≤ 0.01; *** = P(Z) ≤ 0.001.

[b] Percent reduction = 100 [1 - (no. of larvae from *Bti*-treated pond/ no. of larvae from control pond)].

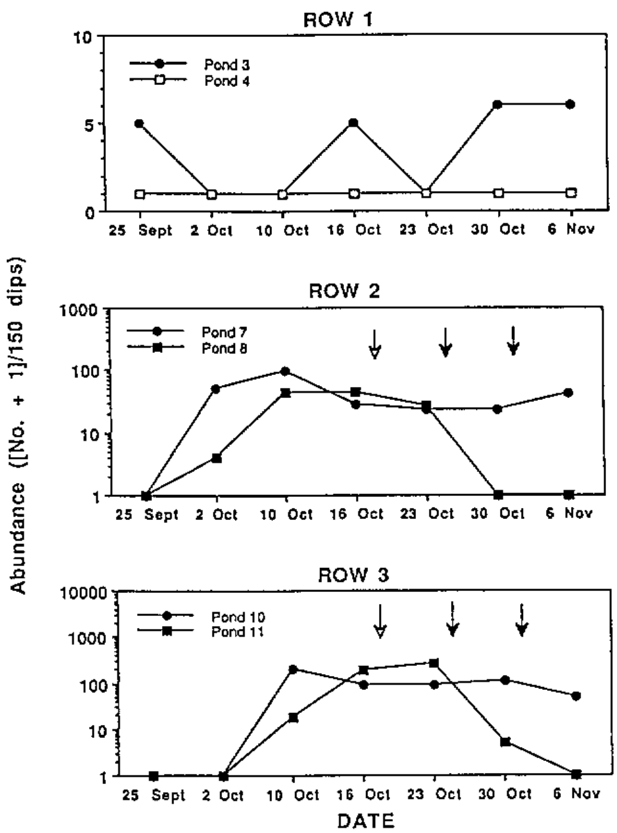

Figure 2. *Culex tarsalis* larval abundance (3rd-4th instars) in duck club ponds at Adohr Valley Farms during 1989. Vectobac treatments at a per pond rate of 0.12 L/ha and 1.2 L/ha are indicated by the open and closed arrows, respectively. • = control pond populations, ▪ = *Bti*-treated pond populations (ponds were not treated in row 1).

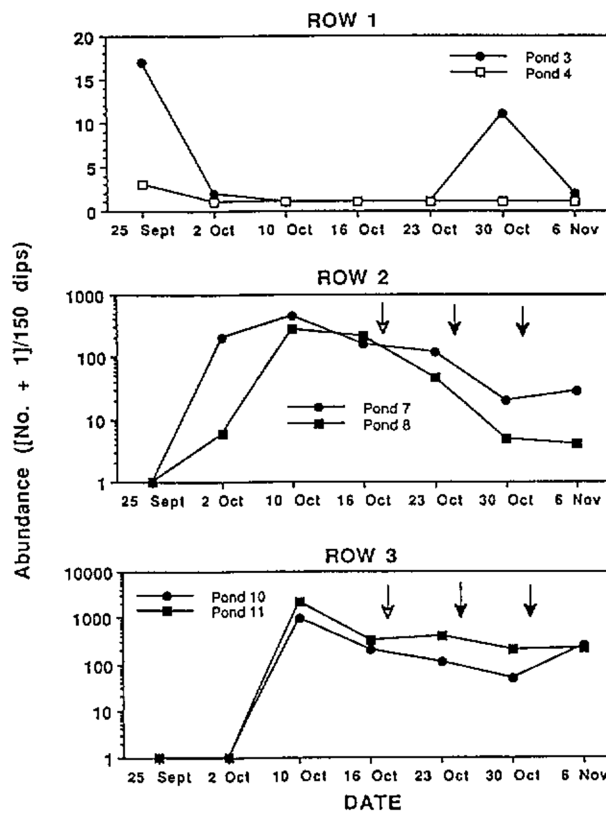

Figure 3. *Culex tarsalis* larval abundance (1st-2nd instars) in duck club ponds at Adohr Valley Farms during 1989. Vectobac treatments at a per pond rate of 0.12 L/ha and 1.2 L/ha are indicated by the open and closed arrows, respectively. • = control pond populations, ▪ = *Bti*-treated pond populations (ponds were not treated in row 1).

10, larval abundance (3rd-4th instars) was reduced slightly and was nearly constant through November 6 (Fig. 2).

Larval abundance in ponds that contained mosquitofish did not differ significantly from that observed in ponds without *Gambusia* at 11 and 18 days (October 16 and 23, respectively) after fish were added to Ponds 7 and 10 (Table 2). For the third control pond (Pond 3), the numbers of *Cx. tarsalis* 3rd-4th instars in dip samples were very low (≤ 5 larvae/150 dips) from September 25 to November 6 (Fig. 2).

The failure of mosquitofish stocked at current operational densities (1.4 kg/ha) to reduce *Cx. tarsalis* larval populations in 1989 corroborates our 1988 studies in which mosquitofish stocking rates were manipulated in small enclosures and mesocosms. In 1988, *G. affinis* stocked at 1.4 kg/ha did not significantly reduce mosquito larval populations as compared to fishless controls in 16 m^2 enclosures at Adohr Valley Farms (Walton and Mulla 1990b). During the summer, *Gambusia* significantly reduced *Cx. tarsalis* larval populations when mosquitofish were stocked at the very high rate of 4 kg/ha in 36 m^2 mesocosms at our Coachella Valley research facility. However, a *G. affinis* stocking rate of 1 kg/ha did not significantly reduce mosquito larval populations as compared to fishless controls (Walton and Mulla 1990b, Walton unpubl. data). In both vernal and autumnal studies, the impact of *G. affinis* on *Cx. tarsalis* was apparent 2-3 weeks after fish were stocked into mesocosms. In 1989, *Cx. tarsalis* larval abundance did not decline to nearly zero at 2-3 weeks after stocking mosquitofish or at any time during the one month period after *G. affinis* was added to the ponds.

Mosquitofish catches in minnow traps either declined or were near zero during the three weeks following October 5 (Table 3). For Ponds 7 and 10, the increases in mosquitofish numbers observed on November 6-7 were due to migration of fish from thickly-vegetated ponds into duck loafing ponds as water was being diverted into Ponds 5, 6 and 9. Relative to catches during the previous three weeks, comparatively high numbers of large-sized *G. affinis* were captured in minnow traps adjacent to the dropboxes entering Ponds 7 and 10.

The screens surrounding the dropboxes effectively excluded *G. affinis* from the *Bti*-treated ponds (Ponds 4, 8 and 11). Mosquitofish were not captured by minnow traps in Ponds 4, 10 and 11 on November 13-14.

Implications for mosquito control programs. Service (1983) suggested that integrated control programs which combine biological agents such as mosquito predators and parasites, or utilize biological agents and larvicides, often fail because: 1) larvicide-induced reductions of mosquito populations result in food shortages for the biological control agents, 2) predators or high parasite-induced larval mosquito mortality often interfere with the transmission of mosquito parasites, and 3) the dispersion and aggregation behavior of mosquitoes provide spatial refuges for mosquito larvae. Mosquitoes also colonize a variety of habitats. For example, *Cx. tarsalis* is found in habitats that range in size from small, ornamental containers to large, duck club ponds (Durso and Burguin 1988). Differences in habitat preferences of mosquitoes and their predators, and the enormous number and variety of habitats utilized by this mosquito, make biological control an arduous, if not impossible, task.

In addition to the confounding factors listed above, differences in the life history characteristics of mosquitoes and their predators provide a temporal refuge for mosquitoes (Service 1983). *Culex tarsalis* colonizes newly inundated habitats and develops more rapidly than do many of its predators (Walton et al. 1990).

Last, integrated control programs that combine biological control agents and chemical insecticides often fail because some mosquito predators/parasites are also susceptible to chemical larvicides and their populations often take longer to recover from insecticide-induced mortality than do mosquito larval populations. There are many examples of the enhancement of mosquito larval populations, relative to those in the controls, after treatment with chemical larvicides (e.g. Hoy et al. 1972; Miura et al. 1978).

Integrated control programs which combine larvivorous fishes and bacterial larvicides against *Cx. tarsalis* might, in theory, be successful in duck club ponds because many of these problems are mitigated. Treatment with mosquito-specific, bacterial larvicides will be required during the period when fish populations are small and do not significantly reduce mosquito larval populations. Once mosquitofish populations are large enough to control mosquitoes, repeated applications with the larvicide are no longer necessary. By reducing the number of larvicide applications, this integrated control program also reduces costly larviciding and continued selection for *Bti* resistance in *Cx. tarsalis*.

Will this integrated control strategy succeed in Coachella Valley duck clubs? Our studies demonstrate that bacterial larvicides are very effective against *Cx. tarsalis* populations in duck

Table 2. Efficacy of *G. affinis* against *Cx. tarsalis* (3rd and 4th instar larvae) in Adohr Valley Farms duck club. For each comparison, n_1 and n_2 in the Mann-Whitney U test equal 30.

Date	Days[a]	Comparison (ponds)	U	|Z|	P(Z)[b]
October 16	11	7 vs 8	423.5	0.450	ns
		10 vs 11	423.5	0.408	ns
October 23	18	7 vs 8	438	0.212	ns
		10 vs 11	340	1.701	ns

[a] Days since *G. affinis* was stocked into ponds 7 and 10 at a rate of 1.4 kg/ha.
[b] ns = $P(Z) > 0.01$.

Table 3. The average number (± 1 SD) of *G. affinis* captured in minnow traps at Adohr Valley Farms duck club. Numbers in parentheses are total number of fish captured/24 hrs.

	average no. captured/minnow trap/24 hrs.		
Date	Pond 3	Pond 7	Pond 10
October 16-17	1.0 ± 2.0 (4)	7.0 ± 5.7 (28)	0 (0)
October 23-24	0.5 ± 0.6 (2)	4.5 ± 8.3 (18)	0 (0)
October 30-31	0.8 ± 1.5 (3)	3.8 ± 3.0 (15)	1.0 ± 1.4 (4)
November 6-7	0.3 ± 0.5 (1)	8.0 ± 10.2 (32)	5.0 ± 6.2 (20)

Table 4. The perimeter vegetation of duck loafing ponds at Adohr Valley Farms duck club.

Family	Species	Abundance
Aizoceae	*Sesuvium varicosum*	common
Chenopodiaceae	*Allenrolfea occidentalis*	common
	Bassia hyssopifolia	rare
Cyperaceae	*Eleocharis macrostachya*	rare
	Scirpus robustus	rare
Poaceae	*Cyndon dactylon*	rare
	Distichlis spicata	common
Tamaicaceae	*Tamarix ramosissma*	common
Typhaceae	*Typha angustifolia*	rare

club ponds. However, at current operational stocking rates, mosquitofish do not significantly reduce mosquito larval populations. Walton and Mulla (1990b) concluded that mosquito abatement in Coachella Valley duck clubs is complicated by the interactions among 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 development sites during duck hunting season.

Typical duck loafing ponds are devoid of interior vegetation and mosquitofish populations are subject to factors that reduce survivorship and reproduction. Thermally-stressful conditions during August and September, large populations of piscivorous birds, and, perhaps, low food abundance in loafing ponds reduce mosquitofish numbers and exacerbate the natural, photoperiodically-induced decline of mosquitofish reproduction during autumn. The size and persistence of piscivorous ardied (herons and egrets) populations in autumn has increased concomitantly with the advent of commercial fish aquaculture in the Coachella Valley (H. Johnson personal communication). While we have shown via mesocosm studies that very high *G. affinis* stocking rates are necessary in the late summer and autumn to significantly reduce *Cx. tarsalis* larval populations, it is unlikely that increasing mosquitofish stocking rates into typical loafing ponds will solve the current *Cx. tarsalis* problem in the Coachella Valley. A large proportion of the enhanced mosquitofish populations would likely succumb to predation by birds in the nearly vegetation-free loafing ponds.

Last, we briefly consider the importance of perimeter vegetation and alternative control strategies for *Cx. tarsalis* populations in duck club ponds. The perimeter vegetation of loafing ponds often provides favorable developmental sites for mosquitoes and can be inhabited by dense larval aggregations (>100 larvae/dip; Walton personal observation). Our 1988 studies verified that removing the perimeter vegetation significantly reduced mosquito larval abundance (Walton and Mulla 1990b). As compared to unmanipulated plots, *Cx. tarsalis* larval populations were reduced significantly in 16 m^2 plots where the perimeter vegetation was removed.

The differences in larval mosquito abundance among the rows in the 1989 study were probably due to the availability of the perimeter vegetation for developmental sites and the extent of cover by grasses. After September 25, water levels in Pond 4 were maintained below the perimeter vegetation and late instar larvae were not collected in dip samples. This was also true for Pond 3 on the same sampling dates. Additionally, the proportion of the pond perimeter covered by grasses, primarily salt grass (*Distichlis spicata*), was smallest for row 1 (Pond 3; 38%, Pond 4; 6%) and increased in rows 2 (Pond 7; 50%, Pond 8; 40%) and 3 (Pond 10; 88%, Pond 11; 50%). Since water levels in row 1 were low, the grasses often were not inundated.

Three other plant species were common along dikes without grasses (Table 4). However, very few mosquito larvae were collected in dip samples within these plants. For the period October 10-23, the total number of larvae collected in dip samples was positively correlated with the abundance of grasses (meters of the pond perimeter covered by grasses: Spearman rank correlation coefficient $=0.823$, $P<0.001$). Rejmánková et al. (1988) also found that *Cx. tarsalis* densities were directly related to graminoid (rice) and sedge (*Cyperus difformis*) abundance in rice fields.

Environmental and insecticidal control are less difficult to achieve than is biological control (Service 1983) and the former may afford a successful cooperation between the duck club ranch managers and the abatement district. Source reduction by the ranch manager should include the removal of perimeter vegetation, particularly salt grass. However, such manipulations are generally contraindicated for waterfowl. Presently, vegetation management differs markedly among the duck clubs. The perimeter vegetation is removed completely in some duck clubs, while in others, perimeter vegetation is encouraged. Not surprisingly, mosquito larval populations are large in the latter duck club group.

Collins and Resh (1989) suggested that manipulating water levels to influence the types of vegetation and reduce the availability of mosquito developmental sites was an alternative ecological control in non-tidal wetlands. For shallow duck club ponds (maximum depth of approximately 30 cm) which are fed by a single well, water management is not very precise and water levels cannot be manipulated to the extent required for ecological control. Water levels in loafing ponds would have to be maintained below the grasses at the interface of the pond bottom and the dikes and, consequently, might be too shallow to attract migrating waterfowl and for hunting purposes (i.e. deployment of decoys). Shallow water depths caused by water diversions or conservation (during the period when hunting ceases in mid-season) also complicate integrated control measures by increasing mosquitofish mortality (Walton and Mulla 1990b). For ecological control via hydrological regimes, complete drawdown and augmentation should occur within seven to eight days (Collins and Resh 1989). Given the current gravity-fed hydrological systems and soil characteristics, this drawdown/augmentation rate is not possible in the large duck clubs.

Vegetation management via ground disturbance (i.e. disking, harvesting) offers a more promising method of environmental control in duck club ponds. Because of air quality considerations, burning of the perimeter vegetation is typically discouraged. However, the importance of perimeter vegetation in Coachella Valley duck clubs as a food source and attractant for migrating waterfowl needs to be established before implementing vegetation control measures. Unlike wildlife preserves where natural vegetation provides food, cover, and nesting material for waterfowl, southern California duck hunting clubs provide supplemental forage to attract ducks and to prevent damage to commercial agriculture by migrating waterfowl.

The abatement district must continue to monitor larval mosquito abundance and treat problem areas in duck clubs. By reducing the perimeter vegetation in loafing ponds, the number of problem areas should decline and be limited to ponds that develop interior vegetation; usually the first pond flooded. Occasional surveys of a thickly vegetated pond during 1989 revealed that *Cx. tarsalis* larval populations were densest (50-75 3rd-4th instar larvae/dip) in inundated salt grass on the pond perimeter and were much lower in the pond interior (<2 3rd-4th instar larvae/dip). Because larval production is concentrated in the perimeter vegetation, reducing the perimeter vegetation of ponds with interior vegetation will also aid abatement efforts. Although larval mosquito populations are comparatively less abundant in the interior vegetation than in the perimeter vegetation, adult mosquitoes are produced from the entire pond instead of only along the dikes. Therefore, ponds which contain interior vegetation are more difficult to treat with larvicides than are loafing ponds.

An integrated control strategy using bacterial larvicides and enhanced mosquitofish populations may be effective in ponds with interior vegetation. The interior vegetation reduces water temperatures and mosquitofish mortality (Walton and Mulla 1990b). As compared to loafing ponds which lack interior vegetation, ponds with interior vegetation support larger mosquitofish and macroinvertebrate predator populations (Walton and Mulla 1990b). Water management is important because, even in thickly-vegetated ponds, mosquitofish populations can be adversely affected by shallow water depths.

Conversely, this integrated control strategy is ineffective in loafing ponds because mosquitofish populations are never large enough to exert significant levels of mosquito control. For loafing ponds, environmental control by the duck club ranch manager and, if necessary, insecticidal control by the mosquito abatement district are better alternatives to integrated control measures using *Bacillus* and *Gambusia*. Additional studies of the effectiveness of enhanced mosquitofish stocking rates and source reduction via vegetation manipulation are necessary. Our studies in duck club ponds have shown that *Bti* is an efficacious alternative to current insecticides.

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