

DISTRIBUTION OF *CULEX TARSALIS* LARVAE IN A FRESHWATER MARSH IN ORANGE COUNTY, CALIFORNIA

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ABSTRACT. The distribution and abundance of mosquito larvae in a freshwater marsh were determined during a low water period in the late summer. *Culex tarsalis* larval abundance was significantly associated with the percent cover by *Typha* spp. root masses and *Typha* spp. stem density in 1-m² quadrants. Larval mosquito abundance was not significantly related to bulrush (*Scirpus californicus*) stem density, position in the marsh (transect compass direction), position in the inundated vegetation on each transect or several physiochemical factors. As water levels decline seasonally, mosquito developmental sites in San Joaquin Marsh change from mats of decaying vegetation to cattail root masses.

Freshwater marshes are developmental sites for many mosquito species and water and vegetation management can ultimately influence the resultant adult mosquito populations. In many shallow duck hunting club ponds of southern California, emergent vegetation is restricted to the periphery, water levels often fluctuate on a short-term basis (e.g., weekly or biweekly), and ideal mosquito developmental sites are alternately inundated and dried (Walton and Mulla 1990). In comparatively deeper habitats such as marshes, the emergent vegetation is not necessarily restricted to the peripheral dikes and the amplitude of water level fluctuations is greater than the small-scale fluctuations that occur in many shallow developmental sites. As water levels change seasonally, mosquito developmental sites may change as preferred developmental sites of one type desiccate and sites of another type become available. Mosquito abatement agencies that rely on larvicides to control pestiferous and disease-transmitting mosquitoes must continuously assess the abundance and distribution of larval mosquitoes in such marshes or rely on adult mosquito abundance in traps as indicators that treatments are needed. A thorough understanding of hydrological factors (e.g., the storage, transport and quality of water) and their effect on the other components of wetland systems, such as vegetation type and growth, the abundances of herbivores, mosquitoes and their predators, is critical for the development of ecological (Collins and Resh 1989) and integrated control programs, and for the successful manipulation of marshlands to satisfy the, sometimes contrary, goals of wildlife management/marsh preservation and mosquito abatement (Resh and Balling 1983, Batzer and Resh 1988, Walton and Mulla 1990).

The San Joaquin Marsh is an 81-ha wildlife reserve that is located approximately 72.4 km southeast of Los Angeles in Irvine, California (Cope et al. 1986). Water levels in the San Joaquin Marsh fluctuate between 1 and 1.5 m on a seasonal basis (W. L. Bretz, personal communication). During periods when the water level is high, *Culex tarsalis* Coq. and *Culex erythrorhox* (Dyar) are found in association with floating mats of decaying cattails (*Typha* spp.) and bulrushes (*Scirpus californicus*) (Berkelhamer and Bradley 1989). Berkelhamer and Bradley (1989) showed that the mats of decaying *S. californicus* provide both a refuge from predators and a source of nutrition to developing mosquitoes. Water levels decline during the late summer and early fall until the marsh is re-flooded in September or October. During this low water period, the majority of the floating mats of vegetation are stranded above the water in the thick growth of emergent vegetation. Although the mats of decaying vegetation are no longer available as developmental sites, large numbers of adult mosquitoes emerge from the San Joaquin Marsh (Bangs et al. 1986). During September 1989, we studied this marsh to: 1) determine the distribution and abundance of mosquito larvae, and 2) identify and characterize the larval developmental sites.

The distribution and abundance of mosquito larvae were studied in Pond 5 (Fig. 1; maximum surface area = 2.4 ha) in the San Joaquin Marsh. This pond contains a luxuriant growth of *Typha latifolia*, *T. angustifolia* and *S. californicus* which covers all but approximately 1,600 m² of the surface. On September 8, the water surface area was only approximately 2,500 m². We established 10 transects by assigning each transect a 3-digit compass direction with a random numbers table. For each transect, the "100" degrees coordinate was assigned first and was limited to 0, 1, 2 or 3. The "10" degrees coordinate could take a value ≤ 9 ; unless a 3 had been drawn for the "100" degree coordinate. In this case, the "10" degree coordinate could vary from 0 to 5.

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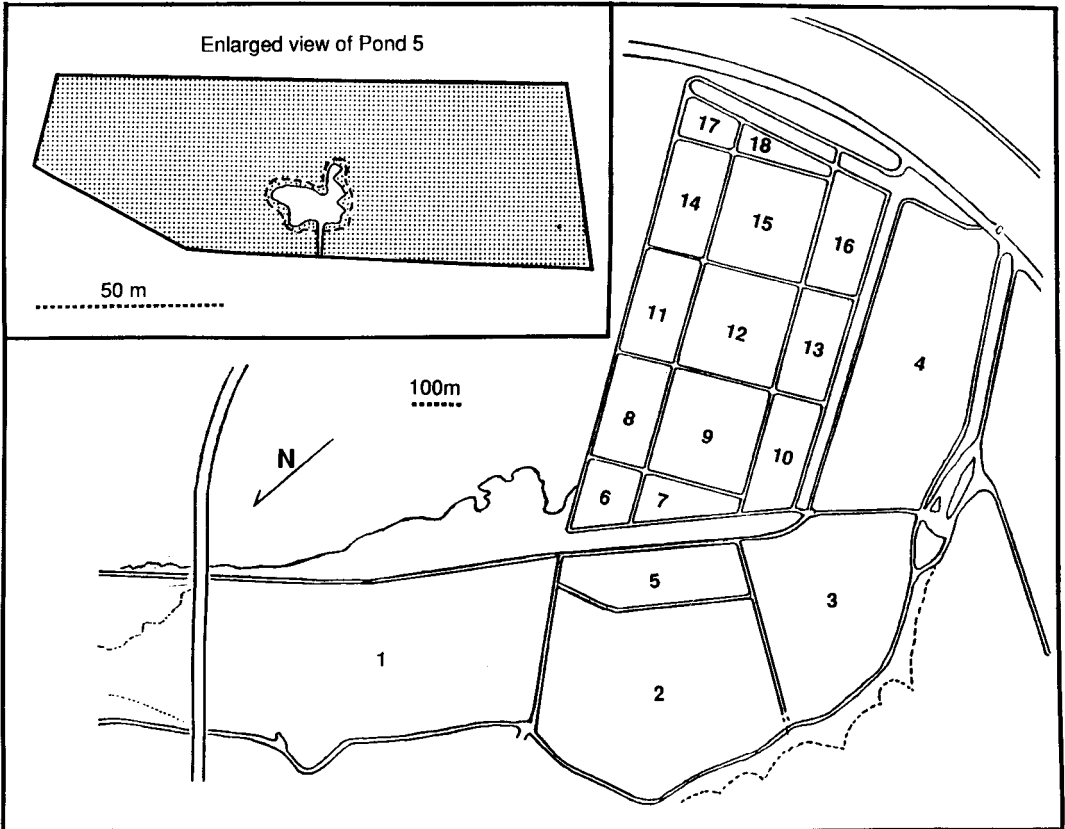


Fig. 1. Diagram of the 5 large ponds and 13 duck ponds in the San Joaquin Marsh Natural Reserve, Irvine, CA. Pond 5 is enlarged in the inset (upper left) to show the extent of the emergent vegetation (dots) and the water surface area (dashed line) on September 8, 1989.

The "unit" degree coordinate could range from 0 to 9.

A stake was positioned in the center of the pond as a reference point and 1-m² quadrats were positioned along each compass direction in 2 habitats: the vegetation at the open water-vegetation interface (OV) and the vegetation along the shoreline (SH). Quadrats were delineated by placing redwood stakes, joined previously and separated by 1 m with fishing line, on 2 sides of each quadrat. The distance between the 2 pairs of redwood stakes was measured to 1 m with a meter stick. We did not place quadrats in the open water because mosquito larvae were not collected in samples from quadrats in this habitat during a preliminary study on September 1, 1989.

Mosquito larvae were sampled by carefully dipping (dipper volume: 350 ml) at 16 equally spaced sites within each quadrat. Although Andis et al. (1983) showed that an area sampler was more precise at detecting low abundances and early instars of *Psorophora columbiae* (Dyar and Knab) and *Anopheles crucians* Wied. than

was a dipper, because the height and density of the emergent vegetation in San Joaquin Marsh would have necessitated that we significantly alter the quadrats before sampling with an area sampler, we sampled within the emergent vegetation and cattail root masses using the quick hand-dipping method (Collins and Resh 1989) and the draining-dipping method (Knight 1964), respectively.

Culex tarsalis and *Anopheles* sp. were captured in dip samples on September 8; however, the latter genus was rare (<7% of the larvae collected). Anopheline larvae were collected only in *Typha* spp. stands and were associated with the *Typha* spp. root masses. Although *Cx. erythrorhox* adults were encountered occasionally in the vegetation, only one larva was collected in a cattail root mass during preliminary study. Because the other mosquito species were rare, we will focus below on the distribution of *Cx. tarsalis*.

A Kruskal-Wallis test (Sprent 1989) was used to test for significant differences in *Cx. tarsalis* larval abundance/quadrat among the transects

(SH + OV comparison). We also used the Kruskal-Wallis test to compare *Cx. tarsalis* abundance/dip sample among the quadrats within each position: SH or OV. For each of the 3 comparisons, the Kruskal-Wallis statistic (T') was corrected for ties. When the Kruskal-Wallis test was significant ($\alpha \leq 0.05$), differences of *Cx. tarsalis* abundance among the 10 transects were tested statistically using a nonparametric analogue of a least significant differences multiple comparison (Sprent 1989).

The mean numbers of *Cx. tarsalis* larvae/quadrat in the 2 positions (SH vs. OV) were tested with a t test. The variance of larval counts in dip samples (per quadrat) was greater than, and increased directly with, the mean number of *Cx. tarsalis* larvae/dip sample in each quadrat. Comparisons of the variance and the skewness of the data suggested that the log-normal distribution was a more suitable model (estimate of the index of dispersion (\hat{k}) = 0.16) than were the negative binomial or several other distributions given by Elliott (1977). Therefore, prior to analysis, the number of *Cx. tarsalis* larvae/quadrat was log+1 transformed.

Larval developmental sites also were characterized by physicochemical factors and emergent vegetation type and density. Water temperature, depth, conductivity and pH were measured at the center of each quadrat. Water temperature was measured with a hand-held thermometer. Water depth was measured with a meter stick. Conductivity and pH were measured in the field with a hand-held meter (model PC, Lakewood Instruments, Compton, CA). After dipping the quadrats, the vegetation was cut just above the water surface, mapped on a grid, and photographed. The density and species composition of the emergent vegetation, and the percent cover by *Typha* spp. root masses were measured in each quadrat. *Culex tarsalis* larval counts in each quadrat were summed and then log-transformed (number + 1). The relationships between larval abundance and physicochemical factors, and larval abundance and vegetation characteristics, were examined by regression analyses.

On September 8, the numbers of larvae collected in quadrats did not differ significantly among the transects in Pond 5 (SH+OV: $T'_9 = 14.30$, $P > 0.05$). Larval abundance/quadrat in the shoreline vegetation (SH) also did not differ significantly from that in the vegetation at the open water-vegetation interface (OV) ($t_{10} = 1.17$, $P > 0.25$). Within each position, *Cx. tarsalis* abundance in dip samples differed significantly among the quadrats (OV: $T'_9 = 19.48$, $P < 0.025$; SH: $T'_9 = 29.08$, $P < 0.001$). Although the numbers of *Cx. tarsalis* larvae/quadrat in transects at 12°, 191° and 335° were greater than those in the other transects (28°, 107°, 161°,

231°, 244°, 290° and 332°), the total number of larvae collected was small and, in the latter 2 comparisons above, there were many ties for the ranks of larval abundance/dip sample. Multiple comparisons showed that the median larval abundance/dip sample in the OV or SH positions did not differ significantly between the transects.

The total number of *Cx. tarsalis* larvae in each quadrat was not associated significantly with any physicochemical factor; all correlations were not significant at the 0.05 level. Only water depth differed significantly ($t_9 = 3.33$, $P < 0.01$) between the quadrats in the shoreline vegetation (mean \pm 1 SD: 7.1 ± 2.0 cm) and the vegetation at the open water-vegetation interface (11.1 ± 2.5 cm). Conductivity and pH averaged $12,418 \pm 461$ μ MHOS/cm² and 7.74 ± 0.26 , respectively. Mean water temperature was $18.2 \pm 2.0^\circ$ C. While turbidity was measured spectrophotometrically (model DR-EL/2, Hach Chemical Co., Ames, IA) in water samples from only 4 locations, the water contained large amounts of suspended material; mean turbidity = 190 FTUs (Formazin turbidity units).

Vegetation type and the proportion of the quadrat covered by *Typha* spp. root masses were better predictors of larval abundance than were compass direction (i.e., transect) or physicochemical factors. The proportion of a quadrat covered by root masses (Fig. 2a, $r = 0.711$, $P < 0.01$, $n = 14$) and cattail stem density (Fig. 2b, $r = 0.547$, $P < 0.025$, $n = 17$) were correlated significantly with *Cx. tarsalis* abundance. The former comparison was based on quadrats that contained only *Typha* spp. If the quadrats containing a mixture of cattails and bulrushes were included in the analysis, then the association between larval abundance and the proportion of the quadrat covered by *Typha* root masses was still significant, but weakened ($r = 0.509$, $P < 0.022$, $n = 17$). However, *Culex tarsalis* abundance in the quadrats was not correlated significantly with total (*Typha* spp. + *S. californicus*) stem density ($r = 0.305$, $P > 0.14$, $n = 20$). *Typha* density averaged 25 stems/m² and was less variable (95% confidence limits: lower = 17.0, upper = 35.3 stems/m²) than was *S. californicus* density (mean density = 43.2 stems/m²; 95% confidence limits: lower = 14.6, upper = 127.2 stems/m²). Although mosquito larvae were collected in dense stands of bulrush, *Scirpus* density was not correlated significantly with *Cx. tarsalis* abundance ($r = 0.082$, $P > 0.87$, $n = 6$).

The San Joaquin Marsh is a dynamic system where mosquito developmental sites change with the water level. During high water periods, large numbers of mosquito larvae are found in association with mats of decaying vegetation. As water levels decline so does the number of veg-

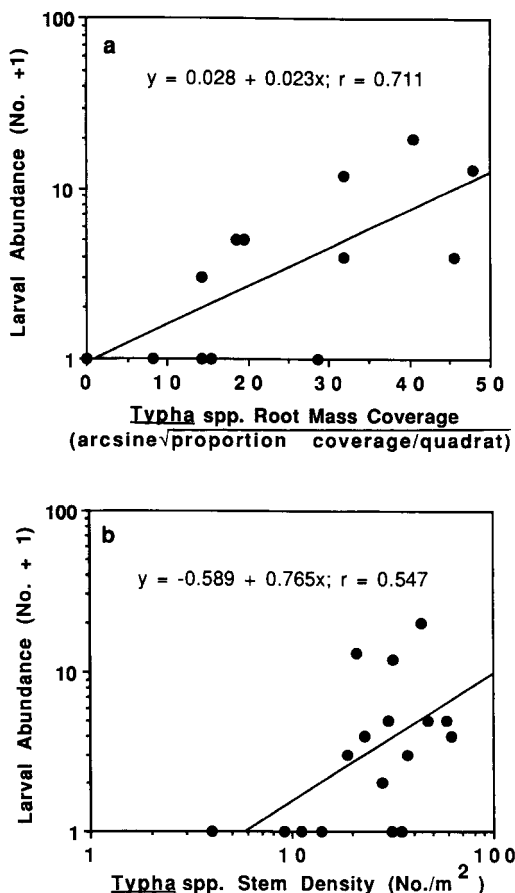


Fig. 2. Regressions of the number of *Culex tarsalis* larvae per quadrat on (a) the proportion of the quadrat covered by *Typha* spp. root masses and (b) *Typha* spp. stem density.

etation mats. During low water periods *Cx. tarsalis* larvae are found primarily in association with cattail root masses. Because of the extensive coverage of *Typha* spp. in Pond 5 (Fig. 1), and in the other large ponds of the San Joaquin Marsh, root masses are available as developmental sites for a large fraction of the summer.

The root masses provide mosquito larvae protection from predators and perhaps nutrition (detritus, etc.). *Gambusia affinis* (Baird and Girard), mosquitofish, were prevalent in the open water and among the stems within the vegetated quadrats. As water levels recede, *Cx. erythrothorax* and *Anopheles* sp. larvae presumably also use *Typha* spp. root masses as developmental sites. Walker et al. (1988) found that *An. quadrimaculatus* larval numbers in quadrats were related significantly to the length of downed, floating plant stems and were not significantly associated with the number of emergent stems or the area of algal mats. Whereas cattail root

masses may be analogous to downed, floating stems, factors other than predator avoidance and nutritional resources may account for the prevalence of mosquito larvae in root masses. Walker et al. (1988) suggested that physical forces at the water surface or orientation behavior also might explain the accumulations of *Anopheles* sp. larvae at plant edges.

The thick stands of emergent vegetation in the San Joaquin Marsh have made larviciding from the dikes nearly impossible. Emergent vegetation was approximately 3.7–4.6 m in height and averaged nearly 34 stems/m². Consequently, current formulations and application methodologies of bacterial larvicides have been ineffective against *Cx. tarsalis* and *Cx. erythrothorax* (G. Challet, personal communication). At present, repeated adulticiding is required to reduce the mosquito populations. To meet the future needs of mosquito abatement and marsh preservation, suitable pelletized larvicide formulations and innovative water/vegetation management strategies are necessary to protect the encroaching human population from disease-transmitting and pestiferous mosquitoes and preserve the integrity of the marsh ecosystem.

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