SEASONAL AND SPATIAL DISTRIBUTIONS OF THREE MOSQUITO SPECIES IN THE COACHELLA VALLEY OF CALIFORNIA AND THEIR INFLUENCE ON EXPOSURE TO INSECTICIDAL SELECTION[1]

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ABSTRACT. The seasonal and spatial distributions of *Culex tarsalis*, *Culex pipiens quinquefasciatus* and *Culiseta inornata* larvae and adults from the Coachella Valley of southern California are presented and their influence on the extent of insecticidal exposure of the species involved is discussed. The peak of abundance for *C. inornata* adults occurred in November while the larvae of this species were most frequently collected in January. *C. tarsalis* and *C. p. quinquefasciatus* were most prevalent in the spring and fall, and exhibited summer and winter depressions in occurrence and abundance.

The major portion of insecticides used in the valley for mosquito control are applied from May through October. Thus, *C. inornata* with a peak of abundance during winter months would avoid exposure to the bulk of insecticides applied and would therefore be less likely to develop high levels of resistance. The data for insecticide usage in each study area and the spatial distributions of *C. tarsalis* and *C. p. quinquefasciatus* indicate that, overall, a larger portion of the *C. tarsalis* in the valley is under heavy insecticidal pressure relative to *C. p. quinquefasciatus*. This situation, combined with population mixing achieved through adult dispersal, would be expected to provide the impetus for development of higher levels of resistance in *C. tarsalis*.

Through irrigation the Coachella Valley of southern California has been transformed from an inland desert into agricultural and pasture land. Ample mosquito breeding habitat has been created, especially in areas of poor drainage. The mosquitoes in the valley are exposed to a variety of insecticides used by farmers and by the Coachella Valley Mosquito Abatement District (CVMAD). An investigation of insecticide resistance in mosquitoes in this area, currently in progress, has revealed considerable disparities in the levels of resistance exhibited by the species involved. It was therefore considered likely that this situation stems from certain differences in the biologies of the mosquito species which influence the extent of their exposure to insecticidal selection in the field. A study was undertaken to explore this hypothesis.

A number of studies have already been conducted on the biology of mosquitoes in the Coachella Valley and surrounding areas (Chew and Gunstream 1970, Gunstream and Chew 1964, Gunstream and Chew 1967, Hagstrum 1971, Hagstrum and Gunstream 1971); however, the phenological and spatial relationship of both larval and adult stages of mosquitoes in the valley does not appear to have been investigated. This report presents the seasonal and spatial distributions of *Culex tarsalis* Coquillett, *Culex pipiens quinquefasciatus* Say, and *Culiseta inornata* (Williston) larvae and adults in the Coachella Valley, and discusses their influence on the extent of insecticidal exposure of the species.

METHODS AND MATERIALS

DESCRIPTION OF STUDY AREA. The Coachella Valley covers approximately 570 square miles and ranges in elevation from —232 feet at the Salton Sea to 1000 feet at the western end. Mosquito breeding habitats are diverse, but relatively distinct. In this study the valley was roughly divided into three areas (designated as A, B, C) each containing a predominant type of breeding habitat (Fig. 1). A description of each study area follows.

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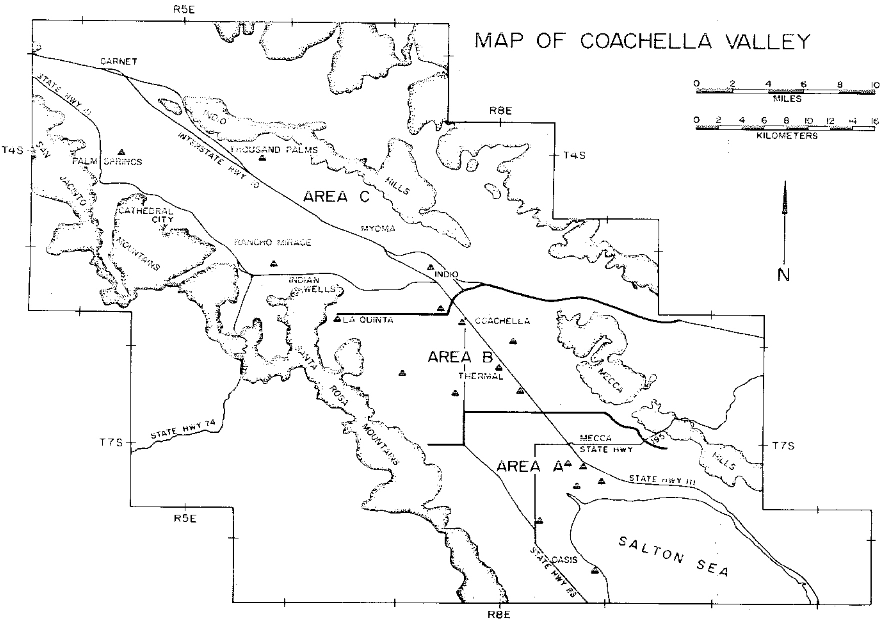

FIG. 1.—Map of the Coachella Valley showing study areas and location of New Jersey light traps (▲).

Area A. This area covers approximately 133 square miles. There are 22 miles of shore line along the Salton Sea with large seepage areas which breed mosquitoes. Lesser breeding habitats include duck club ponds, flowing wells, agricultural crops and their attending tail waters, pastures and flooded ditches. The seepage areas and duck ponds are usually dry in the summer. The human population is low.

Area B. This area is higher in elevation and covers approximately 103 square miles. It is away from the Salton Sea and therefore large seepage areas are absent. The mosquito breeding sources are predominantly of agricultural origin and include water reservoirs, wells, and the tail waters from pasture, alfalfa, citrus and date grove irrigation systems. The human population is higher than in area A, consequently more domestic breeding sources are available. Several cattle feedlots are also present.

Area C. This area is highest in elevation and encompasses 234 square miles. It includes several cities, and contains the highest human population of all three areas. The mosquito breeding sources are predominantly domestic in origin. Cesspools, curb waters, fish ponds, golf course lakes, sewage evaporation ponds, and water reservoirs are common. Few date or citrus groves exist.

COLLECTION METHODS. Larval collections are taken routinely by personnel of the CVMAD during surveillance activities throughout the valley. All permanent water sources and temporary breeding habitats are sampled for the presence of mosquito larvae which are identified to species in the laboratory of the CVMAD. For the purposes of this study, the frequencies of occurrence of larvae of each species were calculated from these surveillance records. The values given were obtained by dividing the number of samples containing each species by the total number of samples. Adult mosquito abundance was determined from counts of New Jersey light trap collections made by CVMAD personnel. Abundance values were calculated by dividing the total number of captured adult females of each species by the number of light traps and nights the traps were operative. The locations of light traps are shown in Fig. 1. The data cover the 5-year period 1968–1972.

INSECTICIDE USAGE. The data concerning insecticide applications were retrieved from the records of the CVMAD. Amounts given represent pounds of actual material applied. Formulated material is applied at the same rate against all mosquito species throughout the district, i.e. no one species is considered to be a primary target for these spray operations.

RESULTS AND DISCUSSION

The seasonal abundance of the three species throughout the valley is shown in Fig. 2. Adult abundance is generally congruent with larval occurrence. The peak of abundance for *C. inornata* adults occurred in November while the larvae of this species were most frequently collected in January. *C. tarsalis* and *C. p. quinquefasciatus* were most prevalent in the spring and fall, and exhibited summer and winter depressions in occurrence and abundance.

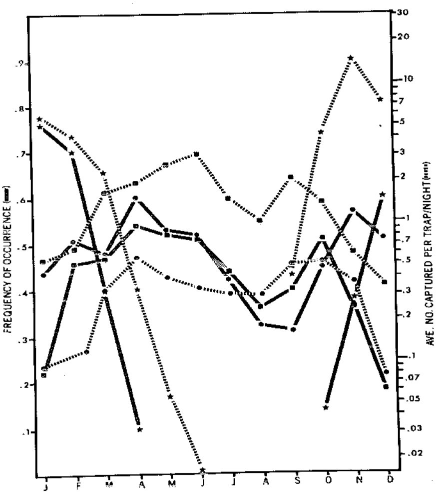

FIG. 2.—Abundance of adult female mosquitoes (– – –) and frequency of occurrence of larvae (——) throughout the Coachella Valley; *Culex tarsalis* (■), *Culex pipiens quinquefasciatus* (●), *Culiseta inornata* (★).

Although the adults of *C. tarsalis* and *C. p. quinquefasciatus* were present in the valley at different levels of abundance, the larvae of both species were collected with similar frequency. This apparent anomaly may be explained by the fact that the larval records concern the occurrence of each species in the samples, rather than its relative abundance. However, the data as presented illustrate the distribution of these species throughout the valley, which would tend to mask any spatial difference in occurrence and abundance.

In Table 1 is shown the occurrence of larvae of the three species in each study area. It is apparent that the frequency with which each species occurs in each area is different. *C. tarsalis* larvae were most frequently collected in area A (62% of samples) and least in area C (20%) while the occurrence of *C. p. quinquefasciatus* larvae was the opposite, i.e. highest in area C (78% of samples) and lowest in area A (22%). Larvae of both species were collected with similar frequency in area B. *C. inornata* larvae were found in a smaller percentage of the samples from each area, and appear to be distributed in the study areas at similar levels of occurrence (9–11% of samples). It is evident from the data in Figure 2 and Table 1

TABLE 1.—Number of mosquito larval samples (N) taken in each area, and percent of samples containing each species.

Area	N	*Culex tarsalis*	*Culex pipiens quinquefasciatus*	*Culiseta inornata*
A	1499	62	22	10
B	1679	45	40	11
C	982	20	78	9

that a disparity in temporal as well as spatial distributions exists among the three mosquito species in the Coachella Valley. This disparity is further substantiated by the detailed data for the phenologies and abundance of the species in each study area presented graphically in Figures 3–5.

An explanation for the differences in the phenological and spatial distributions of the species may be provided by their preference or fitness for specific environmental conditions. Shelton (1973) studied the growth and development of *C. inornata* and *C. p. quinquefasciatus* under various temperature regimes in the laboratory. The greatest percentage of *C. inornata* survived to the imaginal stage between 15° and 20° C, while the optimal temperature for *C. p. quinquefasciatus* survival was 23° C. In *C. tarsalis*, Hagstrum and Workman (1971) found the larval stages to be shorter at 30° than 20° C. Graham and Bradley (1969) report that *C. inornata* consistently inhabits pools lower in temperature than *C. tarsalis*. Thus, high temperatures appear to limit the distribution of *C. inornata* while the opposite is suggested for *C. tarsalis* and *C. p. quinquefasciatus*. This could explain the decrease in abundance of *C. inornata* and increase of *C. tarsalis* and *C. p. quinquefasciatus* with the approach of spring, and the occurrence of the opposite in the fall. The frequencies of occurrence of *C. p. quinquefasciatus* larvae were not depressed during winter months as greatly as those of *C. tarsalis*, which may indicate that *C. p. quinquefasciatus* is more tolerant of lower temperatures.

Both *C. tarsalis* and *C. inornata* were reported by Hagstrum and Gunstream (1971) to be widely distributed in waters of a broad range of ionic concentrations in contrast to *C. p. quinquefasciatus* which they found to be rather limited to waters high in ammonium and nitrate ions. Hagstrum and Gunstream (1971) attribute this to the preference of *C. p. quinquefasciatus* for polluted water which usually contains higher concentrations of these ions. In the present study a direct relationship was found between the distribution of *C. p. quinquefasciatus* and the presence of

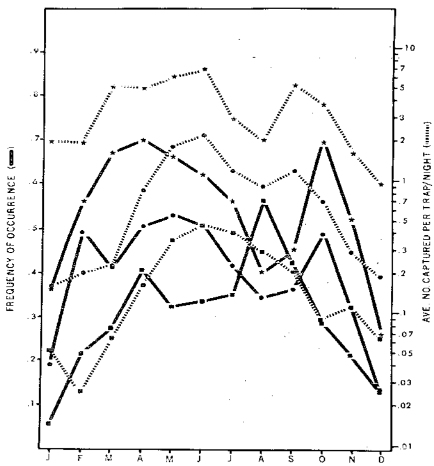

FIG. 3.—*Culex tarsalis:* abundance of adult female mosquitoes (– – –) and frequency of occurrence of larvae (——); area A (★), area B (●), area C (■).

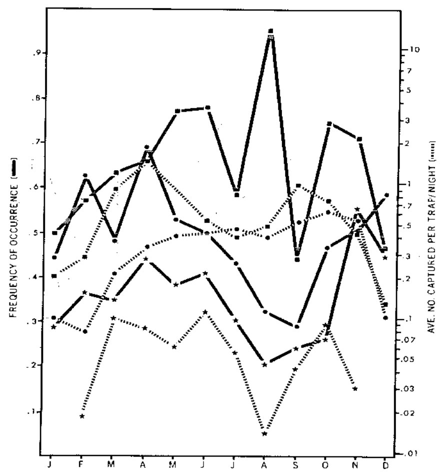

FIG. 4.—*Culex pipiens quinquefasciatus:* abundance of adult female mosquitoes (– – –) and frequency of occurrence of larvae (——); area A (★), area B (●), area C (■).

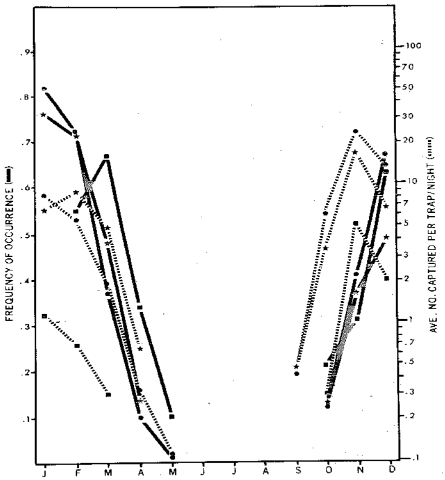

FIG. 5.—*Culiseta inornata:* abundance of adult female mosquitoes (– – –) and frequency of occurrence of larvae (——); area A (★), area B (●), area C (■).

breeding sources of domestic origin. However, the distribution of *C. tarsalis* appears to be incongruent with the broad tolerance of the species with respect to water quality. It is possible that the specific preference of *C. p. quinquefasciatus* for breeding sources of domestic origin enhances the competitiveness of this species over *C. tarsalis* in these habitats. In our laboratory at UC Riverside, *C. p. quinquefasciatus* was discovered on several occasions to have invaded and successfully dominated colonies of *C. tarsalis.* Thus, interspecific competition from *C. p. quinquefasciatus* could contribute to the lower occurrence and abundance of *C. tarsalis* in area C.

A general increase in the frequency of *C. p. quinquefasciatus* and *C. tarsalis* larval collections occurred in area C during August. This may reflect an increase in the amount of breeding habitat available in this area. Domestic use of water would undoubtedly increase during the summer months while natural sources would gradually diminish. In this regard, summer depressions in mosquito populations in the other areas may be due to a decrease in the availability of breeding sources rather than mortality from high temperatures.

The observed disparity in the geographical and temporal distributions of the three species may be expected to influence the extent of their exposure to insecticides. Table 2 shows the seasonal usage of insecticides over the study areas. The major portion of insecticide applications occur from May through October. Ethyl parathion is the larvicide used most extensively throughout the year, but only 5.34% of the total amount is applied during winter and early spring. Likewise, methyl parathion and fenthion applications do not begin until summer, and end in late fall. Use of naled, a mosquito adulticide, occurs principally in the spring and summer (95.54% of total). Consequently, a mosquito such as *Culiseta inornata* with a peak of abundance during the winter months (Fig. 2) would avoid exposure to the bulk of insecticides applied and would therefore be less likely to develop high levels of insecticide resistance. In contrast, *Culex tarsalis* and *Culex p. quinquefasciatus,* being prevalent in the spring, summer and fall (Fig. 2), would be exposed to the major portion of the insecticides applied and thus may both be expected to exhibit a high propensity for development of resistance.

This is, of course, assuming that the insecticides are applied uniformly throughout the valley. However, the available data indicate that the total amount of insecticides applied varies from one area to the other. For example, during 1971 and 1972 an average of 1.08 lbs. of larvicide was used per application in area B (9.78 acres/application), whereas only 0.60 lb. and 0.37 lb. were used in areas A (4.84 acres/application) and C (3.46 acres/application), respectively. Since the breeding habitats in area B are small and discrete the larger amounts of larvicide and acreage treated per application indicate that the same habitats were treated repeatedly. This would indicate that the

Table 2.—Seasonal usage of insecticides against mosquitoes in the Coachella Valley Mosquito Abatement District from September 1969 to December 1972.

Insecticide	total applied (lbs. a.i.)	Percent of total for each compound											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Ethyl parathion	2668.11	....	0.03	1.51	2.90	8.06	15.41	24.12	22.20	18.53	6.31	0.57	0.36
Methyl parathion	527.93	....	....	....	....	2.18	15.88	10.95	31.21	38.63	1.14	0.01	....
Fenthion	6122.26	....	....	....	....	....	0.05	0.39	3.05	78.62	6.86	11.03	....
Naled	1731.05	0.07	....	6.12	2.12	8.29	15.37	6.75	29.39	27.50	3.49	0.90	....

intensity of selection for resistance is greatest in area B, where *C. tarsalis* and *C. p. quinquefasciatus* both have high frequencies of larval occurrence. The mosquito populations in this area would be expected to exhibit high levels of resistance only if they successfully maintain their genetic integrity, i.e. there is no movement of adult mosquitoes between the study areas. However, both *C. tarsalis* and *C. p. quinquefasciatus* are capable of long flight (Bailey *et al.*, 1965; Dow *et al.*, 1965; Reeves *et al.*, 1948). In view of their spatial distributions, the dispersal of these species can be visualized as radiating from areas of abundance into peripheral breeding habitats. Any resistance contributed by individuals surviving the insecticide treatments would tend to be diluted by individuals emanating from the less heavily sprayed areas. Thus, insecticide resistance in *C. p. quinquefasciatus* would be diluted by the dispersal of mosquitoes from the less heavily treated area C, where this species is most abundant. Contrary to this, *C. tarsalis* dispersal from the more heavily treated area A, where it is most abundant, would have a less deleterious effect on resistance in this species. The data for insecticide usage in each study area presented above and the spatial distributions of *C. tarsalis* and *C. p. quinquefasciatus* (Table 1) indicate that, overall, a larger portion of the *C. tarsalis* in the valley is under heavy insecticidal pressure relative to *C. p. quinquefasciatus*. An additional factor to be considered is the persistence of toxic residues in mosquito breeding habitats. The toxicities of several OP compounds, including methyl parathion, parathion and fenthion, in the polluted water habitat of *Culex pipiens* L. have been shown to be reduced as a result of adsorption to organic matter and inactivation by microorganisms (Hirakoso and Uchida 1966, Yasuno *et al.*, 1965). It is likely that this would occur in the polluted water habitat of *C. p. quinquefasciatus* in area C, where breeding sources of domestic origin predominate. These situations, combined with population mixing achieved through adult dispersal would be expected to provide the impetus for development of higher levels of resistance in *C. tarsalis*. The spectrum of resistance exhibited by the three species will be presented in a subsequent paper.

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