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BIONOMICS AND MANAGEMENT OF PEST MOSQUITOES AT THE AGRO-URBAN INTERFACE SANTA CRUZ VALLEY, ARIZONA

The University of Arizona PH.D. 1985

BIONOMICS AND MANAGEMENT OF PEST MOSQUITOES AT THE AGRO-URBAN INTERFACE SANTA CRUZ VALLEY, ARIZONA

by

Kenneth James Kingsley

A Dissertation Submitted to the Faculty of the

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In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Kenneth James Kingsley

entitled Bionomics and Management of Pest Mosquitoes in the Agro-Urban Interface, Santa Cruz Valley, Arizona

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.

Dr. David Byrne	Date 9/3/85
Dr. L. Irene Terry	Date 9/3/85
Dr. Robert Smith (Dissertation Director)	Date 9/3/85
Dr. E. Lendell Cockrum	Date 9/9/85
Dr. R. R. Johnson	Date 9/3/85

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copy of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Dissertation Director	Date 9/10

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Citizens of the Santa Cruz valley contributed information about mosquito breeding sites and their complaints were an important measure of the success or failure of the project. Neil Johnson of Sahuarita provided especially useful information.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

The Santa Cruz valley in Arizona is a rapidly urbanizing area. Complaints by residents of the area about pest mosquitoes prompted the investigation of mosquito breeding sources and a search for management techniques that would reduce mosquito populations.

Many types of mosquito breeding sites were found in the area, and eight species of mosquitoes were identified. The greatest source of mosquitoes was a 2400 hectare irrigated pecan orchard. The most numerous and annoying mosquitoes were Aedes vexans (Meigen) and Psorophora columbiae (Dyar and Knab).

The orchard is irrigated ca. every two weeks from April through October by flooding level areas, called borders, between rows of trees. Mosquitoes hatched with every irrigation studied, from April through September, but reached annoying numbers from late April through mid-September. A. vexans was the dominant species in early spring and P. columbiae was dominant in summer. Highest populations were reached coincident with the summer rainy season in July and August.

Tests were performed to determine the efficacy of Bacillus thuringiensis israelensis (B.t.i.) as an additive to irrigation water for control of mosquito larvae. The larvicidal material was effective at all concentrations from .586 to 2.344 l/ha and with all techniques used. The most cost-effective application technique was to use fertilizer tanks to

drip a mixture of B.t.i. into irrigation water in ditches before the water ran into fields. The general rate of three parts larvicide per million parts irrigation water was found to be effective, especially when supplemented with a spray of one part larvicide to 64 parts water applied to the ends of borders two to three days following irrigation. An increase in larvicide concentration was found to be necessary during the peak of mosquito season.

A successful management program was developed and applied for 1 year, during which no mosquito complaints were made by citizens, the population of mosquitoes in the orchard was reduced to a point where farm laborers were no longer annoyed, and farm managers were satisfied that the program was cost effective.

INTRODUCTION

Pest mosquitoes of several species have long been known to breed in a variety of habitats created by irrigated agriculture (Barber et al. 1929, Rowe 1952, Hess 1958, Hayes and Nielsen 1978). Most of these are floodwater mosquitoes that breed in large numbers in temporary flood puddles and attack people and other warm-blooded animals near this breeding habitat. Although most species are not serious vectors of disease organisms, the severe annoyance and physiological reactions caused by their bites are a public health concern. Furthermore, a few species of mosquitoes that are potential vectors breed in habitats created by irrigated agriculture, although generally in smaller numbers than non-vector species. Generally the people affected by these mosquitoes are farmers and agricultural workers who live and work in the breeding areas, and many of them develop a tolerance of the pests as an inescapable part of their work. Mosquitoes have an adverse (but unmeasured) impact on the productivity and well-being of agricultural workers. They may also adversely affect growth rates for livestock near breeding sites (Steelman 1979).

In Arizona, much agricultural land has been, and will be, developed as residential areas for the State's rapidly increasing population. The mosquito population may increase as a result of the increased adult carrying capacity and the new residents are likely to be plagued by swarms of hungry mosquitoes. Although residential development of agricultural lands may eventually lead to a net reduction in mosquito breeding habitat area, this may take many years. Agriculture may continue to operate in close

proximity to the residential areas and continue to produce mosquitoes. Old irrigation ditches may persist after the area has undergone residential development and may still serve as mosquito breeding sites. New types of mosquito breeding habitats may result from residential development (Roberts and Dill 1983; Resh and Grodhaus 1983). Developments are frequently constructed with little or no attention to drainage, resulting in puddles that may make excellent mosquito breeding sites. Golf course ponds, sprinkler puddles, sewage treatment ponds, reservoirs, bird baths and other mosquito breeding sites provide alternative habitats for mosquitoes that have been displaced by the conversion of agricultural lands to urban use. The species composition of the mosquito fauna may change over time with available habitats. Without good management protocols, these changes may result in a net increase in mosquito populations and an increase in the relative abundance of potential disease vector species (Horsfall 1985).

The Problem

Along the Santa Cruz River, south of Tucson, the retirement community of Green Valley has grown within an agricultural area containing a 2400 hectare irrigated pecan orchard. Fig. 1 shows the general pattern of land use in the area. North of Green Valley, but still within the agricultural area, is the small community of Sahuarita. Fig. 2 illustrates the land use pattern in the Sahuarita area. The human population of the Santa Cruz valley has increased from a few hundred in 1965 to approximately 15,000 in 1985 and is expected to increase to more than 100,000 people in the next twenty years. At the same time, the valley still supports agriculture, which

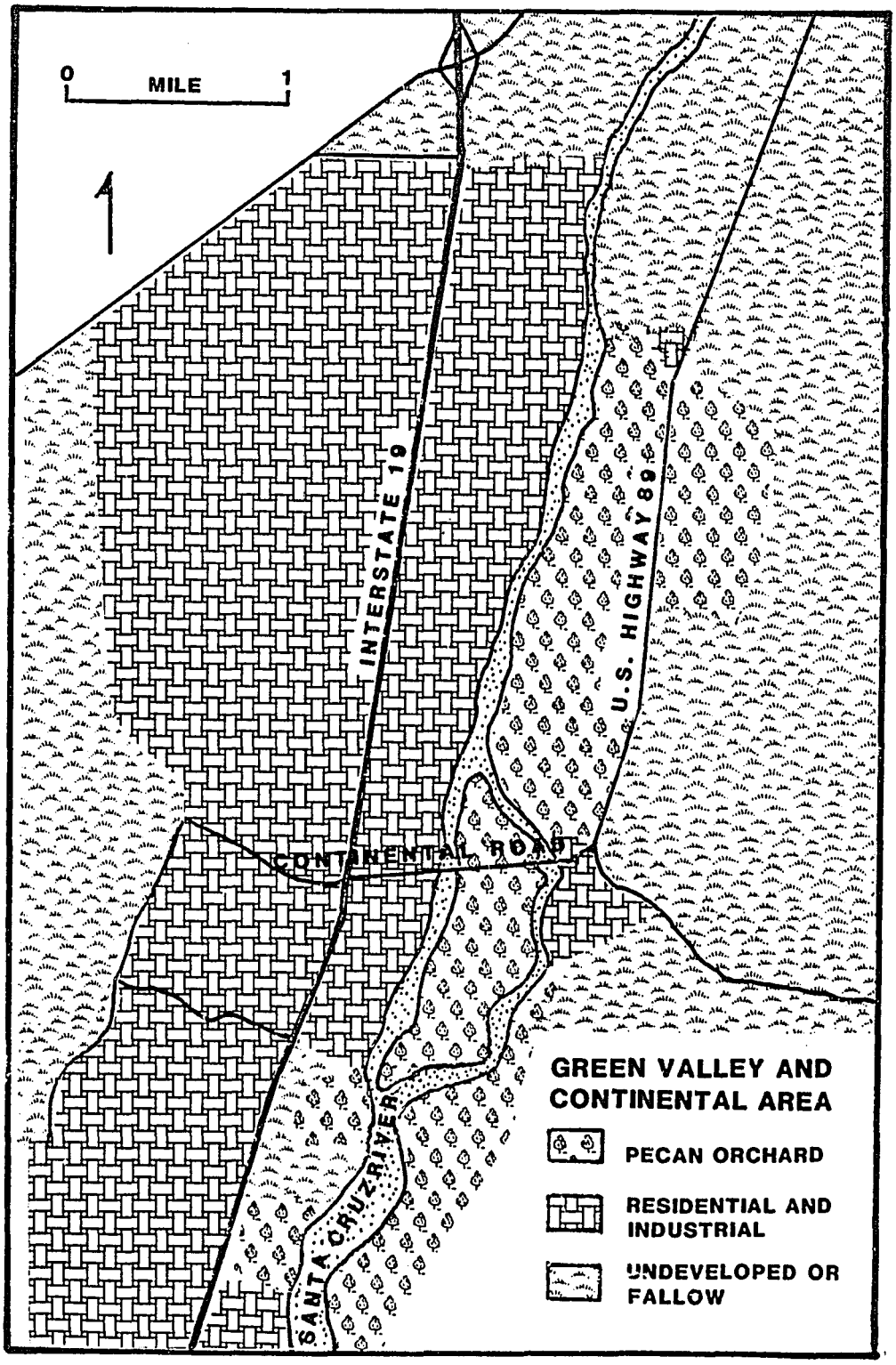


Fig. 1. Map of Green Valley and Continental Ranch

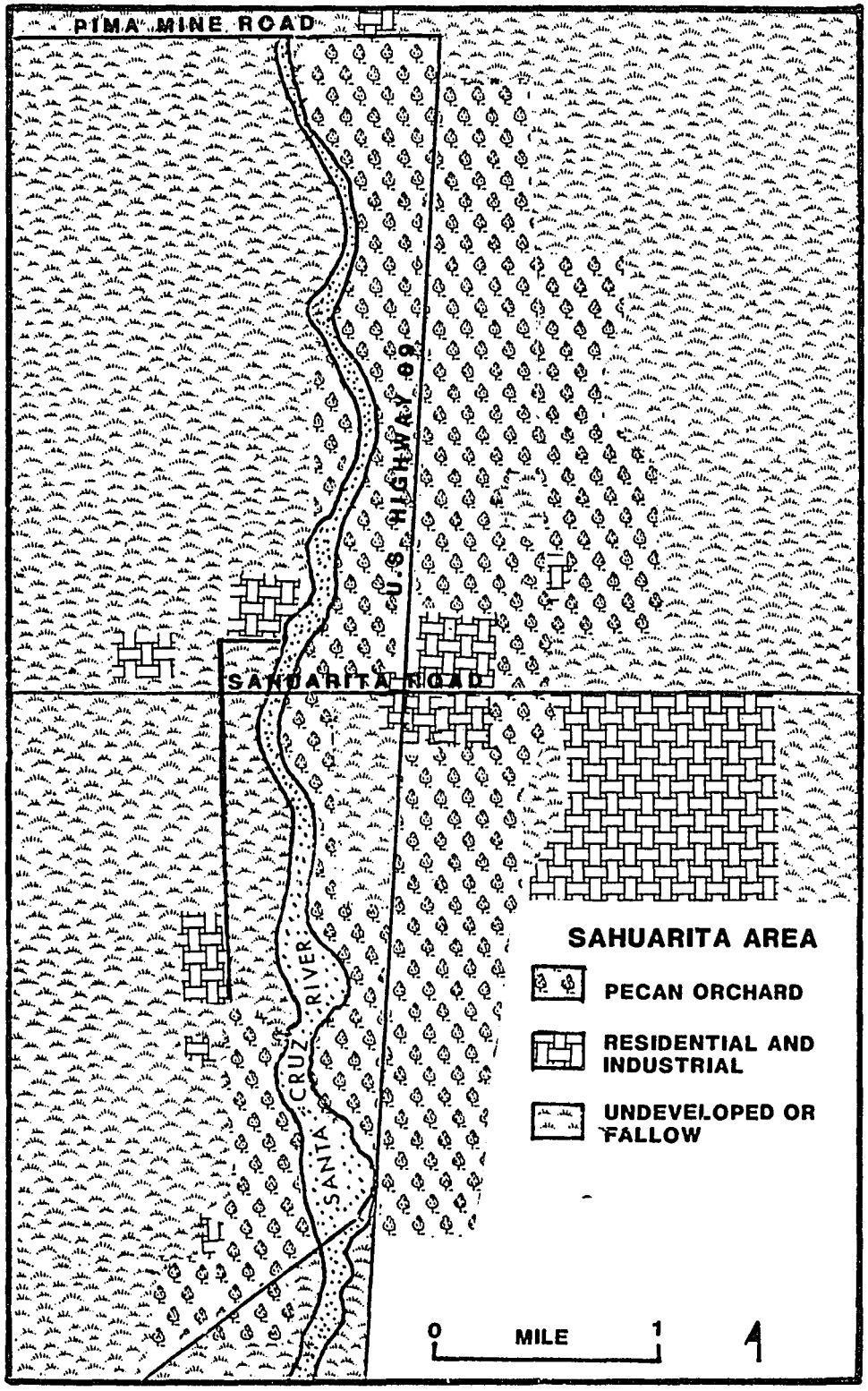


Fig. 2. Map of Sahuarita Ranch and Vicinity

is expected to continue indefinitely within parts of the the area that are either not suitable for residential development or have not yet been developed. Poor planning in the initial stages of urban development has resulted in serious drainage problems in the community of Green Valley that have created mosquito breeding sites. Better management of floodwaters will be required in the future development of the area, but the emphasis will be on flood prevention not reduction of mosquito breeding sites. Other potential mosquito breeding habitats in the area include mine tailings ponds and cattle watering ponds, which will also require more careful stewardship.

The number of complaints to the Pima County Health Department about the mosquito problem in Green Valley and Sahuarita have increased in recent years (J. Hensley pers. comm.). This is attributable in part to the increase in number of residents of the area, but also, long-term residents of the area have noted that the problem has intensified each year. Reasons for this are not clear, but may include weather conditions or may be a result of maturation of the habitat. Increases may also be the result of easier access to human blood meals for preoviposition females. Residents (pers. comms.) complain that they can not go outside their houses between sunset and sunrise during the warmer months of the year without being bitten by large numbers of mosquitoes. Use of recreational facilities is limited during mosquito season because of the swarms of mosquitoes.

Further development of the area is likely to be adversely influenced by the mosquito problem because present residents complain to prospective residents, and prospective residents discover the problem first-hand while visiting. Analysis of formal complaints to the Pima County Health

Department shows that residents closest to the pecan groves are most likely to complain. This indicates that the pecan groves provide the largest concentration of breeding and resting sites for mosquitoes and that the mosquitoes fly from the groves to feed on the first mammals encountered. Future development is planned within the area that is now in pecans, and the mosquito problem may be worse for residents of the planned developments than it has been for present residents. If this is the case, development plans and property values may be affected as a result of the mosquito problem. The severity of the mosquito problem may also influence zoning of land by planners and county authorities.

At the onset of this study, a solution to the mosquito problem was clearly needed, to reduce the anxiety of present residents and for the economic success of future development. The solution needed to be economically feasible and could not have adverse environmental impacts. In the past, control efforts had been adulticiding with chemical pesticides (K. Walden pers. comm.) in response to complaints. This had not been an effective solution. Suppression of adults diminished the problem for brief periods following treatment, but frequent treatment throughout the mosquito season was necessary. The growers were concerned about the pesticide load in the environment, particularly with the potential of agricultural pests developing resistance to the limited number of pesticides registered for use on pecans (K. Walden pers. comm.). No single control tactic was likely to be successful. Rather, an integrated pest management strategy was most likely to yield acceptable long-term results. It was clear that greatest emphasis

should be placed on reduction of the number of breeding sources and larviciding in sources that could not be eliminated.

Previous Control Efforts

The Pima County Health Department has conducted superficial investigations of the problem in response to complaints by local residents over the past eight years. The Vector Control Officer of the Pima County Health Department has conducted monthly light trap surveys at several sites in the area to gather specimens for arbovirus analysis by the Arizona State Health Department. He has also noted the locations of several breeding sites, and attempted to involve the owners of the sites in control programs, but these measures have had only limited success.

Previous control efforts have consisted primarily of adulticiding with malathion and other insecticides. These efforts were conducted in response to complaints through the Pima County Health Department, invariably after large numbers of mosquitoes had bitten residents. Whereas adulticiding has often had a dramatic short-term effect on adults, previously laid eggs are ready to hatch immediately following the next irrigation or rainfall. These control efforts have been limited to the pecan orchard, and have been performed by personnel of Farmer's Investment Company (FICO), the owners of the orchard. Other control efforts have been performed by the Pima County Vector Control Officer at sites outside the orchard, and have consisted of planting mosquito fish, Gambusia affinis, or larviciding with Pyrethrin Tossits^{R}, Flit^{R} Mosquito Larvicidal Oil, or Altosid^{R} briquets (G. Edwards pers. comm.). These larviciding techniques

have generally been effective when applied at the appropriate time. Most permanent bodies of water in the area, such as livestock ponds and golf course ponds, are stocked with mosquito fish and also contain large numbers of insect predators. Larviciding in temporary livestock ponds, roadside ditches, and flood puddles has been a consistent problem because the mosquito population development in them can occur very rapidly and a brood of mosquitoes can develop before control measures can be taken. (The county Vector Control Officer is solely responsible for all vector control activities in Pima County.)

Biology of the Species

The species of mosquitoes found in the area by the Vector Control Officer include: Aedes vexans (Meigen) and Psorophora columbiae (Dyar and Knab) as the most numerous floodwater pest species, and Culex quinquefasciatus Say, C. tarsalis Coquillet, and Anopheles franciscanus McCracken as less common species that breed in standing water. Also present, but apparently less common and annoying are the floodwater species P. signipennis (Coquillet) and P. howardii Coquillet (G. Edwards pers. comm.). The only vector-borne disease isolated from the area was one case of Western Equine Encephalitis in a horse found in 1980 at Sahuarita. (G. Edwards pers. comm.).

A large body of previous research exists on all of these species in many different situations, but there are apparently no published reports of mosquitoes breeding in irrigated pecan orchards and very little information specifically addressing mosquito problems at an agro-urban interface.

Although there is much literature on each of the species involved, little work has been done on the dynamics of seasonal fluctuation in species composition of mosquito faunas including these component species and on the comparative ecology of them. Previously published reports, discussed below, from other situations indicate that this combination of mosquito species occurs with some frequency in the Southern U.S. Extrapolation from the literature on the biology of the species strongly suggests that the combination of factors present in the Santa Cruz Valley appears to result in ideal habitat for these species and portends a chronic, progressively worsening problem in the absence of a comprehensive management program.

Curtis and Frank (1981) demonstrated that A. vexans has become established and developed to serious pest proportions in new citrus groves in Indian River County, Florida. Curtis (1985) studied habitat selection strategies of A. vexans, P. columbiae and P. howardii in Florida citrus irrigation furrows. He determined that A. vexans eggs were deposited higher in the furrow than those of the two Psorophora species, probably because A. vexans required water of longer duration to develop. Development times from egg to adult for these species in Florida were A. vexans: mean 8.0 days, range 5.0-17.0 days; P. columbiae: mean 5.5 days, range 4.08-8.0 days; P. howardii: mean 4.5 days, range 3.5-8.0 days. In his study, A. vexans eggs hatched and larvae were present any time the furrow was filled by irrigation, whereas the two Psorophora species hatched only during the months from May through December. The vegetation structure and irrigation regime of the citrus groves are similar to those of the pecan orchard. Citrus groves, however, are irrigated all year and water remains in furrows for

more than 2 weeks, whereas pecans are irrigated only from April through October and water typically remains in borders for less than one week.

Gunstream and Chew (1964) reported on the ecology of A. vexans in irrigated date groves in southern California. Al-Azawi and Chew (1959), Gunstream (1965), and Gunstream and Chew (1967) studied the ecology of P. columbiae (as confinnis) in these same date groves. Again, the vegetation structure and irrigation regime of the date groves is similar to those of the pecan orchards. Gunstream and Chew (1964) found A. vexans selecting oviposition sites characterized by a canopy of shrubs or trees and a dense undergrowth of herbs (agricultural weeds). Al-Azawi and Chew (1959) pointed out that P. columbiae breeding sites were generally weedy areas. Gunstream and Chew (1967) demonstrated that at summer temperatures water need only persist 3 to 3.5 days to permit development of a brood of P. columbiae.

Meek and Olson (1976 and 1977) studied oviposition sites of P. columbiae in Texas ricelands, and discovered that cattle hoofprints and tire tracks were the most important oviposition sites for this species. Olson and Meek (1977) in laboratory tests corroborated by field studies demonstrated that this species selects oviposition sites on the basis of soil moisture content, selecting muddy soil. Strickman (1980 a & b, 1982) experimentally determined that A. vexans selected oviposition sites characterized by muddy soil that had previously been used by this species and shaded by a canopy of trees or large shrubs. Russo (1979) demonstrated experimentally that A. vexans selects oviposition sites characterized by a "wall" of some sort, that may include fallen trees, branches, stumps, or bunches of grass. Although he did not suggest it, the "wall" very probably can also be the elevated rows of

trees at the edges of irrigation borders and tire tracks in the borders. Bodman and Gannon (1950) demonstrated that A. vexans selected oviposition sites characterized by heavy soil under a partial canopy with a debris layer of duff.

The pecan orchards in the Santa Cruz valley create a canopy of trees on raised rows over irrigation borders that are intermittently flooded during the warmer months of the year. The system of irrigation is called the flooded level border system (D. Fangmeier, pers. comm.). Trees are planted on slightly raised rows. Between rows of trees are flat, level strips of land 10 m wide, called borders. Borders are flooded with irrigation water to depths of between 10 and 25 cm. The decision to irrigate is based on tensiometer readings (Walden 1970), and irrigation is done approximately every two weeks for each field. Because there are many fields, some are being irrigated at all times during the season. A general description of the orchard as an ecosystem appears in Kingsley (1985). Fig. 3 shows a typical flooded border between rows of trees. Within the orchard are numerous small sites with very heavy soil that do not permit easy percolation and at which puddles lasting more than four days are found. Because these sites are muddy, weed-cutting is often not feasible and, consequently, they develop dense stands of weeds. Tracks left by agricultural equipment are prominent features in the irrigation borders. In short, conditions appear ideal for the breeding of A. vexans and P. columbiae, on the basis of previously published descriptions of their breeding habits. The problem is further compounded by more than a dozen livestock watering ponds, several mine tailings ponds, and

Fig. 3. Mosquito Breeding Habitat in an Irrigation Border

many roadside puddles and ditches that may produce mosquitoes, although these provide less than ideal conditions for mosquito breeding.

The other species of mosquitoes found in the area (C. quinquefasciatus, C. tarsalis, A. fransciscanus, P. howardii, and P. signipennis) may have different breeding habitat requirements or may be able to breed in the same sites and under the same conditions as the previously discussed species. The two Culex species breed in catch basins, rain barrels, tanks, tin cans, storm drains, septic tanks, standing ditch water, sewage waters, and almost any artificial container that holds water (McDonald et al. 1973). Anopheles franciscanus breeds in ground pools, stock ponds, receding streams, and artificial containers such as large water tanks (McDonald et al. 1973). Psorophora howardii is most commonly found in open or partly shaded ground pools where rain or irrigation water has accumulated, and P. signipennis is found breeding in temporary ground pools in the desert, roadside ditches, and partly dried up stream beds (McDonald et al. 1973). Little or no published work exists on the comparative bionomics of these latter two species and their relationships to A. vexans and P. columbiae which are found breeding in the same habitats.

There is probably considerable ecological overlap of all of the mosquito species in the Santa Cruz valley study area. Some evidence suggests that competition is avoided by temporal partitioning (Shemanchuk 1959, Breeland and Pickard 1963, Chew and Gunstream 1970, Curtis 1985). The proximal factor influencing temporal separation may be preflood pemperature conditioning of the eggs (Gunstream 1965). Oviposition sites were found to differ between A. vexans and two Psorophora species in citrus

irrigation furrows (Curtis 1985). The more rapidly developing Psorophora species oviposited in a portion of the furrows that was flooded by rainfall as well as light irrigation, whereas A. vexans oviposited only in the portions of the furrows that would be flooded by heavy irrigation, insuring that water would be present throughout the longer period of development of the larvae.

Eggs may withstand repeated floodings at appropriate temperatures before hatching. Only a portion of the eggs present in the environment may hatch after any given flooding while others remain in diapause awaiting subsequent flooding (Gunstream 1964). Breeland and Pickard (1963) found that a sufficient number of overwintering eggs were present in soil to allow a substantial mosquito population to be produced through six consecutive floodings without additional eggs being deposited. Furthermore, they found that the population density did not decline steadily with successive floodings, as might be expected, but actually increased after five floodings with no additional oviposition. This would be of great survival value in the event that the first flooding was not of sufficient duration to permit full development of the larvae to adulthood. Furthermore, this differential hatching creates a problem in terms of mosquito control by requiring treatment with each irrigation until all eggs present in the soil have hatched and all of the resulting mosquitoes killed.

Knowing time of hatching may be important in determining the proper time of application of short-lived larvicidal materials. Eggs of floodwater mosquitoes generally hatch within a short time following flooding, provided temperature and other water conditions are appropriate (Borg and Horsfall

1953). Reduction in dissolved oxygen, usually resulting from microbial activity, appears to be an essential hatching stimulus. Horsfall et al. (1973) described laboratory studies reporting that all eggs of A. vexans hatched within 30 to 40 minutes following exposure to deoxygenated water. Following exposure to dilute nutrient broth at 35° C., all eggs hatched in eight hours, with most hatching within four hours. At 25°, 24 hours were required to hatch all eggs in the most concentrated nutrient broth, and only 25% of the eggs hatched after 24 hours exposure to the most dilute broth. This was attributed to rates of microbial activity, which are temperature and nutrient dependent. Under crowded conditions, all eggs hatched in three to four hours at all temperatures from 16° to 24°, whereas under less crowded conditions, fewer eggs hatched and the time required was longer. This was attributed to the effect of oxygen consumption by the embryos being greater under crowded conditions (Horsfall et al. 1973). Gjullin et al. (1950) found that rate of hatching following flooding varies with the degree of dormancy of embyros and with the temperature of water at the time of flooding. In May, hatching began in one hour following flooding with water at 21°, and 88% of eggs hatched in two hours. Gunstream and Chew (1964) found first instar larvae of A. vexans present in irrigated date fields in Southern California 15 minutes after flooding. In the laboratory, Gunstream (1964) found that 14-day old eggs of P. columbiae required up to six hours to hatch. Breeland and Pickard (1963), in field studies, found "general" hatching of several species including A. vexans and P. columbiae within two to three hours following flooding in May and June in Alabama. They found that both A. vexans and P. columbiae hatched in one to three hours.

The distribution of mosquito larvae within their habitat has been shown to be highly aggregated. Gunstream (1964) working with P. columbiae in date groves in California found no association between larval distribution and water depth, pH, or temperature. Distribution of larvae was not altered by water temperature variation in the range of 27 to 40° However, A. vexans larvae appeared to avoid temperatures over 37° He did find an association with substrate type. More larvae occurred over grassy substrates than over mud. He attributed the association to selective behavior by the larvae and suggested that the presence of plants in flooded areas must greatly increase substrate for microorganisms that are food for mosquito larvae. However, larval distribution over grassy substrates was highly variable. By sampling at irregular intervals from the lower (downstream) end of the flooded area towards the upper end, Gunstream found that larvae were more abundant in the lower portion than the upper portion. This, he concluded, was the result of passive transport of larvae by water current and increased oviposition at the lower end due to the greater duration of soil moisture.

Stewart, Miura and Parman (1983) found that most C. tarsalis larvae were found in the exit water end of rice fields studied in California. They suggested a revision of standard sampling patterns to take into account this distribution. No explanations for this concentration of larvae were postulated. Hocking (1953) studied the activities of A. communis De Geer in a forest pool near Churchill, Manitoba, Canada. He found that aggregations formed in shallow areas that received direct sunlight, but that they then moved to shaded areas after a few minutes. He also found that aggregations

appeared to select the highest temperature areas in the pool. Aggregations moved slowly around the pool during the course of the day. Iversen (1971) working with A. communis in a temporary pool in a Danish beech wood, found that aggregations were usually found in areas with temperatures approximating an optimum of 16° C., and that these were generally characterized by proximity to shore and presence of a mat of leaves on the water surface. Andis and Meek (1984) found that larvae of P. columbiae were highly aggregated in Louisiana rice fields and that before harvest over 93% of the larvae collected were found within 1 meter of the contour levees. Following harvest, no significant differences were found. They attributed this to oviposition behavior: prior to the first flooding, females deposited eggs near the levees, but following the first harvest, they deposited eggs along tire tracks as well as along levees. They also found changes in the distribution pattern as larvae developed. This they attributed to the process of dispersal and the operation of mortality factors. They concluded that a knowledge of spatial distribution of larvae would be useful in planning sampling schemes, enabling direction of effort to those areas with the highest densities of larvae or that were easiest to sample. Such knowledge might also contribute to our general understanding of the biology of the species studied.

Potential Management Strategies

Farmers' Investment Company expressed interest in managing their mosquito problem. The corporation recognized its immediate and long-term self interest in reducing mosquito populations. However, they expressed

several concerns that had to be taken into account. The plan needed to be cost-effective, not requiring large expenditures of funds or personnel for control measures. It needed to be readily integrated with farming operations and could not adversely affect pecan production or the environment. Corporation officials also expressed a desire to improve their corporate image in the community, which had suffered as a result of the problem.

An integrated management protocol might best be based primarily on source reduction (Shisler and Harker 1981) through the improvement of soils to prevent ponding of water and larviciding irreducible sources. The obvious advantages of these approaches are: they would effect long-term control at minimum expense, increase pecan production by soil improvement, and they would control mosquito populations while still at the harmless stage and before they could reproduce (larviciding). Adulticiding would be an emergency measure to occasionally augment larviciding that failed to achieve adequate depression of populations.

The simplest method of controlling mosquitoes in this situation might appear to be tillage of the soil. This buries eggs to a depth from which larvae cannot escape (Cooney et al. 1981). However, tillage would result in decreased pecan production by damaging feeder roots of the trees (Walden 1970a and b; Wolstenholme 1979). Killing larvae in the water would probably be more effective and economical than killing adults that have dispersed. Dense orchard canopy together with the high expense precludes aerial application of larvicides. The extent of the area to be treated (approximately 1400 ha.) makes larvicide application by ground spray equipment difficult and uneconomical. Addition of larvicidal agents to the

irrigation water at its origins prior to distribution into fields was deemed the most economical means to control larvae in this situation.

Several devices have been developed for the addition of mosquito larvicides to irrigation water. Smith and Geib (1949) described a device for dispensing DDT into irrigation water for control of Aedes species in alfalfa fields. Gahan and Noe (1955) reported the results of tests on several water-soluble organophosphorus insecticides applied by drip into rice fields in Arkansas. Sjogren and Mulla (1968) described the use of a device for dripping chemical larvicides into irrigation water to control mosquitoes of several species in a variety of situations. This device was improved by Sjogren et al. (1969). Mulla et al. (1969) conducted experiments to test larvicidal chemicals dripped into irrigation water for the control of Aedes species in irrigated pastures. They found the method highly cost-effective relative to other methods. This method had the added benefit of producing no drift, but required more material than would have been used in conventional ground or aerial application. Fredeen (1970) described a constant-rate liquid dispenser for use in blackfly larviciding. This system drips a steady flow of an unspecified larvicide into a stream. McLaughlin (1983) described a constant flow device for dispensing liquid mosquito larvicides to irrigation water which he tested in Louisiana rice fields. He used his device for adding a liquid formulation of B.t.i. to control larvae of P. columbiae. This achieved good results in small-scale experimental situations (McLaughlin and Vidrine 1984a). In a large-area operational test, McLaughlin and Vidrine (1984b) determined that the method could be successfully used to control larval populations of P. columbiae in rice fields, but operational dif-

ficulties included poor timing of treatments because of lack of communication between farmers and mosquito control personnel, variations in irrigation rates, and improper placement of equipment. Mosquito control efforts in these tests were performed by personnel of the local mosquito abatement district and not by farm personnel.

It is surprising that, considering the positive results produced by all of these studies, none of these techniques has become a standard procedure for the management of floodwater mosquitoes in irrigated crops or for testing new larvicides. Reasons for this are not clear, but may include resistance to new methods by workers in the field. In each of these cases, the devices for dripping larvicides required special equipment that was unfamiliar to farm workers. In Southwestern U.S. pecan groves, farm workers are familiar with the use of fertilizer dripping tanks for the addition of liquid fertilizer to irrigation water (Fig. 7). The subject operation had several dozen of these tanks, which were supplied free by the fertilizer manufacturer. In this study, the familiar fertilizer drip tanks were tested for the application of mosquito larvicides to irrigation water.

Potential Use of Bacillus thuringiensis israelensis

The bacterial larvicide Bacillus thuringiensis israelensis (B.t.i.) has shown considerable promise in a variety of situations. It has been effective against all species of mosquitoes tested, including those identified as pests in the Santa Cruz valley. Furthermore, it is relatively specific to mosquitoes, with little or no effect on non-target organisms except filter-feeding aquatic nematoceran Diptera at levels greatly exceeding

those required for mosquito control. B.t.i. is therefore a good choice to integrate with natural predator populations in pesticide-sensitive habitats.

History of B.t.i. Bacillus thuringiensis (B.t.) is a common, naturally occurring soil bacterium (Burges 1984). Formulations of B.t. have been used for more than 20 years in agriculture and forestry for control of lepidopterous larvae. These products are of such low mammalian toxicity that they are exempted from tolerances on food crops, may be applied up to the day of harvest, and have become popular with organic gardeners. No case of human intoxication resulting from B.t. exposure has been reported in over 23 years of use (Margalit and Dean 1985). Varieties of B.t. that have been useful against Lepidoptera have not proved to be effective against mosquitoes and other Diptera. In 1976, researchers in Israel discovered a naturally-occuring population of a variety of B.t. that was killing mosquito larvae in a temporary pond. This variety was isolated, identified and named as B. t. var. israelensis (B.t.i.). It was experimentally tested under a variety of situations, and developed as a commercial product by several companies. All presently available B.t.i. products are derived from cultures of the bacteria originally isolated from the pond in Israel (Margalit and Dean 1985). Presently, several companies in the United States make commercial formulations of B.t.i. Use of the product for mosquito and blackfly control is rapidly growing, particularly in situations where conventional chemical control might adversely impact nontarget organisms.

B.t.i. is a stomach poison which must be ingested by target organisms in order to be effective. Mosquito larvae are filter-feeding aquatic animals that consume bacteria, yeasts, algae, and particulate

organic material. When mosquito larvae consume B.t.i., rapid destruction of the lining of the midgut ensues, resulting in death of the larvae (Lahkim-Tsror et al. 1983). Exact mode of action is not known, and the active consituents have not been completely characterized (Margalit and Dean 1985).

Efficacy in various environments. In experimental and practical applications over the past few years, B.t.i. has proved effective against practically all filter-feeding mosquito and blackfly larvae on which it has been tested. It has repeatedly been shown to be effective against P. columbiae and A. vexans in a variety of situations. Presently, commercial formulations of B.t.i. are being used for management of pest mosquitoes in fish ponds (Mulligan and Schaefer 1981), freshwater marshes (Mulligan and Schaefer 1983), saltwater marshes (Webb and Dhillon 1984; Merriam and Axtell 1983; Purcell 1981), snowmelt pools (Fanara et al. 1984; Eldridge et al. 1985), duck ponds (Mulligan and Schaefer 1983; Garcia et al. 1983), rice fields (Lacey and Inman 1985; McLaughlin and Billodeaux 1984; Stark and Meisch 1983), and irrigated pastures (Garcia et al. 1983; Mulla et al. 1983). In Arizona, current large-scale applications of B.t.i. include: marsh areas in Mohave and Yuma counties for control of mosquitoes (J. Dahl pers. comm.) and in Bullhead City for blackfly control (G. Bohmfalk pers. comm.).

Nontarget organisms. Numerous tests have determined that B.t.i has no measurable detrimental effects on nontarget organisms with the exception of closely related aquatic dipteran larvae such as chironomids. Garcia et al. (1980) reported acute toxicity tests on more than 40 nontarget species of aquatic animals exposed to B.t.i. in concentrations greatly

exceeding those recommended for mosquito control. These included amphibians, fish, crustaceans and many species of aquatic insects. Predatory animals were fed mosquito larvae that had fed on B.t.i.. Toxic effects were observed only in filter-feeding Culicidae (mosquitoes), Simuliidae (blackflies), and midges in the families Dixidae, Chironomidae, and Ceratopogonidae. Garcia et al. (1981) tested dosages up to 100 times the rates needed for effective mosquito control on 23 species of aquatic organisms and found no effects on nontarget species except Diptera larvae. Miura et al. (1981) conducted field tests of B.t.i. at concentrations known to be effective against mosquitoes. They found no adverse effects on nontarget organisms, including Gambusia and several species of crustaceans. Dipteran larvae, chironomids and psychodids were killed at higher than recommended dosages. Mulla et al. (1982) reported no adverse effects on mayfly and dragonfly naiads, adult and larval diving beetles, and ostracods at concentrations two to five times that required for mosquito control in small experimental ponds.

No studies of long-term repeated applications at mosquito-larvicidal rates have appeared in the literature. It is highly unlikely that there would be any direct effects on nontarget organisms. Indirect ecological effects, especially shifts in trophic pattern by predators, may occur, but likewise have never been addressed in the literature.

Formulations and Applications. Presently available formulations of B.t.i. include: Teknar^{R} Water Dispersible Concentrate, Teknar^{R} High Potency Dispersible, and Teknar^{R} Granules, manufactured by Zoecon Corporation;

Bactimos^{R} Briquets, Bactimos^{R} Granules, Bactimos^{R} Wettable Powder, and Bactimos^{R} Flowable Concentrate, distributed by Biochem Products; and Vectobac^{R} Granules and Vectobac^{R} Aqueous Suspension, manufactured by Abbott Laboratories. Application techniques include: conventional ground spray, conventional aerial spray, ULV aerial spray, and drip into irrigation water for liquid and wettable powder formulations, and broadcast by air or ground granule spreaders for granular formulations. As far as is known, all formulations are effective and safe when applied to the appropriate situations at the proper rates.

McLaughlin (1983) tested B.t.i. as a drip in irrigation water in Louisiana rice fields with good results. McLaughlin and Vidrine (1984a) examined the distribution of B.t.i. from a point source in irrigated rice fields and found that there was larvicidal effectiveness throughout a large area but that effectiveness declined with distance from the point source. The hydrodynamics in the rice fields are different from those in the pecan orchards, but it is likely that the same general principles apply to both systems (McLaughlin pers. comm.).

Zoecon Corporation, producers of Teknar^{R}, provided the material and funding to test their products in this situation. Two formulations, Teknar^{R} WDC and Teknar^{R} Granules were tested.

Significance of this Study

The mosquito problem in the Santa Cruz Valley presents several opportunities for novel and useful investigations. Mosquito problems at agro-urban interfaces have been little studied, especially in new housing

developments that convert agricultural land to urban use in the Southwestern United States (Roberts and Dill 1983; Resh and Grodhaus 1983). There have been no published studies on mosquitoes in pecan agriculture, and few on mosquitoes in other tree crops (Curtis 1985; Curtis and Frank 1981; Gunstream 1964, 1965; Gunstream and Chew 1964, 1967; Al-Azawi and Chew 1959). Because of the small amount of land used for irrigated pecan culture, no previous studies have been made of mosquito control techniques in this crop, and no chemicals have been specifically tested on these insects in this crop. Previously published studies of floodplain mosquitoes in agricultural situations, have dealt with crops having irrigation regimes different from that used for pecans. Biological data on species composition and succession in mosquito populations produced by irrigated agriculture are rare. An understanding of the distribution of mosquito larvae in their habitat is necessary as a foundation for the development of meaningful sampling schemes and evaluation of control efforts. Drip application of larvicides has seen little study, and drip application of B.t.i. in irrigation water has only been studied in rice fields. The development of a mosquito management program based upon the efforts of farm workers rather than mosquito abatement personnel and the use of equipment that is already a part of agriculture is apparently unique. And finally, the cooperative nature of this project appears to be unique: cooperation of persons from agriculture (FICO), industry (Zoecon), government (Pima County Health Department), academia (the University of Arizona), and the citizens of the Santa Cruz valley communities may serve as a model for future problem-oriented research in an agro-urban interface.

Objectives of this Study

The objectives of this study were: 1. determine the species of mosquitoes creating a problem in the Santa Cruz valley; 2. monitor the levels of populations of pest mosquitoes over time; 3. ascertain seasonal abundance of species; 4. locate the breeding sites of these mosquitoes; 5. study the comparative ecology of species; and 6. test methods of managing mosquito populations, specifically test the efficacy of several application methods of two formulations of Teknar^{R}.

The ultimate objective was to use the information gained in the study to develop a comprehensive integrated pest management plan to mitigate the mosquito problem in the Santa Cruz Valley and apply the plan to determine its viability.

METHODS AND MATERIALS

Bionomics

In the summer of 1982, a general mosquito survey of the problem area was conducted to determine the species of mosquitoes and their distribution in time and space. The procedures described below by life stadia were followed.

Adults

S.S.A.M. light traps as described by Driggers et al. (1980) (purchased from J.W. Hock Inc.) baited with dry ice (Newhouse et al. 1966), were placed at various locations in the area, primarily in the pecan groves. Data from these was supplemented by data provided by the County Vector Control Officer, who had regularly trapped adult mosquitoes in the area for several years. Additionally, adult mosquitoes were collected from human investigators and a dog when mosquitoes landed on them to bite. Biting collections were made with a simple glass tube aspirator (Service 1976), and placed in labeled vials of alcohol. Landing rate counts were made at each locality visited. Any data regarding adult mosquitoes, particularly data obtained by bite counts and trapping, is relative at best, and subject to considerable variability as a result of weather conditions, time of day, presence or absence of roosting sites, and stage in the life history of mosquitoes at the sampling locality, as well as by differences in the attractiveness of the baits used (Acuff 1976; Barr et al 1963; Bidlingmayer 1967; Feldlaufer and Crans 1979; Gojmerac and Porter 1969; Service 1977,

1976). These data were used only to identify species and to obtain a broad concept of the dynamics of mosquito populations.

Complaints of local residents to the Pima County Health Department were investigated. The address of each complainant was visited, several of the complainants were interviewed, and the vicinity searched for potential mosquito breeding sites. The location of each complaint was indicated on a map of the area. Additional records of complaints were obtained from the Pima County Health department over a period of several years, and the addresses were mapped. FICO personnel were interviewed in the field throughout this study, and questioned about locations at which mosquitoes were biting and the relative severity of the problem.

Larvae

Site Surveys. Breeding sites were investigated by examination of Pima County Health Department records of known breeding sites and by a general search of the area for locations that had not been previously known. U.S. Geological survey topographic maps (Sahaurita and Green Valley quadrangles) were examined for livestock ponds, tailings ponds, and other bodies of water, both permanent and temporary, that might be mosquito breeding sites. Area residents were encouraged, by means of newspaper and television news coverage and presentations at group meetings, to report known or suspected mosquito breeding sites. Each suspected potential site was examined at least once, and the citizens who reported the sites were interviewed. Each likely area was examined at least once at a time of year at which water was expected to be present. Mosquito larvae present in each site were collected by means of a standard pint dipper or a fine-mesh

aquatic net, transferred to alcohol-filled vials bearing locality data, and returned to the laboratory for identification. Estimates of the number of larvae present per dip were made by taking at least ten dips. Identifications were made using the key to the larvae in Carpenter and LaCasse (1956), with nomenclature updated by Knight and Stone (1977). Larvae that were in stadia before the fourth were kept alive in plastic cups in the laboratory and fed small quantities of powdered brewers' yeast until they reached the fourth instar because the available keys required this stage.

FICO personnel charged with irrigation were interviewed to determine specific locations within the orchard where water remained standing for more than three days following irrigation. Each of these sites was examined at least once on the third or fourth day following irrigation, when larvae were expected to be in the fourth instar, and mosquito larvae present were collected and identified. Additionally, almost every field in the orchard was at least superficially examined for breeding sites one or more times on the third or fourth day following irrigation. A few fields were selected for more intensive study, and checked following each irrigation throughout the season.

Finally, I drove extensively throughout the area during the summer rainy season, searching for roadside puddles, flooded culverts, old tires, and other potential breeding sites. Larvae found in each site were collected and identified, and the sites were described.

Bionomics of Mosquito Larvae in Irrigated Borders

Four pecan fields were selected for intensive study. Criteria for this selection were: ease of access, proximity to complainants, extensive

areas of breeding habitat, and the presence of large numbers of mosquitoes. Intensive study of these fields commenced in the spring of 1983 and continued through the summer of 1984.

Egg Distribution. To determine if eggs of mosquitoes were distributed in any consistent pattern within the pecan groves, samples of soil were taken from two fields on 16 March 1983. This was before the first irrigation of the season, so any eggs present would have been overwintering eggs. In each field, a sampling pattern as illustrated in Fig. 4 was followed. Borders to be sampled were selected randomly by computer (Hebbler 1979), given the number of borders in the field and the number of borders that I wanted to sample. Within each border, soil samples were taken from the base of the tree row, from a point in the center of the border, and from a point midway between the first two points, in a transect across the border. At alternate sampling stations, I alternated the side of the border that was the point of origin of the transect. Each border sampled had 3 transects, one at the low end of the border, one at the upper (ditch) end, and one in the approximate center. Leaves and surface debris were swept aside, then the soil sample taken. Samples were obtained by pressing a 63 mm diameter plastic jar into the soil to a depth of approximately 15 mm, twisting the jar, then lifting it with the contained soil sample. This gave a soil sample of approximately 63 mm diameter and 15 mm depth, or a volume of 46.8 cc. Each soil sample was placed in an individual plastic sandwich bag labelled with the location and date. A total of 63 samples was taken from each field. The soil samples were held in a storeroom in the laboratory until 17 June, when they were transferred to individual plastic cups and flooded with aged tap

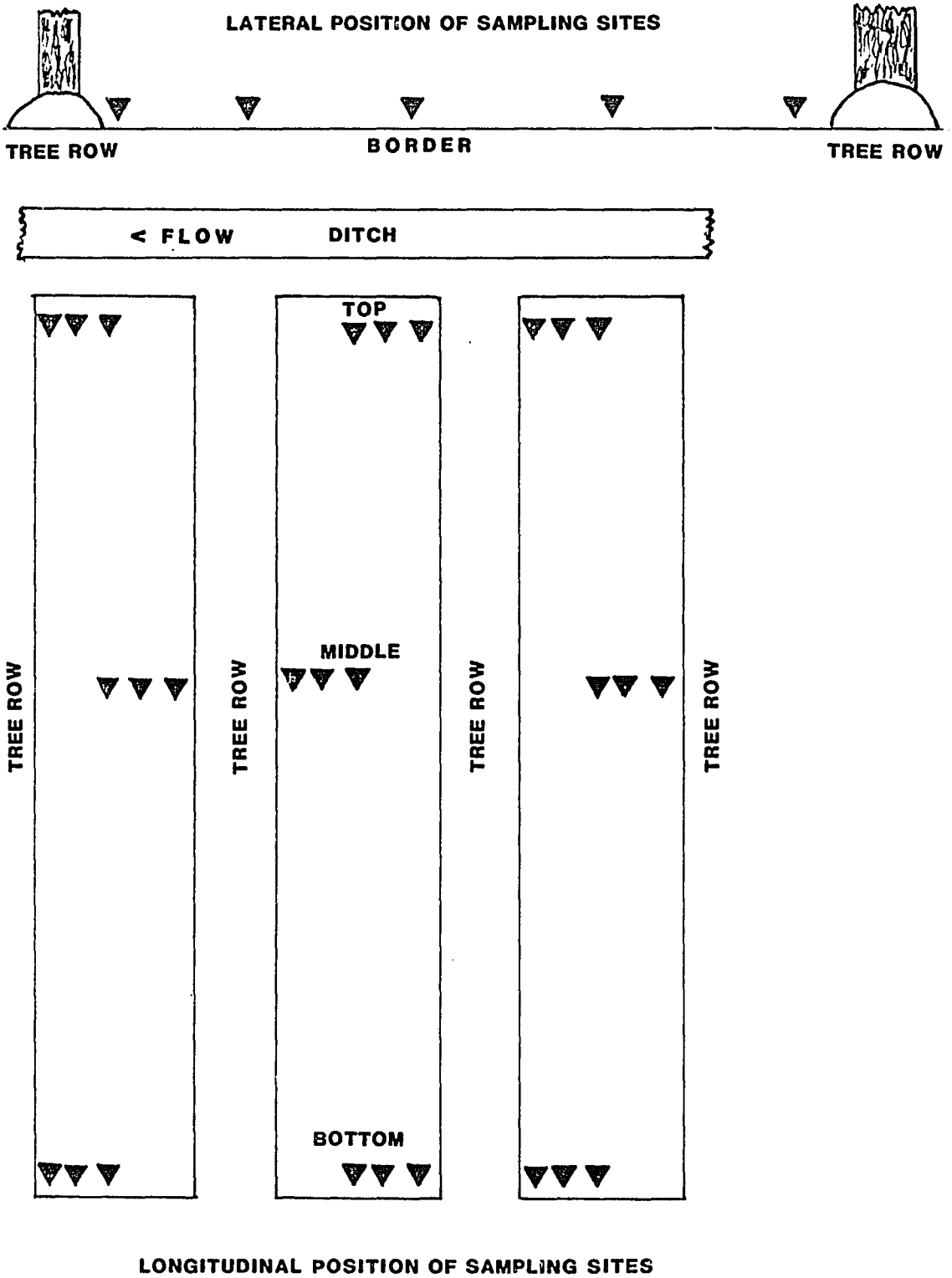


Fig. 4. Sampling Pattern for Eggs

water (allowed to age at least 24 hours in a galvanized metal cooler). Larvae that eclosed were transferred to vials of 70% ethyl alcohol and held for identification and counting. After the water had evaporated, the samples were flooded again on 29 August and larvae that eclosed were removed and held for identification and counting. A third flooding was done on 29 December, but no larvae eclosed.

Eclosion Time. An additional set of 57 soil samples was taken on 11 July 1983 from field 82NW, using a similar method but taking samples only from the bases of tree rows because the preliminary study indicated that this locus was most likely to yield eggs. The purpose of this second sample was to determine the time following flooding at which larvae first appeared in water. Soil samples were brought to the laboratory, placed in individual plastic cups and flooded to a depth of five cm with irrigation water obtained from a ditch at 30° C. The water was examined for larvae each hour for the first eight hours, and intermittently over the next 48 hours. Larvae were removed on first observation and preserved for identification. I recorded the hour at which larvae were found and the cup in which they eclosed.

Larva Distribution. Distribution of larvae in the flooded borders was examined to study effects of position in the border, water temperature, shade, water depth, and species associations. Four borders, previously found to contain larvae, were selected for this sampling. Sampling was done on 1, 18, and 24 June, 1983. Each border was sampled in transects of five sampling stations across its width, as illustrated in Fig. 5. The first station was at or near the tree row on one side, the third at the approximate center of the border, the fifth at the opposite tree row, and

the second and fourth stations were placed at midpoints between the first and third or third and fifth, respectively. Transects were spaced ten paces (ca. 7 m) apart, beginning at the bottom end of the border and continuing until 20 transects had been run or the end of habitat reached. At each sampling station, a standard pint dipper was used to remove a dip of water, the number of larvae in the dip was counted and the larvae preserved in ethyl alcohol in a labeled Whirlpak^{R} bag. Grid coordinates, water depth and temperature, and extent of shade (as total, partial, or none) were recorded for each dip. The presence or absence of a mat of vegetation debris (leaves and weed cuttings) was noted. These data were taken for 350 sampling stations. Larvae were subsequently identified in the laboratory.

Additional information on the spatial distribution of larvae was gathered in the process of evaluating control methods. The number of larvae per dip and the grid coordinates of each dip were recorded while I sampled to test the efficacy of the various treatments. In these evaluations, only ten transects per border were consistently sampled, and only the number of larvae per dip was recorded. Data from all borders sampled with ten or more transects were pooled to test for a consistent pattern of larval distribution. A total of 1300 untreated and 650 treated stations, at 26 untreated and 13 treated borders, were analyzed.

Data were analyzed by means of the Chi-square technique (Hebbler 1979) to determine if larvae had aggregated in relation to individual variables. Expected values for positive dips were calculated by using the row totals and column totals for each variable condition. Expected values for number of larvae were calculated for each condition by apportioning the

total of 402 larvae according to the number of total dips with that condition. For example, if ten percent of the total dips were in the temperature interval 15 to 20 degrees, the expected number of larvae would be ten percent of the total, or 40.2 larvae would be expected at that temperature interval if larvae were distributed without regard to temperature.

Management

Each active breeding site that was discovered during the survey phase of this project was evaluated to determine the best methods of mosquito management. Emphasis was placed upon managment methods that either eliminated the breeding site or used biorational methods such as mosquito fish or B.t.i..

Larvicide Tests

The most important breeding sites were in the pecan orchard, and most mosquito population management research was applied to this situation. As stated in the Introduction, Teknar^{R} was chosen as the larvicide to use in several experiments. Two formulations were tested: the commercial formulation of liquid Teknar^{R} Water Dispersible Concentrate (WDC) containing 1500 AA units per milligram and an experimental granular formulation designated SAN 402 I GR 68. An additional test using fenvalerate as a drip additive to irrigation water was performed. Fenvalerate was the chemical insecticide used by FICO for aphid control in 1983.

In the summer of 1983, I conducted a series of 15 larvicide tests. These tests are summarized in Table 1. With exceptions noted in the test descriptions, treated borders were compared to untreated control borders, either in the same field, or in nearby fields that were similar in soil type, weeds, and mosquito breeding history.

Bioassays. As part of the tests using liquid Teknar^{R} dripped into irrigation ditches, bioassays for larvicidal activity were attempted. Water samples were taken by dipping water present in borders on the day following application of Teknar^{R}. Three borders were selected for sampling for each treatment, one border at each end of the treated field, the third from the center of the field. Samples were taken at the bottom of each border and at intervals marked by every 5th tree (approximately 50 meters). Water was removed from the border with the standard mosquito larvae dipper and 100 ml of water from each site was placed in a labeled Whirlpak^{R} bag. Water samples were kept cooled in an ice chest and taken to the laboratory. Samples were then transferred to labeled wax paper cups and 10 2nd instar mosquito larvae were pipetted into each sample. Mosquito larvae were either collected from other locations on the farm, or raised from Aedes aegypti eggs provided by the U.S.D.A. Gulf Coast Mosquito Research Laboratory. Larvae were observed 24 hours following the start of the bioassay, and the percent mortality recorded for each sample. The locations from which effective larvicidal activity were observed were mapped.

Sampling technique. Border sampling was designed to include those nearest and farthest away from larvicide emitters and one or more at intermediate distances. Each border was sampled separately, and each

Table 1. Larvicide Tests Performed in 1983.

TEST NO.	MATERIAL	RATE l/ha	DEVICE	DATE	FIELD NO.	N ROWS	N DIPS	CONTRAST WITH
1	TEKNAR^R C	.586	FT	5/28	82NW	4	100	CONTROL
2	TEKNAR^R C	1.172	FT	7/4	82NE	3	150	CONTROL
3	TEKNAR^R C	2.344	FT	7/4	82NW	3	150	CONTROL
4	TEKNAR^R C	.586	FT	7/19	82NE	8	400	CONTROL
5	TEKNAR^R C	1.172	MCL	7/20	82NW	5	250	CONTROL
6	TEKNAR^R C	.586	B&G	7/19	82NE	1	50	BEFORE
7	TEKNAR^R C	.586	PS	8/8	82NE	4	200	CONTROL
8	TEKNAR^R C	1.172	PS	8/8	82NE	4	200	CONTROL
9	TEKNAR^R C	.586	PD	8/8	82NE	7	350	CONTROL
10	TEKNAR^R C	1.172	MCL	8/11	82SW	4	200	CONTROL
11	TEKNAR^R C	1.172	B&G	8/11	82NW	1	50	BEFORE
12	FENVAL.	.438	FT	9/11	82NE	5	250	CONTROL
13	TEKNAR^R G	3.3*	OS	7/17	82SE	2	100	BEFORE
14	TEKNAR^R G	5.6*	OS	8/10	82NW	1	50	BEFORE
15	TEKNAR^R G	6.7*	OS	8/4	82SE	1	50	BEFORE

ABBREVIATIONS: TEKNAR^R C= TEKNAR^R LIQUID CONCENTRATE; TEKNAR^R G= TEKNAR^R GRANULES; FENVAL.= FENVALERATE; FT= FERTILIZER TANK; MCL= MCLAUGHLIN DEVICE; B&G= B&G^R COMPRESSED AIR SPRAYER; PS= POURED AT SIPHON; PD= POURED IN DITCH; OS= ORTHO^R SEEDER. *=kg/ha.

treated border was considered a replicate of the treatment. An original pattern of sampling was applied throughout most of these experiments to prevent bias resulting from the aggregation of larvae selecting for unknown conditions. Using a standard mosquito dipper, I sampled in transects of five evenly spaced dips (Fig. 5) across each border, beginning at the bottom end of the border at the first place at which the water was sufficiently deep to allow a full dip to be taken (ca. 5 cm deep). Transects were spaced 10 paces (ca. 7 m) apart, working upstream until 10 transects had been sampled in each border, giving a total of 50 dips per border. Minor deviation from this pattern was occasionally necessary because of insufficient or patchy habitat. Major differences in sampling pattern are described in the sections detailing particular tests.

Data analysis. The number of larvae present in each dip was recorded as was the position of each dip. This system gave information on the spatial distribution of the larvae, which may be useful not only in understanding more about larval biology, but may also be useful in developing a simpler sampling technique (Stewart et al. 1983, Andis and Meek 1984)) and evaluating the effective distribution of larvicides (McLaughlin and Vidrine 1984a).

Mean number of larvae per dip, variance, total number of larvae in sample, the range of larvae per dip, and the number of dips with no larvae were calculated for each border and each treatment. Because larvae were found to be highly aggregated, nonparametric statistical techniques were chosen for hypothesis testing.

Sampling followed the grid pattern (Fig. 5). To simplify analysis, for each border I combined the number of larvae per dip at each of 10 stations, following the Latin Square design in Fig. 6. All dips from stations at "A" were added, then all from stations "B" and so forth. This gave five sums for each border. I then ranked these sums from smallest to largest for all treated and control borders used in each test. The 1-sided Wilcoxon rank-sum test (Lehmann 1975) was used to test the hypothesis that the treated borders had fewer larvae than untreated borders. In addition, the total number of dips that had no larvae was computed for each treated and untreated border. These numbers ranked from least to most and compared using the Wilcoxon rank-sum test of the hypothesis that the untreated borders had fewer dips with no larvae than treated borders. Finally, the mean number of larvae per dip sampled at each transect position were compared graphically, contrasting treated borders with untreated borders.

Effect of sampling. I sampled several borders at approximately the same stations twice to determine if the process of sampling in itself had an effect on the data obtained. The second dip was taken immediately following the first, with only sufficient time between dips to allow for counting larvae that were captured by the first dip. The standard sampling pattern was used, with 50 dips taken in each border. The numbers of larvae per dip were compared using the 2-sided Wilcoxon rank sum test (Lehman 1975) to test the hypothesis that the number of larvae in second samples was different from the number of larvae in first samples.

Changes from day to day. I sampled 4 borders at approximately the same stations 24 hours apart to test for the possiblity of change from one

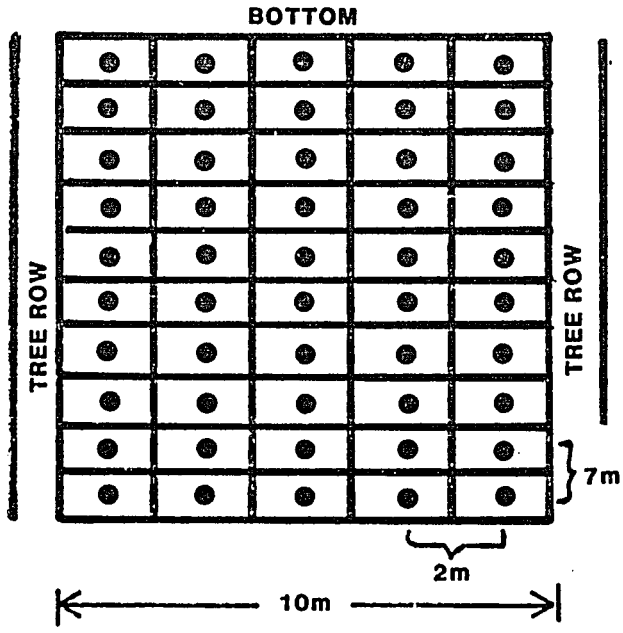


Fig. 5. Sampling Scheme for Larvae

A	B	C	D	E
B	C	D	E	A
C	D	E	A	B
D	E	A	B	C
E	A	B	C	D
A	B	C	D	E
C	D	E	A	B
E	A	B	C	D
B	C	D	E	A
D	E	A	B	C

Fig. 6. Orthogonal Latin Square

day to the next. The standard sampling pattern was used, with 50 dips taken in each border. The numbers of larvae per dip were compared using the 2-sided Wilcoxon rank sum test (Lehman 1975) to test the hypothesis that the number of larvae on the second day was different from the number of larvae on the first day.

Test No. 1. Teknar^{R} WDC was applied to field 82NW on 25 May at the rate of .586 l concentrate per hectare mixed with water to give a total of 757 l. The device used was the standard fertilizer tank (Fig. 7), which was set to drain the tank contents in approximately 12 hours. Irrigation began at 0700 hours and the Teknar^{R} drip was started at 1200 hours, before the front of the irrigation water had reached the bottoms of the borders. Sampling was done on 28 May, when fourth instar larvae were present. Four treated borders were sampled, with 25 dips (5 dips/transect) taken per border, for a total of 100 dips. Four untreated control borders in field 82NE were sampled on 1 June, with 4 transects per border taken to yield a total of 80 dips. This sampling predated development of standard methods, and consisted of beginning the first transect at the bottom of a border, continuing upstream in that border for 5 transects, then crossing to another border and working backward toward the bottom of the second border. Data from this trial could not be used in position analysis or in the standard Latin square design applied in later tests. Number of larvae per dip were compared by the Wilcoxon rank sum test of the hypothesis that the treated borders had fewer larvae than the control borders. The Wilcoxon rank sum test was also performed on the raw data to test the hypothesis that the

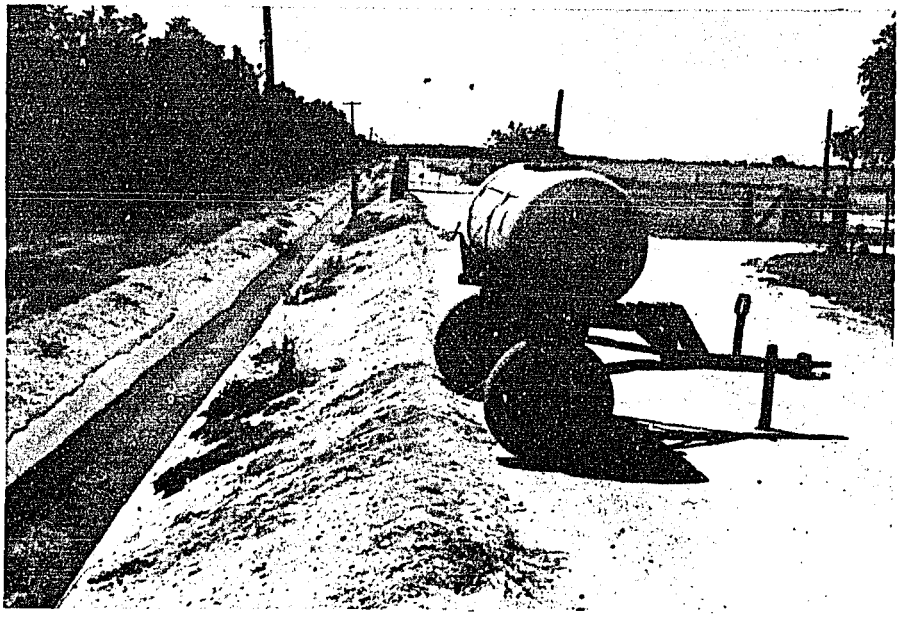


Fig. 7. Fertilizer Tank Used in Larvicide Tests

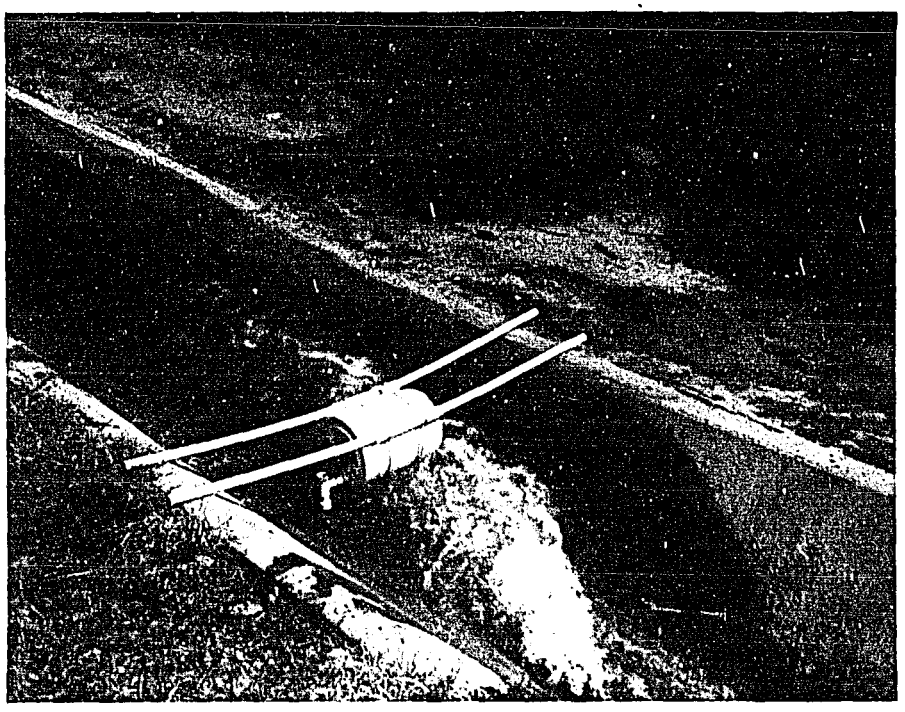


Fig. 8. McLaughlin Device Used in Larvicide Tests

number of dips with 0 larvae was greater in the treated borders than in the untreated borders.

Test No. 2. Teknar^{R} WDC was applied to field 82NE on 1 July at the rate of 1.172 l concentrate per hectare mixed with water to give a total of 757 l. The device used was the standard fertilizer tank, set to drain the contents in approximately 12 hours. Irrigation began at 0700 hours and the Teknar^{R} drip was started at 1900 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was done on 4 July, when fourth instar larvae were present. Three treated borders were sampled, by the standard sampling pattern, to yield a total of 150 dips. As a control, field 82SW was sampled on 8 July, when fourth instar larvae were present. Four untreated borders were sampled using the standard sampling pattern, giving a total of 200 dips. Raw data were transformed using the orthogonal Latin square technique, and the Wilcoxon rank sum test performed to test the hypothesis that the number of larvae present in the treated area was less than the number of larvae present in the untreated area. The same test was performed to determine if the number of dips with 0 larvae was less in the control borders than in the treated borders. The distribution of larvae within the treated and untreated borders was graphed.

Test No. 3. Teknar^{R} WDC was applied to field 82NW on 1 July at the rate of 2.344 l concentrate per hectare mixed with water to give a total of 757 l. The device used was the standard fertilizer tank, which was set to drain the contents in approximately 12 hours. Irrigation began at 0700 hours and the Teknar^{R} drip was started at 1900 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was done

on 4 July, when fourth instar larvae were present. Three treated borders were sampled, using the standard sampling pattern, to give a total of 150 dips. As a control, field 82SW was sampled on 8 July, when fourth instar larvae were present. Four untreated borders were sampled using the standard sampling pattern, giving a total of 200 dips. Data were processed in the same manner as those in Test No. 2.

Test No. 2 vs. Test No. 3. Data from the above two tests were compared to test the hypotheses: 1. treatment with 2.344 l/hectare resulted in fewer larvae than treatment with 1.172 l/hectare, and 2. treatment with 1.172 l/hectare resulted in fewer dips with 0 larvae than treatment with 2.344 l/hectare.

Test No. 4. Teknar^{R} WDC was applied to field 82NE on 16 July at the rate of .586 l concentrate per hectare mixed with water to give a total of 757 l. The device used was the standard fertilizer tank, which was set to drain the contents in approximately 12 hours. Irrigation began at 0700 hours and the Teknar^{R} drip was started at 1930 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was done on 19 July, when early fourth instar larvae were present. Eight treated borders were sampled, using the standard sampling pattern, to give a total of 400 dips. As a control, field 82SE was sampled on 15 July, when fourth instar larvae were present. Five untreated borders were sampled using the standard sampling pattern, giving a total of 250 dips. Data were processed in the same manner as those in Test No. 2.

Test No. 4 vs. Test No. 2. Data from the two above tests were compared to test the hypotheses: 1. treatment with 1.172 l/hectare resulted

in fewer larvae than treatment with .586 l/hectare, and 2. treatment with .586 l/hectare resulted in fewer dips with 0 larvae than treatment with 1.172 l/hectare.

Test No. 5. Teknar^{R} WDC was applied to field 82NW on 17 July at the rate of 1.172 l concentrate per hectare mixed with water to give a total of 19 l. The device used was as described by McLaughlin (1983) attached to a Teknar^{R} drum (Fig. 8). The device was calibrated to drain the entire 19 l in approximately four hours. Irrigation began at 0700 hours and the Teknar^{R} drip was started at 1930 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was done on 20 July, when fourth instar larvae were present. Five treated borders were sampled, using the standard sampling pattern, to give a total of 250 dips. As a control, field 82SE was sampled on 15 July, when fourth instar larvae were present. Five untreated borders were sampled using the standard sampling pattern, giving a total of 250 dips. Data were processed as in Test No. 2.

Test No. 5 vs. Test No. 2. Data from the two above tests were compared to test the hypotheses: 1. treatment with the fertilizer tank, which drained in 12 hours, resulted in fewer larvae than treatment with the McLaughlin device, which drained in four hours and 2. treatment with the McLaughlin device resulted in fewer dips with 0 larvae than treatment with the fertilizer tank.

Test No. 6 Teknar^{R} WDC was applied to the surface of the border between rows 27 and 28 in field 82NE on 19 July, when early fourth instar larvae were present. This border had not been treated with Teknar^{R} in Test No. 4, because it had not been irrigated at the same time as the remainder

of the field. Prior to treatment, I took 50 dip samples at 10 transects, following the standard sampling pattern. Then I applied the Teknar^{R} as a mixture with water at the rate of 30 ml/3.8 l, with a B&G^{R} compressed air sprayer, evenly applying the spray to approximate a rate of .586 l of material per hectare. The following day, I resampled the border, using the same sampling technique and taking samples from approximately the same locations as was done on the previous day. These data were compared using the Wilcoxon rank sum test of the hypothesis: the number of larvae present following treatment was less than the number of larvae present before treatment.

Test No. 7. Teknar^{R} WDC was applied to four borders in field 82NE on 5 August at the rate of .586 l concentrate per hectare. Application was made by pouring 118 ml quantities of concentrate in the borders at the point where siphons emptied. Irrigation began at 0700 hours and Teknar^{R} was added at 1600 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was conducted on 8 August, when third and fourth instar larvae were present. The treated borders were sampled, using the standard sampling pattern, to produce a total of 200 dips. As a control, four untreated borders in the same field were sampled on the same day by the same technique, for a total of 200 dips. Data were processed as in Test No. 2.

Test No. 8. Teknar^{R} WDC was applied to four borders in field 82NE on 5 August at the rate of 1.172 l concentrate per hectare. Application was made by pouring 237 ml quantities of concentrate in the borders where siphons emptied into the borders. Irrigation began at 0700 hours and

Teknar^{R} was added at 1600 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was done on 8 August, when third and fourth instar larvae were present. The treated borders were sampled, using the standard sampling pattern, for a total of 200 dips. The control and analysis were the same as in Test No. 7.

Test No. 9. Teknar^{R} WDC was applied to eight borders in field 82NE on 5 August at the approximate rate of .586 l concentrate per hectare. Application was made by pouring a 1.9 l quantity of concentrate in the ditch at a point two borders upstream from the first of the borders to be sampled. Irrigation began at 0700 hours and Teknar^{R} was added at 1630 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was done on 8 August, when third and fourth instar larvae were present. Seven treated borders were sampled, using the standard sampling pattern, to produce 350 dips. The control and analysis were as in Tests 7 and 8.

Test No. 7 vs. Test No. 8. Data from the two above tests were compared to test the hypotheses: 1. treatment with 1.172 l of concentrate per hectare resulted in fewer larvae than treatment with .586 l per hectare and, 2. treatment with the .586 l per hectare resulted in fewer dips with 0 larvae than treatment with 1.172 l per hectare.

Test No. 8 vs. Test No. 9. Data from the two above tests were compared to test the hypotheses: 1. treatment with Teknar^{R} poured at the siphon, which may have given more even distribution to the material, resulted in fewer larvae than treatment with Teknar^{R} poured in the ditch,

and 2. treatment with Teknar^{R} in the ditch resulted in fewer samples with 0 larvae than treatment with Teknar^{R} at siphons.

Test No. 10. Teknar^{R} WDC was applied to field 82SW on 8 August at the rate of 1.172 l concentrate per hectare mixed with water to give a total of 19 l. Application was by the McLaughlin (1983) device attached to a Teknar^{R} drum and calibrated to drain the contents in approximately four hours. Irrigation began at 0700 hours and the Teknar^{R} drip was started at 1930 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was conducted on 11 August, when fourth instar larvae were present. Four treated borders were sampled, using the standard sampling pattern, for a total of 200 dips. The control, field 82SW, was sampled on the same day, when fourth instar larvae were present. Four untreated borders were sampled using the standard sampling pattern for a total of 200 dips. Data were processed as in Test No. 2.

Test No. 10 vs. Test No. 8. Data from the two above tests were compared to test the hypotheses: 1. treatment with the McLaughlin device, which drained in four hours, resulted in fewer larvae than treatment with the material poured at siphons, with the same dose per hectare and 2. treatment with the material poured at siphons resulted in fewer dips with 0 larvae than treatment with the McLaughlin device.

Test No. 11. Teknar^{R} WDC was applied to the surface of the border between rows 17 and 18 in field 82NW on 10 August, when third instar larvae were present. This border had not been treated previously during this irrigation. Prior to treatment, I took 50 dip samples at 10 transects, following the standard sampling pattern. Then I applied the Teknar^{R} as a

mixture with water at the rate of 60 ml/3.8 l, using a B&G^{R} compressed air sprayer, at the rate of 1.172 l of material per hectare. The following day, I resampled the border, using the same sampling technique and taking samples from approximately the same locations as was done on the previous day. These data were compared using the Wilcoxon rank sum test of the hypothesis: the number of larvae present following treatment was less than the number of larvae present before treatment.

Test No. 12. Fenvalerate was applied to half of field 82NE on 8 September at the rate of 438 ml formulated material per hectare mixed with water to give a total of 757 l. The application device used was the standard fertilizer tank, which was set to drain the contents in approximately 12 hours. Irrigation began at 0700 hours and the fenvalerate drip was started at 1900 hours, after the front of irrigation water had reached the bottoms of the borders. Sampling was done on 11 September, when fourth instar larvae were present. Five treated borders were sampled, using the standard sampling pattern, for a total of 250 dips. Four untreated borders in the same field were sampled using the standard sampling pattern, for a total of 200 dips. Data were processed as in Test No. 2.

Test No. 12 vs. Test No. 4. Data from the two above tests were compared to test the hypotheses: 1. treatment with fenvalerate resulted in fewer larvae than treatment with Teknar^{R}, and 2. treatment with Teknar^{R} resulted in fewer dips with 0 larvae than treatment with fenvalerate. Because these tests were run at different times of the season, a 2-sided Wilcoxon rank sum test (Lehmann 1975) was performed on the data from the

controls of the two tests to determine if there was a difference between the controls of the two tests.

Test No. 13. Teknar^{R} granules were evenly applied with an Ortho^{R} seeder at the rate of 3.4 kg per hectare to two borders of field 82SE following preliminary sampling on 17 July. The border between rows 67 and 68 was irrigated on 14 July, and all larvae were fourth instar. The border between row 68 and the road was irrigated on 15 July, and the larvae were both third and early fourth instars. Both borders were sampled again, using the same technique, 24 hours following treatment. The Wilcoxon rank sum test was used to test the hypotheses: 1. borders had fewer mosquito larvae present 24 hours after treatment than before treatment; borders were tested individually as well as combined, because the larvae were of different ages; 2. borders had fewer dips with 0 larvae before treatment than after treatment; again, borders were considered individually and combined; 3. the border treated when larvae were in the third and early fourth instars had fewer larvae following treatment than the border treated when larvae were in the late fourth instar; and 4. the border treated when larvae were in the late fourth instar had fewer dips with 0 larvae than the border treated when larvae were in the third and early fourth instar.

Test No. 14. Teknar^{R} granules were evenly applied with an Ortho^{R} seeder at the rate of 5.6 kg per hectare to the border between rows 16 and 17 of field 82NW following a preliminary sampling of the border on 10 August. Larvae were in the late third and early fourth instars. The border was sampled again, using the same technique, 24 hours post treatment. The Wilcoxon rank sum test was used to test the hypotheses: 1. the border had

fewer mosquito larvae present 24 hours after treatment than before treatment and, 2. the border had fewer dips with 0 larvae before treatment than after treatment.

Test No. 15. Teknar^{R} granules were evenly applied with an Ortho^{R} seeder at the rate of 6.7 kg per hectare to the border between row 68 and the road of field 82SE following sampling of the border on 3 August. Larvae were in the late third instar. The border was sampled again, using the same technique, 24 hours post treatment. The Wilcoxon rank sum test was used to test the hypotheses: 1. the border had fewer mosquito larvae present 24 hours after treatment than before treatment and, 2. the border had fewer dips with 0 larvae before treatment than after treatment.

Test No. 13 vs. Test No. 14. Data from the two above tests were compared to test the hypotheses: 1. treatment with the 5.6 kg/ha resulted in fewer larvae than treatment 3.4 kg/ha, and 2. treatment with 3.4 kg/ha resulted in fewer dips with 0 larvae than treatment with 5.6 kg/ha. Controls (before application) of these two tests were also compared, using the 2-sided Wilcoxon rank sum test.

Test No. 14 vs. Test No. 15. Data from the two above tests were compared to test the hypotheses: 1. treatment with the 6.7 kg/ha resulted in fewer larvae than treatment with 5.6 kg/ha, and 2. treatment with 5.6 kg/ha resulted in fewer dips with 0 larvae than treatment with 6.7 kg/ha. Controls (before application) of these two tests were also compared, using the 2-sided Wilcoxon rank sum test.

Large-scale application tests. In June 1984, tests were performed to determine the efficacy and feasiblity of application of Teknar^{R} as a drip

in irrigation water on the very large scale, encompassing the entire 1800 hectares of the Sahuarita ranch. For these tests, liguid Teknar^{R} was applied as a drip from fertilizer tanks equivalent to three parts of Teknar^{R} concentrate per million parts of irrigation water, calculated on the basis of flow meters installed at the wells. McLaughlin (pers. comm.) found that 3 ppm was an optimum concentration for control of mosquitoes in rice fields. The tanks were set at or very close to the wells, with the drip emptying into the main ditches. The Teknar^{R} drip was begun between 1900 hours and 2000 hours. The experiment was run on two successive nights, 1 and 2 June. The first night, the 3 ppm concentration was run for four hours at all wells on the east side of the Sahuarita ranch and six hours on the west side. The second night, the flow was for 12 hours on the east side and water containing no Teknar^{R} was applied to the west side of the ranch as a control. Three days following irrigation, sampling for larvae was done. Instead of following the standard sampling pattern used in 1983, only three transects were run for each border, and three or four borders were sampled in each field. Analysis of previous data indicated that approximately 48 percent of all larvae to be found in treated borders were found in the first 3 transects. I concluded that sampling just three transects per border would yield sufficient data to allow making comparisons and would greatly increase the number of borders that could be sampled in a given amount of time. Because the objective of these tests was to determine the effect of large-scale treatment, I chose to sample as many fields as possible. I sampled 27 borders in nine untreated fields for a total of 415 dips, 25 borders in six fields treated for four hours (375 dips), 16 borders in four

fields treated for six hours (240 dips), and 15 borders in five fields treated for 12 hours (225 dips). The mean number of larvae per dip and the number of dips with 0 larvae were used as the test statistics for each border. These were assigned ranks. The Kruskal-Wallis test (Lehmann 1975) was used to test the hypotheses: 1) treated borders have fewer larvae than untreated borders, and 2) untreated borders have fewer dips with no larvae than treated borders have. Dunn's multiple comparison test (Dunn 1964) was used to test the hypotheses: 1) borders treated for six hours had fewer larvae than borders treated for four hours; 2) borders treated for 12 hours had fewer larvae than borders treated for six hours; 3) borders treated for four hours had fewer dips with no larvae than borders treated for six hours; and 4) borders treated for six hours had fewer dips with no larvae than borders treated for 12 hours.

Following the apparent success of these tests, a program of treatment using 3 ppm Teknar^{R} for four hours was instituted on the entire Sahuarita ranch. This was augmented by application of a concentration of one part Teknar^{R} to 64 parts water sprayed on borders two or three days following irrigation, using a powered single-nozzle tree sprayer. Borders selected for spraying were determined by visual inspection to have mosquito larvae present. Spraying was done by farm laborers, under instruction to attempt to evenly cover the bottom end of each border, reaching back approximately three trees into the tree line. This is roughly the equivalent of 1.172 l Teknar^{R} per hectare. Because the entire farm was being treated, no untreated controls were available, and evaluation of the effect of the treatment was done entirely on the bases of bite counts, casual dip

sampling, interviews with farm personnel and neighbors of the farm, and County Health Department records of complaints.

RESULTS

Bionomics

Survey of Mosquito Breeding Sites

Investigations began on 1 July 1982 and continued through 15 September. One hundred and sixty-four collections were made. A total of 46 sites were identified and examined. Additionally, a number of probable mosquito breeding sites were tentatively identified on the basis of soil and vegetation type, but larvae were not been collected from them because none were present on the dates on which the sites were examined.

Types of sites examined were: livestock watering ponds, livestock watering troughs, urban drainage ditches, golf course ponds, mine tailings ponds, road ditches, road puddles, roadside puddles, railroad grade puddles, sprinkler puddles, tire tracks, old tires, standpipes, irrigation ditches, irrigation overflow ponds, and orchard borders. Not all of these contained mosquito larvae, and many of them contained larvae on some dates of examination and not on others. The most widespread, extensive, and consistently productive sites were orchard borders. Each class of site will be discussed briefly below. Orchard borders will be considered last and most extensively.

Livestock Watering Ponds. Eight livestock watering ponds were examined. One of them was checked 10 times, the others only once each. These ponds are unpredictable as mosquito breeding sites. Permanent ponds in the area have been stocked with Gambusia and support large numbers of

native insect predators on mosquitoes. No mosquito larvae or adults were found at the permanent ponds examined. Temporary ponds may hold water for only a few weeks each year, and may be completely dry between fillings. Sometimes when they are filled, large numbers of mosquitoes may be present. At other times, there may be no mosquitoes but numerous predatory insect larvae and/or potential competitors with mosquito larvae, such as fairy shrimp (Anostraca), may be found. Mosquito species found at livestock watering ponds were Psorophora columbiae, P. signipennis, and Aedes vexans.

Livestock watering troughs. No mosquitoes were found in the four livestock watering troughs I examined. Numbers of backswimmers (Hemiptera: Notonectidae) were present in the the troughs and probably were effective mosquito control agents. These troughs were checked only once each, so they may sometimes be mosquito breeding sites.

Urban drainage ditches. Drainage ditches in the urban Green Valley development were examined periodically for standing water, and those containing water were checked for mosquitoes. Water ponds in drainage ditches only where they are blocked or where basins have been formed by erosion. Filling of the ditches is unpredictable because it depends on rainfall runoff. Only one appeared to be an important mosquito breeding site. It contained larvae of P. columbiae and P. signipennis.

Golf course ponds. Most of the golf course ponds contain large populations of fish or insect predators and few, if any, mosquito larvae. Predators appear to be effective as mosquito control agents in this situation. Only one collection of mosquito larvae was made from a golf

course pond, despite repeated examination of several ponds. The larvae collected from this one pond were Anopheles franciscanus. They were found in a small shallow area of the pond with dense emergent vegetation. Very few larvae were present.

Mine tailings ponds. Several mine tailings ponds, each less than 500 m^2 in area, are located about 1 km west of the urban area. Portions of these fill with rain and runoff water from the large areas of tailings which are devoid of vegetation and make a rather impermeable surface. Filling is intermittent and unpredictable. These ponds were found to be potentially important breeding sites for mosquitoes, with dense populations of P. columbiae larvae in those that I examined. Apparently the ponds are not used by livestock or much wildlife, and they do not drain.

Road ditches. These sites have many of the same characteristics as urban drainage ditches, which makes control of breeding mosquitoes difficult. Only two were found to contain water and mosquito larvae during the course of this investigation. Both contained P. columbiae larvae. Undoubtedly, there are many more road ditches that breed mosquitoes, but they have not yet been identified.

Road puddles. Only one road puddle was found to contain mosquito larvae in the urban area. This is a cul-de-sac that receives runoff water from an area of several blocks and allows water to pond for several days. Larvae of P. columbiae were found in it.

Roadside puddles. These are common throughout the area following heavy rains, and some may be significant mosquito breeding sites. Five of them were examined, and four were found to contain larvae of P. columbiae .

Railroad Grade Puddles. A number of large puddles form along the railroad grade in Sahuarita, near the intersection with Helmet Peak Road. These puddles produced very large numbers of P. columbiae larvae.

Sprinkler puddles. Only one chronic sprinkler puddle was examined, but this type of site may be widespread. Unfortunately, this type of site is also difficult to locate. At the one site examined, the County Sewage Treatment Plant, larvae of Culex tarsalis and C. quinquefasciatus were found.

Irrigation ditches. Most of the presently used irrigation ditches on the FICO property are unsuitable for mosquito breeding because they are cement lined, kept clean, and are quickly drained following use. A few old ditches, not cement lined and not consistently maintained, do support mosquito breeding. Mosquito species found breeding in substandard ditches were: P. columbiae , P. howardii, A. franciscanus, and C. tarsalis.

Irrigation overflow ponds. Only three overflow ponds were found on the FICO property. All three of these ponds are mosquito breeding sites, and two of them are located close enough to urban areas to create significant problems. Species of mosquitoes found breeding in overflow ponds were: P. columbiae, P. signipennis, A. vexans, and C. tarsalis. These sites were eliminated by grading in 1983. Other overflow ponds may be present on the property, but I have not located them.

Miscellaneous breeding sites. Mosquito larvae were found in one old tire (C. quinquefasciatus), two small standpipes (C. quinquefasciatus and P. signipennis), and several tire tracks in dirt roads (P. columbiae, C. tarsalis and A. franciscanus). Large standpipes in the fields do not appear to be

likely to be breeding sites because water moves through them too quickly. One road ditch was filled by water leaking from a canal, and was found to contain larvae of P. columbiae.

Irrigation Borders. These are clearly the most extensive and productive mosquito breeding sites in the study area. Productive borders are widely dispersed among many fields. Virtually every field in the Sahuarita Ranch has some areas of mosquito productive borders. The Continental Ranch has only a few fields that produce mosquitoes. They generally occupy only a small portion of a few rows in each of the fields that have them, but there are a few fields in which almost the entire area can produce mosquitoes. Breeding sites are usually, but not always, characterized by: bare patches of dark soil surrounded by dense weeds that have not been cut because the soil is too muddy to allow operation of mowers, tire tracks in the mud, and mid- to late- summer yellowing of trees as a result of too much water.

Although not every field has breeding sites, some mosquitoes were present as biting adults in almost every field examined. This indicates that even those fields that are not breeding sites may provide shelter for resting adults. The number of adults present in fields with breeding sites was much greater than in fields without evident breeding sites, however. It is possible that very small breeding sites may be found in most fields, but elimination of reproduction at the larger breeding sites may reduce the mosquito problem to a negligible level.

Mosquito species collected at breeding sites in borders were: P. columbiae, P. signipennis, P. howardii, A. vexans, A. trivittatus, C. tarsalis,

C. quinquefasciatus, and A. franciscanus.

Species Accounts

Aedes trivittatus (Coquillett). The only specimens of this species found were larvae collected from an irrigation border on 5 October 1982. Very few larvae were present in the border, and no larvae of other species were found. McDonald et al. (1973) states: "Advanced instars which stay most of the time hidden in vegetation in the bottom of the pool are seldom detected in routine mosquito breeding site inspections. Under ideal weather conditions, adults emerge from breeding sites only eight days after the eggs hatch." The small number of individuals of this species found, then, may be either due to the behavior of the larvae, which makes them difficult to obtain with the standard method used in this survey, or to the fact that few puddles last long enough to produce adults. No adults were found with any of the methods I used. At present, on the basis of very limited data, this can only be considered a very rare species in the Santa Cruz Valley.

Aedes vexans (Meigen). This is one of the two most abundant and annoying species found in the area. Larvae were found in livestock watering ponds, irrigation overflow ponds, and irrigation borders. Larvae were found in the same sites and at the same times as larvae of P. columbiae, P. howardi, P. signipennis, C. tarsalis, C. quinquefasciatus, and A. franciscanus, but they were occasionally found as the only mosquito species present in a breeding site. Adults were found at all sites surveyed in the orchard. This species is most abundant in Spring and Fall, but was present from March through October. Landing rates in excess of 50 per minute were common in untreated fields, and trap catches of several thousand

individuals were frequent. Large numbers of adults were present in fields as little as four days following irrigation, indicating that this species can mature in only four days at appropriate temperatures. Further discussion of the bionomics of this species will be presented in a subsequent section of this dissertation.

Anopheles franciscanus McCracken. This is a rather rare species. Adults were never found in this survey. Larvae were found in a golf course pond, three irrigation ditches, a tire track in a dirt road, and several irrigation borders. All of the sites where this species was found were characterized by water that had been present for more than seven days and where dense algae and/or emergent vegetation were present. Larvae were found in the same site (the tire track) at the same time as another species, C. tarsalis, only once, although they were found in sites that at other times had larvae of other mosquito species.

Culex quinquefasciatus Say. Although not a common mosquito in the area, this species was found in several different types of breeding sites. No adults were collected. Larvae were found in sprinkler puddles in association with C. tarsalis, an old tire with no other species, two small standpipes with P. signipennis larvae, and in irrigation borders with C. tarsalis, P. columbiae, and A. vexans. Because this species often breeds in very small containers of water (McDonald 1973) that might have been overlooked in this survey, it is probably more abundant in the area than my collections indicate.

Culex tarsalis Coquillett. Of the two Culex species found, this is by far the most abundant. Although no adults were collected during the course

of this investigation, they have been frequently found in light traps in the area by the County Vector Control Officer (G. Edwards, pers. comm.). Larvae were found in sprinkler puddles in association with C. quinquefasciatus; in irrigation ditches with A. franciscanus, in irrigation overflow ponds with P. columbiae, P. signipennis, and A. vexans; and in irrigation borders, usually in association with P. columbiae and A. vexans, but occasionally as the only species present. When C. tarsalis was the only species present in a border, usually the water had been present long enough for all of the floodwater species that might have been present to have matured and emerged from the water. Borders that were important breeding sites for this species were uncommon, but were either half borders (between a road and a row of trees rather than between two rows of trees) at the edges of fields, or had rather small, long-lasting puddles at their ends. During the rainy season, this species became much more abundant than it was during the dry season. Borders that might have dried between irrigations during the dry season constantly were kept wet by the combination of irrigation and rainfall when the rains came. Half borders dry much more slowly than whole borders because they have only one row of trees to draw water from them.

Psorophora columbiae (Dyar and Knab). This is the most abundant and widely distributed species, occurring in a greater variety of habitats than any other in the area. It is most numerous during the summer rainy season in the orchard, when landing rate counts were often in excess of 60 per minute and traps were filled with thousands of individuals. It breeds in enormous numbers in irrigation borders, and lesser numbers in livestock watering ponds, urban drainage ditches, mine tailings ponds, road ditches,

road puddles, roadside puddles, railroad grade puddles, substandard irrigation ditches, irrigation overflow ponds, and tire tracks in dirt roads. It was found in association with A. vexans, C. quinquefasciatus, C. tarsalis, P. howardi, and P. signipennis, although it was often the only species found in a breeding site. Further discussion of the bionomics of this species will be presented in a subsequent section of this dissertation.

Psorophora howardi Coquillett. This species was uncommon, but most often found at orchard borders that had water lasting more than five days. Only once was this species found in another type of breeding site, a substandard irrigation ditch. It was always found in association with large numbers of P. columbiae, upon which the predatory larvae were usually found feeding. Typically, there was one larva of this species for several hundred of P. columbiae. The earliest collection date for this species was 15 July and the late date was 9 September. This indicates that it is a summer rainy season mosquito. Adults were found in fields five days following irrigation.

Psorophora signipennis (Coquillett). This is an uncommon species. Larvae were found in livestock watering ponds with P. columbiae and A. vexans, in urban drainage ditches with P. columbiae, in irrigation overflow ponds with P. columbiae, A. vexans, and C. tarsalis, in irrigation standpipes with C. quinquefasciatus, and irrigation borders with P. columbiae, A. vexans, C. tarsalis, and C. quinquefasciatus. Although never common, this species was most abundant during the summer rainy season.

Bionomics of Mosquito Larvae in Irrigated Borders

Distribution of Eggs. All larvae hatched from soil samples taken in March and flooded in June were P. columbiae. Distribution of eggs within the fields was clearly aggregated, with obvious selection in field 82NW for the bases of tree rows. None of the other sample sites in this field yielded larvae. Furthermore, preference for the lower ends of the borders was evident. No larvae were hatched from samples taken in the upper third of the borders. Out of seven borders sampled, four produced larvae. Subsequent field investigation revealed that all four of these borders retain water for at least five days following irrigation and produce large numbers of mosquito larvae. The three borders from which samples did not yield larvae do not retain water for more than three days. Among the samples taken from field 94N, only those from one border gave positive results, and six out of nine samples from this border yielded mosquito larvae. Out of 126 soil samples flooded, only 10 gave positive results. Following the second flooding, three samples that yielded larvae on the first flooding again yielded larvae. Two samples that had no larvae following the first flooding had larvae following the second. Five samples that had larvae following the first flooding had none after the second. The number of larvae eclosed following the first flooding ranged from 1 to 27 per sample (mean= 8.3, s.d.=8.57). Following the second flooding, the number of larvae hatched ranged from 1 to 10 (mean=3.6, s.d.=3.78). Fig. 9 shows the results of this experiment. There is too little data for meaningful statistical analysis, but a pattern is apparent.

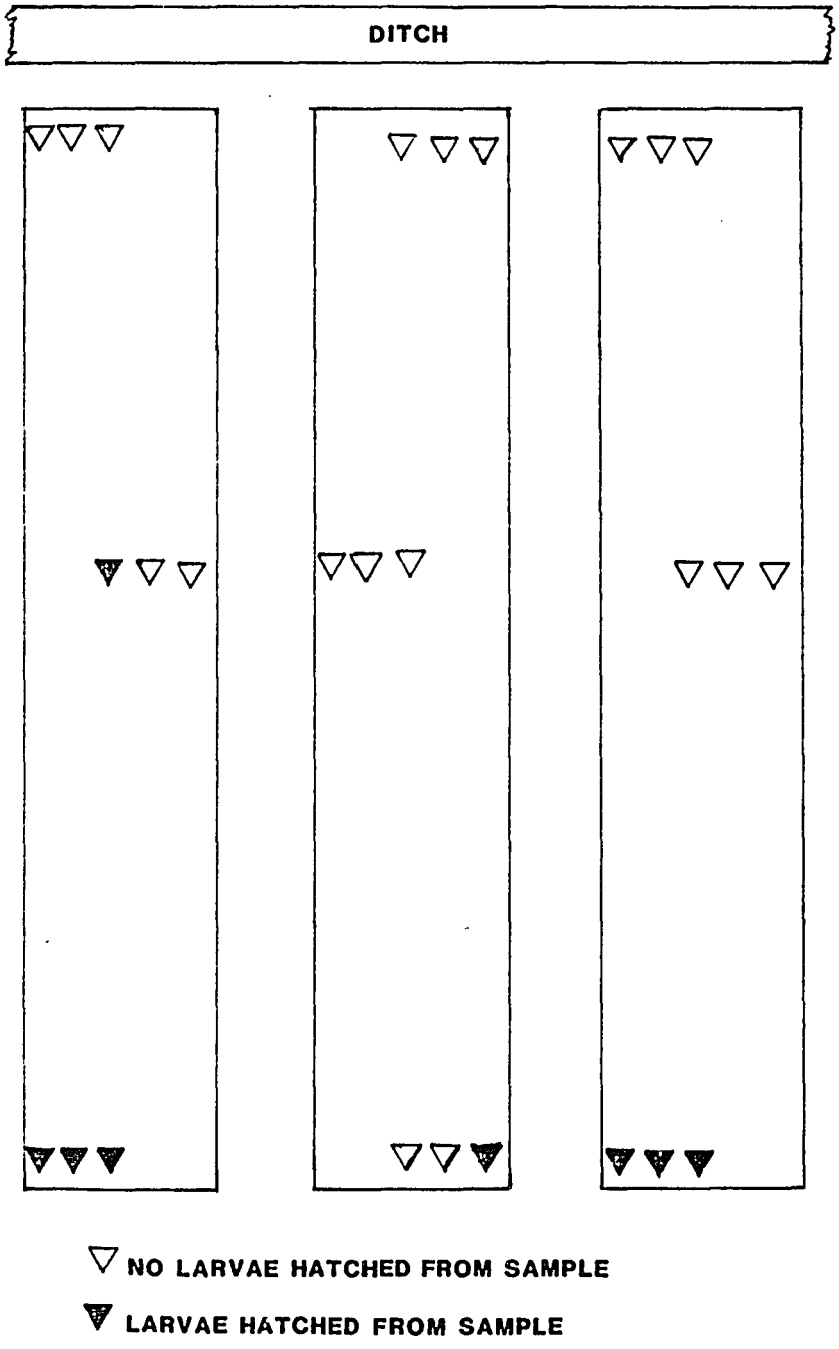


Fig. 9. Distribution of Mosquito Eggs in Irrigation Borders

Eclosion Time. Only seven larvae eclosed following flooding of 57 soil samples. Distribution through time following flooding was: 1 hr, 1 A. vexans larva; 2 hrs, 1 A. vexans larva; 3 hrs, 3 P. columbiae larvae; 4 and 5 hrs, no larvae; 6 hrs, 1 A. vexans larva; no larvae between 7 and 17 hrs; 18 hrs, 1 A. vexans larva. No additional larvae were found in the eight examinations of the samples following the 18th hr. Within the samples, one sample had both A. vexans and P. columbiae larvae, one of each. The A. vexans larva in this sample was found 1 hr before the P. columbiae larva. One sample produced two A. vexans larvae, one in the first hour, the second in the sixth hour. The other samples that produced larvae had only one each.

Seasonal Distribution of Mosquitoes. The relative abundance of the species of mosquitoes that breed in irrigated pecan borders varies during the season. Fig. 10 depicts the relative abundance of the three species collected at weekly intervals. A total of 4937 larvae were collected and identified. The absolute abundance of mosquito larvae also varies with time. Fig. 11 shows the mean number of larvae per dip recorded at untreated sites during 1983, compiled at weekly intervals. This figure represents 12,704 larvae sampled in 3436 dips. Fig. 12 illustrates the proportion of all dips each week that had one or more larvae. The peak of abundance occurs in August, coincident with the local rainy season when climatic conditions are probably most favorable for mosquito survival and reproduction.

Distribution of Larvae with Regard to Spatial Position. Spatial distribution of larvae within untreated borders, as the sum of all 5393 larvae found in 1300 dips at 26 sites sampled with the standard sampling Pattern during the 1983 season is depicted in Fig. 13. The numbers are

greatly influenced by a few large aggregations (as many as 367 larvae in a single dip), that were occasionally captured. Fig. 14 shows the locations of the three largest aggregations in each untreated border.

Species Composition of Aggregations. In the study of three borders in June, 1983, 402 larvae were collected and identified. Table 2 shows the occurrence of the two species found and clearly indicates that the two species were often found together. The high incidence of co-occurrence made any attempt at distinguishing resource partitioning on the basis of any of the factors studied meaningless, with the exception of the factor of water temperature, which is discussed below.

Table 2. Occurrence of *A. vexans* and *P. columbiae* in 123 dips containing larvae.

	Number of Larvae In Dip	
	1 only	>1
Number of dips with only *A. vexans*	34	21
Number of dips with only *P. columbiae*	22	18
Number of dips with both species	——	28
Total dips	56	68
Total larvae	56	346

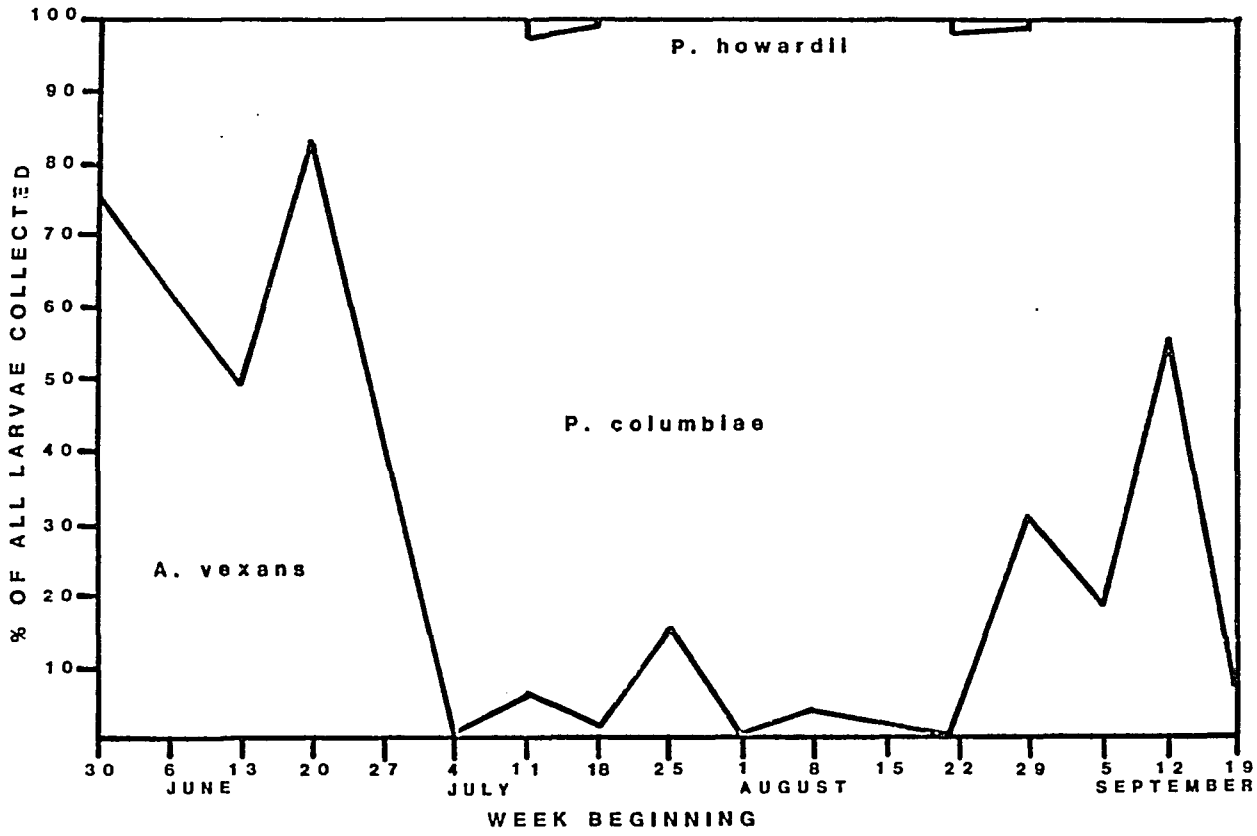


Fig. 10. Relative Abundance of 3 Species of Mosquitoes at Weekly Intervals

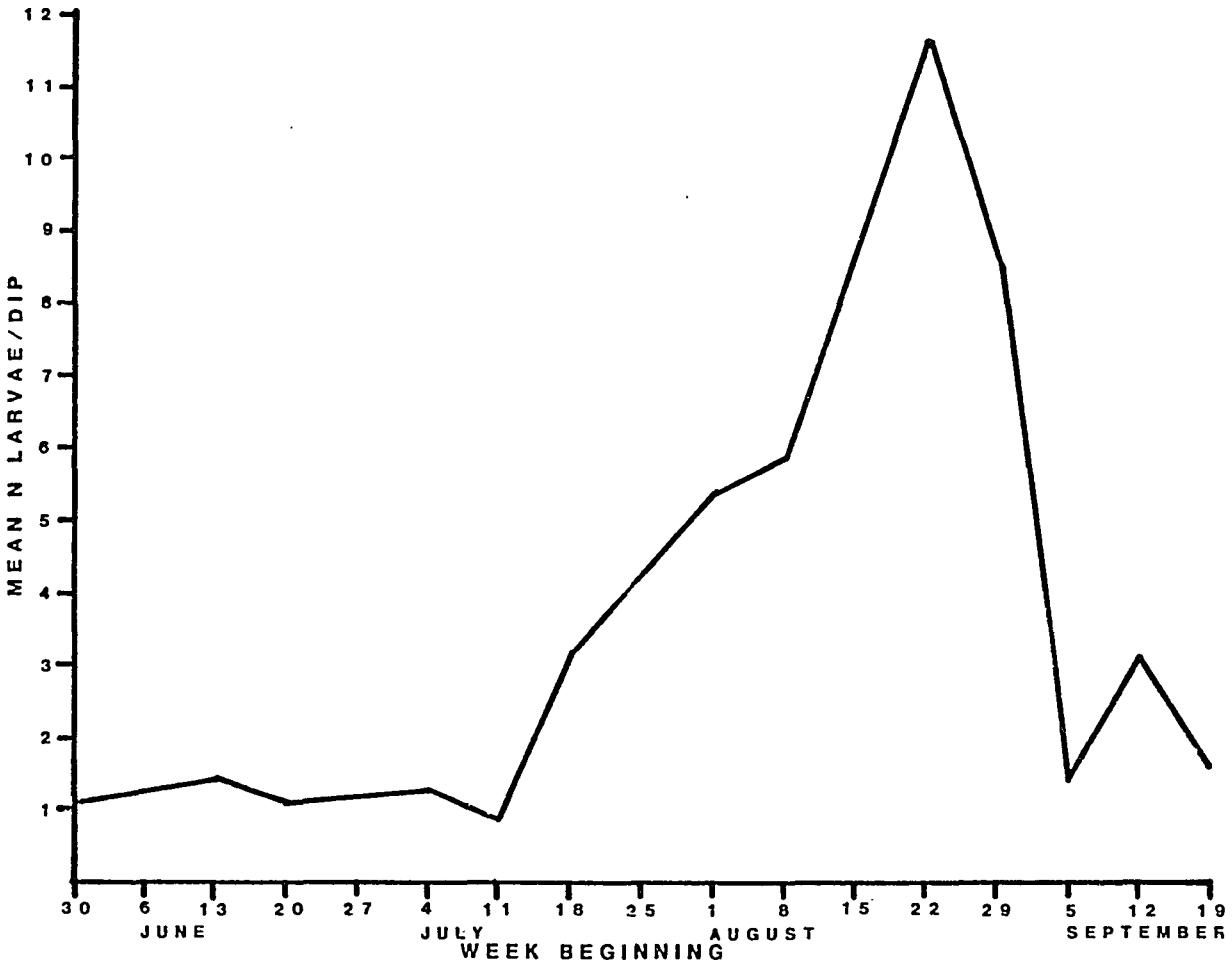


Fig. 11. Mean Number of Larvae per Dip, Untreated Borders, at Weekly Intervals in 1983

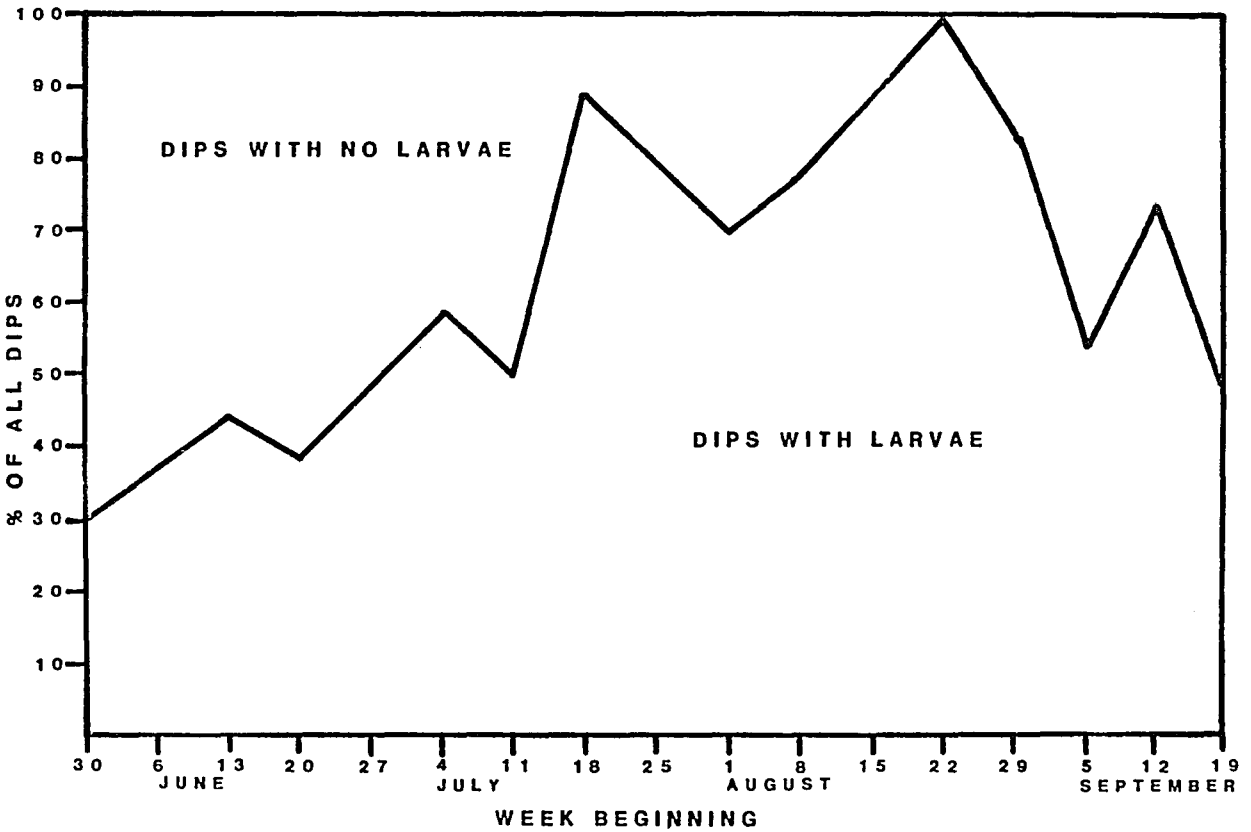


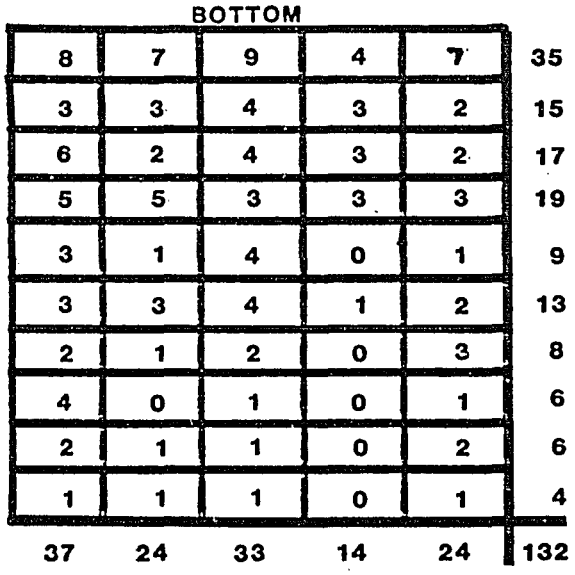
Fig. 12. Proportion of All Dips that Contained Mosquito Larvae at Weekly Intervals, Untreated Borders, 1983

BOTTOM

93	159	468	309	149
72	108	140	119	59
118	59	117	113	89
66	50	103	78	184
73	59	125	230	91
44	43	78	76	143
82	77	67	65	127
109	117	102	114	128
102	102	55	52	68
79	58	141	94	39

TOP (DITCH)

Fig. 13. Number of Larvae Found at Each Sampling Station in 26 Untreated Borders



Expected: 2.64 per station 13.2 per transect 26.4 per line

Fig. 14. Locations of 3 Largest Aggregations of Larvae in 26 Untreated Borders

Distribution of Larvae in Relation to Depth. Data on the distribution of larvae in relation to water depth, for all mosquito larvae found in the three borders intensively studied in June 1983, are summarized in Table 3.

Table 3. Statistical summary of larval distribution in relation to water depth.

Depth cm	N of Dips	Positive Dips Obs	Exp	N of Larvae Obs	Exp.
0-2	6	2	2.11	20	6.87
2-4	71	10	24.95	22	81.57
4-6	111	43	39.01	89	127.47
6-8	101	39	35.49	142	116.02
8-10	44	21	15.46	68	50.53
10-12	12	5	4.22	55	13.79
12-14	2	1	0.70	1	2.29
14-16	2	1	0.70	4	2.29
16-18	0	0	0	0	0
18-20	1	1	0.35	1	1.17
Totals	350	123		402	

Hypothesis #1: Positive dips are distributed without regard to depth. $Chi^2 = 20.5002$, d.f.= 8 p= 0.0092.

Hypothesis #2: Larvae are distributed without regard to depth. $Chi^2 = 217.2$, d.f.= 8, $p<0.00001$

Distribution of Larvae in Relation to Shade. Data on the distribution of larvae in relation to shade, for all mosquito larvae found in the three borders intensively studied in June 1983, are summarized in Table 4.

Table 4. Statistical summary of larval distribution in relation to shade.

Shade	N of Dips	Positive Dips Obs	Exp	N of Larvae Obs	Exp.
None	125	45	43.93	109	143.57
Partial	141	47	49.55	186	161.95
Dense	84	31	29.52	107	96.48
Totals	350	123		402	

Hypothesis #1: Positive dips are distributed without regard to shade. $Chi^2 = 0.3573$, d.f.= 2 p= 0.8377.

Hypothesis #2: Larvae are distributed without regard to shade. $Chi^2 = 13.04$, d.f.= 2, p=0.0019

Distribution of Larvae in Relation to Debris Mat. Data on the distribution of larvae in relation to the presence or absence of a surface mat of vegetation debris, for all mosquito larvae found in the three borders intensively studied in June 1983, are summarized in Table 5.

Table 5. Statistical summary of larval distribution in relation to debris mat.

Mat	N of Dips	Positive Dips Obs	Exp	N of Larvae Obs	Exp.
Present	158	49	55.53	200	181.47
Absent	192	74	67.47	202	220.53
Totals	350	123		402	

Hypothesis #1: Positive dips are distributed without regard to debris mat. $Chi^2 = 2.1778$, d.f.= 1 p= 0.1363.

Hypothesis #2: Larvae are distributed without regard to debris mat. $Chi^2 = 3.434$, d.f.= 1, p=0.0607

Distribution of Larvae in Relation to Water Temperature. Data on the distribution of larvae in relation to water temperature, for all mosquito larvae found in the three borders intensively studied in June 1983, are summarized in Table 6. Analysis of the data by species resulted in the pattern depicted in Fig. 15.

Table 6. Statistical summary of larval distribution in relation to water temperature.

Temp. °C	N of Dips	Positive Dips Obs	Exp	N of Larvae Obs	Exp.
15-19	3	1	1.05	4	3.45
20-24	90	23	31.63	162	103.37
25-29	179	70	62.91	165	205.59
30-34	56	21	19.68	56	64.32
35-39	22	8	7.73	15	25.27
Totals	350	123		402	

Hypothesis #1: Positive dips are distributed without regard to temperature. $Chi^2 = 5.018$, d.f.= 4 $p = 0.2853$.

Hypothesis #2: Larvae are distributed without regard to temperature. $Chi^2 = 46.61$, d.f.= 4, $p < 0.00005$

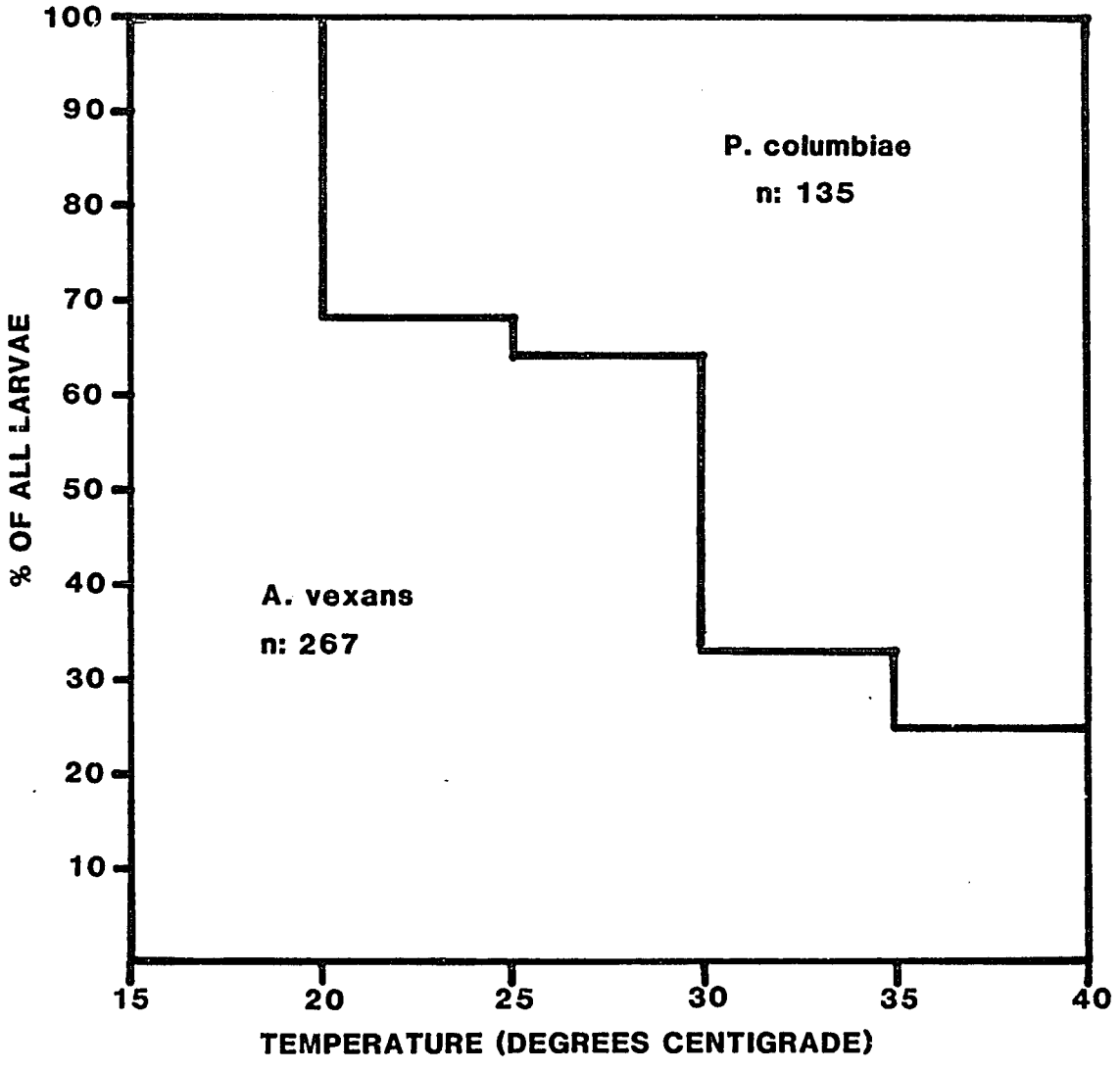


Fig. 15. Relative Abundance of A. vexans and P. columbiae Found at Temperature Intervals at 123 Positive Dip Sites

Management

Larvicide Tests

Results of the 15 tests of larvicides are discussed below and summarized in Table 7.

Table 7. Results of larvicide tests, 1983.

TEST NO.	MATERIAL	RATE l/ha	DEVICE	CONTRAST WITH	MEAN N LARVAE/DIP	SIGNIFICANCE PROBABILITY larvae	#0
1	TEKNAR^{R} C	.586	FT	CONTROL	0.98	.1093	.0287
	CONTROL	-	-	TREATED	1.20	——	
2	TEKNAR^{R} C	1.172	FT	CONTROL	0.51	.0003	.0286
	CONTROL	-	-	TREATED	1.33	——	
3.	TEKNAR^{R} C	2.344	FT	CONTROL	0.38	<.0001	.0286
	CONTROL	-	-	TREATED	1.33	——	
2 v 3	TEKNAR^{R} C	1.172	FT	2.344 l/ha	0.51	.4247	.2000
4	TEKNAR^{R} C	.586	FT	CONTROL	0.29	<.0001	.0162
	CONTROL	-	-	TREATED	0.59	——	
4 v 2	TEKNAR^{R} C	.586	FT	1.172 l/ha	0.29	.3192	.5000
5	TEKNAR^{R} C	1.172	MCL	CONTROL	1.08	.1446	.2327
	CONTROL	-	-	TREATED	0.59	——	
5 v 2	TEKNAR^{R} C	1.172	MCL	FT	1.08	.3654	.5000
6	TEKNAR^{R} C	.586	B&G	BEFORE	0.63	.0002	——
	BEFORE	-	-	AFTER	3.56	——	

Table 7 continued

TEST NO.	MATERIAL	RATE l/ha	DEVICE	CONTRAST WITH	MEAN N LARVAE/DIP	SIGNIFICANCE PROBABILITY larvae	#0
7	TEKNAR^R C	.586	PS	CONTROL	1.07	<.0001	.0045
	CONTROL	-	-	TREATED	4.31	——	
8	TEKNAR^R C	1.172	PS	CONTROL	1.05	<.0001	.0045
	CONTROL	-	-	TREATED	4.31	——	
7 v 8	TEKNAR^R C	.586	PS	1.172 l/ha	1.05	.4840	.3282
9	TEKNAR^R C	.586	PD	CONTROL	3.84	.0009	.0040
	CONTROL	-	-	TREATED	4.31	——	
7 v 9	TEKNAR^R C	.586	PS	PD	1.09	.0047	.3192
10	TEKNAR^R C	1.172	MCL	CONTROL	1.51	.0051	.0571
	CONTROL	-	-	TREATED	3.15	——	
10 v 8	TEKNAR^R C	1.172	MCL	PS	1.51	.3429	.7571
11	TEKNAR^R C	1.172	B&G	BEFORE	0.16	.0043	
	BEFORE	-	-	AFTER	13.34	——	
12	FENVAL.	.438	FT	CONTROL	0.108	<.0001	.0094
	CONTROL	-	-	FENVAL.	0.67	——	
12 v 4	FENVAL.	.438	FT	TEKNAR^R	0.108	.0024	.0329

Table 7 continued

TEST NO.	MATERIAL	RATE l/ha	DEVICE	CONTRAST WITH	MEAN N LARVAE/DIP	SIGNIFICANCE PROBABILITY larvae	#0
13	TEKNAR^{R} G	3.3*	OS	BEFORE	0.27	.0009	——
	BEFORE	-	-	AFTER	0.91	——	
14	TEKNAR^{R} G	5.6*	OS	BEFORE	0.36	.0040	——
	BEFORE	-	-	AFTER	13.52	——	
15	TEKNAR^{R} G	6.7*	OS	BEFORE	0.08	.0043	——
	BEFORE	-	-	AFTER	12.32	——	
13 v 14	TEKNAR^{R} G		3.3*	OS	5.6*	0.27	.3121
14 V 15	TEKNAR^{R} G		5.6*	OS	6.7*	0.36	.0055

ABBREVIATIONS: TEKNAR^{R}C= TEKNAR^{R} LIQUID CONCENTRATE; TEKNAR^{R} G= TEKNAR^{R} GRANULES; FENVAL.= FENVALERATE; FT= FERTILIZER TANK; MCL= MCLAUGHLIN DEVICE; B&G= B&G^{R}COMPRESSED AIR SPRAYER; PS= POURED AT SIPHON; PD= POURED IN DITCH; OS= ORTHO^{R} SEEDER. *=kg/ha.

Effect of Sampling. Two borders in Field 82NW were sampled on 10 August 1983 following the standard pattern, but taking two dips from each station. The second dip was taken immediately after the first had been counted and recorded and the larvae returned to the site from which they were taken. The number of larvae in each dip was ranked froleast to most, and the 2-sided Wilcoxon rank sum test used to test the hypothesis that the number of larvae was not different between samples. Results are shown in Table 8.

Table 8. Comparison of Successive Samples

Border	Sample No.	N Dips	Mean n Larvae/dip	S^2	Range	Significance Probability
19-road	1	50	2.76	19.0224	0-19	——
	2	50	1.90	12.29	0-16	0.2984
17-18	1	50	13.34	330.984	0-78	——
	2	50	15.62	727.236	0-137	0.5892

Changes from day to day. Four borders in three fields were sampled on successive days at approximately the same stations. Results are shown in Table 9.

Table 9. Comparison of Samples on Successive Days

Date	Field: Border	Mean n Larvae/Dip	S^2	Range	Significance Probability
8/2/83	82SE:	21.52	3641.25	0-367	——
8/3/83	68-road	12.32	695.458	0-179	0.1556
8/3/83	82NW:	2.24	8.5024	0-12	——
8/4/83	9-10	3.76	262.26	0-116	0.1936
8/8/83	82NE:	1.0	2.28	0-8	——
8/9/83	24-25	0.96	2.24	0-6	0.8416
8/8/83	82NE:	4.18	45.4276	0-32	——
8/9/83	21-22	3.30	22.01	0-21	0.6244

Test No. 1. The statistics for the four borders treated with Teknar^{R} at the rate of .586 l/ha using the fertilizer tank were:

Mean	Variance	n larvae	N dips	range	# 0
2.92	51.7536	73	25	0-36	15
0.24	0.5024	6	25	0-3	22
0.24	0.6624	6	25	0-4	22
0.52	0.8896	13	25	0-4	17
0.98	14.7196	98	100	0-36	76

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
3.45	106.748	69	20	0-48	10
0.7	0.91	14	20	0-3	12
0.15	0.1275	3	20	0-1	17
0.50	0.85	10	20	0-10	13
1.2	28.885	96	80	0-48	52

Bioassay results showed that four hours after the start of the Teknar^{R} drip, all of the water in the ditch was lethal to 100% of the larvae. The percent mortality incurred as a result of exposure of larvae to water collected from borders in the field 20 hours after the start of the Teknar^{R} drip and its distribution is illustrated in Fig. 16.

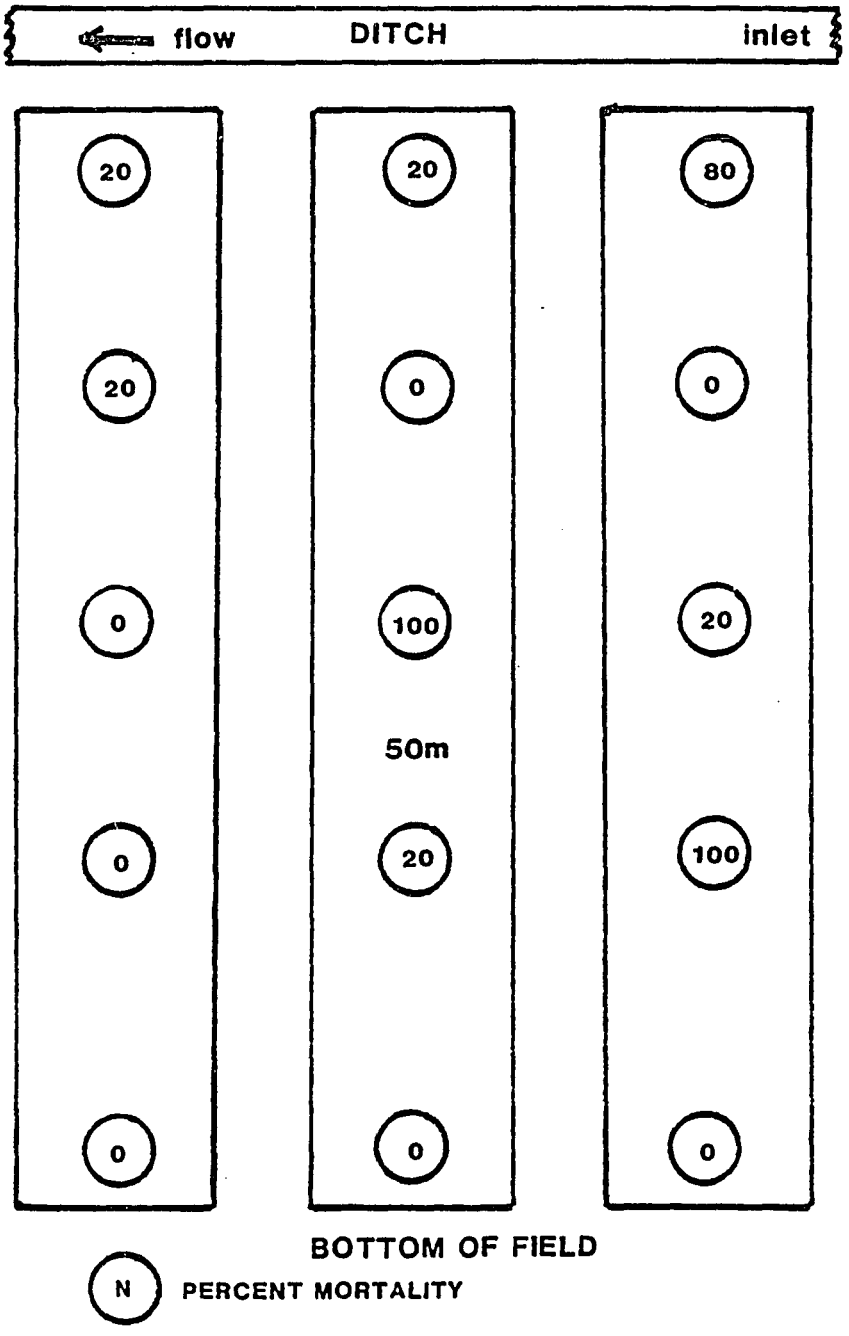


Fig. 16. Bioassay Results, Test No. 1

Test No. 2. The statistics for the three borders treated with Teknar^{R} at the rate of 1.172 l/ha using the fertilizer tank were:

Mean	Variance	n larvae	N dips	range	# 0
0.28	0.4416	14	50	0-3	41
1.24	12.6624	62	50	0-22	36
0.02	0.0196	1	50	0-1	49
0.513	4.6498	77	150	0-22	126

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
1.38	2.9556	69	50	0-9	21
2.06	4.2564	103	50	0-8	15
0.9	1.41	45	50	0-6	25
0.98	2.0196	49	50	0-7	26
1.33	2.8711	266	200	0-9	87

Fig. 17 compares the mean number of larvae per dip at each transect for treated and control borders. Bioassay results, expressed as percent mortality incurred as a result of exposure of larvae to water collected from borders in the field 15 hours after the start of the Teknar^{R} drip and its distribution are illustrated in Fig. 18.

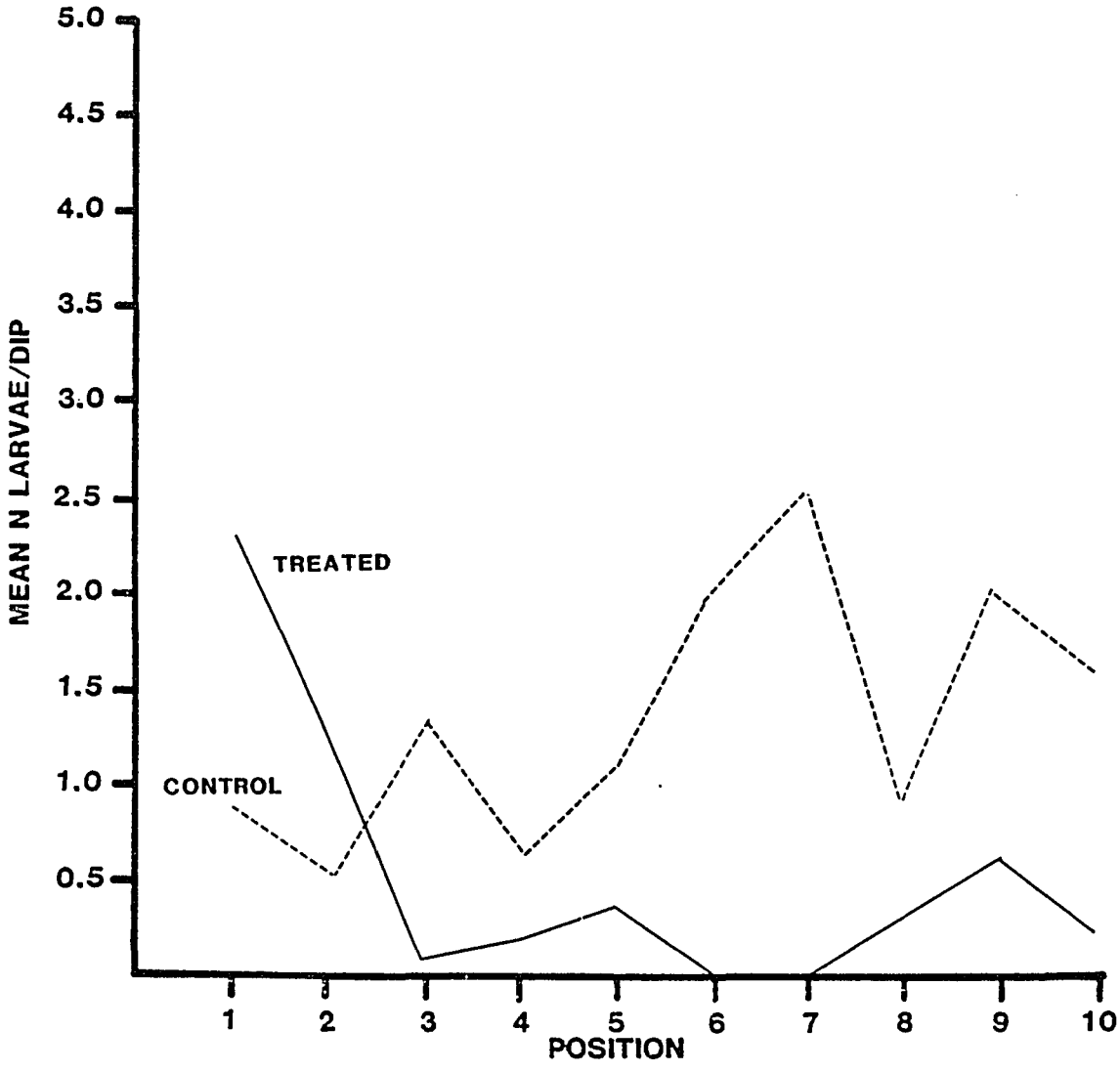


Fig. 17. Mean Number of Larvae per Dip at Transects, Test No. 2 vs. Control

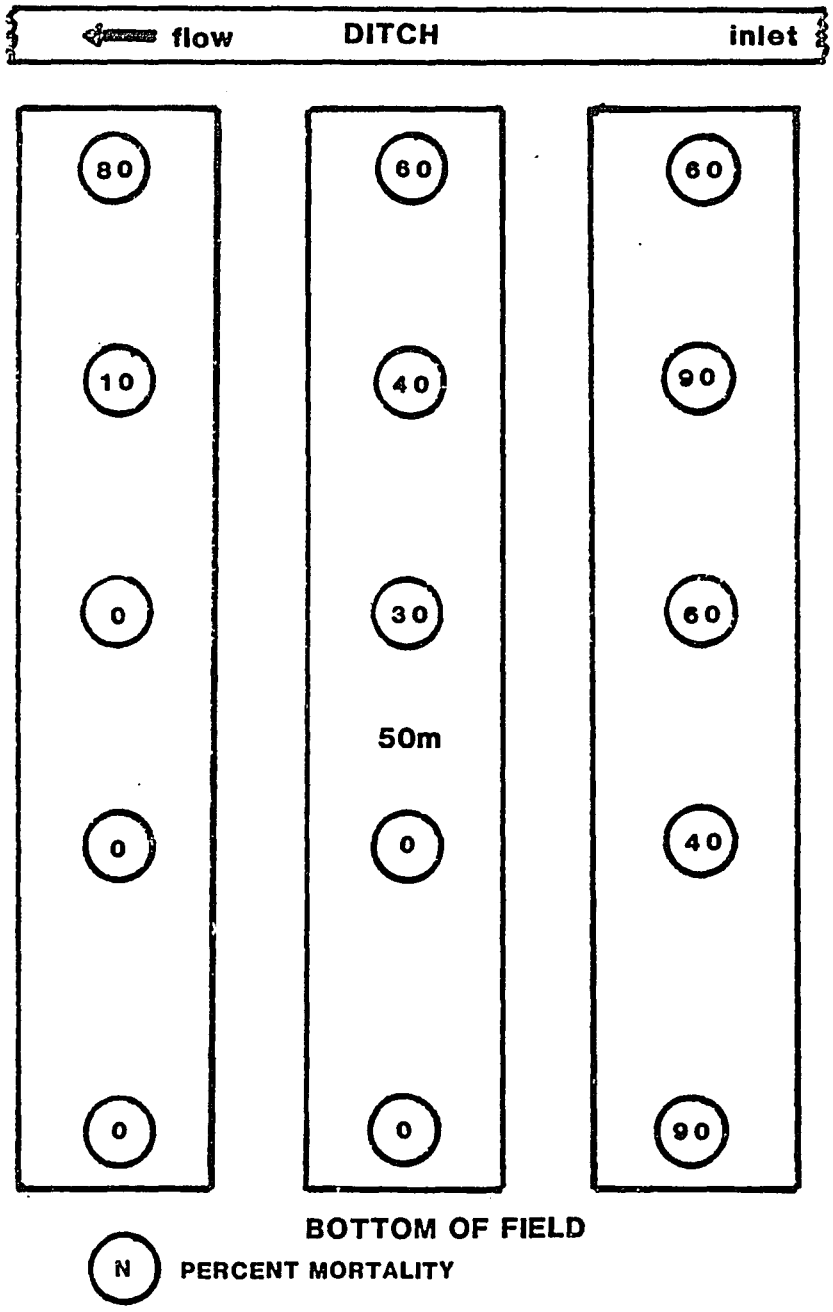


Fig. 18. Bioassay Results, Test No. 2

Test No. 3. The statistics for the three borders treated with Teknar^{R} at the rate of 2.344 l/ha using the fertilizer tank were:

Mean	Variance	n larvae	N dips	range	# 0
0.14	0.5204	7	50	0-5	47
0.18	0.1876	9	50	0-2	42
0.84	3.4836	41	50	0-10	41
0.38	1.4756	57	150	0-10	130

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
1.38	2.9556	69	50	0-9	21
2.06	4.2564	103	50	0-8	15
0.9	1.41	45	50	0-6	25
0.98	2.0196	49	50	0-7	26
1.33	2.8711	266	200	0-9	87

Fig. 19 compares the mean number of larvae per dip at each transect for treated and control borders. Bioassay results, expressed as percent mortality incurred as a result of exposure of larvae to water collected from borders in the field 15 hours after the start of the Teknar^{R} drip and its distribution are illustrated in Fig. 20.

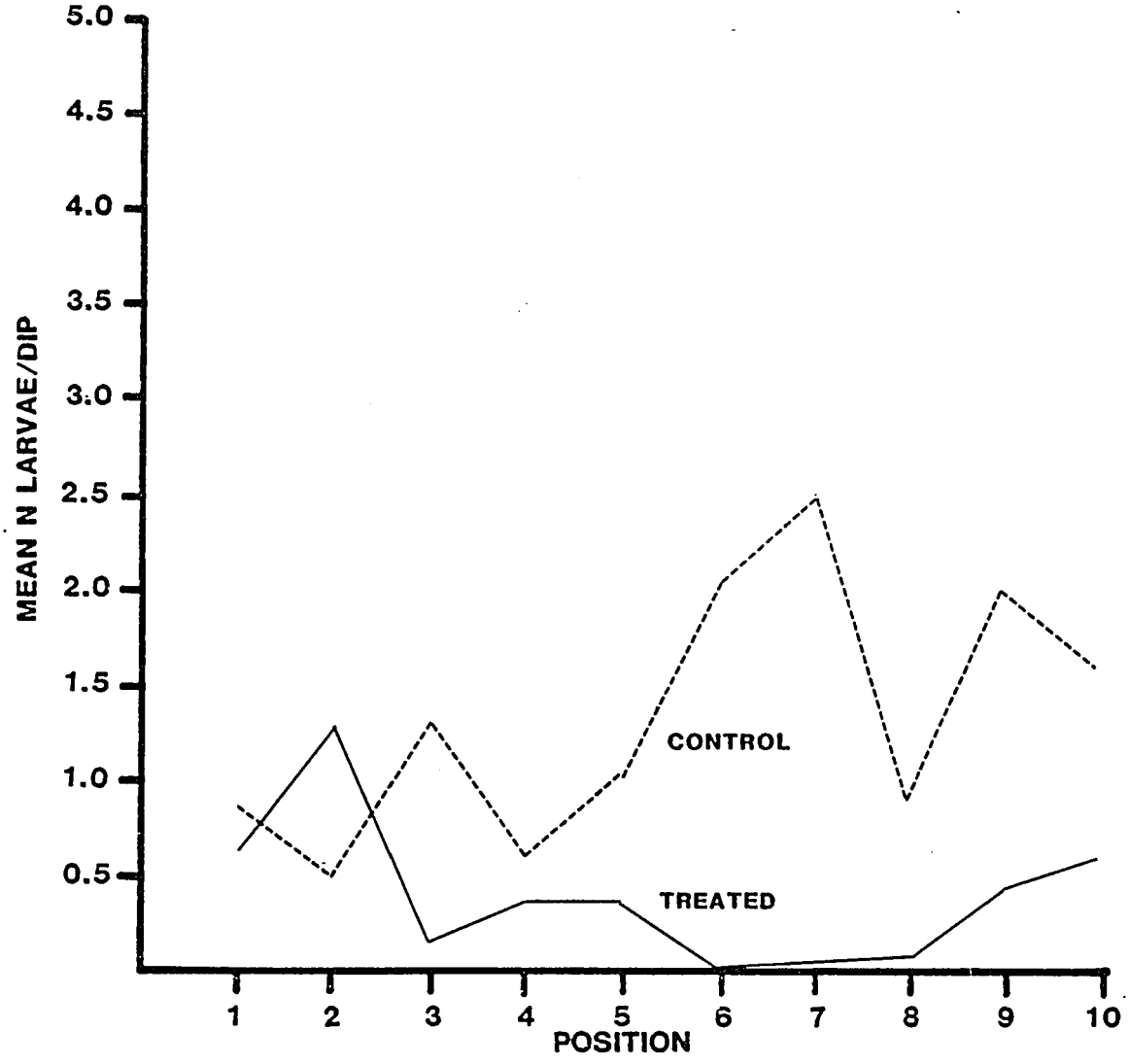


Fig. 19. Mean Number of Larvae per Dip at Transects, Test No. 3 vs. Control

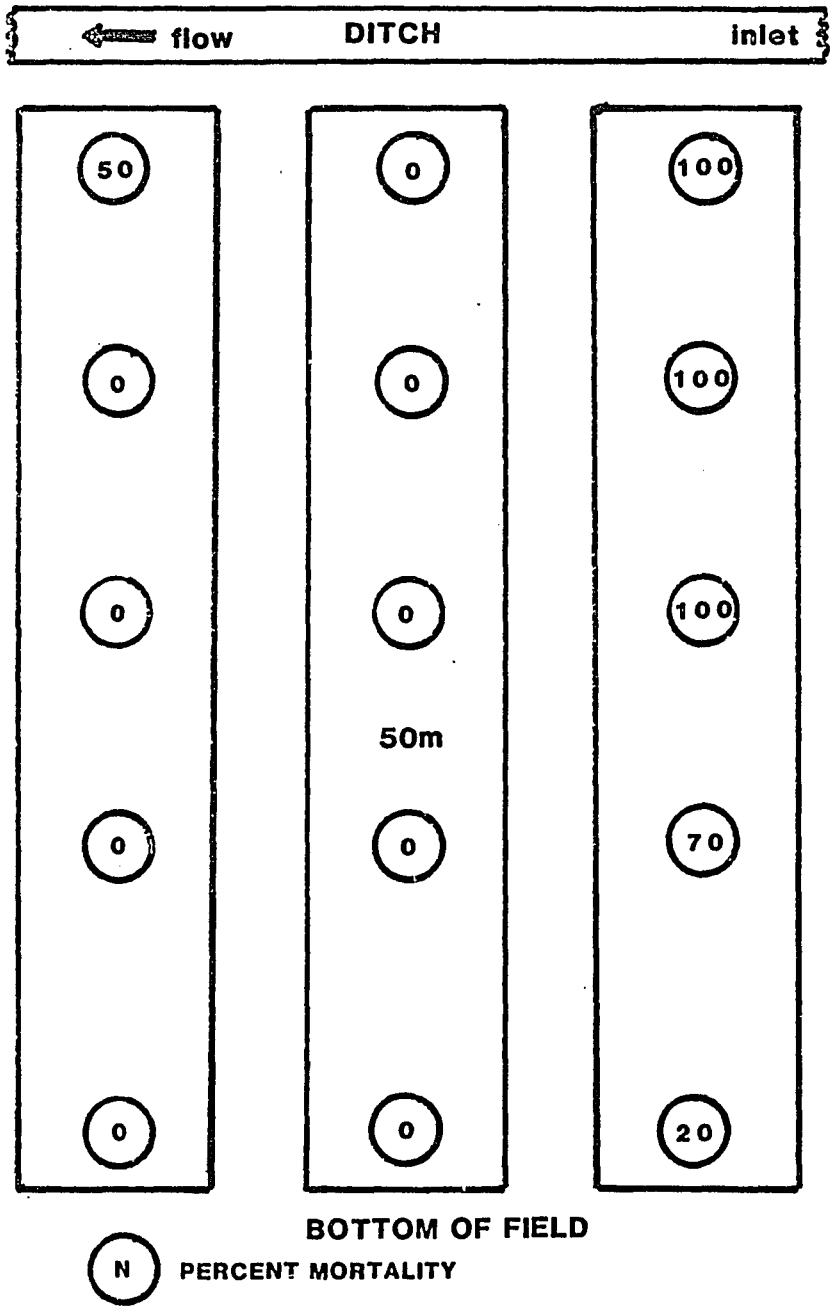


Fig. 20 Bioassay Results, Test No. 3

Test No. 4. The statistics for the eight borders treated with Teknar^{R} at the rate of .586 l/ha using the fertilizer tank were:

Mean	Variance	n larvae	N dips	range	# 0
0.38	0.3556	19	50	0-2	34
0.10	0.09	5	50	0-1	45
0.18	0.1876	9	50	0-2	42
0.08	0.1136	4	50	0-2	47
0.18	0.1876	9	50	0-2	42
0.14	0.1204	7	50	0-1	43
1.2	2.12	60	50	0-6	22
0.08	0.0736	4	50	0-1	46
0.293	0.5319	117	400	0-6	321

The border with a mean of 1.2 larvae per dip may not have been irrigated at the same time the others were. Occasionally, borders near the end of an irrigation set are not irrigated at the same time as the majority of the borders in the set, or are irrigated more slowly than the others. This border was second from the end of the set.

The statistics for the five untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
0.62	0.9156	31	50	0-4	31
0.88	1.1856	44	50	0-4	25
0.44	0.5264	22	50	0-3	34
0.2	0.28	10	50	0-3	42
0.80	1.6	40	50	0-6	30
0.588	0.9623	147	250	0-6	162

Fig. 21 compares the mean number of larvae per dip at each transect for treated and control borders. Bioassay results are shown in Fig. 22.

Test No. 5. The statistics for the five borders treated with Teknar^{R} at the rate of 1.172 l/ha using the McLaughlin device were:

Mean	Variance	n larvae	N dips	range	# 0
3.52	99.8497	176	50	0-62	26
1.71	3.93	85	50	0-8	18
0.16	0.1344	8	50	0-1	43
0	0	0	50	0	50
0	0	0	50	0	50
1.076	22.6872	269	250	0-62	187

The border with a mean of 3.52 larvae per dip had very uneven ground, with a low mound of dirt across the border which may have obstructed the flow of Teknar^{R}. Of the larvae found in this border, 167 (95%) were found downstream from the mound.

The statistics for the five untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
0.62	0.9156	31	50	0-4	31
0.88	1.1856	44	50	0-4	25
0.44	0.5264	22	50	0-3	34
0.2	0.28	10	50	0-3	42
0.80	1.6	40	50	0-6	30
0.588	0.9623	147	250	0-6	162

Fig. 23 compares the mean number of larvae per dip at each transect for treated and control borders. No bioassay was done as part of this test.

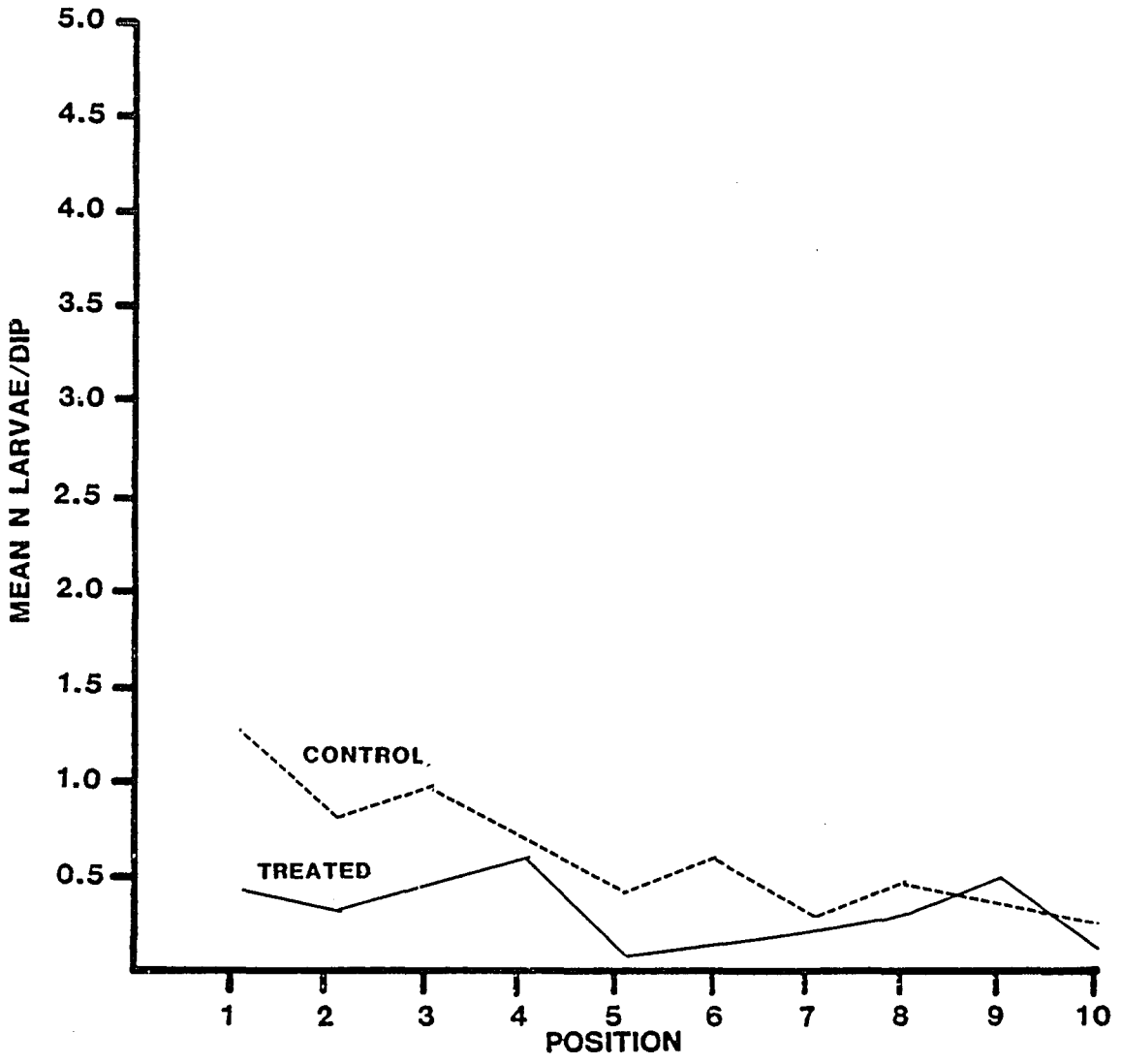


Fig. 21. Mean Number of Larvae per Dip at Transects, Test No. 4 vs. Control

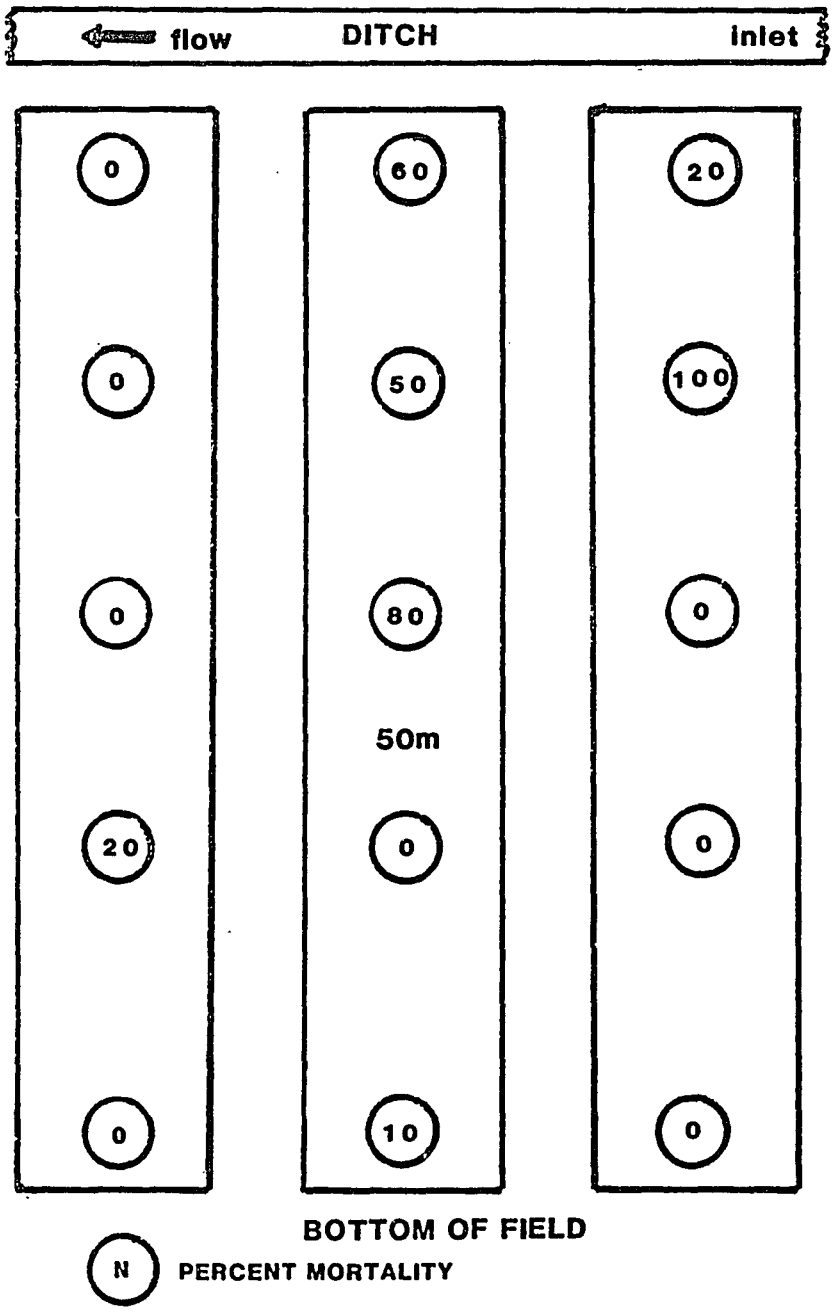


Fig. 22. Bioassay Results, Test No. 4

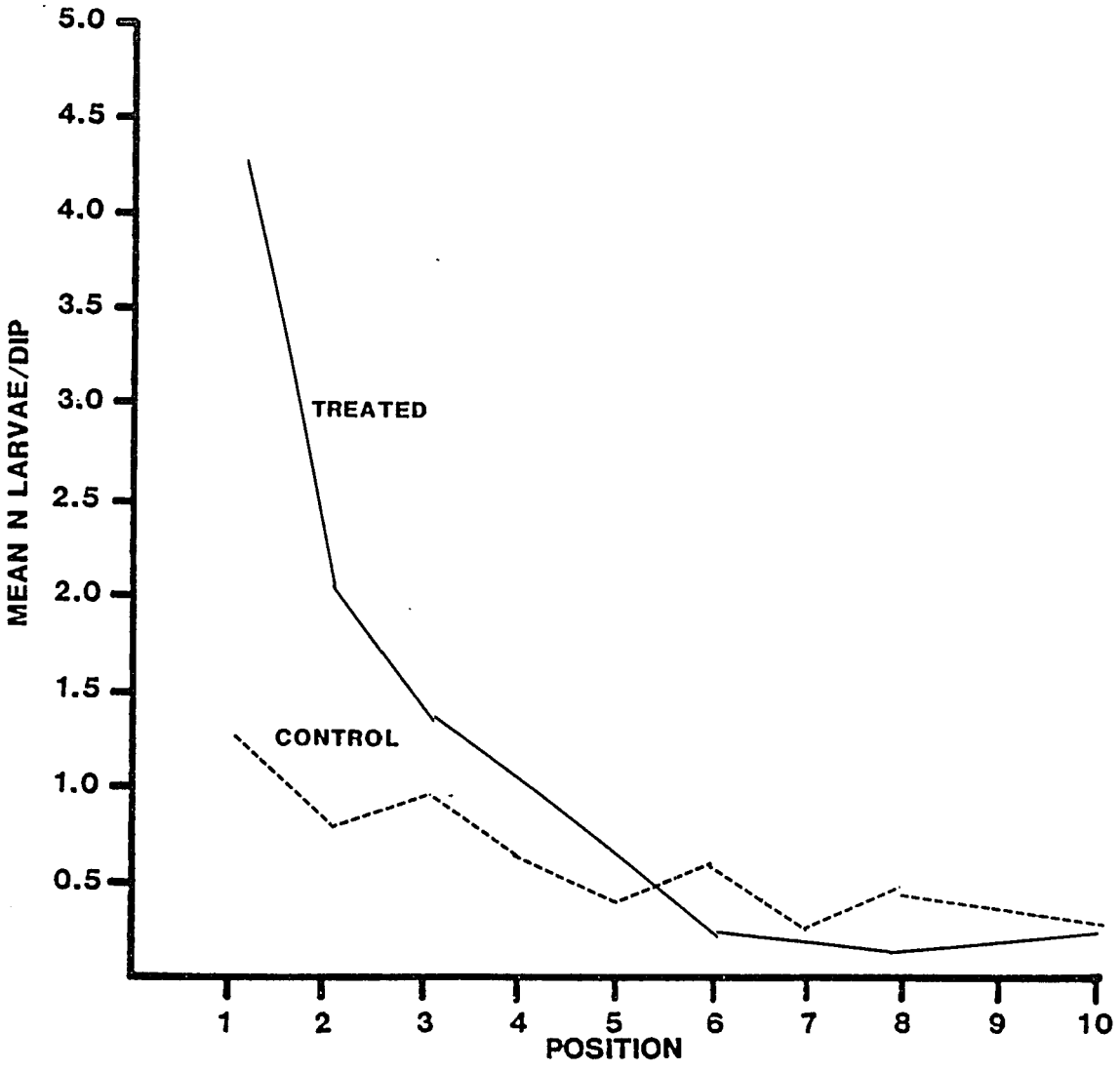


Fig. 23. Mean Number of Larvae per Dip at Transects, Test No. 5 vs. Control

Test No. 6. Before treatment, the mean number of larvae per dip was 3.56. The variance was 3.33. There were 178 larvae in 50 dips. Only 11 dips had no larvae. The largest number of larvae in a single dip was 12. After treatment with Teknar[R] at the rate of .586 l/ha applied with the B&G[R], the mean number of larvae was 0.6. The variance was 1.46. There were 30 larvae (or pupae) in 50 dips and 37 dips had no larvae. Of the mosquitoes found, 22 were pupae, seven were late fourth instar, and one was a P. howardii.

Test No. 7. The statistics for the four borders treated with Teknar[R] at the rate of .586 l/ha poured at the siphons were:

Mean	Variance	n larvae	N dips	range	# 0
1.14	7.4803	57	50	0-16	33
0.10	0.13	5	50	0-2	46
1.28	3.8416	64	50	0-12	21
1.76	3.0624	88	50	0-8	13
1.07	4.0735	214	200	0-16	113

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
4.14	20.1604	207	50	0-16	8
7.5	129.37	375	50	0-58	12
2.18	3.6676	109	50	0-8	10
3.40	16.24	170	50	0-19	10
4.305	46.252	861	200	0-58	40

Fig. 24 compares the mean number of larvae per dip at each transect for treated and control borders. No bioassay was done as part of this test.

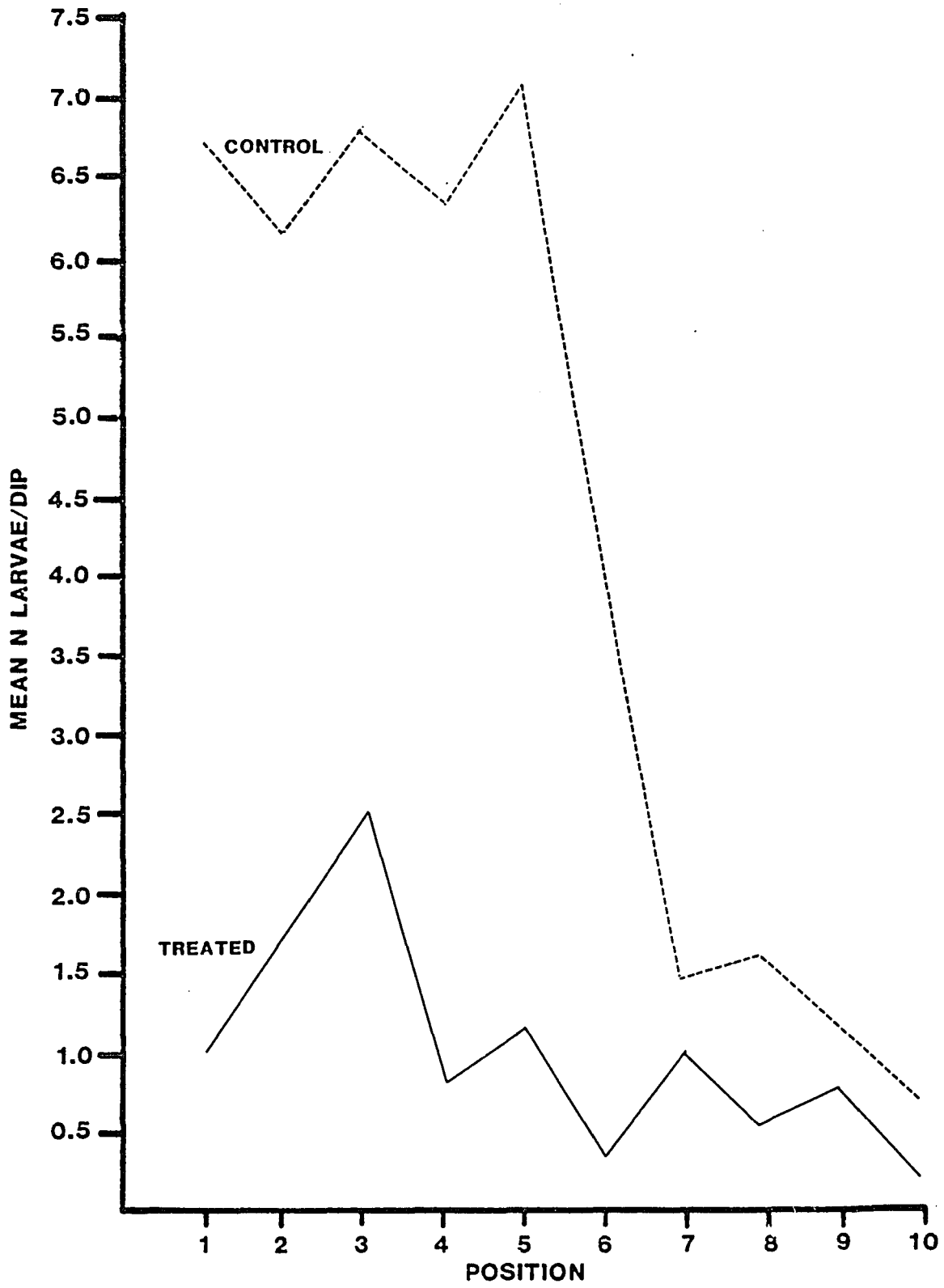


Fig. 24. Mean Number of Larvae per Dip at Transects, Test No. 7 vs. Control

Test No. 8. The statistics for the four borders treated with Teknar^{R} at the rate of 1.172 l/ha poured at the siphons were:

Mean	Variance	n larvae	N dips	range	# 0
0.72	14.4816	36	50	0-27	44
0.30	0.33	15	50	0-2	38
1.96	12.7984	98	50	0-21	21
1.22	3.3716	61	50	0-8	26
1.05	7.3087	210	200	0-27	129

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
4.14	20.1604	207	50	0-16	8
7.5	129.37	375	50	0-58	12
2.18	3.6676	109	50	0-8	10
3.40	16.24	170	50	0-19	10
4.305	46.252	861	200	0-58	40

Fig. 25 compares the mean number of larvae per dip at each transect for treated and control borders. No bioassay was done as part of this test.

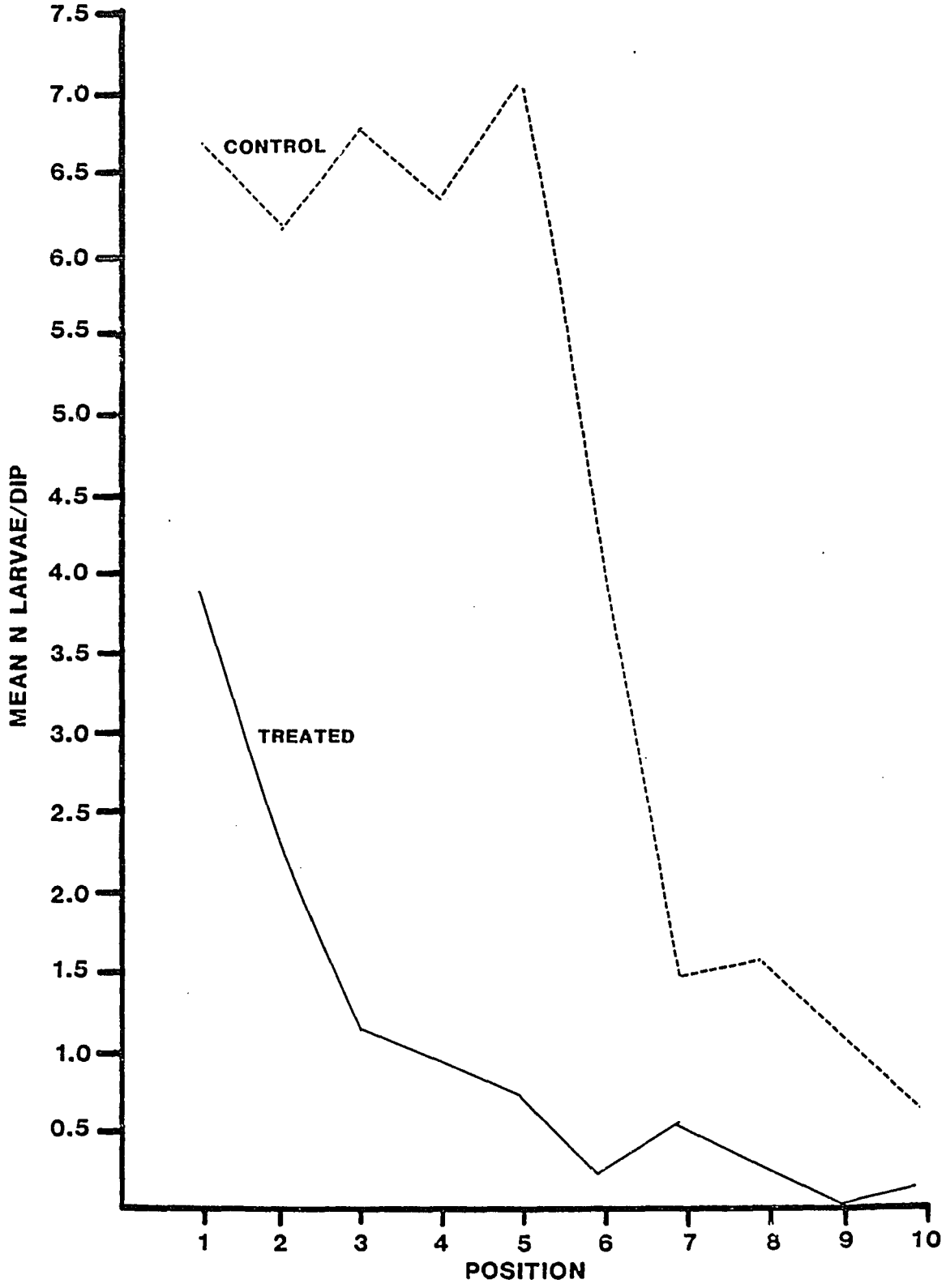


Fig. 25. Mean Number of Larvae per Dip at Transects, Test No. 8 vs. Control

Test No. 9. The statistics for the seven borders treated with Teknar^{R} at the rate of .586 l/ha poured into the ditch were:

Mean	Variance	n larvae	N dips	range	# 0
0.42	0.5636	21	50	0-3	35
2.80	11.84	140	50	0-14	15
1.04	2.5984	52	50	0-7	25
3.30	22.01	165	50	0-21	18
1.00	2.284	50	50	0-8	26
15.58	3253.89	779	50	0-392	19
2.74	23.7924	137	50	0-31	21
3.84	499.327	1344	350	0-392	159

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
4.14	20.1604	207	50	0-16	8
7.5	129.37	375	50	0-58	12
2.18	3.6676	109	50	0-8	10
3.40	16.24	170	50	0-19	10
4.305	46.252	861	200	0-58	40

Fig. 26 compares the mean number of larvae per dip at each transect for treated and control borders. No bioassay was done as part of this test.

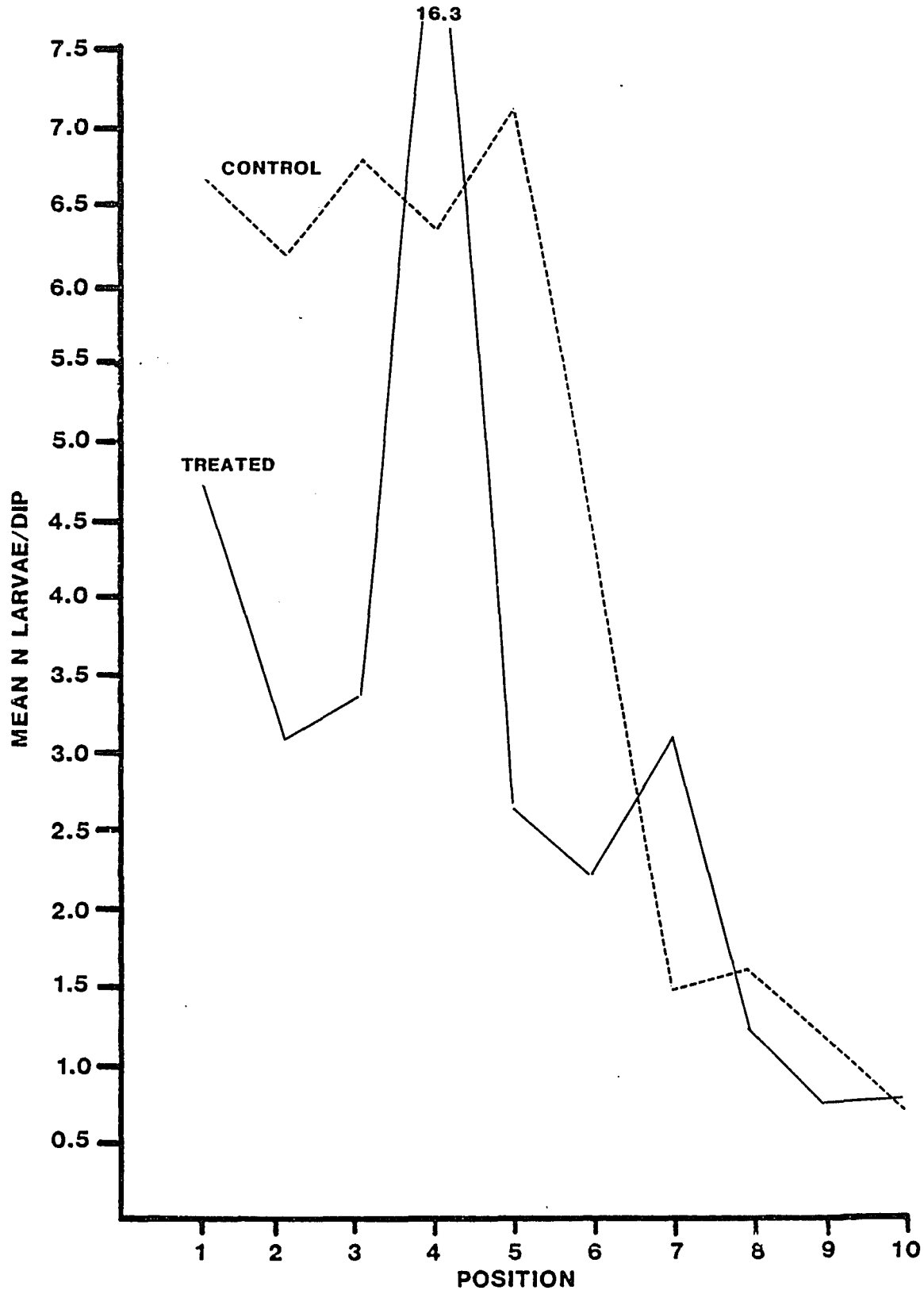


Fig. 26. Mean Number of Larvae per Dip at Transects, Test No. 9 vs. Control

Test No. 10. The statistics for the four borders treated with Teknar^{R} at the rate of 1.172 l/ha using the Mclaughlin device were:

Mean	Variance	n larvae	N dips	range	# 0
0.64	1.2304	32	50	0-4	34
0.62	2.5556	31	50	0-8	37
2.76	110.102	138	50	0-63	35
2.02	5.5796	101	50	0-11	17
1.51	30.7099	302	200	0-63	123

The two borders with the highest mean number of larvae per dip had extremely dense weeds growing in them. The borders with the lowest means had very few weeds growing in them.

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
3.82	25.1476	191	50	0-15	8
1.08	2.2336	54	50	0-9	20
6.44	50.0464	322	50	0-30	5
1.24	2.2624	62	50	0-6	21
3.145	24.724	629	200	0-30	54

Fig. 27 compares the mean number of larvae per dip at each transect for treated and control borders. No bioassay was done as part of this test.

Test No. 11. Before treatment, the mean number of larvae per dip was 13.34. The variance was 330.984. There were 667 larvae in 50 dips. Only four dips had no larvae. The largest number of larvae in a single dip was 78. After treatment with Teknar^{R} at the rate of 1.172 l/ha sprayed with the B&G^{R}, the mean number of larvae was 0.16. The variance was

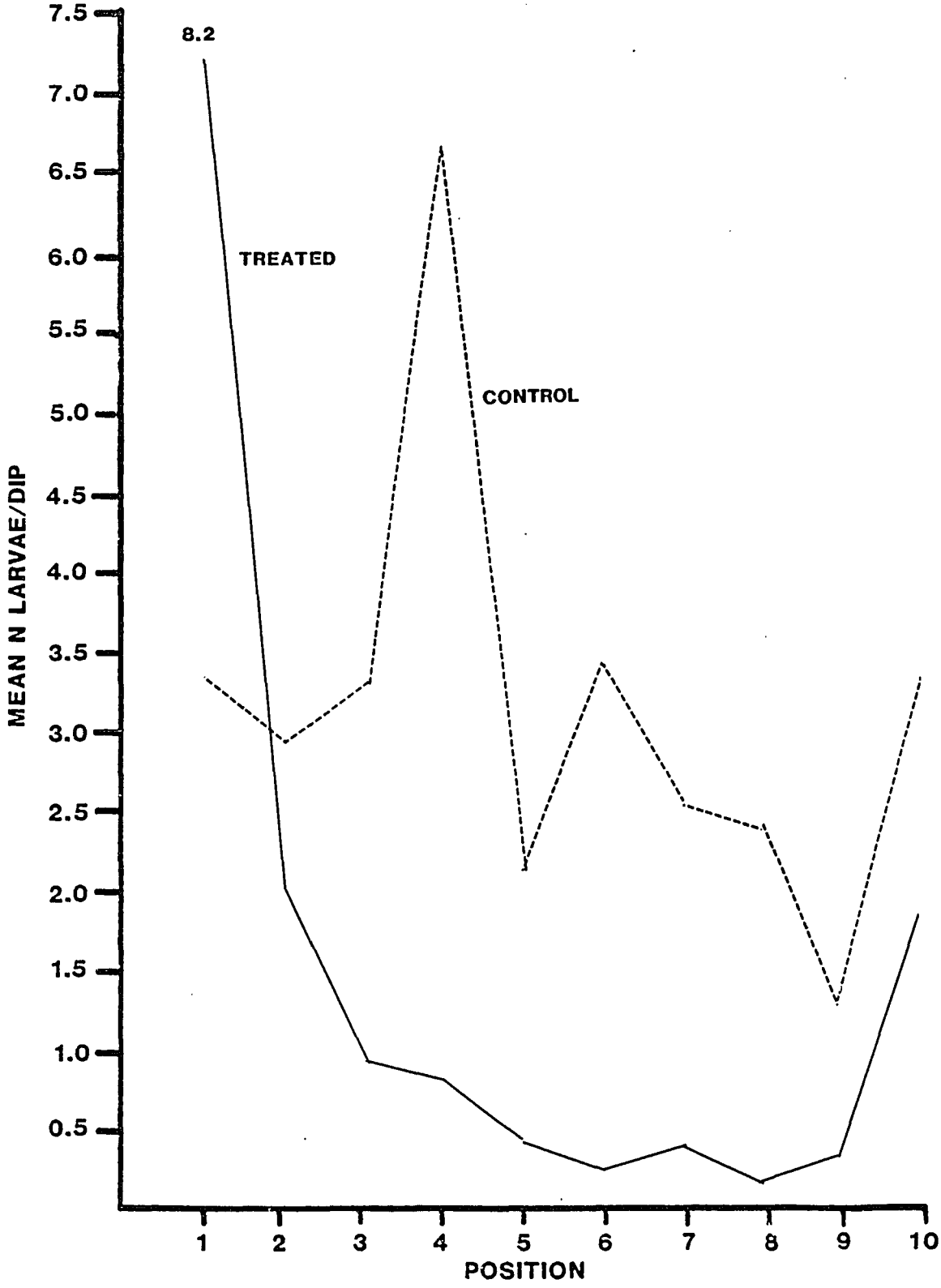


Fig. 27. Mean Number of Larvae per Dip at Transects, Test No. 10 vs. Control

0.7310. There were eight larvae in 50 dips; two of those larvae were P. howardii. The other six were all found in the last transect sampled, which was nearest the upstream edge of the treated area, and may have drifted downstream from the untreated portion of the border. Forty-six dips had no larvae.

Test No. 12. The statistics for the five borders treated with fenvalerate were:

Mean	Variance	n larvae	N dips	range	# 0
0.08	0.0736	4	50	0-1	46
0.02	0.0196	1	50	0-1	49
0.12	0.3856	6	50	0-4	48
0	0	0	50	0	50
0.32	0.4176	16	50	0-2	39
0.108	0.19224	27	250	0-4	232

The statistics for the four untreated control borders were:

Mean	Variance	n larvae	N dips	range	# 0
0.26	0.2724	13	50	0-2	39
0.8	1.36	40	50	0-4	29
0.68	1.9376	34	50	0-7	34
0.94	5.8964	47	50	0-16	34
0.67	2.4411	134	200	0-16	136

Fig. 28 compares the mean number of larvae per dip at each transect for treated and control borders. No bioassay was done as part of this test.

Test 12 vs Test 4. When the controls for these two tests were compared using the two-sided Wilcoxon rank sum test to test the hypothesis

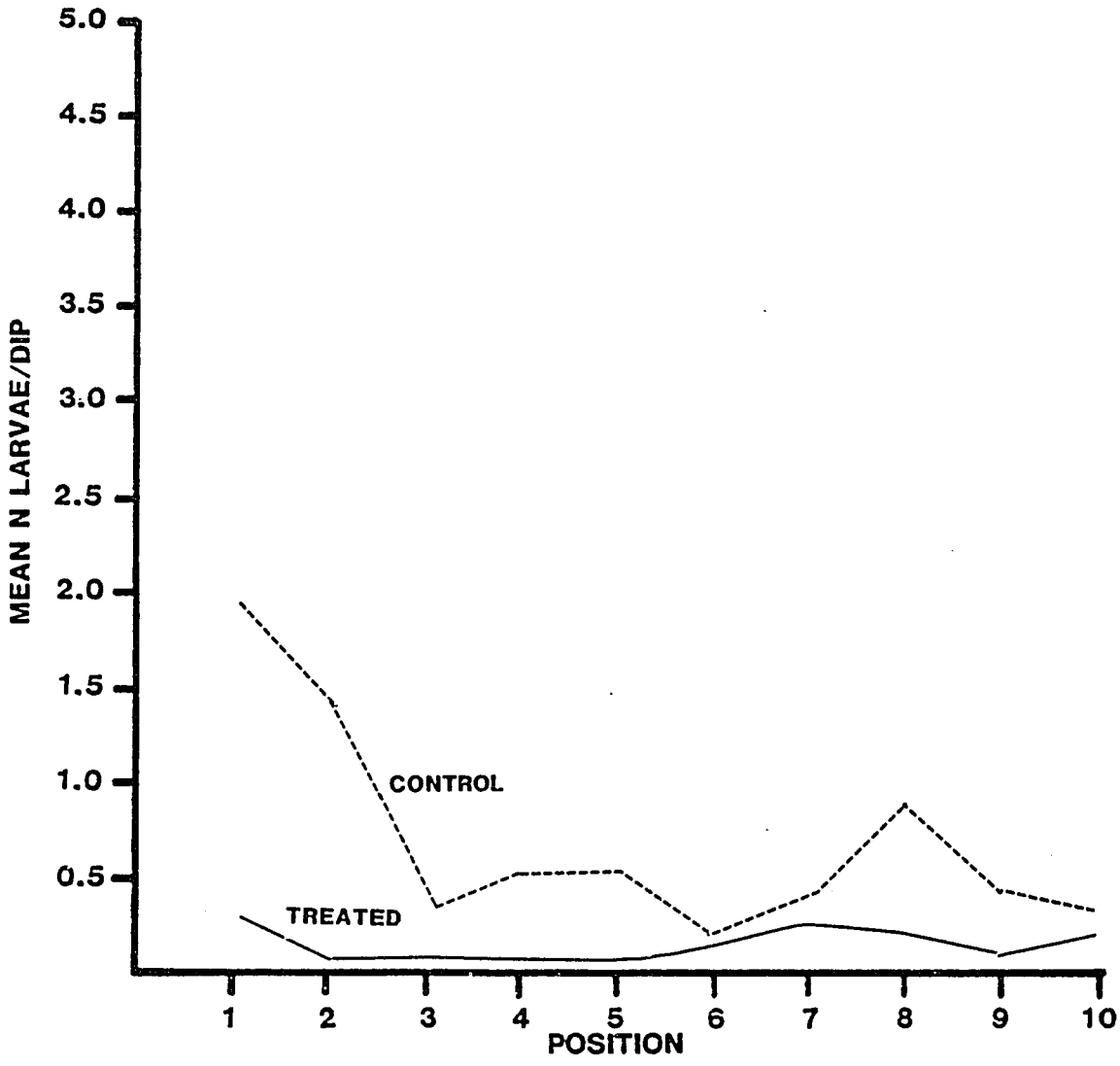


Fig. 28. Mean Number of Larvae per Dip at Transects, Test No. 12 vs. Control

that there was a difference between the controls of the two tests, the significance probability was 0.5418. This indicates that the two control groups were probably not significantly different, and allows comparison of the two treatments. The results of comparing the treatments are included in Table 7.

Test No. 13. Before treatment, the mean number of larvae per dip was 0.91, and the variance was 1.5019. There were 91 larvae in 100 dips in two borders; 51 dips had no larvae. The largest number of larvae in a single dip was five. After treatment with Teknar^{R} granules at the rate of 3.3 kg/ha, the mean number of larvae was 0.27, and the variance was 0.6971. There were 27 larvae in 100 dips; four of those larvae were P. howardii; 85 dips had no larvae. If the two borders are analyzed separately, because the larvae at treatment were approximately 24 hours apart in age, the border with the oldest larvae had more larvae and less effect of treatment. For the first border, the mean before treatment was 0.54, the variance was 0.6884, 27 larvae were found in 50 dips, and 32 dips had no larvae. After treatment, this border had a mean of 0.50, a variance of 1.250, 25 larvae were found in 50 dips, two of the larvae were P. howardii, and 37 dips had no larvae. The significance probability of the test of the hypothesis that the after sample had fewer larvae than the before sample was 0.1660. The second border, before treatment, had a mean of 1.28, a variance of 2.0416, 64 larvae were found in 50 dips, and 19 dips had no larvae. After treatment, only two larvae were found, both of which were P. howardii. The mean was 0.27, the variance was 0.0384, and the number of dips with no

larvae was 48. The significance probability of the test of the hypothesis that the after sample had fewer larvae than the before sample was 0.0040.

Test No. 14. Before treatment, the mean number of larvae per dip was 13.52, and the variance was 411.49. There were 676 larvae in 50 dips; six dips had no larvae. The largest number of larvae in a single dip was 124. After treatment with Teknar^{R} granules at the rate of 5.6 kg/ha, the mean number of larvae was 0.36, and the variance was 0.4704. There were 18 immature mosquitoes in 50 dips; one of those larvae was P. howardii; three were pupae, and 14 were late fourth instar larvae; 37 dips had no larvae. Of the 18 mosquitoes found, nine were on one side of the border, among dense weeds.

Test No. 15. Before treatment, the mean number of larvae per dip was 12.32, and the variance was 695.458. There were 616 larvae in 50 dips; four dips had no larvae. The largest number of larvae in a single dip was 179. After treatment with Teknar^{R} granules at the rate of 6.7 kg/ha, the mean number of larvae was 0.08, and the variance was 0.0736. There were four larvae in 50 dips; two of those larvae were P. howardii; 46 dips had no larvae. No dip had more than one larva.

Locations of Aggregations. The locations of the three largest aggregations of larvae in 38 borders treated with Teknar^{R} WDC drip treatments are shown in Fig. 29. In many cases, there were not three aggregations in a particular border, so only the dips with more than one larva were recorded in Fig. 29.

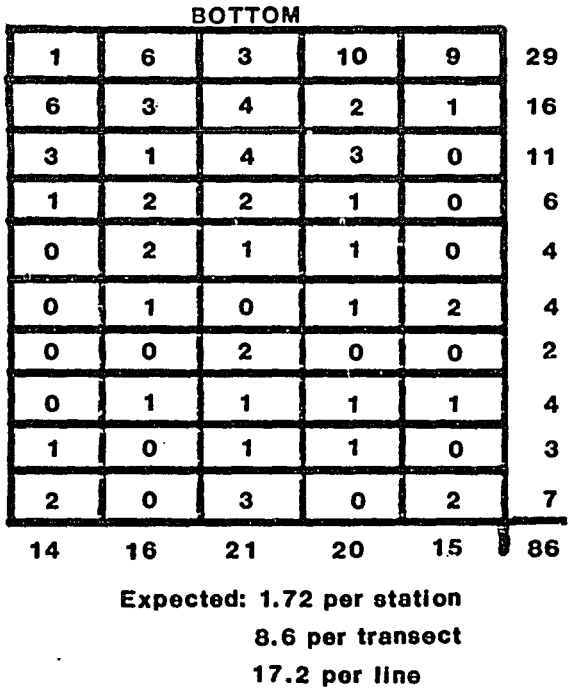


Fig. 29. Locations of Aggregations in Treated Borders

Results of Large-scale Application Tests. The results of the tests of treatment with 3 ppm Teknar^{R} WDC added to irrigation water for 4, 6, and 12 hours were:

Results of Large-scale Application Tests

Treatment	Mean n Larvae/Dip	% of Dips with 0 larvae	Significance Probability larvae	# 0
Control	1.30	51.8	—	—
4 hours	0.168	88.5	.0000	.0000*
6 hours	0.337	82.5	.2776	.2578**
12 hours	0.484	81.8	.4880	.3821**

* Kruskal-Wallis test for all treatment vs control

** Dunn's test for differences between treatments

Results of Continued Large-scale Application. Operational application of Teknar^{R} WDC, at the rate of 3 ppm as an additive to irrigation water began in the second week of June, 1984 and continued through the irrigation season, with modifications as described below. This was supplemented by spray treatment of borders. For the first time in at least the past five years, no complaints about mosquitoes were made to the County Health Department by residents of the area. Farm laborers reported very few mosquitoes, and FICO officials expressed great satisfaction with the results of the management program. Informants in the area told me that they were no longer bothered by mosquitoes. Until the first week in August,

bite counts in treated fields never exceeded five per minute, whereas in previous seasons bite counts (in untreated fields) usually exceeded 50 per minute. Typically, bite counts following treatment were one per five minutes or fewer, but there were occasionally higher numbers.

In August, coincident with the rainy season and the peak of mosquito populations as demonstrated in Figs. 11 and 12 for the previous year, it became apparent that the treatment was no longer effective. Increasing the concentration of Teknar^{R} to 9 ppm effectively brought the population back down to a level at which it was no longer bothersome. This concentration was used for two irrigation cycles, whereupon the concentration was lowered to 3 ppm and kept at that level for one irrigation cycle. Treatment was stopped at the end of September, when it became apparent that the mosquito season had passed and night-time low temperatures dropped below 15^{o} C.

DISCUSSION

Bionomics

Bionomics of Mosquito Larvae in Irrigated Borders

Distribution of Eggs. Return of data for the investment of effort in the investigation of egg distribution was minimal, certainly too small for meaningful statistical analysis. However, results suggested that eggs are deposited in areas most likely to maintain high soil moisture and retain water following irrigation. This is entirely consistent with findings by previous investigators of the species (Curtis 1985; Al-Azawi and Chew 1959; Olson and Meek 1977; Strickman 1980 a & b, 1982; Bodman and Gannon 1950).

Eclosion Time. The extremely small number of larvae that hatched in this investigation is insufficient to permit drawing conclusions. However, when these data are combined with information from prior investigators, it becomes apparent that most of the eggs of floodwater mosquitoes that will hatch following a given flooding will do so in the first few hours. Gunstream (1964) pointed out the advantage of rapid hatching to mosquito larvae in transitory floodwaters. Some understanding of eclosion time is important in the context of the management of mosquitoes by means of B.t.i. added to irrigation water. It appears that the larvicide moves as a wave through the field, and is available at larvicidal concentrations at any point for only a few hours. To be effective, the larvicidal wave must coincide with a time that larvae are actively feeding. Any larvae that hatch after the wave has passed will be unaffected. This suggests a possible mechanism for the

development of resistance to the treatment method. Some larvae may hatch after the wave of larvicide has passed. If eclosion time is heritable, a strain of late-eclosing mosquitoes may develop. In this environment, there is presently little or no selection pressure favoring rapid hatching, because water remains longer than the time required for larvae to mature. Selection pressure under the proposed treatment regime then shifts to favor late hatching. At present, there has been no obvious indication that this is occurring, but data have not been gathered to test this idea. Perhaps such a resistance mechanism, if it is possible, will become apparent over time.

Seasonal Distribution of Mosquitoes. Data gathered in this study support the idea that there is temporal partitioning occurring between A. vexans and P. columbiae (Shemanchuk 1959, Breeland and Pickard 1963, Chew and Gunstream 1970, Curtis 1985). A. vexans is the dominant species in the early and late season, and P. columbiae dominates the mid season. This is entirely consistent with the conclusions of prior investigators of the two species. However, both species are found together frequently, perhaps always (though one may be present only in very small numbers). Therefore, it appears that, at least in the pecan orchard, there are no conditions that absolutely favor one species at the exclusion of the other. From the standpoint of management of populations in this environment, there is no evidence suggesting that management technique should differ for the two species.

The number of mosquitoes present in the environment increases dramatically with the onset of the summer rainy season and decreases rapidly following the end of the rainy season. Whether this peak reflects an

evolutionary cuing on rainfall providing an increased number of habitats, increased humidity providing better conditions for adult survival and dispersal, increased weed growth providing adult food and shelter, more rapid conditioning of eggs, or any one of several other possible factors can not be determined from the data or the literature. Probably some combination of several factors is responsible, both proximally and ultimately, for this population peak. Most of the mosquitoes present during this peak are P. columbiae, but A. vexans is present, and, as was the case in one temporary pond I sampled, may be the only species present in limited habitats. Both species are annoying biters. Mosquito populations throughout the irrigation season, even at their lowest levels, are high enough to result in complaints from citizens. Exceptions may occur if the first irrigation of the year is when temperature is below the threshold necessary for mosquito eclosion, or when temperature at the end of the season drops below the threshold. The threshold temperature has not been determined for the local populations, but other investigators (Gunstream 1964; Horsfall et al. 1973; Al-Azawi and Chew 1959) indicate that there is a definite threshold, but that this varies depending upon immediately previous temperatures. Initiation of larvicidal treatment should be based upon sampling untreated borders, beginning with the first irrigation of the year. When the first larvae are found, treatment should begin. Treatment should continue through the irrigation season, but sampling toward the end of the season may indicate that treatment may be halted when mosquitoes are no longer found in the orchard.

Distribution of Larvae with Regard to Spatial Position. It is obvious that larvae are highly aggregated within borders, but factors influencing this aggregation are not obvious. More larvae are found at the downstream ends of borders than upstream, in general, but this is not always the case. Figs. 13 and 14 show that there is no consistent pattern of larval distribution, but there is a tendency for larvae to aggregate at the downstream end of borders. Larvae are highly mobile in this environment. I have often seen individual larvae move more than 1 m in a continuous burst of activity. Any tendency to congregate at the downstream ends of borders may be because these are loci at which water remains longest, and thereby might help insure survival through the aquatic stage. In borders treated with Teknar^{R} added to irrigation water, this tendency appears to be more pronounced than in untreated borders. This may indicate that larvicide is not as effectively distributed at the downstream ends of borders as it is upstream. This observation suggested the necessity of supplementing treatment of irrigation water with spray application of larvicide to puddles at ends of borders.

Although there may be no definite consistent pattern of distribution in regard to spatial position, it has always been the case that, if larvae are present in a border, some will be found in the first 20 m. Almost always some will be found in the first transect, taken at the downstream end of the border at the first place that water depth exceeds 5 cm (the depth necessary to obtain a reasonable dip sample of water). This observation may suffice as the foundation for a simple sampling scheme for management purposes: take five dips in a line across the bottom of the border at the

first place where water is 5 cm or more deep. If larvae are present, treat the border, if none are present, no treatment is necessary. Further testing of this approach to sampling should be done to test its effectiveness in the long term, but, based on data obtained in this study, this approach should be very effective.

Distribution of Larvae in Relation to Depth. It is clear from Table 3 that larvae are selecting intermediate depths. Water of less than 4 cm depth may offer too little food, may be of too short duration for larvae to mature, or may be susceptible to fluctuations in temperature beyond the range of tolerance of larvae. Reasons for selection against water greater than 10 cm depth are not clear, but the sample size in this range is so small that one can not safely say that such selection is definitely taking place. It may be that there is an optimum balance between depth sufficient to allow larval development to take place, production of food for larvae, and optimum depth for avoidance of predators.

Distribution of Larvae in Relation to Shade. Table 4 shows that there is apparently no relationship between presence of larvae, as positive dips, and shade, but that there is an apparent increase in the number of larvae in association with either partial or dense shade. This suggests that there may be an avoidance of open sunlight. Reasons for this are not clear, but may include: predator avoidance may be facilitated by dense or partial shade; temperature may be subject to less fluctuation in dense or partial shade than in open water; food availablity may differ according to shade conditions; or more eggs may be deposited in sites that receive at least some shade. Strickman (1982) demonstrated experimentally that A. vexans

selects shaded oviposition sites over unshaded sites. Hocking (1953) found that A. communis larvae formed aggregations in sunny areas but that these aggregations then moved into shaded areas. He observed almost constant movement of aggregations throughout the available habitat during the course of a day, but had no suggestions why larvae reacted to shade as they did.

Distribution of Larvae in Relation to Debris Mat. There appears to be some selection by larvae for or against the presence of a mat of debris on the surface of the water, but this does not appear to be consistent. Slightly fewer positive dips were found in association with debris mat than were expected and slightly more positive dips were found in the absence of debris mat, but this was only at the 0.1363 level of significance. The number of larvae associated with debris mat was higher than expected, at the 0.0607 significance level. Presence of mat was highly associated with shade and with position, because mat tended to accumulate on the edges rather than in centers of borders. Association with debris mat may offer larvae some protection from predators. Further, microorganisms that are food for larvae may find more substrate for growth in association with mat.

Distribution of Larvae in Relation to Water Temperature. There appears to be a clear preference for temperatures in the intermediate ranges and/or avoidance of temperature extremes. This preference is not shown by the proportion of positive dips to negative dips, but by the number of larvae only. Gunstream's (1964) observation that distribution was not influenced by temperature was made in an environment with less range of temperature, between 27 and 40^{o}C. My data show that larvae may be found

throughout the range of temperatures sampled, but that they prefer the range, 20^{o} to 24^{o} . The pattern of distribution of the two species strongly suggests that P. columbiae larvae avoid cooler temperatures and A. vexans larvae avoid warmer temperatures. This is consistent with the observations of Gunstream (1964). The evidence of temperature selection, seasonal distribution, and geographic distribution (Carpenter and LaCasse 1955) indicate that the two species probably evolved in different climates, P. columbiae as a tropical mosquito and A. vexans as a temperate zone mosquito, but that both species can share the same environments on the margins of their ranges.

Summary on Variables Affecting Distribution of Larvae. It is evident that the variables measured are not isolated from each other. Shallow water exposed to full sun is hotter than deep water in dense shade. Debris mat occurs more frequently at the edges and downstream ends of borders than in their centers or upstream ends. Deeper water is found at the downstream ends of borders than upstream. The presently available data are insufficient to effectively isolate or combine factors to arrive at valid conclusions for most variables. The frequent occurrence of both species in the same dip sample suggests that any partitioning of resources is only at the extremes of suitable habitat. In regard to management of mosquito populations, these variables are of little or no importance, with the possible exception of the use of sampling only the downstream ends of borders to simplify sampling for management goals.

Management

Mosquito Breeding Sites

Most mosquitoes presently causing annoyance to residents of the area come from irrigated borders of the pecan orchard. However, many other breeding sites are present in the area, and reduction of mosquito populations in the orchard would not eliminate all annoyance or potential health hazard caused by mosquitoes. In fact, if populations in the orchard are reduced, the relative importance of other breeding sites should increase. Furthermore, breeding sites outside the orchard may serve as a source for continual recolonization of the orchard. Continued success in managing mosquito populations in the area depends of management of all breeding sites in the area, and not only those in the pecan orchard. The owners of the orchard have expressed a commitment to managing mosquitoes on their property, and have assigned a significant amount of money and manpower toward that end. But they can not manage mosquito populations off their property. The present situation of having responsibility for mosquito control fall upon the lone County Vector Control Officer is ineffective. It is impossible for one person to successfully manage all of the mosquito populations in the entire County. However, one well-trained and conscientious person might be able to manage mosquitoes in the Santa Cruz Valley study area, with the continued cooperation of FICO.

Legal mechanisms for provision of mosquito management for the area are presently limited. In the long run, either a Mosquito Abatement District should be formed or, minimally, a full-time Vector Control Officer should be assigned to the area, at least during the summer rainy season. From

informal interviews with many citizens, I have developed the impression that the majority want something to be done, but that they want somebody else to do it for them and they want it to be free of costs. The majority of residents blame FICO for all mosquitoes, and demand that FICO handle the problem. FICO officials insist, correctly, that not all mosquitoes in the area come from the orchard, and that something should be done about other breeding sites as well. Clearly, if comprehensive mosquito management is a valid goal for the citizens of the area, some effective political solution must be found.

By no means should it be considered that all mosquito breeding sites in the study area have been located. Many breeding sites are small and transitory, and are therefore easily overlooked. If the community should decide to institute a program of mosquito abatement, it would be necessary to continue the search for breeding sites and management of every site in the area.

Larvicide Tests

Bioassays. Results of bioassays performed with water collected in fields following irrigation with Teknar^{R} added to water were inconclusive. Distribution of larvicidal activity appeared to be inconsistent between tests, but some general patterns are likely. Larvicidal activity as indicated by bioassay tests appeared to be diminished as distance from the Teknar^{R} inlet increased. Larvicidal activity was not evenly distributed throughout a field or border. The data suggest a wave of larvicide passes through the standing water, occasionally leaving behind areas of activity.

Several factors may have complicated the results of these bioassays. In the field, I took water samples from near the water surface, being careful not to disturb the mud under water. All samples were gathered at or after mid-day. By the time samples were gathered, the larvicide may have precipitated from the upper level of the water column or been inactivated by exposure to sunlight. Previous investigators (Ignoffo et al 1981, Stark and Meisch 1983, Sun et al 1980) noted that B.t.i. has a tendency to sink, and Ignoffo et al. (1981) demonstrated that suspended particulates and exposure to sunlight reduce availability of B.t.i. in the environment. Because these possibilities were not considered in my bioassay tests, the tests can not be considered as valid indicators of effectiveness of treatment.

Effect of Sampling. The comparison of successive samples clearly indicates that there was no statistically significant difference between first and second samples from the same place. This suggests that sampling did not disturb the mosquito larvae long enough to influence the samples.

Changes from Day to Day. In no case were there statistically significant changes in the numbers of larvae present in the same borders on successive days. Borders that showed the greatest variances showed the most tendency toward variation from day to day, but the variance and apparent differences are due to the influence of a few dips with many larvae. It is apparent that the relationship between number of larvae and habitat volume does not change significantly from one day to the next, as would be expected if either habitat were diminishing (by percolation or evaporation) or larvae were being removed by natural mortality. At the time

of sampling, no visible changes were noted in habitat volume. Apparently the soil had been so saturated that water percolated very slowly.

This information is useful in considering the results of sampling for larvicide effectiveness because in some cases control and treated borders were not sampled on the same day or at exactly the same time following irrigation. If significant differences were found from day to day, the validity of such samples might be questionable. Also, this information suggests that there are no major mortality factors acting on larvae during this time period.

Larvicide Evaluations. In all cases, there was some apparent effect of the addition of Teknar^{R} to irrigation water. Some tests indicated that the effect was less than anticipated. Close examination of the conditions of these tests reveals complicating factors in each case. Understanding these factors may be important in planning management techniques.

In test No. 1, addition of larvicide began only five hours after irrigation began, well before the front of water had reached the bottoms of the borders. Also, the larvicide was added during the afternoon of a hot and sunny day. These factors may have reduced larvicidal effectiveness. Probably not all larvae had hatched when the larvicide had passed them, or larvicide had either precipitated out, bound to the soil, or been inactivated by exposure to heat and sunlight. The disappointing results of this test prompted the change to starting the Teknar^{R} input at sundown approximately 12 hours after irrigation had begun as a standard procedure in subsequent tests and in the management plan.

In test No. 4, it was apparent that the treated border with the highest number of larvae had not been irrigated at the same time as other borders and had probably not been effectively treated. On occasion, borders at or near ends of irrigation sets are not irrigated at the same time as other borders in the sets. Also occasionally siphons become plugged with debris during the course of irrigation. Such events would, of course, result in ineffective treatment of those borders. Even with this border included in the statistical analysis, the difference between treated and untreated borders was highly significant.

During test No. 5, the McLaughlin device was blown into the ditch by wind before it had completely emptied. Also, a mound of dirt was found across the treated border with the highest number of larvae. This may have greatly influenced larvicide distribution; 95% of the larvae found in this border were found downstream from this mound. This suggests that hydrologic characteristics of the borders may influence larvicide distribution.

Tests No. 7, 8, 9 and 10 were done near the peak of mosquito season, when several of the treated borders were overgrown with weeds. The large number of larvae present, in itself, may require an increase in Teknar^{R} concentration to effect adequate control. Previous investigators (Mulla et al. 1982; Ignoffo et al. 1981) found that larval density had a significant effect on the efficacy of B.t.i. formulations. With high larval densities the level of control with a given rate of application was lower than in similar habitats with lower larval densities. The reason for this is obvious, since B.t.i. is a stomach poison and consumption by larvae removes it from the

effective feeding environment of other larvae. If many larvae are present, some will not get effective doses of material unless the concentration of material is sufficient to provide for all.

These tests appeared to have been additionally complicated by the dense growth of weeds which probably acted as hydrologic baffles interfering with even distribution of material. Results of these tests strongly suggest that an increase in concentration of larvicide is called for during the period of highest mosquito density and greatest weed growth.

In tests of both Teknar^{R} spray and Teknar^{R} granules, it became apparent that the age of larvae was an important factor. Larvae in the fourth instar enter a period of relative quiescence and reduced feeding. In this stage, Mulla et al. (1982, 1980) noted greatly reduced susceptiblility of larvae to B.t.i.. This is clearly confirmed by the results of my test No. 13, in which the border with the older larvae showed little treatment effect, whereas the border with younger larvae showed a very significant treatment effect.

Somewhat of a surprise was the observation that, in general, the concentration of material does not seem to make a significant difference as long as larvae are present in low densities. In each case comparing different concentrations of Teknar^{R} applied in the same manner, with the same device, at approximately the same time, there was no significant difference between doses of .586 l/ha, 1.172 l/ha, and 2.344 l/ha.

The comparison of devices for adding Teknar^{R} to irrigation water was inconclusive statistically. No significant differences could be found between treatment with the fertilizer tank and the McLaughlin device, or

between the McLaughlin device and pouring at the siphons. My data are insufficient to conclude that one device is better than the other. However, the fertilizer tank has the advantage of being familiar to farm laborers, already on hand, and not subject to upset by wind. Pouring at the siphons is less efficient than either of the dripping devices, but is suitable for use in situations in which one or a few borders are irrigated at different times from the majority of borders in a set.

Management Suggestions for Mosquito Breeding Sites

Livestock Watering Ponds. Control of mosquitoes at temporary ponds is a difficult problem. Filling of the ponds is unpredictable. Development of mosquitoes can be very rapid, occurring before control techniques can be applied. Any control agent must be nontoxic to cattle and wildlife that may drink the water. The ideal control agent for mosquitoes in this situation would be one that does not need to be applied each time ponds fill, but can be applied or installed once or twice each year and will be effective when ponds fill. Present formulations of Teknar^{R} do not meet these criteria. However, several companies have produced briquet formulations of B.t.i. that may be of use in this situation.

As an informal experiment, I scattered several handfuls of Teknar^{R} granules, amounting to about 1 kg., into a pond that was densely populated with Aedes vexans third stage larvae. The larvae were so dense as to appear to be black balls, the size of softballs, scattered at approximately 1 m intervals more-or-less evenly about the pond, with the spaces between aggregations peppered with individual larvae. The following day, I returned to the pond and found no living larvae. This approach to controlling mosquitoes in this situation, however, is haphazard at best because timing is critical.

Livestock watering troughs. Although no mosquitoes were found in the livestock watering troughs I examined, these are potentially important breeding sites for standing water mosquitoes. As such, they should be

considered in any area wide management plans as potential sources of disease vectors. Native predators, such as backswimmers (Hemiptera: Notonectidae) which were found in the troughs I examined, may be effective mosquito control agents when they are present, but their presence is unpredictable. Probably the simplest control procedure would be to place Gambusia in all troughs and check them periodically to be certain that the fish are surviving.

Urban drainage ditches. Water ponds in drainage ditches only where they are blocked or where basins have been formed. Filling of the ditches is unpredictable because it depends on rainfall runoff. The most effective and least expensive long-term solution to the problem here is structural modification of the ditches to prevent ponding. Alternatively, a long-lasting larvicide that can be activated by the presence of water might be effective. However, it should be recognized that water will drain from these sites into the Santa Cruz River. In the context of the overall problem, the contribution of drainage ditch puddles to the mosquito problem is small. Despite the obvious fact that drainage in the urban area has been poorly planned from the standpoint of temporary flood damage, it does not appear to contribute significantly to the mosquito problem, simply because few puddles of sufficient duration form in drainage ditches. This assessment is based only on one season's investigation, however, and may change as a result of further research. The importance of drainage ditches as breeding sites may increase when other, presently more important, sites are eliminated or controlled.

Golf course ponds. Mosquito breeding in golf course ponds can be prevented by maintaining healthy fish populations and keeping the ponds free of emergent vegetation which provides harborage for mosquito larvae. Not all of the golf course ponds in the area have been checked during this study, and some that were not checked may support mosquitoes. All ponds should be checked periodically and any that lack fish should have them added. Golf course managers should be informed of the proper techniques for managing their ponds to prevent mosquito breeding.

Mine tailings ponds. A long-lasting larvicide that can be applied once or twice a year, such as chlorpyrifos granules, may be an acceptable means of control in these ponds. Probably the best solution would be to eliminate these ponds by filling and grading. Responsibility for solving this problem should rest with the mining companies.

Road ditches. Undoubtedly there are many more road ditches that breed mosquitoes than those identified in this study. Like drainage ditches, the relative importance of road ditches as mosquito breeding sites is presently rather small, but may increase in the future.

Road puddles. The obvious solution to mosquito problems resulting from this type of source is structural improvement of drainage. However, this may be more expensive than the importance of the mosquito breeding source warrants. Alternatively, identification and inspection of such breeding sites, with larviciding as necessary, would probably be effective.

Roadside puddles. Again, the best solution is probably structural, and the relative contribution to the problem is small but may become important.

Sprinkler puddles. Although only one chronic sprinkler puddle was found, this type of site may be widespread, but difficult to locate. The only reasonable solution lies in eliminating this class of site by proper maintenance of sprinklers. Golf course grounds personnel should be reminded of the importance of sprinkler maintenance periodically, and their assistance should be enlisted in finding potential mosquito breeding sites of this and other types on their courses. Members of the public should also be made aware of this type of breeding site, so that they can practice preventive maintenance around their homes.

Irrigation ditches. Most presently used irrigation ditches on the FICO property are unsuitable for mosquito breeding because they are cement lined, kept clean, and are quickly drained following use. FICO management has done an excellent job on this; however, occasional problems, or potential problems, develop where temporary jams occur. Continued diligence, as demonstrated in the past, is necessary to prevent problems from occurring. A few ditches, not cement lined and not consistently maintained, do support mosquito breeding. In the present context of abundant breeding sites, the relative contribution of these ditches to the mosquito problem is small. However, should control of other sites be effective, the importance of these ditches will increase. The best solution may be to bring these few ditches up to the overall standards of the majority of ditches on the property or to close them. Some of them are temporary, created each year for irrigation season and refilled to facilitate harvest. If they cannot be upgraded, then regular treatment of them is called for. Substandard ditches may also be important breeding sites for dragonflies and other predatory insects that

can go from them to other mosquito breeding sites, but permanent cowponds and golf course ponds are probably more productive of predators. The predator population is unlikely to be significantly impacted if substandard ditches are eliminated, as long as other sites are available to them.

Irrigation overflow ponds. Few overflow ponds were found on FICO property, which is indicative of the attention paid to water management. All of these ponds are mosquito breeding sites, and some of them are located close enough to urban areas to create significant problems. These ponds undoubtedly represent a loss of water to FICO. Elimination of these ponds by structural and/or water management modifications would both solve the mosquito problem and water loss. In 1983, several ponds were eliminated, and no longer pose a problem. Continued identification and elimination of such ponds is called for, until they no longer exist. Treatment of the ponds with B.t.i. may necessary, because mosquito eclosion may not take place until after Teknar^{R} added to irrigation water at the field heads has deteriorated.

Miscellaneous breeding sites. These are all minor sites at present and are unlikely to increase in importance. However, many more sites of this type probably have not been located yet, so the total number of them may be large and the total contribution to the mosquito problem may be greater than is evident from my data. Appropriate management techniques are site-specific, such as eliminating or puncturing discarded tires.

Irrigation Borders. Several alternative possibilities should be considered for management of these breeding sites. In a few cases, because breeding sites will be converted to residental areas eventually and/or

because trees at them have lowered productivity, removal of particular rows or fields may be the best long-term solution. Comparison of known breeding sites with FICO's long-range development plans will suggest which, if any, sites should be managed in this way. In other cases, more careful water management may be practicable and may eliminate sites as breeding places for mosquitoes. Continued leveling of rows, using laser levelling techniques, may eliminate low spots in some fields that create ponding. Filling of existing, and prevention of future, tire tracks in rows may significantly reduce some breeding sites. Elimination of weeds and diligent weed control may also help reduce populations of mosquitoes. However, these techniques will probably be applicable in only a few places, and will not completely solve the problem in them. Remaining sites might best be treated with B.t.i. to kill larvae.

In terms of treating with B.t.i., two types of breeding sites exist in the pecan groves. Major sites, whole fields that appear to be productive, call for treatment of the entire field with liquid B.t.i. added to irrigation water as it is run into the field. Smaller sites, ranging from a few rows to just small puddles present more variables and may require addition of B.t.i. to irrigation water as it is channeled into individual rows or treatment of puddles by application of B.t.i. as a spray. Identification of sites is the first step, some of which has been completed in this study. Effective techniques for treatment have been developed in the course of this study.

For large-scale treatment of whole fields, the general policy of addition of 3 ppm Teknar^{R} WDC for four hours as an additive to irrigation water, beginning the drip approximately 12 hours following start of

irrigation, appears to be effective. Effectiveness can be increased by follow-up treatment, two to three days after irrigation, consisting of spraying 1 part Teknar^{R} WDC per 64 parts water on standing puddles at ends of borders when sampling indicates presence of larvae. However, certain conditions complicate this general treatment plan and require adjustment of the plan to effectively meet them.

During the pollination season, enormous numbers of pollen grains and fallen staminate flowers litter the ground. These appear to greatly increase particulate organic material suspended in the water, and may result in binding and precipitation of B.t.i., reducing its effectiveness. During this season, consistent sampling of borders should be practiced, and, if presence of mosquito larvae indicates that B.t.i. is being less effective than desired at the rate of 3 ppm, the rate should be increased, perhaps doubled. Further experimentation during this brief period should elucidate the importance of this potential problem and determine minimum effective application rate.

During the summer rainy season, several factors combine to reduce effectiveness of the prescribed treatment. Dense weeds apparently act as baffles, reducing distribution of larvicide within borders. Furthermore, there appears to be a natural mosquito population peak, coincident with the rainy season, during which the number of larvae that hatch may greatly excede maximum kill capacity of the 3 ppm application rate. It appears that the only solutions are to increase concentration of B.t.i. applied to fields or to switch to another type of larvicide, such as fenvalerate, that is not affected by these conditions. Practice has demonstrated that a tripling of concentration of B.t.i. is apparently effective in countering these

conditions, but the increase in cost of this approach may warrant a search for alternative means of larviciding during this period. Occasionally adulticiding may be called for during the peak of mosquito season, but timing and careful direction of any program of adulticiding are important to minimize costs and reduce potential adverse effects.

The topography of some fields may reduce effectiveness of B.t.i. as a larvicide. In several fields, it was noted that some borders contained many more larvae than other borders treated identically. Careful examination of topography revealed irregularities, such as low mounds of dirt, depressions, and tire tracks, to be present in many borders that had most larvae. These irregularities may result in precipitation of larvicide before it reaches the bottoms of the borders, and reduce effectiveness of treatment. Levelling of borders, as has been part of a continuing program by FICO, may eliminate these problem spots. Other obstructions, such as fallen trees, occur irregularly, but appear to reduce distribution of larvicide. Removal of such obstacles, as soon as they are discovered, will probably be advantageous.

Occasionally, borders at ends of sets are irrigated hurriedly on the morning following irrigation of the rest of the set. This results in no larvicide being applied to these borders. Either diligent effort must be made to irrigate all borders in a set simultaneously, or application of larvicide by pouring at siphons of those borders being irrigated last should be practiced. Application by pouring larvicide at siphons may not be quite as efficient as application as a drip to irrigation water, but it is better than no treatment at all. This application should be made after water has run on the border

for at least an hour or two, so that larvicide follows the front of water by enough time so that larvae will hatch and ingest the material. In these cases, it is particularly important that spray application of additional larvicide be made to the ends of borders two to three days following irrigation.

Half borders, those that are bounded on one side by a tree row and the other by a road or ditch, are a special case. Water often remains in them longer than in typical borders, probably because there is only one row of trees to draw water. Often a half border would produce a population of floodwater mosquitoes immediately following irrigation, and, several days later, larvae of standing-water mosquitoes (C. tarsalis primarily) would be present. This was most frequent during the rainy season, when rain would replenish the water. Appropriate treatment for half borders should consist of regular treatment at irrigation plus weekly inspection and spraying of the entire half border with the Teknar^{R} 1: 64 mixture if larvae are present. This should control both types of mosquitoes.

Large-scale treatment of the Sahuarita Ranch division of the orchard over most of two mosquito seasons has shown that continued treatment is necessary until such time as all eggs present in soil have hatched. On occasion, one or several borders have missed treatment for a variety of reasons. Large numbers of mosquitoes were produced in these borders and required emergency application of adulticidal material. Presently, I can not estimate when generalized treatment can be halted. Only by continued sampling can it be determined that the egg population has been reduced to a level that will allow a change in treatment regime.

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