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MALATHION RESISTANCE IN MOSQUITOES FROM CHARLESTON AND GEORGETOWN COUNTIES OF COASTAL SOUTH CAROLINA

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ABSTRACT. Susceptibility tests were conducted using the World Health Organization diagnostic test procedure on strains of *Aedes taeniorhynchus, Aedes sollicitans, Aedes vexans,* and *Culex nigripalpus* collected from several localities in Charleston and Georgetown counties of South Carolina. *Aedes taeniorhynchus* was resistant to malathion (mortality 1.0–54.4%) but not to propoxur, permethrin, or fenitrothion. There also were indications that *Ae. sollicitans* and *Cx. nigripalpus* were resistant to malathion, but to a lesser extent than *Ae. taeniorhynchus* (mortalities: 72.1–81.0%, and 46.2%, respectively). *Aedes vexans* was susceptible to malathion (mortality 98.6%). In field tests using ULV application of malathion and field-collected *Ae. taeniorhynchus,* and susceptible *Ae. aegypti* and *Ae. taeniorhynchus,* a noticeably lower mortality also was obtained in the wild mosquitoes.

INTRODUCTION

The black saltmarsh mosquito, *Aedes taeniorhynchus* (Wied.), and the eastern saltmarsh mosquito, *Aedes sollicitans* (Walker), are the 2 most important pest mosquitoes in coastal South Carolina. In Charleston County, SC, 53.8–79.3% of all mosquitoes trapped from 1985 to 1991 constituted these 2 species, with *Ae. taeniorhynchus* being the more numerous. The 2 species constituted a major part of light-trap samples in coastal areas of Georgetown County. In addition to being troublesome pests, the saltmarsh mosquitoes are known to be potential vectors of arboviruses and nematode parasites of man and other vertebrates (Tidwell et al. 1984, Nayar 1985). Mosquito control efforts in coastal counties of the state are, therefore, directed mainly at the 2 saltmarsh mosquitoes.

Aedes taeniorhynchus and *Ae. sollicitans* are prone to develop resistance to organochlorine insecticides and to malathion (Gahan et al. 1956, 1966). The present work was conducted after an incidental test performed in 1990 suggested the presence of malathion resistance in *Ae. taeniorhynchus* collected from the grounds of The International Center for Public Health Research of the University of South Carolina (The Wedge), Charleston County, SC. Mosquito control agencies in Charleston and Georgetown counties had suspected control failure in recent years.

Although Charleston County Mosquito Abatement Program (CCMAP) has used malathion as an adulticide since 1962, The Wedge is in one of the least treated areas of the county. Malathion has also been used extensively as an adulticide in Georgetown County, which lies just north of Charleston County. Resistance tests using malathion and other insecticides were performed on mosquitoes obtained from the 2 counties. To assess the association of resistance detected by laboratory assay with the field performance of malathion, preliminary field assays were conducted using ground ULV application of the insecticide directed at caged mosquitoes.

MATERIALS AND METHODS

In Charleston County, mosquito larvae and pupae were collected from the city of Charleston, from 3 coastal locations south of the city (James Island, Folly Beach, and Edisto Beach at *ca.* 6, 13, and 38 km from the city, respectively), and from 2 barrier islands (Sullivans Island and Isle of Palms) off the town of Mount Pleasant, just east of the city. In Georgetown County, larvae and pupae were obtained from the city of Georgetown, and Wedgefield Plantation and Litchfield (*ca.* 8 km N and 32 km NE of the town, respectively). At The Wedge, instead of immature mosquitoes, females attracted to humans were collected with aspirators.

Field-collected larvae and pupae were reared to the adult stage at The Wedge and the females were tested for susceptibility/resistance to insecticides using the World Health Organization (WHO) diagnostic test procedure and materials (World Health Organization 1981). In this WHO procedure, *ca.* 25 female mosquitoes are kept, usually for 1 h, in a tube lined with paper impregnated with a diagnostic concentration of the insecticide. Mortalities are scored 24 h postexposure. Papers impregnated with 5% malathion obtained from WHO and with 1% fenitrothion, 0.1% propoxur, and 0.25% permethrin obtained

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Table 1. Resistance to malathion of adult female *Aedes taeniorhynchus* from 6 localities in Charleston County, SC, determined by the World Health Organization (1981) diagnostic test procedure during 1991[1].

Locality	Test month	Exposed/ control	Number of rep- licates	Number tested	% mortality ± SE[2]
Charleston	May	Exposed	7	141	26.2 ± 3.7
		Control	5	116	4.3 ± 1.9
	July	Exposed	5	114	7.9 ± 2.5
		Control	3	77	3.9 ± 2.2
	August	Exposed	5	116	2.9 ± 1.6
		Control	4	102	15.7 ± 3.6
Edisto Beach	May	Exposed	6	118	53.2 ± 4.6
		Control	5	115	11.3 ± 3.0
	August	Exposed	5	125	10.6 ± 2.8
		Control	4	99	6.1 ± 2.4
Folly Beach	May	Exposed	7	158	20.9 ± 3.2
		Control	6	126	4.8 ± 1.9
	July	Exposed	4	87	19.5 ± 4.3
		Control	2	49	2.0 ± 2.0
	October	Exposed	5	118	22.0 ± 3.8
		Control	4	101	0.0 ± 0.0
Isle of Palms	August	Exposed	5	112	0.9 ± 0.9
		Control	4	87	0.0 ± 0.0
	September	Exposed	4	92	54.4 ± 5.2
		Control	4	92	0.0 ± 0.0
Sullivans Island	June	Exposed	1	15	7.1 ± 6.7
		Control	1	15	6.7 ± 6.4
The Wedge	September	Exposed	4	80	23.8 ± 4.8
		Control	4	86	0.0 ± 0.0
	June	Exposed	6	155	29.2 ± 3.7
		Control	5	127	7.1 ± 2.3

[1] The September test at The Wedge was done in 1990.
[2] Exposure mortalities were corrected using Abbott's formula when appropriate (World Health Organization 1981).

from the U.S. Army Environmental Hygiene Agency (USAEHA), prepared according to WHO diagnostic dose prescriptions (B. C. Zeichner, personal communication, 1989), were used in this study.

Adults obtained from field-collected immatures were tested for their response to insecticides, irrespective of the species to which they belonged. *Aedes taeniorhynchus* was, by far, the most common and abundant mosquito encountered. The inland floodwater mosquito *Aedes vexans* (Meigen), and *Culex nigripalpus* Theobald were also encountered and tested, as was *Ae. sollicitans,* which was collected at The Wedge. In addition, mosquitoes from insecticide-susceptible strains of *Aedes aegypti* (Linn.) and *Ae. taeniorhynchus* were tested occasionally, to ensure the potency of insecticide-impregnated papers. Both strains originated (the former in 1981 and the latter in 1990) from the Medical and Veterinary Entomology Research Lab, Agricultural Research Service, Gainesville, Florida. Mortalities were corrected using Abbott's formula (World Health Organization 1981) when control mortalities were between 5 and 20%.

The room temperature at the time of exposure was 23–29°C. The usual temperature was *ca.* 25°C. The relative humidity varied from 61 to 87%, but was predominantly *ca.* 70%. The minimum and maximum temperature ranges during the 24-h postexposure holding periods were 24.0–26.0°C, and 23.0–27.5°C, respectively.

Field tests of mosquito adulticides were carried out at Georgetown County Airport. An east–west taxiway at the airport served as the truck route for ground ULV applications. On either side of the taxiway are large fields in which 3 rows of stakes, 25 m apart, were arranged at a

Table 2. Resistance to malathion of adult female *Aedes taeniorhynchus* from 6 localities in Charleston County, SC, determined by the World Health Organization (1981) diagnostic test procedure during 1992.

Locality	Test month	Exposed/ control	Number of replicates	Number tested	% mortality ± SE[1]
Charleston	July	Exposed	3	77	16.9 ± 4.3
		Control	2	49	2.0 ± 2.0
Edisto Beach	September	Exposed	4	99	5.6 ± 2.3
		Control	4	102	5.9 ± 2.3
Folly Beach	July	Exposed	4	102	1.0 ± 1.0
		Control	4	86	0.0 ± 0.0
	August	Exposed	6	149	18.8 ± 3.2
		Control	5	118	0.0 ± 0.0
	October	Exposed	6	139	3.6 ± 1.6
		Control	4	97	1.0 ± 1.0
Isle of Palms	August	Exposed	4	79	13.9 ± 3.9
		Control	4	102	1.0 ± 1.0
	October	Exposed	5	120	12.5 ± 3.2
		Control	4	101	4.0 ± 1.9
James Island	October	Exposed	4	97	2.1 ± 1.4
		Control	4	98	2.0 ± 1.4
Sullivans Island	September	Exposed	4	97	16.1 ± 3.7
		Control	4	94	12.8 ± 3.4

[1] Exposure mortalities were corrected using Abbott's formula when appropriate (World Health Organization 1981).

90° angle to the direction of the taxiway. In each row, single stakes were put up at 50, 100, 150, and 200 m from the taxiway. One row had an additional stake at 250 m. Each stake ended in a polyvinyl chloride (PVC) "T" top on which cages of mosquitoes were suspended, about 1.5 m above the ground. Mosquitoes used in these assays included colony and wild *Ae. taeniorhynchus* and colony *Ae. aegypti.*

Malathion (91% AI) was applied from a truck-mounted Leco 500 ULV machine. Application rates ranged from 36.5 to 58.5 ml/ha. The higher rates were used after noting that the lower rates resulted in unexpectedly low mortalities of wild *Ae. taeniorhynchus*. Vehicle speed was maintained at 8 kph by marking off the truck route in 15.2-m intervals and using a timing sheet to indicate the cumulative number of seconds as flags were passed.

Ground and air temperature as well as wind speed and direction were monitored until conditions were satisfactory for application (wind speed *ca.* 4.8–16 kph, wind direction no more than 30° off the right angle to the taxiway, and ground temperature no greater than 3°C from air temperature). Wind speed and direction were also monitored once a minute during application and for 5 min after completion. Temperature was recorded within the top 2 cm of soil and just above nozzle height. Relative humidity was also recorded. A long wait was often necessary in the field for conditions to be right for spray application. As a result, spraying was done in the hours 1855–0012. The following microclimatic conditions were recorded in July 1991, August 1991, August 1992, and October 1992, respectively: ground temperature 29.0, 29.5, 21.0, 26.0°C; air temperature 27.5, 28.5, 25.0, 23.0°C; relative humidity 87, 76, 83, 74%; minimum and maximum temperature during 24 h postexposure holding period 25.0, 24.5, 22.0, 23.0°C, and 27.0, 26.0, 27.0, 24.0°C, respectively.

Droplet size was monitored with slides mounted on spinners placed at 50 m and 100 m at a right angle to the truck path (Sofield and Kent 1984). Two hundred drops from each distance were measured. Droplet size at 8 m from the sprayer was determined to be of average mass median diameter (MMD) of 14.1 μm by 8 measurements made at various times previously.

Wild and colony *Ae. taeniorhynchus* and colony *Ae. aegypti* were used in the field experiments. Exposure cages consisted of PVC cylinders (10.2 cm diam, 3.8 cm deep) covered on both ends with nylon tulle. About 25 female mosquitoes were aspirated into the cages. If mosquitoes were held overnight, polyester fiber balls lightly soaked with 5% sugar solution were placed on the tops of the cages. Four cages were normally used at each distance from the spray path

Table 3. Resistance/susceptibility to malathion of adult female *Aedes taeniorhynchus* (TAEN) and *Aedes vexans* (VEX) from 3 localities in Georgetown County, and *Aedes sollicitans* (SOL) and *Culex nigripalpus* (NGR) from 2 localities in Charleston County, SC, determined by the World Health Organization (1981) diagnostic test method from 1990 to 1992.

Locality	Test date	Species	Exposed/ control	Number of replicates	Number tested	% mortality ± SE[1]
Wedgefield	Oct. 1990	VEX	Exposed	3	70	98.6 ± 1.4
			Control	3	63	0.0 ± 0.0
Litchfield	Oct. 1990	TAEN	Exposed	4	96	16.7 ± 3.8
			Control	4	95	4.2 ± 2.0
	Oct. 1992	TAEN	Exposed	5	124	5.7 ± 2.1
			Control	4	101	3.0 ± 1.7
Georgetown	July 1991	TAEN	Exposed	5	101	10.9 ± 3.1
			Control	5	98	3.1 ± 1.7
The Wedge	June 1991	SOL	Exposed	4	64	75.8 ± 5.4
			Control	4	92	9.8 ± 3.1
	June 1993		Exposed	6	142	81.0 ± 3.3
			Control	5	133	7.5 ± 2.3
	July 1993		Exposed	6	140	72.1 ± 3.8
			Control	5	126	7.9 ± 2.4
Folly Beach	Oct. 1992	NGR	Exposed	5	119	46.2 ± 4.6
			Control	4	94	2.1 ± 1.5

[1] Exposure mortalities were corrected using Abbott's formula when appropriate (World Health Organization 1981).

with one cage per stake on the 2 outside rows and 2 cages per stake on the middle row and at 250 m. Four control cages were suspended upwind of the spray path. After spraying, the cages were left on the stakes for 15 min. They were then transferred to holding cages (half-pint paper cartons covered with nylon tulle) and provided with polyester fiber balls soaked in 5% sugar solution. The cages were held in moist-towel-lined ice chests for 24 h postexposure, when mortality counts were made. The minimum and maximum temperature within the ice chest during the holding period was recorded. Exposure mortalities were corrected as necessary using Abbott's formula (World Health Organization 1981).

RESULTS

Mortality data obtained in 1990 and 1991 by exposing *Ae. taeniorhynchus* from several localities in Charleston County, SC, to the diagnostic dose of 5% malathion are presented in Table 1. Mortalities of exposed mosquitoes ranged from a very low 0.9 to 54.4%. It was expected that all exposed mosquitoes would be killed if the populations were totally susceptible. In addition, in 1990 and 1991, 300 and 224 specimens of malathion-susceptible colony *Ae. aegypti* and *Ae. taeniorhynchus*, respectively, were tested on several occasions, using the same impregnated papers as for wild *Ae. taeniorhynchus*. All of these susceptible mosquitoes were killed, whereas control mortalities ranged from 0.0 to 10.6%, well within the permissible limit of 20% (World Health Organization 1981). Thus the *Ae. taeniorhynchus* populations from Charleston County had relatively high levels of resistance to malathion.

Table 2 portrays data from susceptibility tests done during 1992 using *Ae. taeniorhynchus*. Exposure mortalities were from 1.0 to 18.8%; lower than in 1990–91. All 276 colony *Ae. taeniorhynchus* and 149 colony *Ae. aegypti* tested this year were killed following exposure to 5% malathion-impregnated papers used in testing the field-collected mosquitoes from Charleston. Control mortalities in 249 and 145 specimens of these 2 colony strains, respectively, ranged from 0 to 9.1%.

In 1991, the overall exposure mortality in *Ae. taeniorhynchus* from Charleston County was 23.8% (285/1,196), with a control mortality of 5.2% (51/979) (Table 1). The 1992 exposure mortality was only 12.8% (110/862), with a control mortality of 3.3% (25/749) (Table 2). The hypothesis that the 1992 exposure mortality is significantly lower than that of 1991 was supported by a statistical test ($\chi^2_1 = 26.71$, $P < 0.001$). Exposure mortalities were corrected using Abbott's formula (World Health Organization 1981), in order to account for the difference

Table 4. Susceptibility of *Aedes taeniorhynchus* females from 4 localities of Charleston County and from Litchfield Beach in Georgetown County, SC, to fenitrothion, permethrin, and propoxur, determined by the World Health Organization (1981) diagnostic test procedure in 1992.

Locality	Test month	Exposed/ control	Number of replicates	Number tested	% mortality ± SE
		Fenitrothion (1%)			
Sullivans Island	Sept.	Exposed	4	102	100.0 ± 0.0
		Control	4	98	17.4 ± 3.8
Isle of Palms	Aug.	Exposed	4	92	98.9 ± 1.1
		Control	4	99	3.0 ± 1.7
Folly Beach	Aug.	Exposed	6	148	100.0 ± 0.0
		Control	6	141	0.7 ± 0.7
		Permethrin (0.25%)			
Edisto Beach	Sept.	Exposed	4	101	100.0 ± 0.0
		Control	4	100	4.0 ± 2.0
Folly Beach	Oct.	Exposed	4	99	100.0 ± 0.0
		Control	4	97	10.3 ± 3.1
Litchfield Beach	Oct.	Exposed	4	102	100.0 ± 0.0
		Control	4	101	4.0 ± 2.0
		Propoxur (0.1%)			
Edisto Beach	Sept.	Exposed	4	99	100.0 ± 0.0
		Control	4	94	9.6 ± 3.0
Folly Beach	Oct.	Exposed	4	97	100.0 ± 0.0
		Control	4	100	1.0 ± 1.0
James Island	Oct.	Exposed	4	102	100.0 ± 0.0
		Control	4	98	1.0 ± 1.0

in control mortalities between the 2 years, before the data were submitted to the statistical test. Data pertaining to The Wedge and James Island were excluded from the statistically analyzed set because neither location was sampled in both years.

Data on the susceptibility of *Ae. taeniorhynchus* and *Ae. vexans* from Georgetown County, and *Cx. nigripalpus* and *Ae. sollicitans* from Charleston County are presented in Table 3. The single test on *Ae. vexans* indicated that the population from Wedgefield was susceptible. However, the *Ae. taeniorhynchus* populations were highly resistant to malathion. The 46.2% mortality in *Cx. nigripalpus* from Folly Beach indicated that this population had substantial resistance also. The *Ae. sollicitans* populations from The Wedge also appear to have had some resistance to malathion.

Further tests were done to determine if the *Ae. taeniorhynchus* populations were cross-resistant to the carbamate, propoxur; the organophosphate, fenitrothion; and the pyrethroid, permethrin. The populations from the various localities were sensitive to all 3 insecticides (Table 4).

Results of ground ULV application of malathion against field-collected and colony mosquitoes are given in Tables 5–8. The applications were made in nearly ideal conditions that are seldom encountered in actual mosquito control operations. In addition, the application rates were relatively high, with that in Table 7 being over the maximum label rate of 62.1 ml/min. Complete mortality of susceptible *Ae. aegypti* and *Ae. taeniorhynchus* was obtained up to 250 m (Tables 5–8). Less than 100% of the wild *Ae. taeniorhynchus* were killed, however, even at the closest distance of 50 m. The low mortalities of *Ae. taeniorhynchus* from Folly Beach and James Island (Tables 7 and 8) are especially disconcerting. Although there is no obvious correlation between mortalities of laboratory and field bioassays, the James Island population of *Ae. taeniorhynchus* was among the least sensitive to malathion in both WHO susceptibility tests and field assays.

DISCUSSION

This study showed that malathion resistance in *Ae. taeniorhynchus* is probably widespread in

Table 5. Results of a ground ULV application of malathion (44.4 ml/min or 36.5 ml/ha) against caged *Aedes taeniorhynchus* collected from Charleston City and Folly Beach, Charleston County, and the town of Georgetown, Georgetown County, SC, as well as *Aedes aegypti* from the colony at The Wedge (July 1991)[1].

Truck-to-cage distance (m)	Insecticide-to-cage distance (m)[2,3,4]	Number exposed	Mortality (%)
	Charleston		
50	55.0	84	96.4
100	110.1	68	80.9
150	165.1	80	87.5
Control	NA	41	4.9
	Folly Beach		
50	55.0	60	96.7
100	110.1	59	91.5
Control	NA	63	1.6
	The Wedge colony		
50	55.0	71	100.0
100	110.1	72	100.0
150	165.1	59	100.0
Control	NA	39	0.0
	Georgetown		
50	55.0	41	92.7
100	110.1	17	94.1
Control	NA	34	0.0

[1] Based on a 90-m swath width.
[2] Average wind speed was 2.2 kph.
[3] Insecticide path distance calculated on the basis of the angle of the wind to the rows of cages.
[4] Droplet mass median diameter: at 55 m—15.4 μm; at 100 m—7.5 μm.

coastal areas of Charleston and Georgetown counties, SC, where the insecticide has been used for a long time. What is more, the resistance appears to have increased over the duration of the study. According to the criteria for interpreting WHO diagnostic test results (Davidson and Zahar 1973, World Health Organization 1986), if mortalities in test mosquitoes range between 80 and 98%, further tests are required to verify the presence of resistance. If such mortalities are less than 80%, however, the tested population is considered to contain resistant individuals.

In Florida, *Ae. taeniorhynchus* was first found to be resistant to malathion in 1965, 10 years after it was introduced for mosquito control (Gahan et al. 1966). This delay in resistance was attributed to a policy requiring the avoidance of contamination of breeding sites, not spraying uninhabited areas, and limiting the frequency of applications. Since then, populations of *Ae. taeniorhynchus* were found to have high levels of resistance to malathion (Mount et al. 1974, Boike et al. 1978). However, no cross-resistance to other organophosphorus insecticides, carbamates,

Table 6. Results of a ground ULV application of malathion (44.4 ml/min or 36.5 ml/ha) against caged *Aedes taeniorhynchus* collected from Isle of Palms, SC (August 1991)[1].

Truck-to-cage distance (m)	Insecticide-to-cage distance (m)[2,3,4]	Number exposed[5]	Mortality (%)[6]
50	52.5	101	85.3
100	105.0	103	49.8
150	157.5	91 (25)	19.4
200	209.9	92 (24)	3.0
250	262.5	69	2.0
Control	NA	85 (23)	5.9

[1] Based on 90-m swath width.
[2] Average wind speed was 8.2 kph.
[3] Insecticide path distance calculated on the basis of the angle of the wind to the rows of cages.
[4] Droplet mass median diameter: at 50 m—5.4 μm; at 100 m—5.4 μm.
[5] The numbers in parentheses represent colony *Ae. taeniorhynchus* exposed at the time. All 49 exposed mosquitoes, as well as 4.3% of the controls, were killed.
[6] Exposure mortalities are corrected using Abbott's formula (World Health Organization 1981).

Table 7. Results of a ground ULV application of malathion (68.0 ml/min or 58.5 ml/ha) against *Aedes taeniorhynchus* from Folly Beach, SC, and *Aedes aegypti* from the colony at The Wedge (August 1992)[1].

Truck-to-cage distance (m)	Insecticide-to-cage distance (m)[2,3,4]	Number exposed[5]	Mortality (%)
50	51.5	62 (71)	6.5 (100.0)
100	102.0	58 (69)	1.7 (95.7)
150	154.5	59 (71)	8.5 (97.2)
200	205.9	67 (68)	3.0 (100.0)
250	257.4	42 (0)	0.0 (NA)
Control	NA	100 (46)	0.0 (0.0)

[1] Based on a 90-m swath width.
[2] Average wind speed was 11.0 kph.
[3] Mean median diameter of malathion droplets at 50 and 100 m was 6.5 and 6.9 μm, respectively.
[4] This distance was calculated based on the angle of the wind in relation to the rows of cages.
[5] Numbers and mortalities within parentheses refer to colony *A. aegypti*.

Table 8. Results of a ground ULV application of malathion (62.1 ml/min or 51.1 ml/ha) against *Aedes taeniorhynchus* from James Island, SC, and susceptible *Aedes aegypti* from The Wedge colony (October 1992)[1].

Truck-to-cage distance (m)[2]	Number exposed[3,4,5]	Mortality (%)
50	93 (53)	18.3 (100)
100	96 (49)	15.6 (100)
150	97 (45)	7.2 (100)
200	94 (48)	6.4 (100)
250	48 (48)	2.1 (100)
Control	100 (50)	4.0 (16)

[1] Based on a 90-m swath width.
[2] As the wind direction was the same as the truck-to-cage direction, there was no need to compute insecticide path-to-cage distance.
[3] Average wind speed was 15.4 kph.
[4] Mass median diameter of malathion droplets at 50 and 100 m was 8.1 and 9.0 μm, respectively.
[5] Numbers and mortalities within parentheses refer to colony *A. aegypti.*

or pyrethroids was found in these populations (Mount et al. 1974). In the present study, malathion-resistant South Carolina *Ae. taeniorhynchus* populations were found to have no cross-resistance to other insecticides either.

Malathion resistance with indications of cross-resistance to naled and fenthion was reported in *Ae. sollicitans* from Virginia (Mount et al. 1969). Some New Jersey populations of the species required 10 times the normal ULV malathion treatment for control (Brown 1986). There is thus evidence for *Ae. sollicitans* developing resistance to malathion.

The relatively low mortality (46.2%) of *Cx. nigripalpus* exposed to the WHO diagnostic dose of malathion is of interest. In Florida *Cx. nigripalpus* populations, malathion resistance has caused concern (Boike and Rathburn 1975, Boike et al. 1978) because the species is a vector of St. Louis encephalitis (Nayar 1982, Boike et al. 1989).

In insecticide-treated areas, pest and vector species known to have the potential for development of resistance should be monitored closely to keep track of any decline in susceptibility. In areas where malathion has been used for a long time, continued widespread use of the insecticide may not be warranted unless studies show that target species are still susceptible.

Insecticide resistance determined in the laboratory does not necessarily reflect the performance of the insecticide at application rates used in control operations (Keiding 1986). Even the dominance of the resistance gene is dose-dependent (Leeper et al. 1986, Roush and Croft 1986). Theoretically, high application rates may kill even homozygous resistants, although it is difficult to tell if this is, in fact, happening in any given field situation. In this study, maximum label rates resulted in markedly low mortalities even at the relatively short distance of 50 m.

Continued use of an insecticide after selection for resistance has started may lead to erosion of the fitness deficiency of emerging resistance, thus enabling resistance gene(s) to coadapt with existing fitness factors (Roush and Croft 1986). This may, in turn, delay the reversion of the population to susceptibility after the selection pressure is relaxed (Keiding 1986).

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