ARTICLES

STRATEGIES FOR THE EMERGENCY CONTROL OF ARBOVIRAL EPIDEMICS IN NEW ORLEANS

M. D. ANDIS, S. R. SACKETT, M. K. CARROLL AND E. S. BORDES

New Orleans Mosquito Control Board, 6601 Lakeshore Drive, New Orleans, LA 70126

ABSTRACT. A study was initiated to evaluate the effectiveness of aerial ULV spraying for the control of *Aedes aegypti* and *Culex quinquefasciatus* as an emergency antiepidemic measure against dengue fever and St. Louis encephalitis, respectively. Malathion was aerially applied at 219 ml/ha over 344 ha area of the Ninth Ward in New Orleans. Laboratory susceptibility tests and field-cage exposures indicated that the target populations were susceptible to malathion and that acceptable coverage of the study area occurred. Two consecutive aerial applications decreased the relative abundance and ovipositional activity of adult mosquitoes. However, suppression was transient and, in the event of an epidemic, multiple treatments may be required to decrease vector abundance below the threshold levels required for the spread of virus to the human populations.

INTRODUCTION

In New Orleans, the integration of weekly releases of the predaceous mosquito, *Toxorhynchites amboinensis* (Doleschall), with a weekly schedule of sequential treatments of malathion applied as a ground ultralow volume (ULV) spray, effectively reduced the population of *Aedes aegypti* (Linn.) by ca. 96% and thereby decreased the probability of dengue transmission in the event of an introduction of this arbovirus (Focks et al. 1986). However, if management schemes fail and an arboviral epidemic does occur, emergency strategies for vector containment must be initiated in a rapid and coordinated manner. These emergency strategies must greatly reduce the number of potential vectors and maintain control to prevent newly emerging adult mosquitoes from becoming infected. If both requisites are fulfilled, transmission of the virus can be successfully interrupted.

The ULV aerial application of insecticide is currently the practical method of choice to eliminate older female mosquitoes that are infected and are, or will soon be, capable of transmitting the virus to humans. This approach seems valid since during recent epidemics, the number of new human cases and the virus isolation rates from vector mosquito populations have declined coincidentally with aerial ULV adulticiding (Sekla 1982, Hopkins et al. 1975, Mahdy et al. 1979). However, due to the emergency nature of these operations and the employment of multiple control measures, there has been little opportunity to evaluate the effectiveness of aerial ULV applications in disease control.

The present project evaluated the effectiveness of aerial ULV spraying for the control of *Ae. aegypti* and *Culex quinquefasciatus* Say as a simulated emergency antiepidemic measure against dengue fever and St. Louis encephalitis (SLE), respectively.

METHODS AND MATERIALS

Prior to initiation of the project, all available data regarding the life cycle of *Ae. aegypti* in New Orleans, the epidemiology of the dengue virus, and our proposed treatment and evaluation protocol were incorporated into a flow chart (Fig. 1). In an emergency situation, this flow chart should serve as a guide for immediate reactions required by mosquito control personnel upon notification of a dengue outbreak. The chart has also proven to be a useful educational tool for explaining the emergency nature of mosquito suppression to the public sector.

The experimental protocol comprised two aerial treatments, 24 hr apart, applied over a 344 ha area of the Ninth Ward in New Orleans. This is a densely populated residential area that has historically been the center of St. Louis encephalitis (SLE) activity and has consistently produced large numbers of *Ae. aegypti*. Housing consists primarily of one and two story dwellings on the perimeter of the blocks with heavily wooded backyards. Typically, the buildings are long and narrow and set 2–4 m apart with an average of 25 dwellings per 1 ha block (Focks et al. 1987). This neighborhood would be considered at risk because of existing environmental factors. Untreated check areas were selected that had similar urban settings and mosquito densities.

The selection of insecticides was restricted to those compounds registered for use as aerial ULV adulticides in Louisiana. Of these, mala-

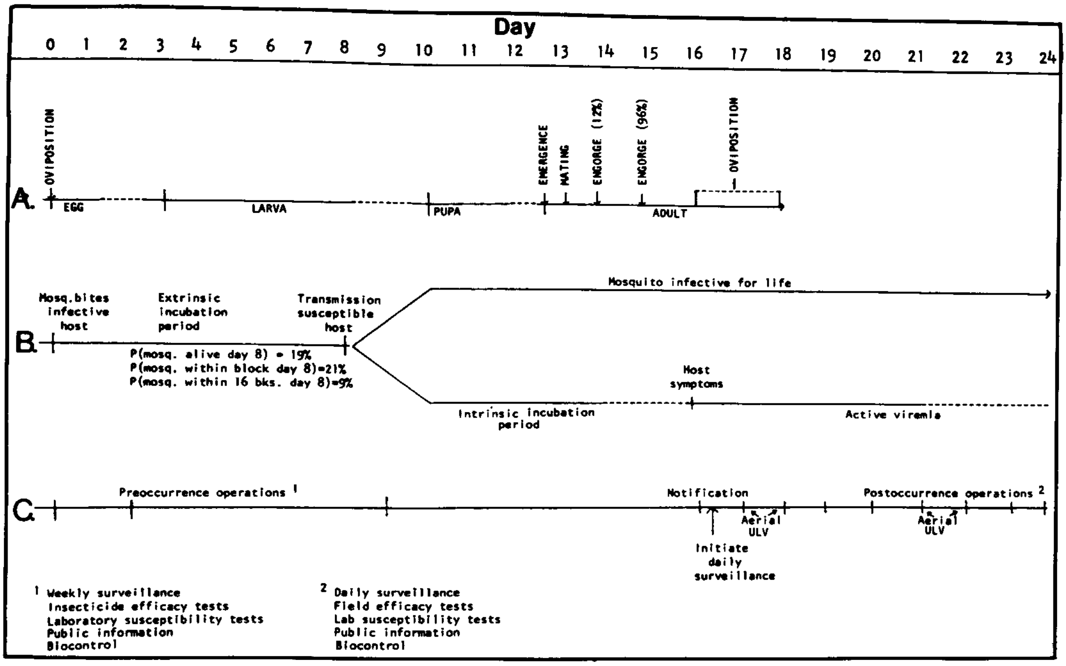

Fig. 1. Flowchart for simulated dengue epidemic. A. *Ae. aegypti* life cycle, B. Cycle of dengue transmission and C. Treatment and evaluation protocol.

thion (Cythion®) and resmethrin synergized at the rate of 1 part with 3 parts piperonyl butoxide (Scourge®) were selected as the chemicals of choice on the basis of mosquito susceptibility, environmental compatibility, public acceptance and economic feasibility. Laboratory studies indicated that the target species were ca. 10-fold more susceptible to resmethrin than malathion. This increased toxicity would allow the New Orleans Mosquito Control Board to economically incorporate Scourge into our emergency aerial application program but, the spray trial was ineffectual and therefore will not be discussed further. Cythion applications were made using a Britten-Norman Islander® twin-engine aircraft equipped with 2 self-contained Micronair® spray pod systems utilizing rotary atomizers. Using a determined swath width of 152.4 m, the aircraft flew at an altitude of 61 m and speed of 185 kph. The treatments overlapped the target area at least 1.6 km on all sides. Both treatments began 0.5 h after official sunrise, with the entire treatment taking ca. 0.5 h to complete. The toxicant was applied at the maximum labeled rate of 219 ml/ha during optimum environmental conditions. During both treatments, an apparent temperature inversion existed, wind velocity was 3–8 kph, ambient temperature was 24–27°C, and relative humidity was 97–100%.

The operational aspects of the control efforts were concurrently evaluated by several methods. Estimates of droplet size were made by impinging aerosol droplets on teflon-coated microscope slides mounted on slide spinners. The length median diameters (LMD) of the droplets were computed as described by Carroll and Bourg (1979). The droplet densities and dispersion patterns were determined by placing 20 oil sensitive cards throughout the study area. Bioassays were also conducted during the treatments to document insecticide coverage and efficacy under field conditions. Cages of twenty, 2–4 day old adult female *Ae. aegypti* and *Cx. quinquefasciatus* of known susceptibilities, and 500 ml plastic containers each containing 20 third instar larvae of each species were placed adjacent to the slide spinners and oil sensitive cards in open and sequestered locations.

The second aspect of the evaluations dealt with the effectiveness of aerial ULV applications in suppressed vector abundance and/or altering the population age structure sufficiently to interrupt virus transmission. To monitor adult densities (independent of both sex and parity), a series of 5 ultraviolet Fay-Prince traps (Kloter et al. 1983) were operated continuously during pretreatment, treatment and posttreatment periods in the treated (spray) and untreated (check) zones. Collections were recorded daily for 8 days prior to and 11 days after the aerial applications. Relative abundance was expressed as numbers of adult males and females collected per day. Older female mosquitoes have a greater potential for transmitting viruses since they have previously fed on a host, possibly an infected host. Therefore, it was this portion of the populations we wanted to suppress. Consequently, all female mosquitoes collected were dissected to determine parous rates as a means of monitoring the age structure of the target populations (Detinova 1962).

An index of the daily ovipositional activity of *Ae. aegypti* in the treatment zone was obtained by the use of twenty-five 0.5 liter black jars containing a fiberboard oviposition paddle and 3 cm of water. The ovitraps were placed in sheltered locations such as under porches and towards the backs of houses. Ovitraps were cleaned and the paddles collected daily. Serving as city-wide controls, 5 ovitraps were monitored daily in each of the following districts of New Orleans: Algiers, Garden District, Mid-City, Mt. Olivet and St. Vincent. *Culex quinquefasciatus* ovipositional activity was monitored daily using 19 liter buckets baited with 29.6 ml of fish fertilizer emulsion in 3.8 liters of water. To compensate for the dynamics of populations in the spray and check zones, percent reduction due to insecticide application was calculated where values for both zones were available before and after treatment (Mulla et al. 1971). Data were then transformed (arcsin $\sqrt{\text{percentage}}$) and subjected to an analysis of variance using the SAS general linear models procedure for testing the hypothesis that the mean captures among areas were equal (SAS 1985). Mean separations were accomplished using the least squares means procedure (SAS 1985).

To determine if the control activities temporarily affected the susceptibility of the target species, insecticide susceptibility tests were conducted immediately before the first and after the final ULV treatment. Adult susceptibility tests were conducted in a wind tunnel and replicated 3 times (Magnuson et al. 1985). A replicate consisted of a series of 2 cages of twenty-five, 2–4 day old females each exposed to a minimum of 6 concentrations of technical malathion diluted with reagent grade acetone that produced mortalities between 0 and 100%. Larval susceptibilities were also determined according to standard criteria of the World Health Organization (1981). Four replications for each of 5 concentrations plus an acetone check were conducted. Each test was replicated 3 times. Mortality counts were recorded at 24 hr postexposure. Lethal doses/concentrations and slopes were computed by probit analysis (Finney 1971).

RESULTS AND DISCUSSION

Figure 2 graphically depicts the frequency distribution of droplet sizes, arranged in 5 μm intervals. There were no significant differences ($P > 0.05$) between the operational parameters measured during treatments 1 and 2 (Table 1). Thus, the operational results of both treatments will be discussed as a single average. The LMD of the insecticide droplets was 48.9 μm. The oil sensitive cards indicated a good distribution of droplets in the open areas, yet significantly fewer ($P < 0.01$) were collected on cards sequestered under shelter or in dense vegetation. This discrepancy in the number of droplets deposited between the 2 habitats was reflected by the mortality of caged adults. A highly significant association ($P < 0.01$; $r^2 = 0.97$) existed between the number of droplets collected and adult mortality. Sentinel mortality also indicated that there was acceptable coverage of the spray zone and substantiates previous investigations which

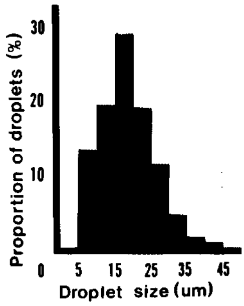

Fig. 2. Frequency distribution of malathion droplets according to diameter in micrometers.

Table 1. Summary results of parameters used to evaluate the operational aspects of aerial ULV adulticide applications.

Parameter[1]	Treatment 1	Treatment 2	Average
Droplet size (μm)	48.8^a	49.0^a	48.9
Droplet dispersion (No./6.5 cm^2)			
Open	19.7^a	24.7^a	22.2^A
Sequestered	8.6^a	10.2^a	9.4^B
% mortality *Ae. aegypti* adults			
Open	94.7^a	96.3^a	95.5^A
Sequestered	48.4^a	49.5^a	49.0^B
Cx. quinquefasciatus adults			
Open	78.6^a	86.7^a	82.7^A
Sequestered	22.2^a	39.6^a	31.0^B
Ae. aegypti larvae[2]			
Open	77.7^a	—	98.3^{bA}
Sequestered	1.3^a	—	6.5^{bB}
Cx. quinquefasciatus larvae[2]			
Open	52.4^a	—	94.8^{bA}
Sequestered	0.8^a	—	6.4^{bB}

[1] Treatment means in the same row followed by the same lower case letter are not significantly different ($P > 0.05$). Overall means for a specific parameter in the same column followed by the same upper case letter are not significantly different ($P > 0.05$).

[2] Average mortality based on larval exposure to 2 consecutive insecticide applications.

indicated that 10 droplets/6.5 cm^2 were required for effective kill (Kilpatrick 1967). The average mortality of caged *Ae. aegypti* was 95.5 and 49% in open and sequestered locations, respectively. In laboratory tests, adult *Cx. quinquefasciatus* were significantly less susceptible to malathion than were *Ae. aegypti*. Consequently, adult cage tests using *Cx. quinquefasciatus* resulted in average mortality rates of 82.7 and 31% in open and sequestered locations respectively, which were significantly less ($P < 0.05$) than the cage mortality rates of adult *Ae. aegypti*. Sentinel larvae were exposed to the initial treatment, mortality rates recorded 24 hr postexposure and then subjected to the second treatment. Mortality of *Ae. aegypti* larvae due to the first aerial application averaged 77.7% in open, and 1.3% in sequestered locations. After exposure to the second application, *Ae. aegypti* larval mortality rates increased to 98.3 and 6.5% in open and sequestered locations, respectively. The mortality rates of sentinel *Cx. quinquefasciatus* larvae due to the initial insecticide treatment increased from 52.4 and 0.8% to 94.8 and 6.4% in open and sequestered locations, respectively, following exposure to the second consecutive treatment. The larval mortality rates of the target species were significantly higher ($P < 0.05$) after 2 consecutive insecticide exposures and suggest that aerial treatments of malathion may exert tremendous selection pressure on the target populations. However, empirical observations indicate that the majority of *Ae. aegypti* and *Cx. quinquefasciatus* breeding sites are located in relatively sheltered habitats and thus the actual mortality of field populations may be insignificant.

Comparing treated and untreated areas is a standard method used to assess the impact of insecticide treatments on the dynamics of natural populations. This method requires the assumption that the population trends in both areas would be similar in the absence of treatment. In this instance, oviposition and adult trap surveillance indicated that, prior to aerial applications, no significant differences existed ($P > 0.05$) in the *Ae. aegypti* or *Cx. quinquefasciatus* population indices among the spray and check zones. Therefore, all data from the 5 untreated (check) areas were pooled for comparison to the spray zone.

Prior to the initial malathion application, the spray and check zones had virtually identical *Ae. aegypti* and *Cx. quinquefasciatus* oviposition levels. Daily ovitrap indices for the target species clearly indicated the effectiveness of the ULV aerial application (Table 2). Two consecutive malathion treatments resulted in an initial 61% decrease in the number of ovitraps positive for *Ae. aegypti* eggs and a 73.6% reduction in the number of eggs deposited/trap. The ovipositional activity of the *Ae. aegypti* population was suppressed for 7 days posttreatment. The ovipositional activity of *Cx. quinquefasciatus* was initially reduced by 100% but the suppression was short term and the control indices returned to prespray levels within 5 days postspray.

Pretreatment data indicated that no significant differences existed ($P > 0.05$) in adult mosquito densities between spray and check areas. Two consecutive malathion applications significantly reduced ($P < 0.05$) the number of adult *Ae. aegypti* and *Cx. quinquefasciatus* collected over a 5 day postspray period (Table 2). The effect of treatments on the parity status of the adult mosquito populations is presented in Table 2. As can be expected with an insecticide treatment producing a high mortality of adult mosquitoes, the parous rates of the 2 target species decreased significantly ($P < 0.05$) after the treatments and were positively associated with the suppression of the adult population levels ($P < 0.01$; $r^2 = 0.91$). Insecticide susceptibility as a function of the presence of a blood

Table 2. Relative levels of population suppression attributable to aerial ULV adulticide applications.

	Percent reduction*							
	Aedes aegypti				*Culex quinquefasciatus*			
Days post-treatment	Positive ovitraps	No. eggs/trap	No. adults/trap	No. parous females	Positive muck buckets	No. rafts/trap	No. adults/trap	No. parous females
1	55.0[a]	71.7[a]	60.4[a]	33.7[a]	100.0[a]	100.0[a]	51.7[a]	28.4[a]
2	61.0[a]	73.6[a]	48.0[a]	32.9[a]	80.0[a]	94.6[a]	50.0[a]	10.9[a]
3	71.1[a]	82.3[a]	57.0[a]	27.1[a]	60.0[a]	92.9[a]	35.0[a]	12.7[a]
4	71.6[a]	79.6[a]	48.0[a]	26.3[a]	20.0[a]	5.4[b]	43.6[a]	8.3[b]
5	64.0[a]	66.8[a]	33.0[a]	31.0[a]	5.0[b]	0.1[b]	27.6[a]	1.5[b]
6	56.7[a]	35.6[a]	2.0[b]	15.2[a]	0[b]	0[b]	0[b]	0[b]
7	35.9[a]	27.1[a]	0[b]	9.6[b]				
8	12.7[b]	5.6[b]	0	0[b]				
9	0[b]	2.2[b]	0	0				

* Means in the same column followed by the same letter are not significantly different ($P > 0.05$).

Table 3. Dosage mortality responses of colonized insecticide susceptible and field collected mosquito adults prior to and immediately after exposure to aerial ULV malathion applications.

Species	Strain[a]	Time	Lethal doses in % AI				Slope
			LD_{50}	(95% CL)[b]	LD_{90}	(95% CL)	
Ae. aegypti	Wild	Prespray	0.051	(0.031–0.062)	0.109	(0.054–0.125)	4.1
		Postspray	0.057	(0.037–0.067)	0.111	(0.53–0.129)	4.3
	Colony		0.032	(0.030–0.039)	0.053	(0.05–0.056)	2.7
Cx. quinquefasciatus	Wild	Prespray	0.55	(0.47–0.59)	1.37	(1.31–1.44)	3.8
		Postspray	0.59	(0.51–0.63)	1.40	(1.36–1.51)	3.6
	Colony		0.29	(0.274–0.306)	0.72	(0.670–0.779)	3.3

[a] "Wild" were field collected as eggs, laboratory reared and F_1 generation tested.
[b] Lower and upper 95% confidence limits for LD value.

meal may explain the survival of gravid/parous females (Brown and Pal 1971). An additional explanation is that females digesting a blood meal or with eggs in the later developmental stages would be less active and thus less likely to encounter the airborne insecticide particles.

Laboratory tests indicated that the susceptibilities of both target populations were approximately equal to those of the reference colonies and did not significantly decrease after aerial application of malathion (Table 3). The dosage-mortality patterns in the susceptibility tests were predictive of mortality among sentinels exposed to aerial ULV applications. Although both species exhibited a homogeneously susceptible response, *Cx. quinquefasciatus* was significantly less susceptible to malathion than *Ae. aegypti*. This relative decrease in *Cx. quinquefasciatus* susceptibility was evident and explains the differences in mortality observed during field evaluations.

Despite the apparent usefulness of aerial ULV applications of technical grade malathion for the emergency control of vector mosquitoes in urban environments, this technique is not a panacea. Control was transient and, under these conditions, multiple applications may be required to limit the spread of the virus should it be introduced. In the final analysis, the elimination of mosquito breeding sites through sanitation and source reduction campaigns, coupled with the judicious use of chemical and biological control agents by environmentally conscious mosquito management programs, still offers the best long term solution to the prevention of arbovirus transmission. From a practical standpoint, a single case of locally acquired dengue in a nonendemic area such as New Orleans would precipitate a city-wide spray operation with multiple treatments due to the mobility of the infected individual(s), the perceived danger, and the resources available. In the event of an arboviral epidemic in New Orleans, the treatment and evaluation protocol developed for the emergency control of vector-borne diseases (Fig. 1C) should enable us to respond in a rapid, coordinated, and effective manner. Undoubtedly, we will increase vector surveillance, adulticide high risk areas, monitor insecticide susceptibilities, intensify our public information program and expand the source reduction, chemical larviciding and biological control programs. However if resources are limited, these would be discontinued in favor of adulticiding efforts.

ACKNOWLEDGMENTS

The authors wish to thank the citizens of New Orleans and the personnel of the New Orleans Mosquito Control Board for their contributions to this study. Special thanks are extended to Daniel Roussel for his technical assistance and Pat Schultz for typing the manuscript.

Note: On July 28, 1986, Mr. George T. Carmichael, Administrator of the New Orleans Mosquito Control Board, retired after 22 years of dedicated service and 32 years of full-time mosquito control work.

REFERENCES CITED

Brown, A. W. A. and R. Pal. 1971. Insecticide resistance in arthropods, 2nd ed. W.H.O. Monogr. Ser. 38. 491 pp.

Carroll, M. K. and J. Bourg. 1979. Methods of ULV droplet sampling and analysis: Effects on the size and spectrum of the droplets collected. Mosq. News 30:645–655.

Detinova, T. S. 1962. Age-grouping methods in Diptera of medical importance with special reference to some vectors of malaria. W.H.O. Monogr. Ser. 47. 216 pp.

Finney, D. J. 1971. Probit analysis, 3rd ed. Cambridge Univ. Press. 333 pp.

Focks, D. A., S. R. Sacket, K. O. Kloter, D. A. Dame and G. T. Carmichael. 1986. The integrated use of *Toxorhynchites amboinensis* and ground-level ULV insecticide application to suppress *Aedes aegypti* (Diptera: Culicidae). J. Med. Entomol. 23:513–519.

Focks, D. A., K. O. Kloter and G. T. Carmichael. 1987. The impact of sequential ULV applications of malathion at current V.S. label rates on the population dynamics of *Aedes aegypti* (L.). Am. J. Trop. Med. Hyg. (in press).

Hopkins, C. C., F. B. Hollinger, R. F. Johnson, H. J. Dewlett, V. F. Newhouse and R. W. Chamberlain. 1975. The epidemiology of St. Louis encephalitis in Dallas, TX, 1966. Am. J. Epidemiol 102:1–15.

Kilpatrick, J. W. 1967. Preformance specifications for aerial ultralow volume application of insecticides for mosquito control. Pest Control 35:80–84.

Kloter, K. O., J. R. Kaltenbach, G. T. Carmichael and D. D. Bowman. 1983. An experimental evaluation of six different suction traps for attracting and capturing *Aedes aegypti*. Mosq. News 43:297–301.

Magnuson, L. J., K. O. Kloter and M. K. Carroll. 1985. Wind tunnel evaluation of commonly used adulticides against New Orleans *Aedes aegypti*. J. Am. Mosq. Control Assoc. 1:233–234.

Mahdy, M. S., L. Spence and J. M. Joshua (eds.). 1979. Arboviral encephalitis in Ontario with special reference to St. Louis encephalitis. Ontario Ministry of Health. 364 pp.

Mulla, M. S., R. L. Norland, D. M. Fanara, H. A. Darwazeh and D. W. McKean. 1971. Control of chironomid midges in recreational lakes. J. Econ. Entomol. 64:300–307.

Sekla, L. (ed.) 1982. Western equine encephalitis in Manitoba. Manitoba Health Service Commission, Winnipeg. 296 pp.

SAS Institute Inc. 1985. SAS® user's guide: Statistics, Version 5 Edition. SAS Institute Inc. Cary, NC. 956 pp.

World Health Organization. 1981. Instructions for determining the susceptibility or resistance of mosquito larvae to insecticides. WHO/VBC/81.807.