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EXPERIMENTAL AERIAL SPRAYING WITH ULTRA-LOW-VOLUME (ULV) MALATHION TO CONTROL *AEDES AEGYPTI* IN BUGA, COLOMBIA[1]

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Aerial ultra-low-volume (ULV) applications of malathion were made in Buga, Colombia, beginning on 16 March 1979, in order to test their impact on the local Aedes aegypti *population. This article reports the results of those trials.*

Introduction

It has been shown that aerial applications of malathion have been effective in controlling *Aedes aegypti* in urban areas of Thailand *(1-3)* and Indonesia *(4)*. Aerial applications of malathion have also been made in the Bahamas and Jamaica during the Caribbean dengue epidemic of 1977 *(5)*, and additional aerial spraying operations have been conducted in Tapachula and other cities of southern Mexico, as well as in Honduras, during 1978 and 1979.

Materials and Methods

The Study Area

The Colombian city selected for the tests described here was Buga, 78 kilometers north of Cali. This small city, which covers about 1,300 acres, has approximately 15,500 houses and a population of about 100,000 people. There are hills to the east, but elsewhere the city is surrounded by cultivated flatlands. Most of the houses have brick walls, and their facades are placed together to form straight lines. There are no gardens in front, nor is there any space between one house and the next. The doors and windows looking onto the street are generally kept closed. However, the back doors, windows, and inside doors are usually kept open during the daytime, a circumstance that allows insecticide to penetrate more easily into house interiors.

Tuluá, the control city, is situated 20 kilometers north of Buga. Although slightly smaller than the latter, its general appearance and the type of houses it contains are quite similar.

The evaluation areas in the two cities consisted of 21 blocks containing 748 houses in Buga and 23 blocks containing 704 houses in Tuluá. The houses were of similar types in both evaluation areas, and earlier surveys had shown that all blocks in both areas were positive for *Aedes aegypti*.

Treatment

The Government of Colombia engaged the services of the Fumivalle Company, which had the equipment, experience, and reputation needed to conduct the operation. The company charged the rates it usually asked for spraying cultivated areas. Although the pilots had never sprayed cities, they had done ultra-

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low-volume (ULV) sprayings using Micronair atomizers.

The company provided a single-engine, 300 horsepower, fixed-wing Cessna 188 aircraft equipped with a 180-gallon insecticide tank. The tank was fitted with four Micronair AU 3000 rotating atomizers having CBP 289 blades 27.7 cm long set at a 25 degree angle to the aircraft's line of flight in order to maximize the rotation rate and hence minimize the size of the droplets. The flow-regulator disc on each atomizer had pinhole apertures that could be adjusted to any of 13 settings.

In making all applications the aircraft flew at 105 miles per hour, which is near its top speed, and at an altitude 15 to 30 meters above the ground.[6] The flight passes were made at fifty-meter intervals. No ground signals were needed to guide the pilot because of the regular pattern of the streets. Specifically, the distance between parallel streets was 100 meters. The plane therefore made one pass along the length of a given street, returned over the middle of the block, proceeded to the next street, and so on.

The insecticide, which was to have been applied at a rate of 6 ounces per acre, was an ultra-low-volume 96 per cent near-odorless concentrate of malathion (Fyfanon®).

Before the actual operation began, a number of short flights were made in order to calibrate the insecticide discharge rate. This calibration was accomplished in the following manner: A few gallons of malathion were placed in the insecticide tank, and the pilot was asked to make a short flight to fill the pipes. Afterwards, the insecticide remaining in the tank was drained, but not that in the pipes. A measured amount of insecticide (15

[6]The plane's altitude during the first treatment was approximately 30 meters, while during the second treatment it ranged from about 15 to about 25 meters. These estimates were based on ground observation of the aircraft as it passed structures of known height.

A photograph of the aircraft making one of its ULV malathion applications over Buga, Colombia.

gallons) was then put in the tank, and the positions of the flow-regulator rings and the pressure control device were fixed. After that a short flight was made, during which the insecticide discharge control valve was kept open for two minutes. Then, when the plane landed, the insecticide remaining in the tank was drawn off and measured, and on this basis the rate of flow per minute was calculated.

The original plan was to administer three treatments at five-day intervals on the assumption that this would eliminate newborn females before they had a chance to lay eggs. Unfortunately, it rained heavily on the fifth day after the first application, which compelled postponement of the second application to the sixth day. The steep drop in the mosquito density after the second application then made a third treatment unnecessary, and it was canceled. Relevant details about the two flights needed to make each application are shown in Table 1.

Biological Tests

One day before each application, a few *A. aegypti* adult females were placed in each of several cages consisting of wire frames covered with mosquito netting, and a number of *A. aegypti* larvae were placed in each of several paper cups containing water (see Table 2). Then, at 5:00 a.m. on the day of the test, one cage and one cup were placed inside each of various test houses, and one cage and cup were placed in the garden of each house. These cups and cages were retrieved two hours after the treatment. Exactly the same procedure (without the treatment) was followed in the control city of Tuluá.

Droplet Size, Density, and Distribution

Samples of the aerosol droplets were collected on glass microscope slides coated with a silicone compound (Drifilm SC-87), which

Table 1. Flight data relating to two applications of ULV malathion made at Buga, Colombia, by a Cessna 188 aircraft equipped with four Micronair atomizers and flying at 105 miles per hour.

	Flights of 16 March 1979		Flights of 22 March 1979	
	1	2	1	2
Take-off time	6:18 a.m.	7:45 a.m.	6:13 a.m.	7:48 a.m.
Landing time	7:08 a.m.	8:38 a.m.	7:08 a.m.	8:48 a.m.
Time spent in the air (minutes)	50	53	55	60
Time spent taking on insecticide or fuel (minutes)	23	37	28	40
Temperature (7 a.m.)	20°C	22°C	20°C	22.5°C
Wind speed (km/hr)	8	0	8	8
Wind direction	SE	–	SE	SE
Direction of line of flight	W-E	Variable	W-E	Variable
Flight altitude (meters)	30	30	15-25	15-25
Aperture setting, Micronair flow regulators	1	3	3	3
Insecticide pressure (pounds per square inch)	45	45	40-45	35
Area treated (acres)	620	760	620	760
Insecticide used (gallons)	15.8	32.5	37.5	43.3
Dosage (ounces per acre)	3.95	6.57	9.33	8.77
Estimated rate of flow[a]	4.06	6.76	9.60	9.01
Calibrated rate of flow[b]	–	6.63	–	9.47

[a]Liters per minute based on dose per acre.
[b]Liters per minute based on calibration flights made after the treatment.

Table 2. Results of biological tests exposing captive *A. aegypti* (fourth-stage larvae bred in an insectary and adult females) to the aerial malathion treatments in Buga and to untreated sites in the control city of Tuluá.

	First treatment (16 March)				Second treatment (22 March)			
	Adult females		Larvae		Adult females		Larvae	
	Indoors	Outdoors	Indoors	Outdoors	Indoors	Outdoors	Indoors	Outdoors
Buga (treated city):								
No. of cages or cups	3	2	5	5	5	5	5	5
No. of adult females or larvae	13	10	40	45	25	50	50	50
% dead in 2 hours	45	70	0	2	15	65	2	21
% dead in 24 hours	100	100	2.5	71	100	100	4	94
Tuluá (control city):								
No. of cages or cups	1	4	2	2	1	1	1	1
No. of adult females or larvae	5	5	17	16	5	5	10	10
% dead in 2 hours	0	0	0	0	0	0	0	0
% dead in 24 hours	0	0	0	0	0	0	0	0

had been placed alongside the cages and cups. In two houses, several slides were also placed flat upon and under beds, at the tops of closets, and both flat and upright on the floor. A hundred-power bacteriologic microscope fitted with an ocular micrometer was used to count the droplets and estimate their size.

A. aegypti *Infestation Levels*

The *Aedes aegypti* infestation levels in the study areas of Buga and Tuluá were estimated by collecting *aegypti* adults with human bait, collecting adults at rest, conducting larval surveys, and collecting eggs in ovitraps. Whether the females were parous or not was also determined.

Collections with human bait. To make this type of collection, the visitor sat alone for 20 minutes in any quiet room in the house, in subdued light, with his trouser legs rolled up to the knees. Adult mosquitoes attracted in this manner were captured with the aid of a butterfly net and were placed in paper cups covered with fine netting for subsequent laboratory examination. Both females (attracted for blood meals) and males (attracted for mating with the females) were captured by this method.

Collection of resting insects. These collections were made by conducting a fifteen-minute search of each house for mosquitoes resting on any surface—including walls, furniture, clothing, and the areas under beds. The mosquitoes found were collected with a suction tube or butterfly net, and were stored in the same way as those captured with human bait.

Larval surveys. These were performed by searching all parts of each house thoroughly for *aegypti* larvae. Records were kept regarding the number of water containers and the number of foci (containers infested with *aegypti* larvae and pupae). Samples of the larvae were taken from the houses for purposes of laboratory identification and for rearing in an insectary.

Ovitraps. Both at Buga and at Tuluá 30 ovitraps (glass jars painted black, each containing 2-3 cm of water and a piece of fiberboard) were placed at sheltered spots near houses. The pieces of fiberboard were then collected after three days and examined for eggs. However, only one of the traps operated before the malathion applications at Buga yielded a positive result, and that disappointing finding prompted us to discontinue this test.

Laboratory examinations. In the laboratory, all the captured mosquitoes were classified by species and sex. The ovaries of all the adult female *Aedes aegypti* were then removed and categorized according to the various Christopher stages. Ovaries at stages I and II were placed in separate drops of water on a slide and dissected. The purpose of this dissection was to determine the presence or absence of tracheal bundles in the ovaries, so as to establish whether the females had or had not laid eggs *(6)*.

The group conducting these collections and examinations was divided into two teams, each consisting of a team chief and five house visitors, with both teams working under one field supervisor. Each visitor was assigned two blocks in each city for the duration of the work. Each such block and each house within it were then numbered. To minimize possible objections by the residents, a schedule for making house visits was set up and arranged so that each house was visited only once every two weeks. Data were then obtained as follows: Every morning, between 8:00 a.m. and noon, each worker visited several houses and made "human bait" collections. Then, in the afternoon between 2:00 and 5:00 p.m., each worker visited houses other than those visited in the morning to conduct searches for *aegypti* larvae and to collect resting adults. Fifteen minutes was spent at each house making these resting collections. Overall, this resulted in each level of collection being carried out at between 40 and 50 houses per day.

Regulating the Discharge Rate

Some difficulty was experienced in properly regulating the insecticide discharge rate. A number of short flights had to be made with various combinations of tank pressures and flow-regulator disc adjustments. Plans for flying the aircraft at 105 miles per hour and creating a swath of insecticide droplets 50 meters wide called for a discharge rate of 6.17 liters per minute in order to achieve the desired coverage of 6 ounces per acre. During the test flights, an insecticide tank pressure of 45 pounds per square inch with the flow-regulator disc set at aperture No. 1 produced a discharge rate of 6.63 liters per minute. However, when this pressure and setting were used on the first flight of the first treatment, the flow was estimated at only 4.06 liters per minute. Therefore, for the second flight of the first treatment the disc aperture was set at position No. 3 while the pressure was left at 45 pounds per square inch. The resulting discharge rate was estimated at 6.76 liters per minute.

The same pressure and setting were used for the first flight in the second treatment over Buga, but the discharge rate during that flight was estimated at 9.60 liters per minute. The tank pressure was therefore reduced to 35 pounds per square inch on the second flight, but this was later estimated to have reduced the discharge rate only slightly, to 9.01 liters per minute. Subsequently, using aperture No. 3 and 35 pounds pressure, the aircraft made another trial run in which the flow vent was kept open for two minutes; this resulted in a discharge rate of 9.47 liters per minute. Yet another two-minute trial run, with the pressure at 45 pounds and flow regulator discs of the two internal atomizers reset to aperture No. 1, a discharge rate of 7.99 liters per minute was obtained.

Droplet Characteristics

The size, density, and distribution of the droplets were good in both treatments. In the first treatment, the average number of drops deposited per square centimeter was 11.91 outdoors and 1.12 indoors. The average diameter of the sample droplets collected was 48 microns outdoors and 14 microns indoors. As expected, smaller drops had a better chance of entering the houses. No drop with a diameter larger than 39 microns was found inside a house, but the largest drops collected outside measured up to 92 microns.

The apparent average densities of the drops deposited in the second treatment were 21.53 drops per square centimeter outdoors and 0.88 drops per square centimeter indoors. The average diameters of the outdoor and indoor drops were 43 and 12 microns, respectively. Drops found on the plates placed under beds and upright on the floors indicated that penetration into the houses was very good.

Results

Biological Tests

Each treatment killed the adult test mosquitoes (all females), both indoors and outdoors, and killed most of the test larvae outdoors but only a few indoors (see Table 2). Both indoors and outdoors, some of the test adults died within two hours of the treatment, and all died within 24 hours. Mortality among the test larvae after the first treatment was 71 per cent outdoors after 24 hours, but only 3 per cent indoors. Larval mortality after the second treatment was 94 per cent outdoors and 4 per cent indoors. No adult or larval mortality was observed in the control area. There was a clear correlation between droplet density and mortality of the test larvae during the first treatment (Table 3).

Natural Infestation Indices

The *Aedes aegypti* infestation levels in Tuluá and Buga prior to treatment were moderate and similar. Fifteen-minute collections of resting mosquitoes in 132 Buga houses before treatment yielded an average of 79.5 adults per 100 houses or 3.2 per man-hour. The percentage of houses found positive for *aegypti* by this method was 34.1 per cent (Table 4). Collections made with human bait were less successful, with twenty-minute collection periods yielding an average of only 24.8 mosquitoes per 100 houses and only 0.74 per man-hour of collection time. By this method, 14.2 per cent of the houses were found positive for *aegypti* (Table 5). Larval searches found an average of 26.5 containers with *aegypti* larvae per 100 houses, 18.0 per cent of the houses yielding positive results (Table 6).

Although the first application (made with flights applying averages of 3.95 and 6.57 ounces of insecticide per acre) produced a quick and sharp reduction in the adult male *aegypti* population, the adult female population was only slightly reduced and made a quick recovery (see Tables 4 and 5 and Figures 1 and 2). More specifically, one day after the first treatment the numbers of adults captured at rest and with human bait were down 58 and 75 per cent, respectively. However, while the numbers of captured males fell dramatically (by 86 and 91 per cent), the declines in the numbers of captured females (3 and 40 per cent) were relatively small. Moreover, within four days of the treatment the adult female population had completely recovered, while resting and human bait collections indicated

Table 3. Insecticide drop densities and average drop diameters resulting from the first treatment, as indicated by detection slides placed next to exposed cups containing *aegypti* larvae at the five test houses in Buga. Deaths among the exposed larvae and the results obtained with larvae exposed at an untreated site in Tuluá are also shown.

No. of test house and city	Indoor exposures: No. of drops per cm² of slide	Indoor exposures: Average drop diameter at cup (in microns)	Indoor exposures: Larval death rate (No. dead/no. tested)	Outdoor exposures: No. of drops per cm² of slide	Outdoor exposures: Average drop diameter at cup (in microns)	Outdoor exposures: Larval death rate (No. dead/no. tested)
1 (Buga)	0.39	12μ	0/7	16.92	51μ	9/9
2 (Buga)	0.16	15μ	0/8	1.47	23μ	2/9
3 (Buga)	0	–	0/9	14.13	53μ	7/9
4 (Buga)	0.47	14μ	0/8	5.43	25μ	5/9
5 (Buga)	4.58	12μ	1/8	21.58	41μ	9/9
Averages for Buga	1.12	14μ	2.5%	11.91	48μ	71%
6 (Tuluá)	0	–	0/17	0	–	0/16

Table 4. "Resting" collections of male and female *aegypti* adults made at Tuluá and at Buga before and after aerial ULV malathion applications in the latter city.

			Females			Males			All adult *aegypti*		
Date	Days after first and second treatments (Buga)	No. of houses visited	% positive houses	Average no. captured per 100 houses	% change from average no. captured in Buga before treatment	% positive houses	Average no. captured per 100 houses	% change from average no. captured in Buga before treatment	% positive houses	Average no. captured per 100 houses	% change from average no. captured per 100 houses in Buga before treatment
Buga before treatment:											
12 March		38	7.9	15.8		28.9	76.3		31.5	92.1	
13 "		48	16.7	25.0		22.9	35.4		33.3	60.4	
14 "		46	21.7	34.8		19.6	54.3		36.9	89.1	
Pretreatment average:			*15.9*	*25.8*		*23.4*	*53.0*		*34.1*	*79.5*	
Buga after first treatment:											
17 March	1	52	15.3	25.0	-3.1	1.9	7.6	-85.7	15.3	32.7	-58.9
20 "	4	53	22.6	34.0	+31.8	13.2	13.2	-75.1	26.4	47.2	-40.6
Buga after second treatment:											
23 March	1	58	8.6	8.6	-66.7	0.0	0.0	-100.0	8.6	8.6	-89.2
26 "	4	55	10.9	10.9	-57.8	1.8	1.8	-96.6	12.7	12.7	-84.0
28 "	6	37	5.4	5.4	-79.1	10.8	10.8	-79.6	16.2	16.2	-79.6
3 April	11	58	13.8	31.0	+20.2	12.1	15.5	-70.8	22.4	46.6	-41.4
18 "	26	23	0.0	0.0	-100.0	0.0	0.0	-100.0	0.0	0.0	-100.0
19 "	27	23	13.0	17.4	-32.6	4.3	21.7	-59.1	13.0	39.1	-50.8
21 "	29	67	16.4	23.9	-7.4	19.4	32.8	-38.1	23.9	56.7	-28.7
23 "	31	66	30.3	53.0	+105.4	16.7	30.3	-42.8	34.8	83.3	+4.8
24 "	32	69	17.4	26.1	+1.2	8.7	8.7	-83.6	21.7	34.8	-56.2
Tuluá:											
10 March		43	37.2	44.2		32.6	51.2		51.2	95.3	
15 "		49	22.4	30.6		22.4	40.8		40.8	71.4	
16 "		48	31.2	56.2		29.2	45.8		43.8	102.0	
21 "		56	17.9	25.0		26.8	50.0		37.5	75.0	
22 "		51	37.3	47.1		15.7	21.6		37.3	68.6	
27 "		60	30.0	50.0		33.3	51.7		43.3	101.7	
29 "		53	20.8	32.1		28.3	47.2		39.6	79.2	
2 April		59	23.7	44.1		32.2	59.3		42.3	103.4	
6 "		58	22.4	34.5		27.6	63.8		37.8	98.3	

Table 5. Human bait collections of male and female *aegypti* adults made at Tuluá and at Buga before and after aerial ULV malathion applications in the latter city.

Date	Days after first and second treatments (Buga)	No. of houses visited	Females			Males			All adult *aegypti*		
			% positive houses	Average no. captured per 100 houses	% change from average no. captured per 100 houses in Buga before treatment	% positive houses	Average no. captured per 100 houses	% change from average no. captured per 100 houses in Buga before treatment	% positive houses	Average no. captured per 100 houses	% change from average no. captured per 100 houses in Buga before treatment
Buga before treatment.											
12 March		29	6.9	6.9		3.4	6.9		10.3	13.8	
13 "		56	5.4	7.1		12.5	14.3		14.2	21.4	
14 "		56	8.9	8.9		12.5	25.0		16.1	33.9	
Pretreatment average:			*7.1*	*7.8*		*9.9*	*17.0*		*14.2*	*24.8*	
Buga after first treatment:											
17 March	1	66	4.7	4.7	- 39.7	1.6	1.6	- 90.6	6.2	6.2	- 75.0
20 "	4	68	7.3	7.3	- 6.4	5.9	3.9	- 77.1	10.3	11.2	- 54.8
Buga after second treatment:											
23 March	1	70	1.4	1.4	- 82.1	0.0	0	- 100.0	1.4	1.4	- 94.4
26 "	4	62	1.6	1.6	- 79.5	1.6	1.6	- 90.6	3.2	3.2	- 87.1
28 "	6	61	3.9	5.9	- 24.4	3.9	3.9	- 77.1	5.9	9.8	- 60.5
3 April	11	74	0.0	0	- 100.0	5.4	5.4	- 68.2	5.4	5.4	- 78.2
18 "	26	24	0.0	0	- 100.0	4.2	4.2	- 75.3	4.2	4.2	- 83.1
19 "	27	28	7.1	7.1	- 9.0	3.6	10.7	- 37.1	7.1	17.9	- 27.8
20 "	28	12	8.3	8.3	+ 6.4	8.3	8.3	- 51.2	8.3	16.7	- 32.7
21 "	29	54	7.4	7.4	- 5.1	1.9	1.9	- 88.8	7.4	9.3	- 62.5
23 "	31	57	1.8	1.8	- 76.9	3.5	3.5	- 79.4	5.3	5.3	- 78.6
24 "	32	71	9.9	11.3	+ 44.8	1.6	1.6	- 90.6	9.9	12.9	- 48.0
25 "	33	52	7.7	7.7	- 1.3	5.8	7.7	- 54.7	11.5	15.4	- 37.9
Tuluá:											
10 March		20	10.0	10.0		5.0	10.0		15.0	20.0	
15 "		41	12.2	12.2		17.1	12.2		19.5	24.3	
16 "		75	10.7	10.7		9.3	10.7		17.3	21.3	
21 "		85	8.2	14.1		4.7	7.1		11.7	21.2	
22 "		73	6.8	13.7		16.4	24.7		19.2	38.3	
27 "		83	6.0	6.0		12.0	14.5		15.6	20.5	
29 "		75	8.0	8.0		6.7	6.7		14.7	14.7	
2 April		85	5.9	7.1		5.9	7.1		14.1	14.1	
6 "		85	4.7	8.2		11.8	14.1		21.2	21.2	

Table 6. Inspections for *aegypti* larvae made at Tuluá and at Buga before and after aerial ULV malathion applications in the latter city.

	Date	Days after first and second treatments (Buga)	No. of houses visited	% positive houses	% positive containers	Average no. of positive containers per 100 houses	% change from average no. of positive containers per 100 houses in Buga before treatment
Buga before treatment:							
	12 March		35	25.7	5.02	40.0	
	13 "		48	18.8	3.34	22.9	
	14 "		46	10.9	2.30	19.6	
Pretreatment average:				*18.0*	*3.40*	*26.5*	
Buga after first treatment:							
	17 March	1	50	22.0	3.14	28.0	+ 5.7
	20 "	4	54	3.7	0.99	7.4	- 72.1
Buga after second treatment:							
	23 March	1	58	8.6	1.07	8.6	- 67.5
	26 "	4	55	23.6	3.90	26.3	- 0.8
	28 "	6	37	10.8	3.00	32.4	+ 22.3
	3 April	11	58	12.1	2.67	31.0	+ 17.0
	18 "	26	23	0.0	0.00	0.0	- 100.0
	19 "	27	23	17.4	3.28	26.1	- 1.5
	21 "	29	67	7.5	1.49	11.9	- 55.1
	23 "	31	65	9.2	1.15	9.2	- 65.3
	24 "	32	69	8.7	1.80	14.5	- 45.3
Tuluá:							
	10 March		36	30.5	6.67	30.5	
	15 "		48	25.0	4.09	35.4	
	16 "		48	25.0	7.37	58.3	
	21 "		56	19.6	3.95	35.7	
	22 "		51	27.4	4.83	37.2	
	27 "		60	21.7	3.99	31.7	
	29 "		53	22.6	3.63	32.0	
	2 April		59	10.2	2.17	16.9	
	6 "		58	13.8	1.64	13.8	

that the adult male population was still down by 65 to 75 per cent.

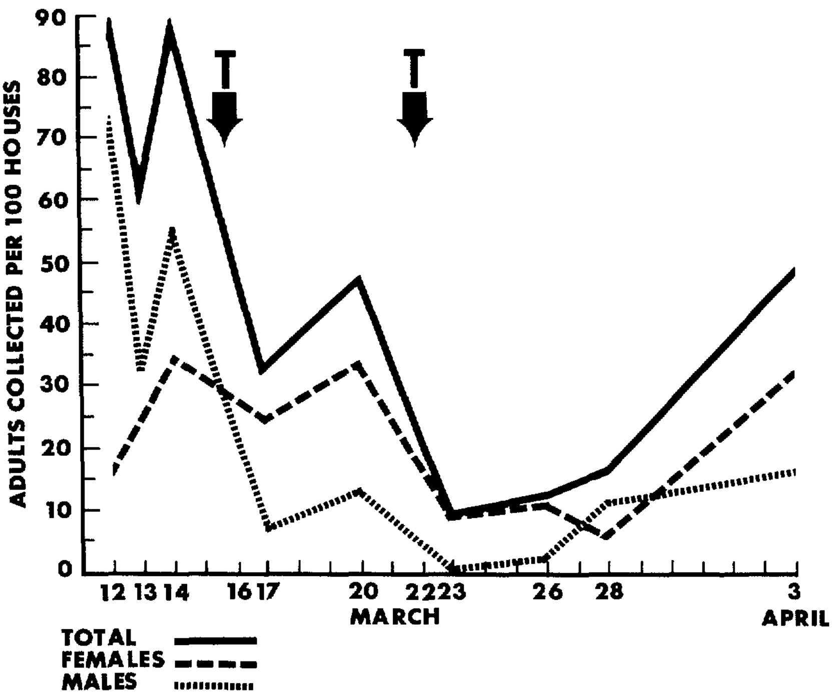
The second application (made with flights applying averages of 9.33 and 8.77 ounces per acre) achieved better results. The males were eliminated completely by the end of the first day, and the female population was sharply reduced for at least six days. Resting and human bait collections of adult females made immediately following this second treatment were 67 and 82 per cent smaller, on the average, than similar collections made before the first treatment. This result, together with the temporarily complete disappearance of adult males, produced a total reduction in the adult *aegypti* population of approximately 89-95 per cent. Six days later, resting collections showed both the adult female population and the total adult population to be down by 80 per cent, while human bait collections showed respective reductions of 24 and 60 per cent. On the eleventh day, resting collections indicated that the female population had completely recovered, even though no females were caught with human bait.

Although reduced larval indices after the first treatment (see Table 6) appeared superficially to be significant, after the first day of the second treatment these indices quickly returned to normal levels, suggesting that the apparent initial reduction was due to random variation.

Rate of Parity

Too few females with ovaries at Christopher stages I and II were captured for valid conclu-

Figure 1. Changes in the infestation rates at Buga of male and female *aegypti* adults, as indicated by "resting" collections made before and after the two aerial treatments.



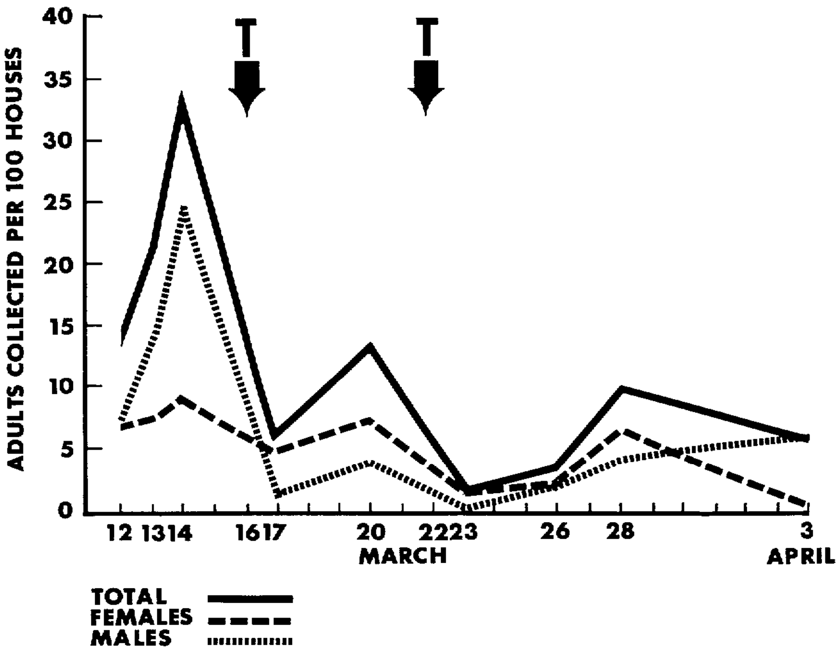
sions to be reached about variations in this group's rate of parity. (As Table 7 shows, most of the collections contained fewer than 10 stage I and II individuals.) However, by combining all the females with ovaries at stages III and IV and the parous females at stages I and II, it was possible to identify those females (all those in this group) that were at least two or three days old. Before the treatments at Buga, and during the study period at Tuluá, this "old" segment of the population held fairly constant, generally accounting for 64 to 80 per cent of the adult female population. After the first treatment in Buga there was no sharp decline in this "old" segment, indicating that most of the adult females collected were survivors of the treatment, rather than new adults just emerged from the pupa.

During the two weeks following the second treatment, only five females were caught with human bait. These biting females were dissected and proved nulliparous. However, 13 females were captured in resting collections made during this period; and their dissection indicated that nine (69 per cent) were "old" females, as compared to 76 per cent of the adult females captured in resting collections made before the first treatment.

Costs

Figures relating to the aerial applications' cost are shown in Table 8, along with the estimated cost of comparable ground applications. The greatest expense, which is judged to have been too high, was that incurred in hiring the aircraft. About 323 liters of malathion were used in the two treatments, around 10 per cent during the calibration flights. In contrast to aerial applications, during ground operations the insecticide is the most expensive single item. Overall, the aerial treatments at

Figure 2. Changes in the infestation rates at Buga of male and female *aegypti* adults, as indicated by "human bait" collections made before and after the two aerial treatments.



Buga cost about double what ground treatments with a "Leco" generator would have cost, even if the insecticide dosages in both cases had been the same.

Discussion

The impact of the two treatments upon the adult *aegypti* population in Buga is clear, with the higher doses obviously being more effective. However, the reductions were not as significant as expected, and the adult female population recovered rapidly. The marked reductions in the male population are probably attributable to the males' greater susceptibility to the insecticide. This difference is the reason why only females were used in the susceptibility tests.

The lowest dosage used—that of the first treatment, which averaged 3.95 ounces per acre—proved insufficient for good control of females. In this vein, it is worth noting that Kilpatrick et al. *(1)* have reported that three ounces per acre, applied aerially to urban areas of Thailand, were insufficient to control *aegypti*, but that six ounces per acre gave good control. The highest dosage used in our trials (9.33 ounces per acre) afforded better control. Although this dosage was higher than that planned, it was not considered excessive.

The established minimum number of droplets for control of *aegypti* (five droplets per square centimeter—*7*) may not always be necessary. Complete mortality of adult females in the biological testing cages was achieved with droplet concentrations as low as 0.16 droplets per square centimeter. It is true that achieving 100 per cent mortality among larvae in biological testing cups required a minimum of 16.92 droplets per square centimeter with an average diameter of 51 microns; however, partial larval mortality was observed with droplets averaging only 23 microns in dia-

Table 7. Identification of older female *aegypti* (those in Christopher stages III or IV plus parous females in stages I or II) among the adults collected in Tuluá and before and after the treatments in Buga.

Place, type of collection, and period	Dates	Weeks after treatment (Buga)	No. of adult females collected	No. of females in Christopher stages I or II				No. of females in stages III or IV	Total no. of older females (in stages III or IV plus those parous in stages I or II)	
				Subtotal	Nulliparous	Parous	Un-classified		No.	% of all females collected
Buga, human bait collections:										
Before treatment	12-14 March		11	5	3	1	1	6	7	64
After first treatment	17-20 "	1	8	3	2	1	0	5	6	75
After second treatment	23-26 "	1	2	2	2	0	0	0	0	0
"	28 March-3 April	2	3	3	3	0	0	0	0	0
"	18-25 April	4	20	12	6	6	0	8	14	70
Buga, "resting" collections:										
Before treatment	12-14 March		25	8	6	2	0	17	19	76
After first treatment	17-20 "	1	31	16	12	2	2	15	17	55
After second treatment	23-26 "	1	11	5	4	1	0	6	7	64
"	28 March-3 April	2	2	0	0	0	0	2	2	100
"	18-25 April	4	73	25	9	15	1	48	63	86
Tuluá, human bait collections:										
(No treatment)	10 March		2	2	2	0	0	0	0	0
"	15-16 "		5	4	1	3	0	1	4	80
"	21-22 "		18	10	5	5	0	8	13	72
"	27-29 "		11	8	3	5	0	3	8	73
"	2 April		6	5	1	4	0	1	5	83
Tuluá, "resting" collections:										
(No treatment)	10 March		18	7	6	1	0	11	12	67
"	15-16 "		12	5	3	2	0	7	9	75
"	21-22 "		38	15	6	6	3	23	29	76
"	27-29 "		44	25	8	17	0	19	36	82
"	2 April		26	14	6	8	0	12	20	77

Table 8. Comparison of the cost of the aerial ULV treatments provided at Buga for 15,500 houses and the estimated cost of providing the same treatments by means of a "Leco" generator mounted on a ground vehicle.

	Aerial application		Ground application	
	Total cost in pesos[a]	Cost per house in pesos[a]	Total estimated cost in pesos[a]	Estimated cost per house in pesos[a]
Amount charged by crop-spraying aircraft company	70,000	4.52	–	–
Cost of insecticide	37,229	2.40	25,415	1.64
Salaries and living expenses of government personnel	7,873	0.51	20,415	1.32
Gasoline, oil, and solvents	525	0.03	6,580	0.42
Total	115,627	7.46	52,410	3.38

[a]US$1.00 = 42.75 pesos, as of May 1979.

meter at a concentration of 1.47 droplets per square centimeter.

Droplet sizes can be as important as droplet numbers, because large droplets have little penetrating power. In our case, for example, droplets up to 106 microns in diameter were collected outside; but only droplets 40 microns in diameter or smaller remained suspended in the air long enough to be carried inside by air currents. Since many *aegypti* adults rest inside houses, droplets larger than 40 microns in diameter had very little effect on the mosquitoes.

Generally, the discharge rates established for one day were of no use the next. However, the estimates of insecticide consumption (cited previously in ounces per acre covered) tallied very well with the results of two-minute discharge tests made at the end of each spraying day. We think the problem of varying discharge rates could have been solved by doing the calibration test every morning before beginning the treatment. This was not done, however, because calibration flights take time, and it was deemed preferable to begin the treatments as early as possible in order to avoid adverse weather conditions.

It should also be noted that an airplane's altimeter is not very accurate when the aircraft is flying at the very low altitudes (15 to 30 meters) required for these applications, and so the actual flying altitude varied a good deal. Also, crop spraying is done in much narrower swaths involving a larger number of passes, and so the company that owned the aircraft erred in charging for urban ULV applications at the same acreage rate it charged for spraying croplands. Partly for this reason, and partly because of other distinctive features of anti-*aegypti* spraying work, it seems clear that aircraft companies should not charge by the acreage involved, but rather by flying time and time spent working on the ground. In this regard, it should also be noted that certain circumstances tend to make urban ULV spraying more expensive than agricultural spraying. Among other things, urban ULV spraying is not routine work, but instead is a public health activity of great importance. For this operation, highly skilled and responsible pilots with long experience are needed; the company must have a plane with proper ULV equipment to turn the toxicant into fine droplets; the equipment must be properly calibrated and must be maintained in good condition; a number of initial flights must be made to establish the proper discharge rates; and postponements due to unsuitable weather conditions, which are common in urban ULV spraying, should be expected.

In general, aerial applications of insecticides in urban areas are particularly useful for emergency vector control during epidemics, but they can also be used in routine vector control operations. Such aerial spraying is much more rapid than other application methods. It is also simpler to organize and carry out, since very few personnel are required; and this means fewer difficulties with such matters as sick leave, organizational delays, or labor problems.

It should also be stressed that any spraying of insecticide in an urban area must be preceded by careful publicity and community education. Of course, when the spraying is done during an epidemic, as it was in the Caribbean and Central America in 1977, the support of the community, the authorities, and the media is easily obtained and opposition is minimal. In contrast, the same spraying done for research purposes in an urban area that is not feeling the impact of an epidemic will encounter obstacles that are difficult to overcome. Among other things, it is apt to stir up heated debates and overreactions by the mass media and by many who consider themselves "ecologically" oriented but do not always understand the value of research.

In the case of the Buga experiment, the community, its authorities, and other local leaders were amply, perhaps overly informed in order to win their support and cooperation. Even so, there were some adverse reactions; and while these did not hinder the project, they did cause limited worry and misunderstanding among some of the residents.

Conclusions

The conclusions that can be drawn from this work include the following:

1) The first aerial treatment of Buga, at an average rate of 3.95 and 6.57 ounces of malathion per acre, gave good control of *Aedes aegypti* males, but not of females.

2) The second treatment, applied at average rates of 9.33 and 8.77 ounces per acre, completely eliminated the males by the next day, and gave good control of both males and females for six days.

3) While the aerial sprayings were performed more quickly and easily than traditional ground applications would have been, they were also more expensive. Such aerial applications may therefore be more useful in dealing with emergency situations than in conducting routine control activities.

4) Calibration tests to determine insecticide discharge rates should be carried out every day before each treatment.

5) Contracts with aircraft companies should be based on the hours of work done (flying time plus time spent working on the ground).

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SUMMARY

Two aerial applications of ultra-low-volume (ULV) malathion were made over the Colombian city of Buga in March 1979 in order to test this mosquito control method's impact upon local infestations of *Aedes aegypti*.

Some difficulty was encountered in regulating the applicator aircraft's insecticide discharge rate, with the result that the discharge rates varied from the desired rate of 6 ounces per acre—the average rates of the two flights applying the first treatment

(on 16 March) being 3.95 and 6.57 ounces per acre, and the average rates of the two flights applying the second treatment (on 22 March) being 9.33 and 8.77 ounces per acre.

Both treatments killed all caged adult female *aegypti* left in exposed locations outdoors and inside local houses. However, not all test larvae left exposed outdoors were killed, and very few were killed at indoor locations. Moreover, collections made of resting adult mosquitoes and of mosquitoes attracted with human bait showed that the first treatment only slightly reduced the wild population of adult females, even though the population of adult males declined sharply. The second treatment had a considerably greater impact, virtually eliminating the adult males on the first day and sharply reducing the adult female population for six days. The cost of these aerial applications was about twice the estimated cost of comparable ground applications made with a vehicle-mounted "Leco" generator.

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