AERIAL ADULTICIDING FOR THE SUPPRESSION OF *CULEX TARSALIS* IN KERN COUNTY, CALIFORNIA, USING LOW-VOLUME PROPOXUR: 1. SELECTION AND EVALUATION OF THE APPLICATION SYSTEM

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ABSTRACT. Propoxur applied aerially at 4.7 liters/ha was an effective adulticide against organophosphate resistant *Culex tarsalis*. Applications by fixed-wing and helicopter underslung spray systems equipped with hydraulic nozzles provided good coverage of test areas as indicated by the mortality patterns of sentinel mosquitoes. However, the propoxur wettable powder in larvicide oil formulation was dispersed in a very broad particle range. The fixed-wing (Ayres Thrush) aircraft treated 260 ha (640 acres) in 45 min and could carry a full load of 1500 liters (400 gal) at temperatures in excess of 38°C. In contrast, the helicopter (Bell UH-1) with an underslung spray system (Simplex Model 6800) required over 2 hrs to treat the same area at lower temperatures and could not carry a full load of 570 liters (150 gal) at temperatures greater than 38°C.

INTRODUCTION

The last major arboviral encephalitis outbreak in California occurred in 1952; there were 420 confirmed human cases (370 western equine encephalomyelitis (WEE) and 45 St. Louis encephalitis). In addition to 50 deaths, 29 cases were children less than one year of age and of these 79% developed sequelae; of the latter, 50% required permanent institutional care (Finley et al. 1967). The threat of another outbreak in California remains since infections of the primary vector, *Culex tarsalis* Coquillett, are found annually; for example, in 1982, 206 of 477 mosquito pools found to harbor arboviruses were *Cx. tarsalis* infected with WEE virus (Emmons et al. 1983).

The 1952 encephalitis outbreak occurred at a time when populations of the vector had become resistant to organochloride insecticides and replacement chemicals were not yet available. Insecticide tolerance in populations of *Cx. tarsalis* is still of great concern because during the past 27 years they have become progressively resistant to the organophosphorous (OP) compounds (Gjullin and Isaak 1957, Apperson and Georghiou 1975, Schaefer 1979); it is very unlikely that OP adulticides would be effective against these populations in an emergency control program.

Should an encephalitis outbreak occur, aerial adulticiding would be the most efficient method of rapidly eliminating infected mosquitoes over large areas. Reisen et al. (1984) suggested that adulticiding at 3-day intervals on 3 consecutive occasions may increase vector mortality sufficiently to interrupt virus transmission. However, attempts to experimentally document protocol effectiveness were hampered by resistance to chlorpyrifos and resmethrin (Yoshimura et al. 1983). In contrast, California mosquitoes have retained susceptibility to propoxur even though this insecticide has been used operationally in the San Joaquin Valley since 1968.

The present study addresses the practicality of area adulticiding in foothill and valley habitats under sunset and sunrise conditions using fixed-wing or helicopter application systems. This first paper describes the spray system and evaluates coverage using caged mosquito sentinels. A companion paper (Reisen et al. 1985) assesses the impact of the propoxur adulticide on *Cx. tarsalis* population dynamics and arbovirus infection rates.

METHODS AND MATERIALS

INSECTICIDE FORMULATION AND SUSCEPTIBILITY. Two formulations of propoxur (o-isopropoxyphenyl N-methylcarbamate) were considered: (1) 0.12 kg AI/liter oil solution (Baygon 1-MOS) and (2) 70% wettable powder (WP). The Baygon 1-MOS has shown good potential in recent field trials in California (Schaefer et al. 1984) and has been used for emergency encephalitis control in Canada (Sekla 1982). However, this formulation was not available in sufficient quantities for area treatments and was not registered for aerial application in the USA. Thus, the WP formulation was selected for evaluation. Although normally dispersed in water, larvicide oil

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(Witco-Golden Bear 1356) was chosen as the carrier, since planned evening applications would be made when temperatures were as high as 38°C and humidities were below 20% causing excessive evaporative losses of aqueous spray.

The susceptibility of *Cx. tarsalis* from the target populations to adulticides in current use was determined throughout the summer. Females collected by CO_2 traps were divided into lots of 20 and exposed to treated glass filter papers (Whatman GF-A) for 1 hr (Georghiou and Gidden 1965). Mortalities were recorded after a 24 hr holding period in untreated cages. Triplicate lots were exposed at each concentration.

APPLICATION SYSTEM. Hydraulic nozzles were selected, since Beecomist rotary nozzles with 20 or 40 u sleeves plugged during attempts to disperse the WP formulation in oil. The fixed-wing aircraft, an Ayres Thrush Commander, was powered by a 1200 hp engine and had a 1500 liter (400 gal) capacity tank. The 11 m spray boom was fitted with 36 D-6 hollow-cone nozzles with No. 45 cores. The Simplex Model 6800 underslung spray unit had a 570 liter (150 gal) tank and was tethered 4.6 m beneath a Bell UH-1 helicopter (Fig. 1). The Simplex unit was powered by a gasoline engine and had a 9 m boom fitted with 33 D-4 hollow-cone nozzles with No. 45 cores. The propoxur was mixed with the larvicide oil in an agitating mixer and immediately loaded into the aircraft hopper. Neither spray system had mechanical agitation so that continued mixing depended upon bypass circulation.

CALIBRATION. To apply the legal limit of propoxur (0.078 kg AI/ha or 0.07 lb AI/ac), 0.024 kg of the 70% WP was suspended per liter of larvicide oil and dispersed at the rate of 4.7 liters/ha (0.5 gal/ac). The Thrush was operated at 225 kph (140 mph) at ca 9 m (30 ft) attitude. The helicopter flew at 93 kph (58 mph) to navigate obstacles and uneven terrain and keep the underslung unit 9 m above the ground. Each flight line was flagged from both ends and radio communication was maintained with the aircraft so that adjustments could be made in altitude or swath alignment. The amount of spray used for each test (total mixed minus the residual drained from the spray system) was used to calculate actual dosage.

Fig. 1. Bell UH-1 helicopter with underslung Simplex Model 6800 spray system.

For swath width calibration, each aircraft was flown for fixed spray periods across lines of mosquito assay cages which were placed 6 m apart on 1.2 m stakes along a 183 m transect perpendicular to the flight path. Each cage contained 20 *Cx. tarsalis* adults and mortalities were recorded 4 hr after spraying to determine effective swath widths.

EVALUATION. To monitor spray coverage and document kill under field conditions, sentinel mosquitoes from the reference Breckenridge 1980 (Br80) colony (n = 15–20 adults per sex per cage) and from the target population (n = 15–20 females per cage collected by CO_2 traps) were exposed in assay cages at 12 locations arranged along N–S and E–W intersecting transects. Four comparison sentinels were positioned >1.5 km outside the border of the spray zone, while 6–10 cages of target females were sequestered under vegetative canopy to bioassay droplet penetration. To detect possible gaps within or between swaths, 20 cages were positioned 6 m apart on 1.2 m stakes along each of two 114 m transects perpendicular to the flight paths. Sentinels were left in the field overnight and mortality recorded the following morning, ca. 12 hr postspray. For the morning spray, sentinels were left in the field for 1 hr postspray and then returned to the laboratory where mortality was recorded the following afternoon, ca. 6 hr postspray.

Spray droplets were collected on Teflon® coated slides which were held in a rotator 1.2 m above the ground and turned 4 times/sec. One hundred droplets were measured on each of 2 slides per location and volume median diamater (Vmd) calculated (Akesson and Yates 1982). One slide rotator was positioned in the middle of each transect of sentinel mosquitoes.

Meteorological conditions were measured just outside the spray zone during each spray. Temperatures were recorded at 2.4 and 9.0 m. Wind speed and direction were recorded at 4.5 m, while relative humidity was recorded by motor driven psychrometer at 1.2 m.

STUDY AREAS. Four treatment sequences of 3 sprays at 3 day intervals were made at 3 sites in Kern County, California during 1983:

1. Poso West. Approximately 320 ha (800 acres) of arid foothill terrain situated 16 km north of Bakersfield were sprayed by fixed-wing aircraft on the late afternoons of June 17, 20 and 23. Mosquito populations in the spray zone develop in rivulets created by oil field effluent (Nelson et al. 1978). Field collected immature *Cx. tarsalis* were exposed to the aerial spray in waxed cups positioned at a breeding site within the spray zone. Irregularities in terrain prevented flagging at the ends of the swaths and the positioning of comparison sentinels to the east.

2. Breckenridge. The study site consisted of 3 relatively parallel canyons, A, B and C (Milby et al. 1983) situated ca. 15 km east of Bakersfield. Wastewater disposed by percolation in a series of ponds and by sprinkling on the canyon walls created an environment suitable for the production of large *Cx. tarsalis* populations. The 24 ha (60 acre) central canyon B was sprayed by helicopter during the late afternoons of July 22, 25, and 28. Ten mosquito fish (*Gambusia affinis* Baird and Girard), and 3–4 immature bass (*Micropterus salmoides* (Lacepede)) and 1 bluegill (*Lepomis* sp.) were placed in minnow traps in 5 and 3 sprayed ponds, respectively, to assess the impact of the propoxur formulation on mortality patterns. Fish were placed in the ponds the afternoon prior to the first spray and were examined daily for mortality. Ponds also were inspected visually for mortality among the resident mosquito fish population.

3. John Dale Ranch. A 314 ha (800 acre) mixed agricultural area situated on the San Joaquin Valley floor ca. 21 km SE of Bakersfield was sprayed by helicopter during the late afternoons of August 16, 19 and 22. The heavily vegetated and centrally positioned Mosesian's Duck Club formed a settlement area for mosquitoes breeding in the surrounding agricultural habitat.

Crops approaching harvest stage forced us to shift the spray zone 1.6 km to the east for the early morning, fixed-wing application. The new spray zone encompassed the Los Pobrecitos Duck Club which consisted of reclaimed and irrigated pasture. A total of 380 ha (950 acres) including Mosesian's Duck Club were sprayed just after dawn on September 13, 17 and 20.

RESULTS

INSECTICIDE SUSCEPTIBILITY. The susceptibility of adult *Cx. tarsalis* from the test sites is shown in Table 1. While these populations were susceptible to propoxur, they were generally tolerant to OP-insecticides as evidenced by the slopes of the ldp (log dosage probit) lines. At present, propoxur is the only commercially-available adulticide which can be used operationally against these populations.

CALIBRATION. To obtain the desired discharge rate, the Thrush system was pressurized

Table 1. Insecticide susceptibility of *Culex tarsalis* females from Kern County, California study areas, 1983.

Date	Insecticide	LD_{50} (μg/cm)	LD_{90}	Slope	Control mortality (%)
		Poso West			
Jun 14	propoxur	1.42	2.57	4.97	1.6
Jun 21	propoxur	1.90	2.73	8.21	0.0
Jun 23	propoxur	2.00	2.84	8.40	0.0
Jul 1	propoxur	1.69	2.86	5.65	0.0
		Breckenridge			
Jul 18	propoxur	2.15	3.34	6.70	3.3
Jul 20	chlorpyrifos	0.07	0.27	2.30	0.0
Aug 1	malathion[a]	11.35	203.32	1.02	0.0
Aug 2	propoxur	2.18	3.20	7.68	0.0
		John Dale			
Aug 11	propoxur	1.46	2.59	5.13	3.9
Aug 15	chlorpyrifos	0.51	2.12	2.08	0.0
Aug 16	malathion	44.01	1002.66	0.94	1.5
Aug 16	propoxur	2.32	3.45	7.45	0.0
Sep 8	propoxur	1.59	2.51	6.51	0.0
Sep 16	ethyl parathion[a]	1.51	6.20	2.09	7.1
Sep 22	propoxur	1.34	.23	5.77	0.0

[a] Duplicate replication per concentration; all other data based on triplicate replication.

to 400 KPa (60 psi) and the Simplex system was pressurized to 267 KPa (40 psi). At 9 m altitude both systems provided an effective swath width of 61 m (200 ft) or greater, depending on wind direction and velocity. All spraying was based on this swath width.

EVALUATION. *Afternoon, fixed-wing spray at Poso West.* Sentinel mortality within the spray zone was greater than 95% at all standards indicating good coverage of the spray zone (Table 2). Vegetative canopy along Poso Creek reduced the percent mortality among sequestered sentinels. Winds gusting to 18 kph from the N caused excessive mortality among comparison zone sentinels positioned ca. 1 km to the S of the spray zone on 20 June. Complete mortality of sentinels along the 2 transects indicated there were no gaps within or between swaths. Survival of immature sentinels (n = 338 larvae and 22 pupae in 6 cups) indicated that the applied dosage lacked larvicidal activity. In addition, mortality was not observed among larvae or pupae at breeding sites.

Heavy spray deposits were observed on rotating slides exposed during all sprays. Droplet sizes ranged from 14 to 238 μ (Table 2). Hot and dry weather conditions may have precluded the collection of the very small 7 μ droplets recovered during subsequent sprays.

Our inability to flag each flight path precluded a careful estimation of the field dosage rates. However, since the entire spray load was used over the 320 ha study site, field dosage approximated the planned rate of 4.7 liters/ha.

Afternoon, helicopter spray at Breckenridge. The slow flight speed and enhanced maneuverability of the helicopter underslung spray unit permitted good coverage of canyon B despite the irregular terrain. Mortality of sentinel females from the target population and from the reference Br80 strain averaged 83 and 84% at stations within the spray zone (Table 2). Mortality was lowest at some peripheral standards that were poorly sprayed. Mortality among sequestered sentinels was reduced by vegetative canopy. Mortality at sentinels in unsprayed canyons A and C was 3% indicating that the spray did not drift out of the central canyon B. Mortality averaged 84–99% and 80–100% at each of 2 transects of sentinel cages. Survival was restricted to cages protected by vegetative canopy and there did not appear to be gaps within and between swaths. However, the larger Vmd of the collected spray

Table 2. Weather conditions, spray droplet size, and sentinel mortality observed during 4 low volume applications of propoxur wettable powder in oil by fixed wing aircraft (F) and helicopter (H) in Kern County, California, 1983.

Habitat:	Foothill						Mixed agricultural					
Site—aircraft:	Poso West—F			Breck.—H			John Dale—H			John Dale—F		
Spray:	1	2	3	1	2	3	1	2	3	1	2	3
Weather:												
Temp (C)	36	31	31	32	27	32	31	27	26	21	19	18
RH(%)	21	16	24	21	32	24	50	62	42	60	53	63
Wind (kph)	12–22	8–18	8–20	10–13	10–17	8–14	7–27	2–12	2–17	2–5	0–7	0–7
Droplet size (μ):[1]												
Transect 1($\bar{x}$)	120	102	115	185	132	262	270	118	186	133	94	185
(range)	14–176	14–170	14–170	7–272	7–272	7–489	7–367	7–183	7–319	7–197	7–183	7–306
Transect 2($\bar{x}$)	103	113	162	165	165	200	170	305	170	140	138	170
(range)	14–176	14–170	14–238	7–326	7–299	7–367	7–238	7–394	7–251	7–340	7–217	7–292
Sentinel mortality (%):[2]												
Br80: spray	99	99	97	74	81	97	88	88	83	97	88	97
comp.	10	15	11	2	0	0	20	0	4	2	6	1
Target♀: spray	99	100	100	80	77	93	87	84	82	99	87	93
comp.	7	22[3]	0	2	0	8	24[4]	5	10	4	0	9
Sequestered	56	47	89	72	39	71	85	60	51	80	66	51

[1] Droplet volume median diameter in μ, n = 100 drops/slide for 2 slides exposed at each site.

[2] Spray and comparison zone sentinels hung from trap standards (n = 15–17 standards per test), sequestered = 6–10 cages placed under vegetative canopy or inside red boxes, Br80 = 1–4 day old ♂ and ♀ from a propoxur susceptible reference strain (n = 15–20 adults/sex/cage), target ♂ = females collected from CO_2 traps in the spray zone (n = 15–20 females/cage).

[3] Excessive mortality caused by >1 km spray drift to S.

[4] Excessive mortality caused by wind storm after comparison and some spray zone sentinel deployment, but before aerial application.

droplets indicated that the slower air speed produced poor and variable atomization (Table 2).

Mortality was not observed among 50 mosquito fish exposed in minnow traps in 5 ponds or among 13 bass and 3 sunfish exposed in minnow traps in 3 ponds within the spray zone for the entire spray sequence. In addition, mortality was not seen among mosquito fish planted in the percolation ponds for mosquito control.

The volume of propoxur dispersed over central canyon B approximated the maximum field dosage rate of 4.7 liters/ha (Table 3).

Afternoon helicopter spray at John Dale Ranch. Sentinel mortality averaged > 82% within the spray zone and <25% within the comparison zone (Table 2). Sentinel survival within the spray zone was limited to cages protected by vegetative canopy. A dust/wind storm on August 16 caused some mortality among comparison and spray zone sentinels during spray 1. Complete mortality among sentinels positioned along the 2 transects indicated there were no gaps within or between swaths.

Heavy spray deposits were observed on all slides (Table 2). Again, the slower flight speed of the helicopter resulted in variable Vmd estimates. The applied dosage approximated that sought (Table 3). The increased size of the spray zone (317 ha) forced the helicopter to be reloaded 3 times. Reloading and slower airspeed elongated the application time to about 2 hr.

Early morning, fixed-wing spray at John Dale Ranch. Mortality of spray zone sentinels averaged >90%, except during 17 September when the center of the Los Pobrecitos Duck Club was not sprayed due to the presence of hunters (Table 2). Mortality among sequestered sentinels was reduced, especially for those positioned inside red box resting sites. Complete mortality among sentinels exposed along the two transects indicated there were no gaps within or between swaths.

Fast flight speed improved the atomization of the spray droplets and the mean Vmd among slide deposits ranged from 94 to 185 μ (Table 2). Increased flight speed and greater tank size enabled the Thrush to treat most of the study area in ca. 45 min.

DISCUSSION

Propoxur 70% WP suspended in larvicide oil effectively killed organophosphate resistant *Cx. tarsalis* adults in field cage exposures. The spray lacked larvicidal properties at the dosage rates applied and did not kill sentinel immature mosquitoes or fish. Therefore, the current formulation would be useful as an adulticide in integrated programs using mosquito fish for larval mosquito control. Although the formulation was satisfactory during the current experimental trials, variable particle size and low volume dispersal rates indicated refinements would be necessary before the present formulation would be effective in an emergency situation. A more suitable carrier with lower volume requirements would increase the size of the area which could be treated without reloading the aircraft, an important consideration if treatments are to be completed during peak mosquito flight activity periods.

Operationally, both sunset and sunrise applications by both fixed-wing and helicopter spray systems effectively killed sentinel mosquitoes. The helicopter underslung system was useful in spraying small areas having irregular terrain, but was cumbersome treating large study sites where slow air speed and reduced pay load greatly increased spray time. In contrast, the fixed-wing system was considered superior for treating large agricultural habitats on the valley floor due to its faster speed and greater load capacity.

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Table 3. Estimated field dosage rates of propoxur applied to 3 test sites in Kern County, California, 1983.

Locality (Aircraft)	Spray	Date	Liters sprayed	Hectares treated	Dosage (liters/ha)
Breckenridge (helicopter)	1	Jul 22	121	24	5.0
	2	Jul 25	106	24	4.4
	3	Jul 28	132	24	5.4
John Dale (helicopter)	1	Aug 16	1467	308	4.8
	2	Aug 19	1495	317	4.7
	3	Aug 22	1514	317	4.8
John Dale (fixed-wing)	1	Sep 13	1544	345	4.5
	2	Sep 17	1628	345	4.7
	3	Sep 20	1628	353	4.6

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