COMBINATION GROUND AND AERIAL ADULTICIDE APPLICATIONS AGAINST MOSQUITOES IN AN ARKANSAS RICELAND COMMUNITY[1,2]

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ABSTRACT. Simultaneous ground and aerial adulticide applications were evaluated against riceland mosquitoes in Stuttgart, AR, during July 1985. Naled was aerially applied at 52.6 ml/ha over 10.4 km^2 surrounding the city. Ground ULV applications of a mixture of malathion, HAN and resmethrin/PBO (1:1:0.0625) were applied within the city at a rate of 221.8 ml/min at 24 kph. Adult populations of *Anopheles quadrimaculatus* and *Psorophora columbiae* were reduced at 24 hr but resurgence of *Ps. columbiae* was evident at 48 hr posttreatment. Posttreatment data indicated that movement of both mosquitoes occurred along the path of prevailing wind.

INTRODUCTION

Anopheles quadrimaculatus Say and *Psorophora columbiae* (Dyar and Knab) are the two primary pest mosquitoes found in Stuttgart, AR, a community in the rice growing region of eastern Arkansas (Meisch and Coombes 1975). Control of *An. quadrimaculatus* and *Ps. columbiae* in the Stuttgart area currently is attempted by ultra low volume (ULV) larviciding with *Bacillus thuringiensis* var. *israelensis (Bti)* (Sandoski et al. 1985) in ricefields surrounding the community and ULV adulticiding with ground (Mount et al. 1972) and aerial (Meisch and Mount 1978) sprays within and surrounding the community. Though excellent control may be achieved initially following ULV ground adulticiding, posttreatment dispersal of mosquitoes from adjacent non-treated areas often necessitates nightly adulticide applications (Walker and Meisch 1982). Knowledge of this movement is necessary to effectively implement community control. Horsfall (1942) stated that the flight range of *An. quadrimaculatus* was approximately 2 miles (3.2 km) while that of *Ps. columbiae* was up to 8 miles (19.9 km). Though *An. quadrimaculatus* appears to be a weak flier in comparison to *Ps. columbiae*, Horsfall (1955) later asserted that the flight range of *An. quadrimaculatus* was not completely resolved.

Rapid replacement of *An. quadrimaculatus* subsequent to mosquito adulticide treatments in Suttgart mandates the need for a better understanding of the flight behavior of this species. The long flight range of *Ps. columbiae*, a floodwater mosquito, precludes larviciding for this species; therefore, control tactics for Stuttgart are predicated upon larviciding for *An. quadrimaculatus* and adulticiding for both species.

During the summer of 1985, a study was conducted to determine if an effective chemical barrier could be created to prevent the dispersal of these two mosquito species into the community of Stuttgart. The effort was directed primarily towards *An. quadrimaculatus* since it was suspected that *Ps. columbiae* would quickly penetrate the barrier. The specific objectives of the study were to determine barrier persistence against each species, direction from which mosquito reinfestation occurred, and relation of wind direction to mosquito movements and barrier effectiveness.

MATERIALS AND METHODS

On the evening of July 3, 1985, between 2200 and 0100 hr, a twin-engine Piper® Aztec aircraft was used to apply 80% naled at 52.6 ml/ha over 10.4 km^2 surrounding the city of Stuttgart, AR. The aircraft was equipped with a tail-mounted boom containing 5 Teejet® 8535 nozzles with D_2 orifices. Altitude was 60–90 m and air speed was 241 kph during application. The treated area comprised a zone 1.6 km in width surrounding the city with additional extensions of approximately 1.6 km to the south and west against the direction of prevailing winds.

Ground ULV applications were conducted during the same period within the community

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using truck-mounted LECO® cold aerosol generators. A mixture (1:1:0.0625) of malathion (91%), heavy aromatic naphtha (HAN) and resmethrin/PBO (18%/54%) was applied at a rate of 221.8 ml/min while traveling at 24 kph. The entire city (ca. 6 km^2) was treated by the ground units on the evenings of July 2 and 3. Intensive larviciding was conducted July 2, on 1,758 ha of rice surrounding the community using Beecomist® applied *Bti*. Temperature during both aerial and ground applications was 28 ± 3°C, and wind velocity was 8–13 kph with gusts up to 16 kph from the southwest. Efficacy of the adulticide treatment was intensively monitored during the study with the 3 following methods.

RESTING STATIONS. Box-type resting stations (76.2 × 45.7 × 30.5 cm) were monitored daily for *An. quadrimaculatus* for 3 days pretreatment and 2 days posttreatment. Resting station design differed slightly from that of Edman et al. (1968) as follows: the inner cloth sleeve was omitted and the interior was painted red rather than black. Three stations were located within the city and 3 were placed within the surrounding buffer zone. One additional station placed outside of the treatment area served as a control. Collections from resting stations were made with hand-held, battery-powered aspirators described by Meek et al. (1985). Each collection was labelled, transported to the laboratory and separated by sex. Data were subjected to ANOVA. Pre- and posttreatment means for each sex were calculated for collections made within the city and the surrounding buffer area. Linear contrasts (SAS 1985) were used to demonstrate significant reductions in *An. quadrimaculatus* density at 12 and 36 hr posttreatment based on counts taken for 3 days pretreatment.

LANDING RATES. Landing rates were determined for both species 2 days pretreatment and 2 days posttreatment along 4 transects (N,S,E and W) that intersected at the center of town. Each transect was divided into 3 zones that included the area within the city treated by ground (Zone 1), the area receiving both ground and aerial treatment (Zone 2) and the aerially treated zone (Zone 3). Eight stations were established at 0.4 km intervals along each transect; thus, each transect covered a distance of 3.2 km from the center of the city in one of the 4 cardinal directions. The first station was located 0.4 km from the center. Zones 1 and 3 each contained 3 stations while zone 2 contained 2 stations along each transect. Four additional stations established 8.0 km outside the treated area served as controls. Two persons sampled each transect. Each station was sampled by waiting after arrival for 1 min and then aspirating alighted mosquitoes for 1 min. Collections from each station were labelled and transported to the laboratory. Data were subjected to ANOVA, and means were calculated by day for each transect and zone. Data were corrected for control reductions with Abbott's formula. Transect means were separated by the least-squares means procedure (SAS 1985), and percentage reductions were calculated for posttreatment counts. Standard errors and percentage reductions were calculated for means of each combination of day and zone.

SENTINEL CAGE OBSERVATIONS. Sentinel cages were used to assess treatment effectiveness against *An. quadrimaculatus*. Adult *An. quadrimaculatus* were collected with battery-powered aspirators from a barn located 15 km S of Stuttgart, AR. Collections consisted of 71, 12, and 17% blooded females, unblooded females, and males, respectively. Aspirator tubes containing mosquitoes were transported to the laboratory in insulated chests with damp paper toweling to maintain humidity. Mosquitoes were anesthetized with CO_2 and transferred to modified World Health Organization insect test kits (Roberts 1982) at a density of 20 mosquitoes/kit. Sentinel cages were placed along transects at each landing rate station (8 cages/transect). Four sentinel cages placed outside the treatment area served as controls. Sentinel cages were positioned at each station just before dusk and picked up immediately after treatments on the evenings of July 2 and 3. Mortality was observed 24 hr posttreatment. Percentage mortality data were corrected with Abbott's formula, transformed (arc sin) and subjected to ANOVA for testing the hypotheses that mortality among treatment regimes and among transects was equal. Means calculated for each treatment regime and transect were separated using the least-squares means procedure (SAS 1985).

RESULTS AND DISCUSSION

Mean pre- and posttreatment counts by zones and posttreatment percentage reductions of *An. quadrimaculatus* collected from resting stations are shown in Table 1. No reductions were observed in check counts at 12 or 36 hr posttreatment. Both longer lasting control and higher levels of reduction were achieved in the aerially treated buffer zone. Reductions of female and male mosquitoes within this zone at 12 hr were 90 and 77%, and at 36 hr, 81 and 84%, respectively. Posttreatment counts from the ground treated zone, inside the city, indicated reductions of only 60 and 56% at 12 hr, and 7 and 39% at 36 hr for female and

Table 1. Mean daily collections and posttreatment percentage reductions of *Anopheles quadrimaculatus* adults from resting stations in and near Stuttgart, AR, during July, 1985.

	Pretreatment		12 hr posttreatment		36 hr posttreatment	
Zone*	Female	Male	Female	Male	Female	Male
1	79.1	84.6	31.7	37.3	73.7	52.0
± S.E.	± 44.3	± 38.0	± 24.7	± 32.5	± 58.2	± 36.4
(% reduction)			(59.9)	(55.9)	(6.8)	(38.5)
2	360.2	647.4	37.0**	148.3**	68.3**	106.0**
± S.E.	±171.3	±317.0	± 33.6	±137.9	± 57.9	±103.0
(% reduction)			(89.7)	(77.1)	(81.0)	(83.6)
Check	103.3	135.7	192.0	296.0	129.0	215.0
± S.E.	± 16.3	± 45.1	—	—	—	—
(% reduction)			(0.0)	(0.0)	(0.0)	(0.0)

* Zone 1 was ground-treated and inside the city. Zone 2 was the aerially treated buffer zone.
** Significant reductions (P < 0.05) indicated by linear contrasts.

male mosquitoes, respectively. This indicated that initial control was lacking in the ground treated zone and that survivors of the ground ULV treatment and recent emergees may have accounted for the density observed after 36 hr.

Mean landing rates and posttreatment percentage reductions of both species are shown in Table 2 for each of the 3 landing rate zones. An initial reduction was indicated for both species in all 3 zones. No reductions were observed for *Ps. columbiae* at 48 hr posttreatment. Control of *An. quadrimaculatus* was achieved for 48 hr within the city (ground treated zone), though no reductions of this species were indicated by landing rate counts at 48 hr in the zone receiving ground and aerial treatments or in the aerially treated zone. Inward dispersal of mosquitoes from surrounding untreated areas would likely account for the increased landing rates in the outer zones at 48 hr posttreatment. Results of 48 hr posttreatment landing rates contradict those obtained from resting stations. The fact that resting stations measure the entire *An. quadrimaculatus* adult population whereas landing rates measure only blood-feeding females may account for this contradiction. Female mosquitoes collected from resting stations within the city at 36 hr may have been recent local emergees or newly migrated and not yet members of the biting population.

Fluctuations in both *Ps. columbiae* and *An. quadrimaculatus* density along each transect are shown in Table 3. Adequate reduction of *An. quadrimaculatus* was achieved at 24 hr posttreatment except along the west transect. However,

Table 2. Mean landing rates (mosq./min.) and posttreatment percentage reductions of *Anopheles quadrimaculatus* and *Psorophora columbiae* by sample period and zone in and near Stuttgart, AR, during July, 1985.

	Zone Means ± S.E.*,**							
	Ground		Ground and aerial		Aerial		Check	
Sampling*** Period	*Anopheles*	*Psorophora*	*Anopheles*	*Psorophora*	*Anopheles*	*Psorophora*	*Anopheles*	*Psorophora*
−48 hr	1.33Aa	3.33Aa	1.75ABa	4.87AaB	2.92Ba	13.50Ba	1.50	26.75
	±0.40	± 0.86	± 0.67	± 1.42	± 0.51	± 1.99	± 0.43	± 6.48
−24 hr	0.92Aa	2.67Aa	1.37ABa	8.12Ba	2.42Ba	12.17Ba	4.25	57.25
	± 0.36	± 0.99	± 0.32	± 2.66	± 0.53	± 2.11	± 0.74	±13.29
24 hr	0.25Aa	0.67Aa	0.62Aa	2.25Ab	1.08Ab	4.17Ab	2.25	47.00
	± 0.18	± 0.38	± 0.42	± 0.98	± 0.36	± 1.89	± 0.41	± 6.03
(% reduction)	(71.6)	(77.7)	(49.3)	(65.4)	(48.4)	(67.5)	(21.7)	(0.0)
48 hr	0.33Aa	3.67Aa	2.67Aa	8.67Aab	3.50Aab	17.33Aab	6.00	83.00
	± 0.33	± 2.73	± 2.67	± 6.23	± 1.75	± 6.24	± 2.16	±43.15
(% reduction)	(70.7)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)

* Means for a particular species in the same row followed by the same upper case letter are not significantly different (P ≥ 0.05) by least-squares means.
** Means in the same column followed by the same lower case letter are not significantly different (P ≥ 0.05) by least-squares means.
*** Percent reductions based on average of pretreatment landing rates.

Table 3. Mean landing rates (mosq./min.) and posttreatment percentage reductions of *Anopheles quadrimaculatus* and *Psorophora columbiae* by transect and sampling period in and near Stuttgart, AR, during July, 1985.

	Transect means*,**				
Sampling*** period	E	N	S	W	Check
−48 hr *Anopheles*	1.75Aab	3.25Aa	2.62Aa	0.50Bb	1.50
Psorophora	8.75Aa	6.00Aa	7.37BCa	8.00ABa	26.75
−24 hr *Anopheles*	0.75Aa	2.25ACa	1.62ABa	1.75Aba	4.25
Psorophora	6.37Aab	4.75ABb	8.87ABab	10.37Aa	57.25
24 hr *Anopheles*	0.25Aa	0.62Ba	0.25Ba	1.50Ba	2.25
(%reduction)	(74.4)	(71.3)	(84.9)	(0)	(21.7)
Psorophora	4.00Aa	0.12Ba	2.50Ca	2.87Ba	47.00
(% reduction)	(47.1)	(97.8)	(69.2)	(68.8)	(0)
48 hr *Anopheles*	rain	0.50BCb	3.50Aab	3.50Aa	6.00
(% reduction)		(81.8)	(0)	(0)	(0)
Psorophora	rain	1.75ABb	17.50Aa	16.00Aa	83.00
(% reduction)		(67.5)	(0)	(0)	(0)

* Means for a particular species in the same column followed by the same upper case letter are not significantly different (P ≥ 0.05) by least-squares means.
** Means in the same row followed by the same lower case letter are not significantly different (P ≥ 0.05) by least-squares means.
*** Percent reductions based on average of pretreatment landing rates.

landing rates had increased at 48 hr along the south and west transects, primarily in the 2 zones outside the city (Table 2). Sustained control in the north may have been due to insecticide drift with prevailing wind and lack of dispersal from untreated areas north of the city against prevailing wind. Data for the east transect were not obtained at 48 hr posttreatment because of heavy rains on the east side of town. Though these data are lacking, it appeared that movement of *An. quadrimaculatus* occurred from the south and west along the path of prevailing wind. These data contradict Horsfall (1955) who stated that *An. quadrimaculatus* dispersed against prevailing wind to feeding sites. Movement observed in this study also may have been unrelated to feeding and merely a function of wind-directed dispersal from breeding or resting sites. Nevertheless, the data indicate that biting *An. quadrimaculatus* did not disperse back into the city within 48 hr posttreatment. Landing rate data for *Ps. columbiae* indicated results similar to those for *An. quadrimaculatus*. Initial reductions at 24 hr were followed by an increase in adult density at 48 hr. Excellent control obtained to the north of the city again was likely due to insecticide drift and lack of dispersal from the north. Resurgence along the south and west transects in all 3 zones (Table 2) at 48 hr posttreatment indicated that *Ps. columbiae* dispersed into the city along the path of prevailing wind.

Percentage mortality of sentinel *An. quadrimaculatus* due to ground applications alone and in combination with aerial applications are shown for each transect in Table 4. The mean mortalities of caged mosquitoes were low for both treatment regimes. Nevertheless, the dosage of naled applied was indeed on the lower portion of the recommended scale. Insecticide drift appeared to play a role in the

Table 4. Percentage mortality of caged *Anopheles quadrimaculatus* at 24 hr posttreatment due to ground ULV applications alone and in combination with an aerial adulticide application in and near Stuttgart, AR, during July, 1985.

	Transect means*,**				
Type of application	E	N	S	W	Check
Ground	4.0Ab	44.0Aa	21.4Aa	3.5Ab	2.0
Ground and aerial	34.0Ba	44.4Aa	51.6Ba	52.8Ba	11.0

* Means in the same column followed by the same upper case letter are not significantly different (P ≥ 0.05) by least-squares means.
** Means in the same row followed by the same lower case letter are not significantly different (P ≥ 0.05) by least-squares means.

degree of mortality exhibited in the downwind portions of the treated area. Mortality of sentinel mosquitoes indicated that significantly (P<.05) greater control was obtained along all transects, except the north, by combination ground and aerial applications. The effect of prevailing wind on insecticide drift may have negated the difference between the 2 treatment regimes along the north transect. Also, the highest mortality of caged mosquitoes exposed to ground and aerial applications was exhibited in the south and west where resurgence was greatest at 48 hr posttreatment. These data further support the contention that reinfestation occurred along the path of prevailing wind. Extensions of the aerially treated buffer zone to the south and west may have induced the higher mortalities of sentinel mosquitoes observed along the south and west transects. If prevailing wind played a role in the effectiveness of the buffer zone, it is possible that widening the buffer selectively could reduce mosquito reinfestation from upwind areas.

The study indicates that movement of *An. quadrimaculatus* was much less rapid than that of *Ps. columbiae*. When outdoor activity and mosquito populations are at extremely high levels, such intensive applications are justifiable, but certainly not on a routine basis. Under these conditions of intensive rice culture, the concept of a perimeter buffer zone in which *An. quadrimaculatus* emergence and *Ps. columbiae* dispersal might be inhibited by both larvicidal and adulticidal agents seems a plausible approach to community protection from riceland mosquitoes. The level of protection achieved should be correlated with the dispersal rate of the most mobile target mosquito and the width of the buffer.

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