EFFECTS OF ULTRA-LOW VOLUME AND THERMAL FOG MALATHION, SCOURGE® AND NALED APPLIED AGAINST CAGED ADULT *CULICOIDES FURENS* AND *CULEX QUINQUEFASCIATUS* IN OPEN AND VEGETATED TERRAIN[1]

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ABSTRACT. The adulticidal effect of ULV and thermal fog malathion, Scourge® and naled was tested at 2× label dosage (1.42, 0.22, 0.39 oz/acre, respectively) against caged *Culicoides furens* and *Culex quinquefasciatus* in open and vegetated (orange grove) terrain. Cages were at 122 cm elevation and positioned at 15.2, 45.7, 76.2, 106.7, 137.2 and 167.6 m from the line of insecticide release. Ultra-low volume applications of all 3 insecticides were markedly more effective than thermal fog under all conditions, especially in vegetated terrain. Of the 3 insecticides, malathion performed the poorest, especially against *Cx. quinquefasciatus* (in which there was some resistance) and particularly when applied as thermal fog. Scourge and naled were about equally effective. The best adulticide against *C. furens* was naled, which was clearly superior applied as ULV. It yielded 75% mortality out to 283 m in the open, and to 38 m in the presence of dense vegetation.

INTRODUCTION

The importance of biting midges (*Culicoides* spp.) as pests of man in many parts of the world has been extensively documented in the literature for many years (Linley and Davies 1971, Linley 1976). Several species, particularly *Culicoides furens* (Poey), *C. barbosai* Wirth and Blanton, *C. hollensis* (Melander and Brues) and *C. mississippiensis* Hoffman are prominent pests in the heavily populated and economically important coastal areas of Florida, where extensive and costly control programs are carried out against biting insects, particularly mosquitoes, by many control agencies. Although it has long been recognized that midges are major pests of man in these areas, very few attempts have been made to determine the most effective insecticides and application methods for control of adult *Culicoides*. Similarly, no information exists on how the presence of vegetation may influence adulticidal measures. Wind tunnel tests, using wild-caught midges, have been used for comparative evaluation of specific insecticides (Kline et al. 1981, Floore 1985), but very few field experiments have been reported. Giglioli et al. (1980) applied ultra-low volume (ULV) fenitrothion (Sumithion) aerially at 2.7 oz/acre against *C. furens* and obtained better than 99% control. Haile et al. (1984) achieved similar results against *C. hollensis* with 2 consecutive (1 day apart) aerial applications of naled (Dibrom 14) at 1 oz/acre. Most control agencies do not use aerial equipment, however, and instead rely on ground applications at considerably lower dosages, aimed primarily at mosquitoes, but with some expected effect against *Culicoides*. Limited tests of naled applied as thermal fog (Linley et al. 1987) and as ULV spray (Linley et al. 1988) had been completed, but there was no comprehensive information on the effectiveness of ground adulticiding methods against *Culicoides* under field conditions simulating those in most normal operations. The primary aim of our tests was to provide comparative evaluations of 3 insecticides (malathion, Scourge®, naled) applied against adult *Culicoides furens*. The compounds were applied as ULV and thermal fog, in both open and vegetated terrain. The open condition was included as representative of the best result that could be expected, where no vegetation impeded movement of insecticide. Vegetated terrain, with a fairly dense growth of small trees, was selected to reflect quite adverse conditions that might be encountered during some control operations. Parallel tests with *Culex quinquefasciatus* Say served to provide a measure of the control achieved against a mosquito as compared to *Culicoides*, and to provide separate data for this mosquito.

MATERIALS AND METHODS

Adult female *C. furens* used in the tests were collected by aspiration at a number of sites within a few kilometers of the laboratory. Multiple sites had to be used because it proved impossible throughout the 2 year study to find a single site that would consistently yield enough midges for the tests. Once collected, midges were returned to the laboratory and kept with access to 10% sucrose in 473 ml (1-pint) ice cream

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cartons placed in a humidified box. *Culex quinquefasciatus* females were from a laboratory colony originated from collections in the area of Disney World (Orlando, FL). The resistance profile of this colony, when tested against a susceptible strain at the John A. Mulrennan Sr. Research Laboratory, showed some resistance to malathion (resistance ratio of 19.6), but little or none to Scourge (ratio 0.6) or naled (ratio 1.8). Similar tests with the midges were not possible owing to practical difficulties; however, they were more susceptible than the *Culex*, based on our results.

Insects were exposed to insecticide in cages obtained from the World Health Organization and appropriately modified. Each consisted of a cylindrical exposure chamber ca. 12 cm (4.7 inch) long, 4.5 cm (1.8 inch) wide, made almost entirely of stainless steel mesh, separated by a sliding aperture from a postexposure chamber of clear plastic, in which only the top of the end lid had been cut out and covered with mesh. This opening was covered with masking tape during exposure to insecticide, but once tape was removed, it allowed insects to be blown easily from the exposure to postexposure chambers. The mesh (Tetco Inc., Elmsford, NY) was 15.7 mesh/cm (40/inch) for midges and 6.2 mesh/cm (15.7/inch) for mosquitoes.

Prior to test, midges and mosquitoes were loaded into the exposure chambers after carbon dioxide anesthesia. *Culex quinquefasciatus* females were kept torpid on a cold plate and counted into the chambers (15/cage), but this procedure could not be used for *Culicoides* as they became trapped in condensation and were too small and easily damaged to be handled with tweezers. Instead, midges were repeatedly anesthetized in the cartons and loaded, 10–20/cage, by gentle aspiration.

Dosages at which insecticide should be applied were discussed with control district personnel before work began. The consensus was that evaluations should be based on extending control effect beyond the commonly accepted baseline of 91.4 m (300 ft) from the point of insecticide release, to 152.4 m (500 ft), as more appropriate to the larger residential blocks being treated in normal control operations. Preliminary tests in open terrain with ULV malathion against *C. furens* at 2× and 3× label dosages showed that 2× was an acceptable level for the tests envisaged, the primary objective of which was to provide comparative information on application method and the presence or absence of vegetation. Accordingly, the oz/acre dosages of the 3 insecticides were: malathion—1.42, Scourge—0.22, naled—0.39. The ULV applications were done with a Curtis Cyclotronic Dynafog ULV machine yielding droplets in the range 12–17 μm and thermal fog (droplets 1–2 μm) with a Leco HD 120.

The open site was initially an unplanted orange grove. It was planted with small citrus trees 46–76 cm (1.5–2.5 ft) tall, about 3.6 m (12 ft) apart half-way through the study, but this did not affect the open character of the site. The vegetated site was a mature grove with trees 2.4–3.6 m (8–12 ft) high, forming a fairly dense and uniform array of vegetation. Two visits to a test site were required to complete a series of experiments for each insecticide and each application method. At each visit, 3 runs of the vehicle applying insecticide were made. During each of these, a single cage was suspended at 122 cm (4 ft) elevation on each of 12 poles arranged in 2 lines 15.2 m (50 ft) apart, with the first pole of each line at 15.2 m from the line of insecticide release and more distant poles at 45.7, 76.2, 106.7, 137.2 and 167.6 m (150, 250, 350, 450 and 550 ft). Thus, 12 replicate determinations at each pole position were done in each complete experimental series. At the vegetated site, poles were placed close to the planted trees. A single control cage was suspended some distance upwind, where it would not be exposed to insecticide. Tests were run only at wind speeds from 4.8 to 14.5 kph (3–9 mph), in the early morning or late afternoon and early evening, when conditions were similar to those prevailing during normal control operations. Cages were collected after exposure as soon as it was judged that the insecticide had completely cleared the lines, then were quickly returned to the support vehicle, where insects were blown into the postexposure chambers and the cages placed in humidified boxes for return to the laboratory. Collection of cages was done as soon as possible to prevent false, high levels of mortality caused by insects crawling over contaminated mesh. Mortality in each cage was determined 12 h after exposure and adjusted, where appropriate, by Abbott's formula.

Complete data for each test were plotted and evaluated by regression analysis of the untransformed percentage data. Arcsine transformation was not used because: 1) it is of some value only when the percentages are above 90 or below 10 (Sokal and Rohlf 1981), 2) it was considered a confusing element for the primary audience of this paper, and 3) the differences it made to quantitative estimates were negligible. For *Cx. quinquefasciatus* treated with thermal fog malathion in vegetation, for example, where mortality was below 10% in many cages, predicted kill levels at 30.5, 91.4 and 152.4 m (100, 300, 500 ft) were 11, 4 and 1% with untransformed data, 7, 2 and 0.2% with data transformed. The regression analyses for all ULV experiments showed that the linear model provided an appropriate description, but for several of the thermal fog applications, negative logarithmic regression provided a more accurate fit, which was preferentially used in such cases.

RESULTS AND DISCUSSION

The full data for each insecticide, grouped by terrain type and application method, are shown (for *C. furens*) in Figs. 1–4 (M = malathion, S = Scourge, N = naled). The full *Cx. quinquefasciatus* data are not shown. Mortalities at 30.5, 91.4 and 152.4 m (100, 300, 500 ft), calculated from the regression equations, are summarized for easy comparison in histograms, above which the calculated values also are shown (Figs. 5–8).

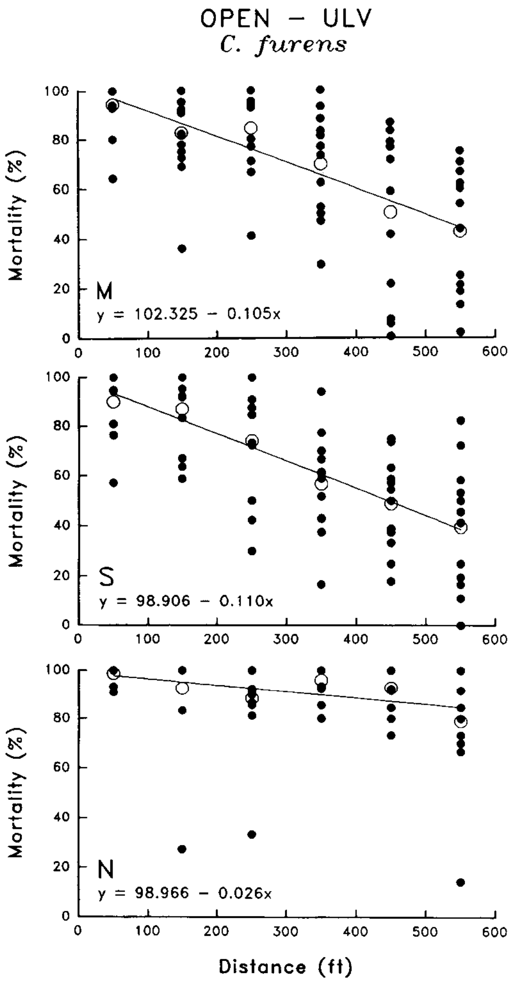

Fig. 1. Results for *Culicoides furens*, open terrain, ULV. Open circles denote mean mortalities.

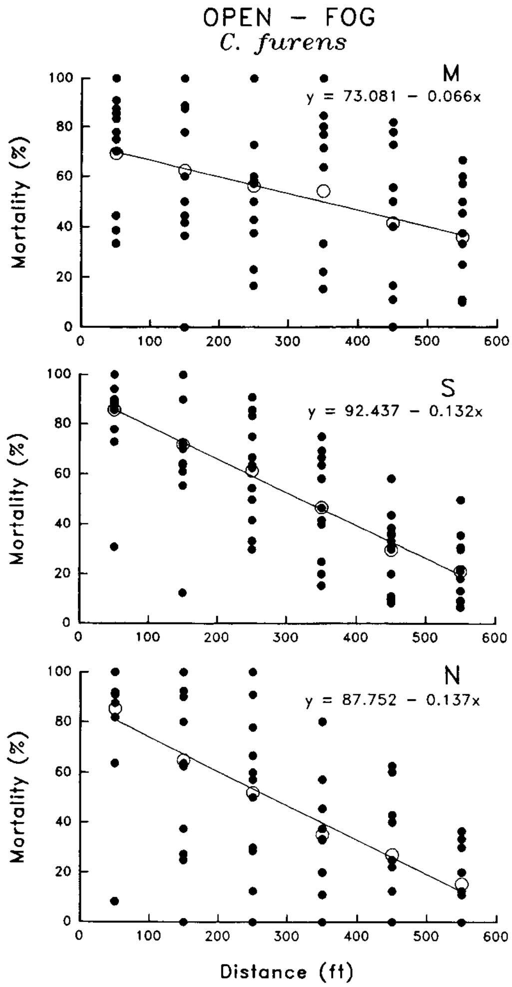

Fig. 2. Results for *Culicoides furens*, open terrain, thermal fog. Open circles denote mean mortalities.

The distances at which 40, 75 and 90% mortality could be expected in each case are given in Table 1.

General comments: In all the tests there was great variation in the mortality observed at any particular distance from the release point (Figs. 1–4), with neither application method obviously more consistent. Less variation was expected in open as opposed to vegetated terrain, but this proved not to be the case. Differences between replicates could have been connected with differences in the distributions of insects within the exposure chambers. There were some places (e.g., close to the sliding aperture) where the solid plastic rim might have provided some shelter from insecticide. This factor was considered unlikely to have accounted for all the variation, however. Pronounced unevenness, augmented by effects of local air currents, apparently exists

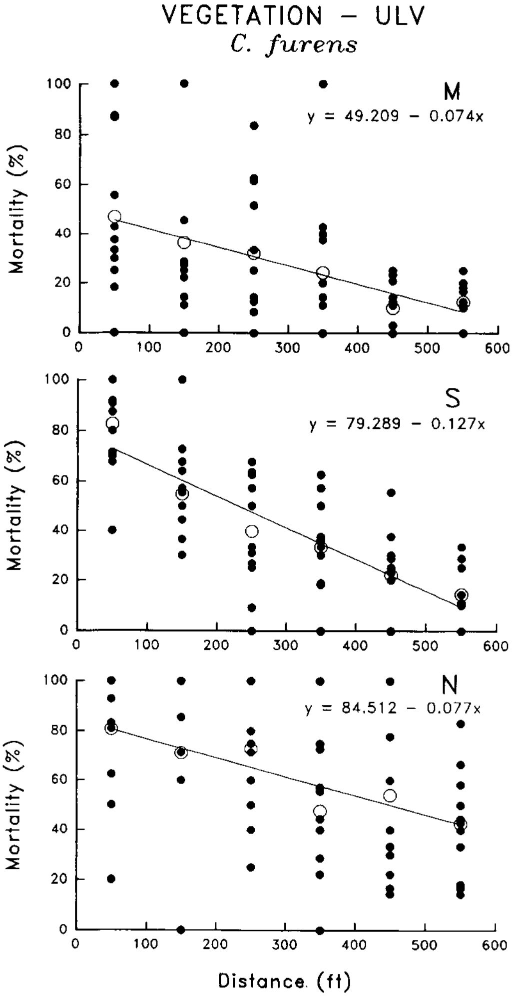

Fig. 3. Results for *Culicoides furens*, vegetated terrain, ULV. Open circles denote mean mortalities.

within the stream of insecticide, even at very short distances from the release point. Many instances were observed where the mortality at 15.2 m (50 ft) varied between less than 40% and 100% (Figs. 2–4), and there were some in which 0% occurred in one replicate, 100% in another (Figs. 3, 4).

Open terrain: Malathion and Scourge applied as ULV in the open performed about equally well with *C. furens* (Fig. 1) and also with *Cx. quinquefasciatus*, with predicted mortalities that were quite similar for the 2 species (Figs. 5, 6). Kill was slightly higher for the *Culicoides* with malathion (the *Culex* were somewhat resistant), somewhat better with Scourge for *Culex* (Figs. 5, 6). However, neither of these materials achieved particularly good levels of control. Ninety percent mortality of *Culicoides* extended only to 35.7 m (117 ft) for malathion and 24.7 m (81 ft) for Scourge (Table 1), with comparable figures for *Culex* of 11.3 m (37 ft) and 46.0 m (151 ft). In contrast, naled as ULV was strikingly more effective against *Culicoides* than the other 2 compounds (Fig. 1), but only about equal to them when used against *Culex*. The relative success of naled against midges is emphasized by the predicted mortalities at 3 distances (Fig. 5), where, even at 152.4 m (500 ft), 86% of the *C. furens* died. In these experiments, 90% mortality was sustained out to 105.8 m (347 ft) and, with the regression coefficient indicating only 2.6% diminution in kill per 30.5 m (100 ft), 75% kill sustained out to 282.9 m (928 ft).

Thermal fog applications in the open were less effective (Fig. 2) than ULV, especially

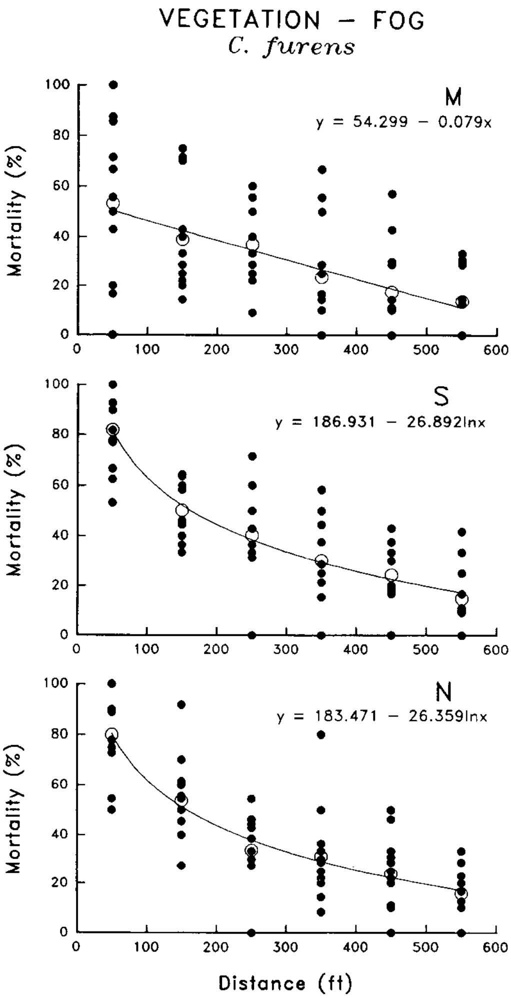

Fig. 4. Results for *Culicoides furens*, vegetated terrain, thermal fog. Open circles denote mean mortalities.

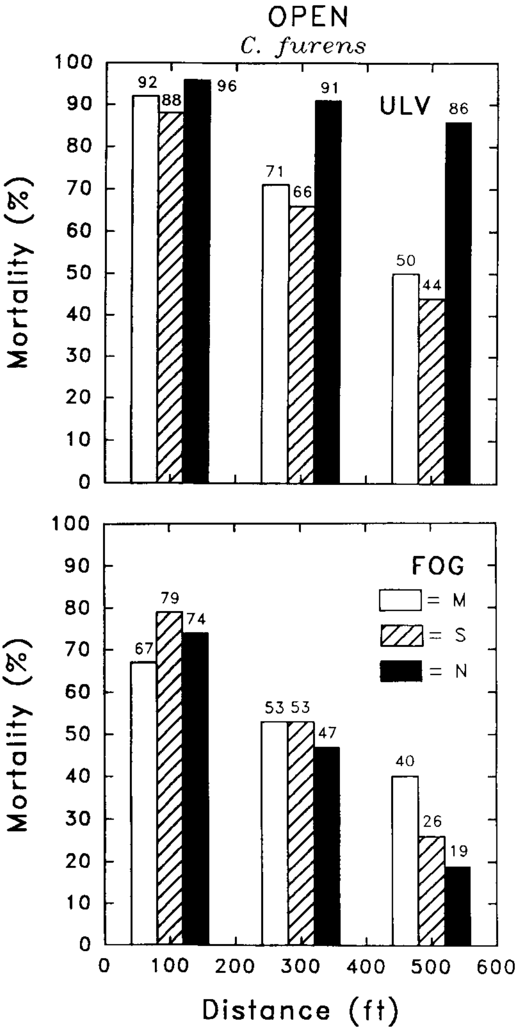

Fig. 5. Predicted mortalities at 30.5, 91.4 and 152.4 m (100, 300, 500 ft) for *Culicoides furens*, open terrain.

against *Cx. quinquefasciatus*, as is particularly obvious from the calculated mortalities at 3 distances (Fig. 6). Against *Culicoides*, naled did not maintain its superiority over malathion and Scourge; all 3 performed quite similarly (Figs. 2, 5), giving generally poor levels of control (Table 1). Malathion as thermal fog against *Cx. quinquefasciatus* proved almost totally ineffective (Fig. 6), partially because of resistance, but the other 2 compounds fared only slightly better. In general, control with thermal fog was better compared with ULV against *Culicoides* than against the *Culex*, where ULV was substantially superior (Fig. 6). Overall, however, ULV was clearly the most effective application method, especially so in the case of naled against *Culicoides*.

Vegetated terrain: With vegetation present, the relative performance of the 3 compounds as ULV against *C. furens* was similar to the pattern observed in the open, except that the level of control with malathion was somewhat depressed compared with Scourge (Figs. 3, 7). Naled again was clearly superior (Fig. 7, Table 1) and maintained better levels of control at all distances from the release point (Fig. 7). However, control was rather poor for all 3 insecticides; none achieved 90% mortality even at 30.5 m (100 ft), and even naled maintained 75% control or better (Table 1) only out to 37.8 m (124 ft). As with the *Culicoides*, ULV applications of malathion against *Cx. quinquefasciatus* performed poorly

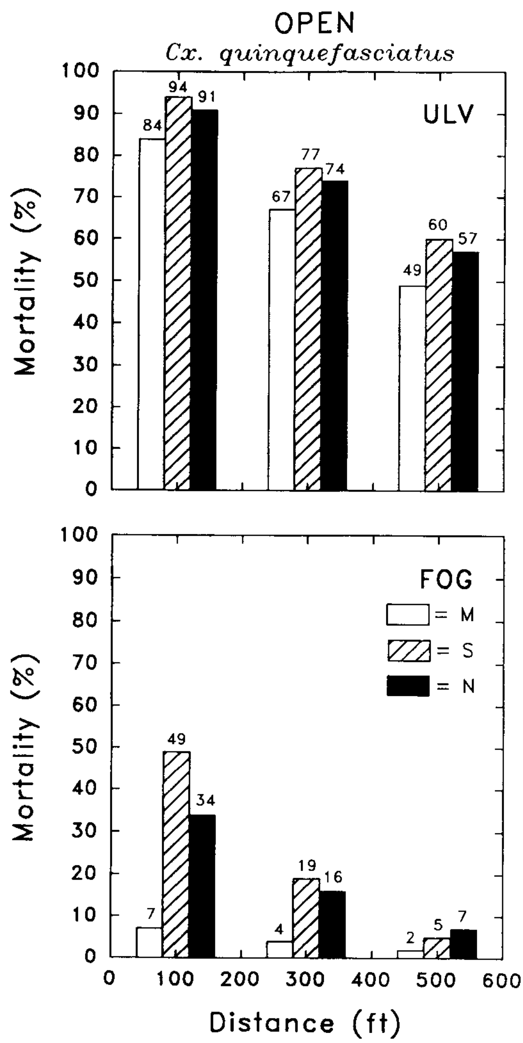

Fig. 6. Predicted mortalities at 30.5, 91.4 and 152.4 m (100, 300, 500 ft) for *Culex quinquefasciatus*, open terrain.

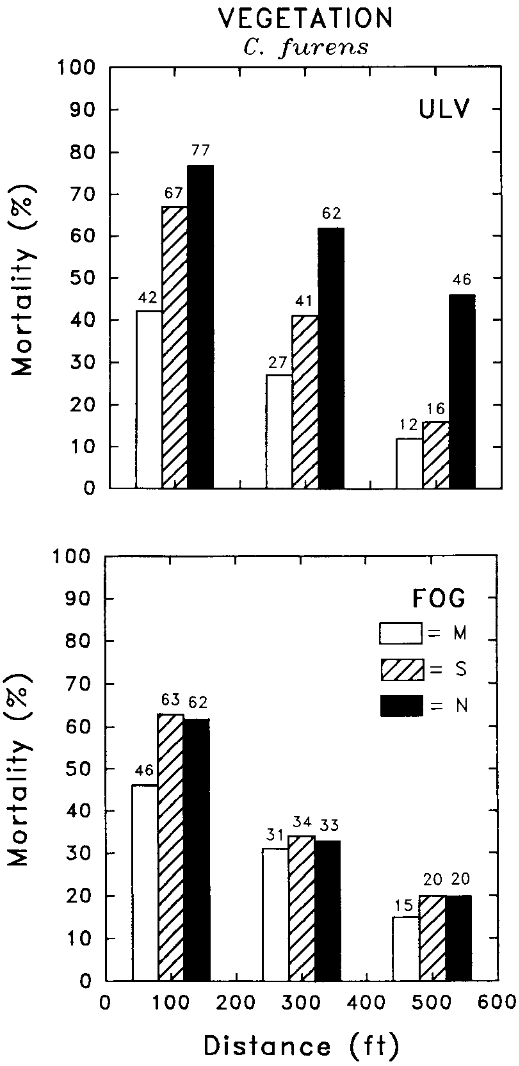

Fig. 7. Predicted mortalities at 30.5, 91.4 and 152.4 m (100, 300, 500 ft) for *Culicoides furens*, vegetated terrain.

relative to the other 2 chemicals in vegetated as compared with open ground (Fig. 8). Scourge, which had given slightly better control than naled as ULV in the open (Fig. 6), showed an increase in this tendency when trees were present (Fig. 8). Overall control of *Cx. quinquefasciatus* by ULV in vegetated terrain was, however, poor with all 3 insecticides, none of which (Table 1) achieved 90% predicted control even at 30.5 m (100 ft), and only rarely did so in individual replicates at 15.2 m (50 ft).

As in the open, all 3 chemicals applied as thermal fog in the presence of vegetation achieved comparable mortalities of *C. furens* (Figs. 4, 7). Predicted mortalities at 30.5 m (100 ft) ranged from only 46 to 62%, however, and at 152.4 m (500 ft) were degraded to 15–20% (Fig. 7). While these results were poor, those with *Cx. quinquefasciatus* were considerably worse. In vegetated terrain, thermal fog applications of all 3 insecticides achieved only minimal kill of the mosquitoes (Fig. 8, Table 1), with predicted mortalities ranging from only 11 to 15% at 30.5 m (100 ft), and with virtually no effect at distances of 91.4 m (300 ft) or greater (Fig. 8). A few replicates exceeded 40% control at 15.2 m (50 ft), but at 45.7 m (150 ft) or beyond, none reached 30%.

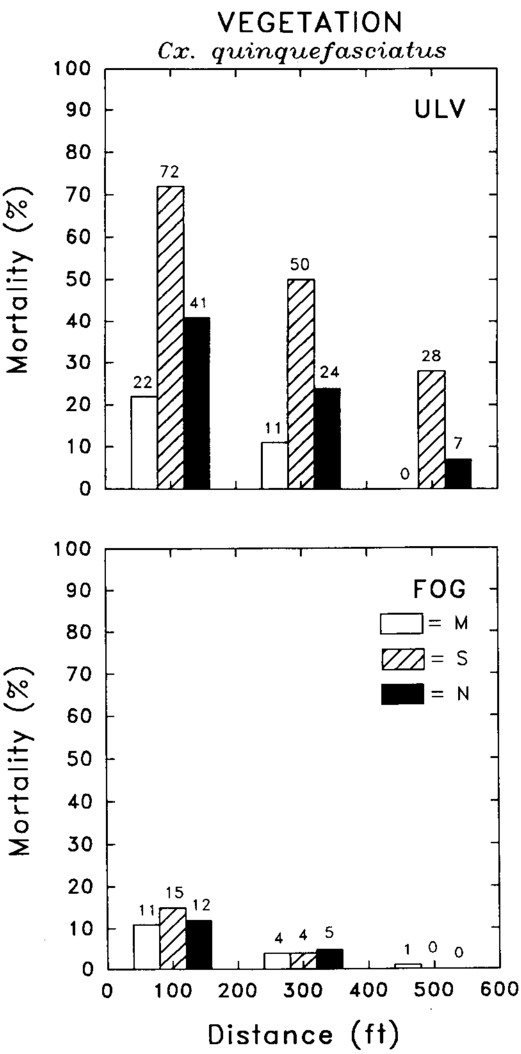

Fig. 8. Predicted mortalities at 30.5, 91.4 and 152.4 m (100, 300, 500 ft) for *Culex quinquefasciatus*, vegetated terrain.

Table 1. Calculated distances (m/(ft)) for mortalities of 40%, 75% and 90% in *Culicoides furens* and *Culex quinquefasciatus* adults exposed to ULV and thermal fog malathion (M), Scourge (S) and naled (N) at 2× label dosage in open and vegetated terrain.

Application method	Mortality (%)	*C. furens* M	*C. furens* S	*C. furens* N	*Cx. quinquefasciatus* M	*Cx. quinquefasciatus* S	*Cx. quinquefasciatus* N
			Open				
ULV	40	180	164	696	183	225	210
		(591)	(537)	(2284)	(601)	(738)	(688)
	75	79	66	283	63	100	88
		(259)	(218)	(928)	(206)	(327)	(288)
	90	36	25	106	11	46	35
		(117)	(81)	(347)	(37)	(151)	(116)
Fog	40	152	121	106	0	42	22
		(499)	(396)	(348)	(0)	(139)	(71)
	75	0	40	28	0	12	3
		(0)	(132)	(93)	(0)	(39)	(9)
	90	0	5	0	0	7	1
		(0)	(18)	(0)	(0)	(22)	(4)
			Vegetation				
ULV	40	38	94	177	0	119	35
		(124)	(309)	(581)	(0)	(389)	(114)
	75	0	10	38	0	23	0
		(0)	(34)	(124)	(0)	(74)	(0)
	90	0	0	0	0	0	0
		(0)	(0)	(0)	(0)	(0)	(0)
Fog	40	55	72	70	0	3	1
		(181)	(236)	(231)	(1)	(9)	(4)
	75	0	20	19	0	0	0
		(0)	(64)	(61)	(0)	(0)	(0)
	90	0	11	11	0	0	0
		(0)	(37)	(35)	(0)	(0)	(0)

Open versus vegetated terrain: In normal control operations it will be quite rare for the treated area to be completely open and devoid of vegetation. Some trees will almost always be present, together with shrubs and other low plants, particularly in residential areas, and the density of vegetation will vary considerably. In addition to the effects of vegetation, adulticidal treatments will be influenced also by any buildings present. We did not attempt to run the tests in an area with buildings because of the impossibility of repeated treatments in such areas, and because such sites are highly individual, with considerable complexities introduced by the local effects of buildings on insecticide movement, flow and distribution. Within these limitations, we considered it most useful to obtain measures of control in a uniform and quite densely vegetated site, in this case a mature orange grove, that would give an indication of the greatest extent to which vegetation might reduce effect.

As anticipated, the results were consistent in showing diminished mortality in the presence of vegetation for any particular treatment (compare Figs. 5 and 7 for *C. furens*, Figs. 6 and 8 for *Cx. quinquefasciatus*). The extent of reduction can be appreciated from the differences in predicted kill at 30.5 and 91.4 m (100 and 300 ft) in the open as opposed to in vegetation. For *C. furens* (malathion, Scourge, naled applied as ULV), these differences were 50, 21, 19 and 44, 25 and 29%, respectively, and for *Cx. quinquefasciatus* (same treatment) were 62, 22, 50 and 56, 27 and 50%, respectively. These reductions were in the presence of relatively dense vegetation, and some improvement might be expected in most areas since the vegetative cover would be less complete.

As regards the effects of vegetation relative to the 2 methods of application, there was some evidence that thermal fog was less impaired than ULV. With *C. furens*, for example, the predicted kill for thermal fog at 3 distances seems less diminished (compare Figs. 5, 7) than in the case of ULV. The figures bear this out, as open minus vegetation differences at 30.5 and 94.4 m (100 and 300 ft) were 21, 16, 12% and 22, 19, 14%, compared with 50, 21, 19% and 44, 25, 29%, as already cited above. The smaller fog particles remain suspended to a greater degree, as fog flows through foliage, while ULV droplets may tend to impinge more on intervening vegetation. Despite this difference, however, ULV still achieved better results in vegetated terrain, and would remain the method of choice.

CONCLUSIONS

For the many mosquito control agencies that presently use naled in their operations, this study presents an important finding concerning the control of *Culicoides furens*. Of the chemicals tested, naled was by far the most effective against midges, especially in the open (Figs. 1, 5). At 2× label dosage it achieved 90% control out to 105.8 m (347 ft) from the point of release and 75% out to 282.9 m (928 ft). Its performance was diminished in the presence of quite dense vegetation, but it was still the most effective adulticide. Control operations against mosquitoes with naled must certainly have a major simultaneous impact against *Culicoides*. Haile et al. (1984) had previously demonstrated excellent control of *C. hollensis* with aerially applied naled, but at 1 oz/acre, approximately 2.6× the dosage used here. Our study indicates that, if reasonably effective control of midges out to 152.4 m (500 ft) is the desired effect, then the test dosage (2× label, ground application) will suffice, since it achieves 86% mortality at 152.4 m in the open (Fig. 5) and 46% even with heavy vegetation present (Fig. 7). The latter figure does not represent good control, but actual residential and other areas are likely to be less densely vegetated, often considerably so, than the mature grove. Thermal fog applications are not to be recommended as they produced inferior results both in the open and in the grove (Figs. 5, 7), and naled as fog was only about equal in performance to the other 2 compounds.

With *Cx. quinquefasciatus*, ULV again achieved the greatest mortality under both terrain conditions (Figs. 6, 8), but the effect was not as good as against *Culicoides*, and naled was not markedly better than malathion or Scourge. At the experimental dosage, control was rather poor in the open (49–57% at 152.4 m (500 ft)), very poor in the grove (0–28% at this distance). Thermal fog applications, especially of malathion, were ineffective, although this was no doubt caused in some measure by moderate resistance in the strain used.

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REFERENCES CITED

Floore, T. G. 1985. Laboratory wind tunnel tests of nine insecticides against *Culicoides* species (Diptera: Ceratopogonidae). Florida Entomol. 68:678–682.

Giglioli, M. E. C., E. J. Gerberg and R. G. Todd. 1980. Large scale field tests and environmental assessments of Sumithion (fenitrothion) against adult biting midges in Grand Cayman, West Indies. Mosq. News 40:1-5.

Haile, D. G., D. L. Kline, J. F. Reinert and T. L. Biery. 1984. Effects of aerial applications of naled on *Culicoides* biting midges, mosquitoes and tabanids on Parris Island, South Carolina. Mosq. News 44:178–183.

Kline, D. L., D. G. Haile and K. F. Baldwin. 1981. Wind tunnel tests with seven insecticides against adult *Culicoides mississippiensis* Hoffman. Mosq. News 41:745–747.

Linley, J. R. 1976. Biting midges of mangrove swamps and salt-marshes (Diptera: Ceratopogonidae). pp. 335–376, *In*: L. Cheng (ed.), Marine insects. North-Holland Publishing Co. (American Elsevier Publishing Co.), New York.

Linley, J. R. and J. B. Davies. 1971. Sandflies and tourism in Florida and the Bahamas and Caribbean area. J. Econ. Entomol. 64:264–278.

Linley, J. R., R. E. Parsons and R. A. Winner. 1987. Evaluation of naled applied as a thermal fog against *Culicoides furens* (Diptera: Ceratopogonidae). J. Am. Mosq. Control Assoc. 3:387–391.

Linley, J. R., R. E. Parsons and R. A. Winner. 1988. Evaluation of ULV naled applied simultaneously against caged adult *Aedes taeniorhynchus* and *Culicoides furens*. J. Am. Mosq. Control Assoc. 4:326–332.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Co., New York.