Efficacy of Two Pyrethroid Insecticides Applied as Barrier Treatments for Managing Mosquito (Diptera: Culicidae) Populations in Suburban Residential Properties

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ABSTRACT Increased threat of mosquito-borne disease coupled with decreased tolerance of nuisance mosquitoes has opened a market for pest management professionals to offer mosquito control services for homeowners. A pest management professional applied bifenthrin (0.08%) and lambda-cyhalothrin (0.1%) at their maximum label concentrations as barrier treatments. We tested treatments residual efficacy in reducing adult mosquito populations and compared these chemicals against a water control at 24 residential properties (eight replications by three treatments). Mosquito populations were measured on each property by using five methods: CO_2-baited Centers for Disease Control (CDC) light traps (without a light), human landing rates, CDC gravid traps, ovitraps, and sweep nets. Populations were monitored weekly for 2 wk before treatment and 8 wk posttreatment. Additionally, to confirm residual efficacy of each insecticide, a randomly treated leaf underwent a no-choice bioassay with laboratory-reared *Aedes albopictus* (Skuse). Trap collections were dominantly *Aedes albopictus* and *Culex pipiens* L. Both insecticidal treatments significantly reduced *Aedes* spp. lambda-Cyhalothrin- and bifenthrin-treated sites had 89.5 and 85.1% fewer *Ae. albopictus* bites than the untreated control, respectively. *Ae. albopictus* bioassay results showed significant residual efficacy for both insecticides up to 6 wk posttreatment. There were no significant differences between properties treated with the two insecticides. In contrast, *Culex* spp. were not reduced by either insecticidal treatment. Our study indicated that barrier sprays applied to low-lying vegetation do not properly target adult daytime resting sites for *Culex* mosquitoes but that they can reduce *Aedes* mosquitoes. Perhaps by treating upper tree canopies *Culex* spp. abundance may be reduced.

KEY WORDS *Aedes*, *Culex*, adulticide, lambda-cyhalothrin, bifenthrin

In North America, West Nile (family *Flaviviridae*, genus *Flavivirus*, WNV) virus is one of many mosquito-transmitted pathogens that concerns homeowners. This much-publicized *Flavivirus* caused >9,800 cases of disease in the United States in 2003 (CDC 2004). Birds, particularly corvids, serve as the reservoir for WNV; thus, most WNV isolations are from bird-feeding *Culex* mosquitoes (Hayes 1989, Hubalek and Halouzka 1999, Turell et al. 2001). In the eastern half of North America, the *Cx. pipiens* complex is responsible for the majority of WNV isolations from field-collected mosquitoes (CDC 2000), although *Aedes albopictus* (Skuse), *Ochlerotatus atropalpus* (Coquillett), *Ochlerotatus japonicus* (Theobald), and other species are efficient laboratory vectors of WNV (Turell et al. 2001).

Public awareness of WNV has generated a demand for residential mosquito control services. Some members of the pest control industry are offering a service based on application of a pyrethroid insecticide to landscape foliage where adults of some mosquito species may rest. This service is a barrier treatment adapted to the small spatial scale of a homeowner's backyard. Typically, these treatments create an insecticidal barrier between the mosquito population and the area within the community (Perich et al. 1993). Large-scale barrier treatments have been effective against numerous adult mosquitoes, including *Aedes taeniorhynchus* (Wiedemann), *Aedes sollicitans* (Walker) (Madden et al. 1947, Anderson et al. 1991), *Ochlerotatus stimulans* (Walker) (Helson and Surgeoner 1983), *Anopheles quadrimaculatus* Say (Ludvik 1950), *An. albimanus* (Taylor et al. 1975), and *Anopheles darlingi* Root (Hudson 1984). Commonly used insecticides include pyrethroids (e.g., bifenthrin and lambda-cyhalothrin) and organophosphates (e.g., deltamethrin), all bearing long residual efficacy on a variety of surfaces and labeled for residential mosquito control (Ansari et al. 1986, Singh et al. 1989, Yadav et al. 1996).

Although barrier treatments have been successful in the past, little is known about the efficacy of barrier treatments applied on a residential backyard scale for mosquito control. These marketed services claim to reduce mosquito populations, mosquito bites, and

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even disease risk within the small spatial scale of a suburban backyard (Meehan 2002). However, anecdotal evidence and artificial trials (small laboratory studies and field studies) are the backbone to these claims. Data from controlled experimentation are lacking. Consequently, we tested two commonly used commercial products for their ability to suppress mosquito populations in a controlled suburban backyard study.

Materials and Methods

In late May 2004, eight neighborhoods of similar age in Lexington, KY (084° 28′ W, 038° 04′ N), were selected for study based on verbal reports provided by local pest control professionals of elevated mosquito biting rates. To participate in this experiment, we solicited 25 homes within each neighborhood. Solicitation was via preprinted door hangers distributed to those homes meeting the following criteria: single dwelling residencies, easily accessible backyard, vegetation height >0.35 m, no pets visibly present, and spaced at least four homes apart. Interviewed respondents had their property and vegetation inspected, measured, and mapped. Vegetation at each property included flowering plants [i.e., daffodils (*Narcissus* L.) and daisies (*Gerbera* spp.), ≈0.25–1 m in height], hedges and bushes [i.e., juniper (*Juniperus* L.) and honeysuckle (*Lonicera* L.), ≈0.5–1.5 m in height], ornamental trees [i.e., Japanese maple (*Acer palmatum* Thunb) and holly (*Ilex* spp.), ≈1.5–5 m in height], and large established trees [i.e., oaks (*Quercus* spp.) and poplars (*Poplus* spp.), 5 to >20 m in height]. Based on these visits, three homes from each neighborhood were selected for a total of 24 residences enrolled in our study.

Each property (testing site) in each neighborhood was randomly assigned one of three treatments: a water control, bifenthrin (TalstarOne, 79.01 ml active ingredient [AI]/liter, FMC, Philadelphia, PA.), or lambda-cyhalothrin (Demand CS, 62.52 ml [AI]/liter, Syngenta Crop Protection, Greensboro, NC.). On 16–18 June 2004, a certified commercial pesticide applicator applied all three treatments (All-Right Pest Control Inc., Lexington, KY). Applications occurred when the weather was forecasted to be clear, dry, and with little or no wind. Using a backpack mist blower (model SR-420, Stihl Corp., Virginia Beach, VA), mist was directed to all vegetative surfaces between ≈0.3 and 3 m in height. For thick foliage, such as hedges, we inserted the mist blower tip into the foliage shortly to ensure that the interior of the canopy was well treated. Other (i.e., nonvegetative) resting sites (as described by Schreiber et al. 1993), such as the undersides of raised decks, also received treatment. Residential structures themselves were not directly treated. In addition, this application method did not target upper tree canopies; rather, only low-lying vegetation was thoroughly treated. The pest management professional treated surfaces to just before runoff in accordance with the label. Spray volumes and time spent at each testing site, along with prevailing weather conditions at the time of application, were recorded for each application. The volume of finished spray applied at each testing site ranged from 5 to 52 liters, depending on the amount of foliage and testing site size (site size ranged from 192 to 4,403 m^2).

Mosquito Monitoring. We monitored mosquito populations once a week from 2 wk before to 8 wk after treatment (10 wk total). Because of practical limitations (e.g., time constraints and home accessibility), mosquito populations in two neighborhoods (six properties) were monitored per night totaling four nights of sampling per week. Populations were monitored using five sampling methods: 1) Centers for Disease Control (CDC) miniature light traps (model 512, John W. Hock, Gainesville, FL), 2) human landing rates, 3) sweep samples, 4) CDC gravid traps (model 1712, John W. Hock), and 5) ovitraps fabricated from empty coffee cans. During each sampling interval, trap contents were transferred to the laboratory, frozen, identified (Darsie and Ward 1981), and counted.

CDC traps were operated without lights, baited with ≈2.3 kg of pelleted dry ice, and placed 5 m from the back property line at a height of 1.5 m. Small 1.89-liter blue coolers (Contour 0.5 Gallon, Igloo Products Corp., Houston, TX) held the dry ice, allowing CO_2 to escape via three holes: one hole drilled in the side, one hole drilled at the bottom, and the opened cooler spout at the top. A 0.6-m length of clear Tygon tubing (1.27 o.d. by 0.97 cm i.d. vinyl tubing) connected the bottom of the cooler to the top of the trap, thereby directing CO_2 directly to the top of the trap. CDC traps were operated overnight between 1800 and 1000 hours.

Human landing rates were conducted weekly at each property when the senior author (R.T.T.) exposed 510-cm^2 skin surface (thigh and shin) while standing for 10 min near a high-traffic area (e.g., patio, deck, or walkway) between 1800 and 2100 hours when homeowners indicated they were more likely to be outdoors. Thus, this sampling method was bias toward crepuscular mosquitoes. Positioned opposite of one another, R.T.T. and collector also aligned themselves perpendicular to the wind current. R.T.T. wore blue jeans with four holes on each leg (63.75 cm^2 per hole), two above holes and two holes below the knee. The collector wore a light-colored long-sleeved shirt and light-colored khakis. Dress and bathing products were standardized throughout the experiment. The collector field-identified actively biting mosquitoes if the specimens landed within the designated area (the hole), and destroyed them to avoid recounting error.

A 38-cm-diameter aerial sweep net (model 7615S, BioQuip Co., Gardena, CA) collected resting mosquitoes. Sweep collections occurred between 1800 and 2100 hours, just before landing rate counts. This timing allowed us to disturb resting mosquitoes and attempt to collect those mosquitoes not likely questing while traps were set up (i.e., diurnal mosquitoes). Swept vegetation included flowering plants, bushes, hedges, and the lower canopies of ornamental and established trees. The vegetation around each testing site was

swept 25 times and collected specimens frozen until identified.

To collect ovipositing mosquitoes, we placed gravid traps on the inner side of the homeowner's perimeter vegetation at ground level and baited them with 4 liters of infused water. The infused water consisted of a 2-wk-old mixture of 0.5 liters of fescue grass (*Festuca* L.), ≈100 g of rabbit food (Big Red Rabbit Food, Pro-pet LLC, St. Mary's, OH), and 19 liters of distilled water. Gravid traps operated overnight between 1800 and 1000 hours weekly at each testing site for 1 wk pretreatment and 8 wk posttreatment.

Ovitraps were metal coffee cans (4 liters) painted flat black on the exterior. Egg paper (76-lb. seed germination paper, Anchor Paper Co., Minneapolis, MN) lined each ovitrap and infused water prepared as described above baited each can. These traps were hung near or in treated vegetation, ≈1.5 m from the ground, to emulate tree holes. Collections of ovitrap contents occurred weekly, 2 wk pretreatment, and 7 wk posttreatment. The collected specimens (eggs and larvae) were reared in an environmental chamber (27 ± 1°C, 75% RH, and a photoperiod of 15:9 [L:D] h) to fourth instar and identified to species.

During each visit, R.T.T. recorded meteorological data in the evening at trap setup and the next morning during trap retrieval. A hand-held meteorological instrument (Kestrel 3000, Nielson-Kellerman, Boothwyn, PA) was used to measure temperature (°C), relative humidity (% RH), heat index (°C), wind speed (meters per minute), and wind direction. To determine operational conditions, meteorological data from the evening and morning were averaged.

Laboratory Bioassays. To evaluate activity of insecticide residues, we also conducted laboratory bioassays. From each testing site posttreatment (three treatments × 8 replications), one random deciduous leaf from the outer portions of vegetation ranging from 1 to 2 m in height was randomly collected. In general, the leaf was a broad leaf that was a minimum of 25 cm^2 and typically had little to no extra defense mechanisms such as trichomes or hairs. Excised leaves were placed individually into plastic bags, refrigerated, and brought to the laboratory. Each leaf was then placed in a 7-dram plastic vial (Acorn Naturalists, Tustin, CA.) containing ≈10 laboratory reared *Ae. albopictus* for a total of 24 bioassays per wk. Situated at the top inside of the vial, the leaf's placement allowed mosquitoes to land on the abaxial side as they would in nature. A growth chamber set at 27°C and 75% RH held the vials with mosquitoes for 24 h. Once time elapsed, bioassay assessment of mosquito mortality occurred by comparing number alive to number dead in each vial. We defined death as no movement through stimulation; intoxication by the insecticides was not considered death.

Statistical Analyses. All statistical analyses were preformed using the SAS (SAS Institute 2001). The mosquito counts were $\log(x + 1)$ transformed and analyzed by PROC MIXED with a repeated measures analysis of variance (ANOVA). Means separation was accomplished with Tukey's test. Using Mulla's formula (Mulla et al. 1971), we calculated trap percentage of population reductions as

$$percent\_reduction = 100 - \left(\frac{C_1}{T_1} \times \frac{T_2}{C_2}\right)100$$

where C_1 is the number of mosquitoes at the control site pretreatment, C_2 is the number of mosquitoes at the control site posttreatment, T_1 is the number of mosquitoes at the treatment site pretreatment, and T_2 is the number of mosquitoes at the treatment site posttreatment (Mulla et al. 1971). Because laboratory bioassays did not include a pretreatment analysis, percentage of reduction could not be calculated using Mulla's formula. Rather, bioassay data were adjusted to the controls by using the Henderson–Tilton correction (Henderson and Tilton 1955). The resulting corrected percentage of mortality was then analyzed by PROC MIXED with means separated using Tukey's test. Laboratory bioassay data were not transformed.

Results

The mean temperature during the entire study was 29.7 ± 0.4°C (18.7–36.9°C). The mean relative percentage of humidity was 69.5 ± 1.8% RH (39–100% RH). The overall mean wind speed among the three treatments was 0.4 ± 0.05 m/min. The overall mean heat index was 34.4 ± 4.1°C (17.7–36.9°C). In total, 35.9 cm of precipitation fell over the course of the experiment. This amount was 11.9 cm above normal for this period.

During treatment applications, environmental conditions at the eight test neighborhoods were not significantly different from one another, with a mean wind speed of 0.9 ± 0.1 m/min, temperature of 28.0 ± 0.5°C, and heat index of 32.0 ± 0.8°C. The mean relative humidity for sites treated with lambda-cyhalothrin was 72.7 ± 3.9% RH and with bifenthrin was 67.9 ± 3.5% RH. The control was 78.8 ± 4.8% RH. None of these means were significantly different.

Pretreatment Culicidae abundance with any of the sampling methods did not produce a significant treatment effect ($F = 0.33$; df = 2, 44; $P = 0.72$) or week effect ($F = 0.75$; df = 1, 44; $P = 0.39$). During the 10-wk sampling period, 12,862 mosquitoes were collected, consisting primarily of *Culex* spp. (53.7%) and *Aedes* spp. (40.3%), although several *Ochlerotatus* spp., *Psorophora* spp., and *Anopheles* spp. also were collected (Table 1). CDC traps collected 1,270 adult mosquitoes over the 10-wk study. Of these, 60.4% were *Aedes* spp., 30.2% were *Ochlerotatus* spp., and 6.1% were *Culex* mosquitoes. Human landing rates collected 635 mosquitoes, of which 97.5% were *Ae. albopictus.* Gravid traps collected 5,204 adult mosquitoes during the 9-wk sampling period, of which 96.3% were *Culex* spp. and 2.9% were *Aedes* spp. The ovitrap collected 5,646 immature mosquitoes. This was the only trap effective at collecting both *Aedes* spp. (63.3%) and *Culex* spp. (32.1%). Only 107 mosquitoes were collected with sweep samples in 10 wk. *Aedes* spp. was the dominant genus (69.2%); minimally represented were *Anopheles*

Table 1. Numbers of mosquitoes collected in suburban backyards (7 June–12 August 2004) at Lexington, KY residences

Species[a]	CDC trap	Human. landing rate	Gravid trap[b]	Ovitrap[c]	Sweep collections	Total
Ae. albopictus	375	619	136	3,431	24	4,585
Ae. vexans	369	0	13	134	39	555
Aedes sp. unknown	12	1	4	9	11	37
Anopheles spp.[d]	10	0	3	0	11	24
Cx. erraticus	4	0	1	14	0	19
Cx. pipiens	58	0	4,368	1,633	0	6,059
Cx. pipiens or *restuans*	10	0	567	36	0	613
Cx. restuans	5	0	56	103	0	164
Culex sp. unknown	0	0	22	24	0	46
Oc. triseriatus	25	6	7	29	1	68
Oc. trivittatus	358	9	2	129	8	506
Psorophora sp.[e]	18	0	0	0	0	18
Unknown/unidentifiable	14	0	24	104	13	155
Total	1,270	635	5,204	5646	107	12,862

[a] Species included in smaller numbers not included in the table are *Ae. aurfier* (11 CDC), *Oc. canadensis* (1 CDC), and *Oc. japonicus* (1 gravid).
[b] Gravid traps collected adult mosquitoes and operated for only 9 wk, beginning 14 June 2004.
[c] Ovitraps collected immature mosquitoes and operated for only 9 wk, ending 5 August 2004.
[d] *Anopheles* species collected include *An. punctipennis, An. quadrimaculatus,* and *An. walkeri.*
[e] *Psorophora* species collected include *Ps. columbiae, Ps. ferox, Ps. horrida,* and *Ps. mathesoni.*

spp. (10.3%) and *Ochlerotatus* spp. (8.4%). From the 10-wk samples within all traps, *Aedes* spp. predominantly came from ovitraps (68%), CDC traps (14%), and landing rates (12%). The specimens were primarily *Ae. albopictus* (88%) and *Ae. vexans* (11%). We collected 6,901 *Culex* mosquitoes, predominantly *Cx. pipiens* (88%), *Cx. restuans* (2%), or *Cx. pipiens/restuans* (8%). Specimens from this genus were collected frequently in gravid (73%) and ovitraps (26%). Because some specimens were difficult to identify the analyses were conducted as *Culex* spp. Mean posttreatment results differed with each trapping method; backtransformed significant means and their reductions are presented in Table 2.

The majority of the CDC trap collections were *Aedes* species (60%), specifically *Ae. albopictus* (29.5%). A significant treatment effect ($F = 4.65$; df = 2, 182; $P = 0.0107$) and week effect ($F = 2.06$; df = 7, 182; $P = 0.0497$) was observed for *Aedes* spp., but there was no significant treatment week interaction (Fig. 1A). Both lambda-cyhalothrin ($T = -2.50$, df = 182, $P = 0.0132$) and bifenthrin ($T = -2.76$, df = 182, $P = 0.0064$) significantly reduced *Aedes* spp. compared with the control, but means did not differ one another (Fig. 1A). Likewise *Ae.*

Table 2. Backtransformed mean ± SEM mosquitoes collected in suburban backyards after treatment in Lexington, KY

Trap	Wk	Control	Bifenthrin	Lambda-Cyhalothrin
CDC trap	1	10.88 ± 4.65	4.13 ± 1.47	4.63 ± 1.13
	2	7.88 ± 2.12	1.13 ± 0.35	1.50 ± 1.69
	4	5.00 ± 1.44	3.25 ± 0.65	5.13 ± 1.63
	6	7.88 ± 3.81	2.75 ± 0.53	3.63 ± 2.13
	8	4.00 ± 2.65	3.88 ± 1.87	2.63 ± 1.34
Posttreatment mean		6.94 ± 0.82a	2.91 ± 0.36b	3.47 ± 0.46b
Landing rate	1	3.50 ± 1.45	0.50 ± 0.27	0.50 ± 0.38
	2	4.63 ± 1.70	0.88 ± 0.61	1.38 ± 1.02
	4	5.00 ± 2.09	1.00 ± 0.87	0.75 ± 0.37
	6	8.00 ± 2.20	2.00 ± 1.05	3.25 ± 2.02
	8	2.71 ± 0.75	1.14 ± 0.34	1.43 ± 0.65
Posttreatment mean		5.06 ± 0.58a	1.53 ± 0.33b	1.42 ± 0.32b
Ovitrap	1	65.38 ± 56.75	0.00 ± 0.00	8.00 ± 6.25
	2	91.13 ± 39.92	11.38 ± 4.78	31.38 ± 15.90
	4	28.00 ± 22.53	5.00 ± 2.44	38.38 ± 15.35
	6	41.00 ± 18.12	21.88 ± 7.83	45.63 ± 18.94
	8	NS[a]	NS	NS
Posttreatment mean		49.04 ± 8.40a	12.23 ± 3.16b	29.14 ± 5.13c
Total	1	100.25 ± 57.15	16.13 ± 6.32	25.63 ± 8.87
	2	139.00 ± 51.22	57.63 ± 19.23	56.50 ± 16.46
	4	58.25 ± 11.92	28.38 ± 8.35	69.25 ± 16.77
	6	109.38 ± 31.95	67.75 ± 20.59	84.88 ± 22.36
	8	25.13 ± 4.10	22.00 ± 6.34	14.88 ± 3.60
Posttreatment mean		82.97 ± 29.33a	44.47 ± 15.72b	54.23 ± 19.17b

Means followed by the same letter in the same row are not significantly different based on total analysis of posttreatment data (Tukey's honestly significant difference; $\alpha = 0.05$).
[a] NS, not sampled.

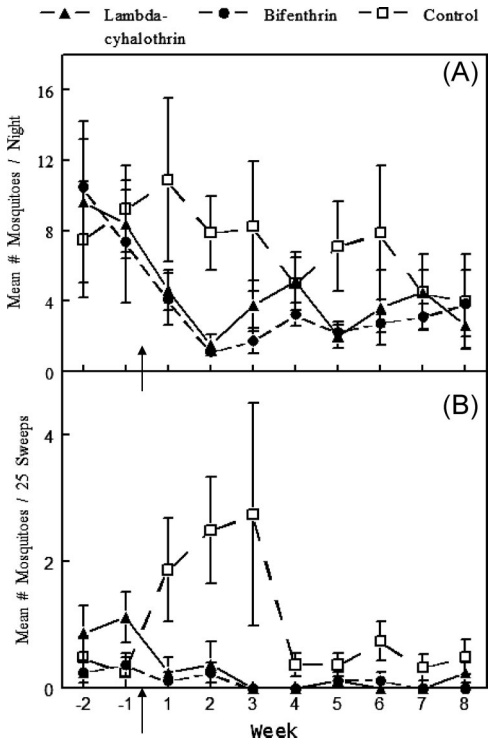

Fig. 1. Mean *Aedes* mosquitoes per night collected by two monitoring methods used to evaluate lambda-cyhalothrin and bifenthrin compared with a water control as mosquito control agents. *Aedes* collected in CDC traps (A) and sweep samples (B) had significant treatment effects. All treatments applied between weeks −1 and 1 (arrows).

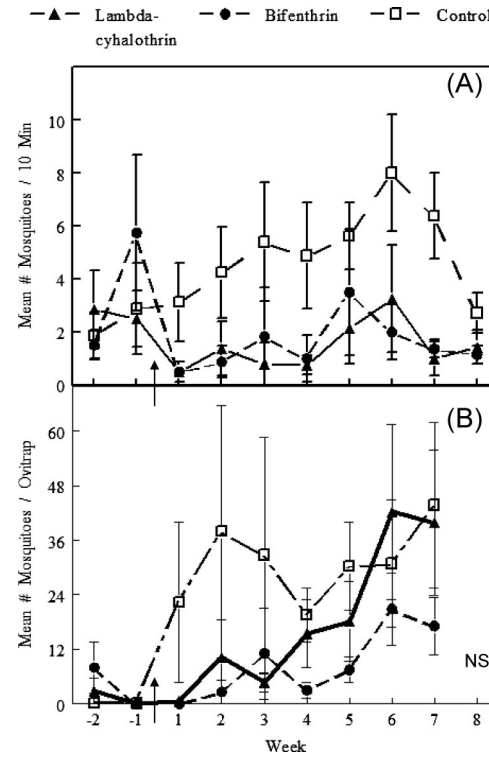

Fig. 2. Mean *Ae. albopictus* mosquitoes per night collected by two monitoring methods used to evaluate lambda-cyhalothrin and bifenthrin compared with a water control as mosquito control agents. *Ae. albopictus* in landing rates (A) and ovitraps (B) were significantly reduced compared with the water control. All treatments applied between weeks −1 and 1 (arrows).

albopictus demonstrated both a significant treatment ($F = 3.56$; df = 2, 182; $P = 0.0304$) and week ($F = 3.13$; df = 7, 182; $P = 0.0038$) effect. *Ae. albopictus* was significantly reduced compared with the controls for lambda-cyhalothrin ($T = -1.95$, df = 182, $P = 0.0531$) and bifenthrin ($T = -2.55$, df = 182, $P = 0.0115$). *Ae. albopictus* in CDC traps was reduced by 67.1% at lambda-cyhalothrin-treated sites and 73.4% at bifenthrin-treated sites 4 wk posttreatment compared with the untreated control. *Culex* mosquitoes were not significantly reduced by either chemical treatment ($P > 0.05$).

More than 97% of the bites occurring during the landing rates were *Ae. albopictus* (97%). Analysis of *Ae. albopictus* from landing rate collections show treatment ($F = 29.24$; df = 2, 171; $P < 0.0001$) and week effects ($F = 2.27$; df = 7, 171; $P = 0.03$), but not a treatment by week interaction effect. Sites treated with lambda-cyhalothrin ($T = -6.79$, df = 171, $P < 0.0001$) or bifenthrin ($T = -6.46$, df = 171, $P < 0.0001$) had significantly fewer biting *Ae. albopictus* mosquitoes than control sites, but these sites did not differ not from one another (Fig. 2A). *Ae. albopictus* bites were reduced by 89.5% at lambda-cyhalothrin-treated sites and by 85.1% at bifenthrin-treated sites 4 wk posttreatment compared with the untreated control sites. No *Culex* mosquitoes were collected with this method.

Gravid trap collections were dominantly *Culex* spp. (96%). Because it was difficult to decipher *Cx. pipiens* from *Cx. restuans*, the analyses were lumped. Analysis of *Culex* species within gravid traps did not depict a significant treatment effect ($F = 0.43$; df = 2, 182; $P = 0.6518$) (Fig. 3A).

The mosquitoes collected by sweep sampling were mostly *Aedes* spp. (69%), especially *Ae. vexans* (36%) and *Ae. albopictus* (22%). Sweep net samples showed a significant treatment effect for *Aedes* spp. ($F = 20.23$; df = 2, 177; $P < 0.0001$), and they were significantly reduced by both lambda-cyhalothrin ($T = -5.42$, df = 177, $P < 0.0001$) and bifenthrin ($T = -5.60$, df = 177, $P < 0.0001$) compared with the control, but not with one another (Fig. 1B). Percentage of reductions was not calculated using Mulla's formula, because no *Aedes* spp. were collected pretreatment at the control sites. However, mosquitoes (10 *Aedes* spp. at seven sites) were collected pretreatment at the treated sites before treatment. *Culex* spp. collected from sweep samples were not significantly controlled by either insecticide ($P > 0.05$).

Ovitraps collected *Aedes* mosquitoes on egg papers and *Culex* mosquitoes in gravid water. Collections consisted of *Ae. albopictus* (60%), *Culex* spp. (32%),

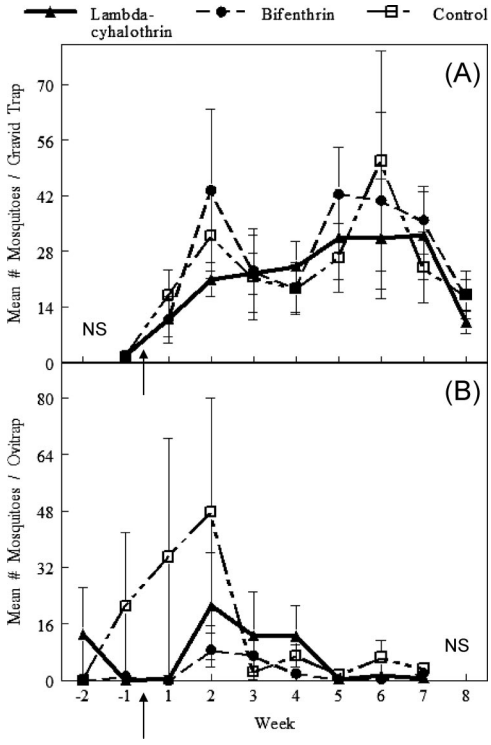

Fig. 3. Mosquitoes collected per week from gravid traps were *Culex* spp. (A) and *Cx. pipiens/restuans* from ovitraps (B). Only *Cx. pipiens/restuans* raised from ovitraps experienced significant treatment effects. All treatments applied between weeks −1 and 1 (arrows). NS, not sampled.

and *Ae. vexans* (2%). *Ae. albopictus* collected from ovitraps ($F = 8.86$; df = 2, 159; $P = 0.0002$) demonstrated significant treatment effects and week effects ($F = 9.12$; df = 6, 159; $P < 0.0001$), and both lambda-cyhalothrin ($T = -2.24$, df = 159, $P = 0.03$) and bifenthrin ($T = -4.21$, df = 159, $P < 0.0001$) testing sites significantly differed from control testing sites. Moreover, the two chemical treatments differed significantly from one another ($T = 1.97$, df = 159, $P = 0.0509$) (Fig. 2B). *Ae. albopictus* reared from collected egg paper were 100% fewer at lambda-cyhalothrin-treated sites and 99.7% at bifenthrin-treated sites than at control sites. Analysis of *Cx. pipiens/restuans* collected from ovitrap containers ($F = 3.62$; df = 2, 159; $P < 0.03$) demonstrated significant treatment effects (Fig. 3B). Both lambda-cyhalothrin ($T = -2.02$, df = 159, $P = 0.04$) and bifenthrin ($T = -2.55$, df = 159, $P = 0.01$) sites were significantly less in numbers compared with the control sites; neither chemical treatment differed significantly from one another. *Cx. pipiens/restuans* were not collected every week from ovitrap water at lambda-cyhalothrin-treated sites and bifenthrin-treated sites. Additionally, percentage of reductions were not calculated using Mulla's formula, because only two sites collected *Culex* spp. before treatment.

Laboratory Bioassays. Analyses of all bioassay data (all posttreatment) indicated significant treatment

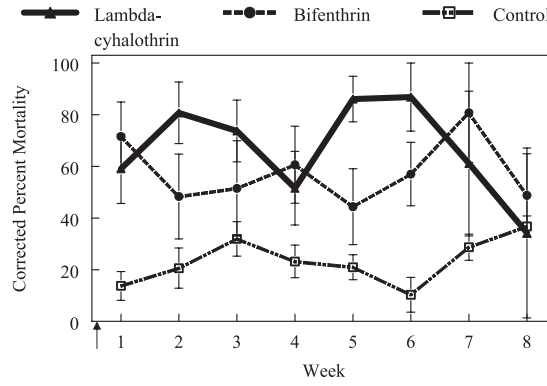

Fig. 4. Bioassay data analyses indicate that a significant treatment effect ($F = 7.36$; df = 2, 101; $P = 0.0010$) and a significant treatment × week interaction effect ($F = 3.06$; df = 14, 42; $P = 0.0026$) resulted. All treatments applied before week 1 (arrow).

($F = 7.36$; df = 2, 101; $P = 0.0010$) and treatment by week interaction effects ($F = 3.06$; df = 14, 42; $P = 0.0026$) of mortality by laboratory-reared *Ae. albopictus.* Mortality rates in mosquitoes exposed to both lambda-cyhalothrin- ($T = 3.57$, df = 101, $P = 0.0005$) and bifenthrin-treated leaves ($T = 2.67$, df = 101, $P = 0.0088$) differed significantly compared with the control leaves (Fig. 4).

Discussion

Bifenthrin and lambda-cyhalothrin significantly reduced peridomestic *Aedes* mosquito populations for one month, whereas *Culex* populations were not significantly reduced. Significant week effects occurred immediately after treatment (i.e., week 1 and 2 posttreatment) and among those weeks later in the study (i.e., week 7 and 8 posttreatment). Significant week effects occurred for all trapping methods except with CDC traps. Week effects suggest the treatments will begin to lose their efficacy 4–6 wk posttreatment for *Aedes* mosquitoes as suggested by the homeowner field study and the laboratory bioassays.

Our sampling methods biased the collections. Questing mosquitoes were typically *Aedes* spp., were collected with CDC traps and human landing rates, and they were suppressed with the residual treatments. The combination of CDC traps operating at ground level and landing rates operating during crepuscular hours may have been responsible for differences in genera collections, because *Aedes* mosquitoes are crepuscular and prefer ground level traps, whereas *Culex* mosquitoes are active at later hours (Becker et al. 1995, Kline and Mann 1998, Bowen 1991, Rueda et al. 2001). *Culex* spp. were collected primarily with gravid traps. Because mosquitoes collected in questing traps were significantly reduced and those collected in gravid traps were not, perhaps our biased trapping methods is the reason for our discrepancy in mosquito control; *Aedes* spp. controlled and *Culex* spp. not controlled. Our questing traps biased for *Aedes* collec-

tions; had we operated another CDC trap in the tree canopy and/or conducted landing rates at later hours, perhaps we would have effectively collected questing *Culex* mosquitoes.

We think *Aedes* spp. were reduced more than *Culex* spp. because of our biased collection methods, the species respective questing behaviors, or a combination. Both CDC traps and human landing rates collected questing *Aedes* mosquitoes. As mentioned, we targeted *Aedes* species by conducting landing rates during crepuscular hours; had we conducted the landing rates later, more *Culex* species would have been collected. Additionally, CDC traps targeted low-lying mosquitoes. *Culex* may prefer a different resting site or questing trap methodology. Our traps at ground level and our treatment application method deposited little insecticide above 3–4 m, perhaps too low to affect many *Culex* individuals. A height study conducted by Farajollahi et al. (2005) in New Jersey collected *Cx. pipiens* and *Cx. restuans* primarily in tree canopies 8–10 m in height. Additional reports indicate *Culex* spp. resting sites residing within tree canopies perhaps in proximity to roosting birds, because a majority are orniphilic (Burgess and Haufe 1960, Main et al. 1966, Novak et al. 1981, Lundstrom et al. 1996, Bellini et al. 1997, Anderson et al. 2004). Slightly contrasting reports show male *Culex* mosquitoes resting at lower heights (Schreiber et al. 1993), but these reports were conducted in Irvine, CA (a different environment) and primarily concerned *Cx. quinquefasciatus* (which was not observed in this study).

Another interest was significant mosquito control for both genera within ovitraps. These collections consisted of immature specimens and perhaps this life stage explains for the difference in control; adult *Culex* spp. were not reduced, whereas larval collections were significantly reduced. This may have resulted from one adult female laying multiple rafts with several eggs. A single female can contribute a large number of future offspring to the ovitrap population, whereas other traps collected the single adult as one specimen.

Another explanation for immature *Culex* control and lack of adult control may be a change in female behavior. Perhaps a gravid female may search for oviposition sites, becoming more erratic with less frequent resting sites. Consequently, our results may suggest behavioral differences among questing and gravid mosquitoes. Female mosquitoes travel long distances for bloodmeals and oviposition sites (Bowen 1991). In our study, perhaps questing mosquitoes landed on treated vegetation (indicating control), whereas gravid mosquitoes may have bypassed vegetation or rested immediately in the grass (which was not treated). This searching behavior may have produced the lack of control within gravid mosquitoes. Previous research may contribute to this hypothesis. Davis (1984) noticed that newly emerged females fly less, not seeking blood hosts. Gillet (1979) concluded that some behavioral differences within mosquito life stages may exist and females seeking bloodmeals may fly making periodic dips to detect wind sheer. Perhaps these dips allow questing mosquitoes to contact chemically treated vegetation. Further research, such as that done by Marsh et al. (1978) with Lepidoptera, needs to be conducted to investigate mosquito flight characteristics, such as orientation, questing patterns (e.g., turns, frequency, and velocity), and landing patterns. These questing differences should be answered with further research.

The significance of suppressing *Aedes*, but not *Culex*, is 1) *Aedes* are the most numerous anthrophillic species in Lexington, so homeowners receiving this treatment will experience a great reduction in mosquito bites; but 2) this suppression cannot ensure a reduced risk of zoonotic diseases, such as WNV. Thus, these professional mosquito management services should not market this claim. This is an effective technique for low-resting (3-m), peridomestic mosquitoes. To control higher resting peridomestic mosquitoes, such as *Culex* spp., a different application method is needed for homeowner backyards.

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