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EVALUATION OF SIX MOSQUITO TRAPS FOR COLLECTION OF *AEDES ALBOPICTUS* AND ASSOCIATED MOSQUITO SPECIES IN A SUBURBAN SETTING IN NORTH CENTRAL FLORIDA[1]

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ABSTRACT. We compared 6 adult mosquito traps for effectiveness in collecting *Aedes albopictus* from suburban backyards with the goal of finding a more suitable surveillance replacement for the Centers for Disease Control and Prevention (CDC) light trap. Trap selection included 2 commercial propane traps (Mosquito Magnet™ Professional trap and Mosquito Magnet Liberty trap), 2 *Aedes*-specific traps (Fay-Prince Omnidirectional trap and Wilton trap), 1 experimental trap (Mosquito Magnet-X trap), and a standard surveillance CDC light trap that served as a control. Traps that did not generate carbon dioxide were provided with bottled CO_2 at a flow rate of 500 ml/min. Those traps designed for use with chemical attractants (Mosquito Magnet traps) were baited with Lurex™ (L-lactic acid) and octenol (1-octen-3-ol) commercial baits, known attractants to *Ae. albopictus*. Three repetitions of a 6 × 6 Latin square test yielded a total of 37,237 mosquitoes, of which 5,280 (14.2%) were *Ae. albopictus*. Significantly more ($P < 0.05$) *Ae. albopictus* were collected from the experimental and commercial traps (4,244/5,280; 80.3%) than from the CDC light trap and *Aedes*-specific traps. The Mosquito Magnet Liberty collected the most *Ae. albopictus* (1,591), accounting for 30.1% of the total take, followed closely by the Mosquito Magnet-X (1,468) and the Mosquito Magnet Pro (1,185). The omnidirectional Fay-Prince trap performed better than the CDC or Wilton trap. Twenty-seven mosquito species were collected during these trials, 9 species in large enough numbers for meaningful analysis. *Aedes albopictus* was the second most common mosquito trapped. The results of these trials indicate that propane-powered commercial traps would serve as useful substitutes in lieu of CDC traps in *Ae. albopictus* surveillance efforts. Trap features advantageous for collecting *Ae. albopictus* and other mosquito species are discussed.

KEY WORDS *Aedes albopictus*, Mosquito Magnet Professional trap, Fay-Prince trap, CDC Wilton trap, Mosquito Magnet-X trap, Mosquito Magnet Liberty trap

INTRODUCTION

Aedes albopictus (Skuse), a competent vector of dengue viruses and dog heartworm, has expanded its range throughout the southeastern and central portions of the United States from 911 counties in 25 states in 1999 (Moore 1999), to 1,035 counties in 32 states including California (Linthicum et al. 2003) as of December 2004 (McKnight, personal communication). *Aedes albopictus* became established in Hawaii approximately a century before its introduction into the continental USA (Perkins 1913, Sprenger and Wuithiranyagool 1986). It is particularly well adapted for colonizing artificial containers and the forested environs typically found in suburban settings in much of the USA. Once established, it rapidly reaches nuisance population levels and has proven difficult to control. Like other *Aedes* (*Stegomyia*) mosquitoes (including *Aedes aegypti* L.), *Ae. albopictus* are small black and white mosquitoes, weak fliers, mostly silent in flight, and often capable of taking a blood meal with no immediate noticeable effect. *Aedes aegypti* and *Ae. albopictus* are the most important yellow fever and dengue virus vectors in most of the world. Although *Ae. aegypti* preferentially feeds on man (Harrington et al. 2001) and breeds almost exclusively in artificial containers, *Ae. albopictus* is an aggressive opportunistic feeder (Savage et al. 1993) and breeds in both natural and artificial containers (Hawley 1988), facilitating its colonization of suburban and rural areas while consequently making it more difficult to control than other peridomestic mosquitoes.

Unfortunately, diurnally active mosquitoes do not respond well to light traps; such is the case with most *Aedes* (*Stegomyia*) mosquitoes (Thurman and Thurman 1955), making distribution and population assessments difficult with commonly used adult mosquito surveillance traps such as the New Jersey light trap or the Centers of Disease Control and Prevention (CDC) light trap (Service 1993).

Several traps designed for surveillance of *Ae. aegypti* may also be effective for collecting *Ae. albopictus*. *Aedes*-specific traps rely on key visual features deemed highly attractive to lure them to these traps, which are often baited with dry ice or bottled carbon dioxide to increase capture (Rudolfs 1922, Gillies 1980). Highly attractive

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visual features include alternating black and white stripes and checkerboard patterns (Sippell and Brown 1953), broad black surfaces, and enamel surfaces, which are favored over flat black-painted surfaces, thought to be because of a mirroring effect of the enamel surface (Peterson and Brown 1951). Kennedy (1940) showed that visual cues were as important attractant factors for host-seeking adult female *Ae. aegypti* as airborne animal emanations, and more so when movement was added. These behavioral characteristics led to the development of several *Aedes*-specific traps utilizing black–white color contrast (Fay and Prince 1970) or black color to serve as highly attractive visual cues for increased surveillance efficacy (Fay 1968, Wilton and Kloter 1985). Successful experimental traps that were not commercialized also used color contrast (Freier and Francy 1991) and movement (Dennett et al. 2004) to survey for *Ae. aegypti* and *Ae. albopictus*. Our goal was to compare trap efficacy of a standard-use CDC light trap against 2 CO_2-producing commercial traps, 2 *Aedes*-specific traps, and 1 experimental trap for efficacy in collecting *Ae. albopictus*.

MATERIALS AND METHODS

We tested 6 adult mosquito traps for their ability to collect *Ae. albopictus* from backyard suburban settings. The following is a detailed description of each trap and its chemical baiting regimen.

A CDC light trap served as a standard for comparison against other traps because this trap is routinely used by control and public health agencies for mosquito surveillance. The CDC light trap (model 512; John W. Hock Company, Gainesville, FL) used a 6 V DC motor and a CM-47 lamp (0.52 candlepower of incandescent light) and was set 152 cm (5 ft) above ground. The CDC light trap is compact, lightweight, and portable and enables mosquito surveillance in locations lacking main line electricity. In these trials CO_2 was provided from a 9 kg compressed gas cylinder for all traps not generating their own (CDC light trap, MM-X trap, Wilton trap, Fay-Prince trap) at a flow rate of 500 ml/min (15 psi single-stage regulator with microregulators and an inline filter; Flowset 1, Clarke Mosquito Control, Roselle, IL). Carbon dioxide was delivered through clear plastic Tygon® tubing (2 m × 6.4 mm OD) (Saint-Gobain Performance Plastic, Akron, OH). Power was provided by a 6 V, 12 ampere-hour (A-h), rechargeable gel cell battery (Battery Wholesale Distributors, Georgetown, TX).

Commercial traps

Two of the more successful commercial mosquito traps were selected for this study (Kline, unpublished data): the Mosquito Magnet™ Professional trap (MM Pro) and Mosquito Magnet Liberty trap (MM Liberty), manufactured by American Biophysics Corporation (North Kingstown, RI). At the time of this study (2004), both traps were commonly advertised in print media and over the Internet and were among the first carbon dioxide (from catalytic combustion of propane) -generating traps available for homeowner use. We optimized attractiveness of these models to *Ae. albopictus* by adding both Lurex (L-lactic acid) and 1-octen-3-ol (octenol) cartridge baits to their exhaust ports (Hoel et al. 2007). Both baits are formulated in a gel or matrix slow-release cartridge, which releases minute quantities of attractant over a 2–3-wk period.

The MM Pro uses propane to generate mosquito attractants and to power the unit. Briefly, propane is continuously converted into water vapor, CO_2 (520 ml/min, Karen McKenzie, personal communication), and heat. Heated water vapor and CO_2 are exhausted to the outside of the trap, providing a plume of mosquito attractants. Catalytic heat is provided to a second device adjacent to the catalyst, the thermoelectric module, which generates electricity to power the fan that exhausts downward the plume of attractants while providing a counterflow updraft to capture insects. The MM Pro is a heavy (32 kg) standalone unit, somewhat difficult to move over long distances, and should be shut down before being moved to prevent malfunctioning of the thermoelectric module. The collection net is protected by a PVC shell mounted on a black metal stand and base. The trap stands 100 cm high and is supported by an 84 cm × 56 cm stainless steel base equipped with wheels and a storage slot for a 9 kg propane tank. The intake tube opening stands 52 cm above ground. Unlike CDC light traps, the intake tube is oriented downward, and mosquitoes are drawn up into the tube and retained in a net, where they die of desiccation and are in poor condition for identification purposes. The smaller exhaust tube protrudes 10 cm below the center of a flared intake tube and releases the attractant plume. The black exhaust tube serves as a visual attractant and contrasts with the light gray or white intake tube. In addition to visual, heat, moisture, and CO_2 attractants, the MM Pro was baited with an octenol and Lurex™ (lactic acid) cartridge to maximize *Ae. albopictus* collections. All cartridges were replaced after the completion of each trial (after 8 days of use) in those traps supplemented with these lures (MM Pro, MM-X, and MM Liberty).

The MM Liberty is similar to the MM Pro in form and functions also as a counterflow geometry trap, but is smaller and usually powered by main line electricity. A 12 V battery (SeaGel Deep Cycle Gel 31; West Marine, Watsonville, CA) was used to power the unit to avoid shutoff due to AC power outage. Water vapor, heat, and CO_2 (420 ml/min; K. McKenzie, personal communication) are provided by combustion of propane as described above, and the unit is similarly baited with octenol and Lurex baits. This wheel-mounted ground unit is lighter (14.5 kg), more compact, and easier to transport than the MM Pro. It stands 84 cm high, with the intake tube 54.5 cm above ground. The black exhaust tube is seated in similar fashion as the MM Pro. The head housing the motor and collection net is supported by 2 black steel tubes (3 cm diameter) that may serve as visual attractants. Similar to the MM Pro, the MM Liberty offered a large visual target to host-seeking mosquitoes.

Aedes (*Stegomyia*) traps

The omnidirectional Fay-Prince trap (model 112; John W. Hock Company, Gainesville, FL) is a downdraft suction trap designed specifically to capture *Ae. aegypti* (Fay and Prince 1970) from all directions. The Fay-Prince trap consists of four 40.5 cm × 17.5 cm sheet metal arms set at 90° angles to each other with a fan at the center of the arms. The 4-blade fan is set in an 8.5 cm diameter black plastic cylinder, to which a collecting net is attached. The fan is covered by a 40 cm^2 rain shield set 10 cm above 4 vertical metal panels and at their center. The Fay-Prince trap consists of visually attractive black and white reflective panels, and it was supplemented with CO_2. It was set with the top of the cylinder 90 cm (3 ft) above ground and powered by a 6 V rechargeable gel-cell battery. It is bulky and heavier (2.7 kg) than most other portable, non-CO_2-generating mosquito traps.

The CDC Wilton trap (model 1912; John W. Hock Company, Gainesville, FL) is a downdraft suction trap designed to capture *Ae. aegypti* and *Culex quinquefasciatus* Say (Wilton and Kloter 1985). It is believed to mimic tree holes and thought to be attractive to gravid adult females seeking an oviposition or resting site. It consists of a single 14.5 cm long × 8.5 cm diameter flat black cylinder that serves as a visual attractant and a 4-blade fan driven by a 6 V direct current (DC) motor powered by a 6 V rechargeable battery. Mosquitoes are collected in a removable white plastic cup with a stainless steel screen bottom set inside the cylinder between the trap opening and the fan. The Wilton trap was set 90 cm (3 ft) above ground and was supplemented with compressed CO_2 (500 ml/min) to collect host-seeking adult mosquitoes in addition to gravid females. This small trap was lightweight (less than 2 kg) and easy to set. The constant high velocity of air flow resulted in collections of mosquitoes that were difficult to identify.

Fig. 1. The MM-X experimental trap is a battery-powered counterflow geometry trap for collecting hematoghagous insects. An exhaust plume exits the narrow tube protruding below the larger white intake tube. Mosquitoes are safely held away from the uptake airflow, resulting in low mortality while maintaining mosquitoes in good physical condition.

Experimental trap

The Mosquito Magnet-X (MM-X; American Biophysics Corp., North Kingstown, RI) is a counterflow geometry updraft trap similar to the MM Pro and MM Liberty (Fig. 1). It does not use propane and requires an independent power and CO_2 source. The MM-X is moderately bulky (56 cm × 23 cm) but lightweight (2.7 kg). It consists of an 80 mm intake fan, an oval-shaped clear PVC shell, a 40 mm exhaust fan, and exhaust and intake tubes. Screening inside the PVC shell allows air movement and prevents insect escape. Mosquitoes collected in this trap are well preserved and easy to identify. Contrasting black exhaust and white intake tubes provide visual attraction for mosquitoes. The unit is equipped with 3.2 mm × 6.4 mm inside diameter/outside diameter flexible vinyl tubing with quick connect Luer fittings that connect compressed CO_2 directly to the trap head. The unit was powered by a 12 V rechargeable battery and baited with octenol and Lurex cartridges to maximize *Ae. albopictus* capture. The MM-X was set with the intake tube 50 cm above ground.

These 6 traps were evaluated with 3 replications using 6 separate suburban neighborhoods in Gainesville during the summer of 2004. Selection of the 6 test locations was based on homeowner complaints of severe nuisance populations of biting mosquitoes on their properties. Initial surveys confirmed the presence of *Ae. albopictus* at all test locations. All test sites consisted of a mix of pine and hardwood trees with varying amounts of undergrowth, typical of suburban neighborhoods in Gainesville. Additionally, 1 site was planted extensively in *Neoregelra* (red finger nail), *Billbergia pyramidalis*, and *Billbergia* spp. bromeliads; a second site had lesser numbers of

Table 1. Composition of mosquito collections in different traps over 3 trials in suburban neighborhoods in Gainesville, FL ($n = 18$ periods of 48 h).

Species	MM Liberty	MM-X	MM-Pro	Fay-Prince	CDC trap	Wilton trap	Total	Spp. mean
Ae. albopictus	1,591	1,468	1,185	473	325	238	5,280	293.33
Cq. perturbans	8	71	9	23	66	6	183	10.17
Cx. erraticus	29	46	13	80	152	20	340	18.89
Cx. nigripalpus	2,682	8,603	499	5,893	7,511	1,209	26,397	1,466.50
Ae. atlanticus	4	75	1	27	33	4	144	8.00
Ae. infirmatus	127	590	108	647	1,152	221	2,845	158.06
Ae. triseriatus	34	51	15	42	51	31	224	12.44
Ps. ferox	53	146	14	201	424	264	1,102	61.22
Wy. mitchellii	21	30	11	41	44	113	260	14.44
Total	4,563	11,143	1,863	7,452	9,873	2,145	36,775	

Neoregelra bromeliads. Another site contained a large number of artificial containers and tree holes, ideal breeding sites for *Ae. albopictus* (Watson 1967). Traps were placed in shaded areas under trees or just inside a tree line next to open spaces. The 6 test locations were separated by a minimum of 1 mile.

Trapping occurred from July 12–24, August 2–17, and August 25 to September 10, 2004. Traps were left in place 48 h (1 trapping period) to allow for 1 uninterrupted daylight period because *Ae. albopictus* most actively feeds in the early morning and late afternoon. During trial 3, traps were withdrawn from the field for 24 h on August 13 (Hurricane Charlie) and from September 4–8 (Hurricane Frances). Captured mosquitoes were lightly anesthetized with CO_2, stored in labeled paper cups (Solo Cup Company, Urbana, IL) and frozen for later identification to species using the keys of Darsie and Morris (2000). All *Anopheles quadrimaculatus* Say, *Anopheles crucians* Wiedemann, and *Aedes atlanticus* Dyar and Knab/*Aedes tormentor* Dyar and Knab were pooled because these mosquitoes were taxonomically indistinguishable from sibling species.

Traps were randomly rotated between sites in a 6 × 6 Latin square design. Trap, period (48 h), and position effects were evaluated using a 3-way ANOVA (SAS Institute 2001) for the mean number of *Ae. albopictus* collected. Multiple comparisons were made with the Ryan-Einot-Gabriel-Welsh (REGW) multiple range test to determine significant differences between trap means ($\alpha = 0.05$). Those mosquito species collected in large enough numbers for meaningful analyses were analyzed with respect to trap, period, and position as mentioned above. All capture data were transformed with $\log_{10}(n + 1)$ prior to analysis, and pretransformed means are presented in tables and figures. Paired *t*-tests were used to detect significant differences ($\alpha = 0.05$) between trap categories (commercial traps, *Aedes* traps, experimental trap, and surveillance trap) for mosquito species of concern.

RESULTS

Eighteen trap periods (48 h each) over 3 trials from 6 suburban sites yielded a total of 37,237, mosquitoes with the 9 most abundant species totaling 36,775 mosquitoes (Table 1). The remaining 462 mosquitoes comprised 22 different species. *Aedes albopictus* made up 14.2% of the entire catch (5,280 adults). Total *Ae. albopictus* collection by trap and through 3 trials is shown in Table 2. There were significant differences between trap means ($F = 48.0$, df = 5, $P < 0.0001$), site means ($F = 14.9$, df = 5, $P < 0.0001$), and trial means ($F = 2.2$, df = 17, $P = 0.0086$). Order of trap effectiveness was the MM Liberty > MM-X > MM Pro > Fay-Prince trap > CDC light trap > Wilton trap (Table 3). Apart from *Ae. albopictus*, only 22 males were collected. Of the 5,280 *Ae. albopictus* collected, 1,370 (35.0%) were male; commercial and experimental traps caught much larger numbers of *Ae. albopictus* males than did the *Aedes*- and the CDC trap. Male to female ratios were: MM Pro (1:1.6), MM Liberty (1:2.1),

Table 2. Total adult *Aedes albopictus* mosquitoes caught in different traps over 3 trials in suburban neighborhoods in Gainesville, FL, over 36 days ($n = 18$ periods of 48 h).

Trap	Trial 1	Trial 2	Trial 3	Total	Mean (SE)
MM Liberty	739	474	378	1,591	88.39 (8.40)
MM-X	535	520	413	1,468	81.56 (13.94)
MM Pro	462	408	315	1,185	65.83 (11.91)
Fay-Prince	130	176	167	473	26.28 (3.87)
CDC trap	125	91	109	325	18.06 (3.24)
Wilton trap	141	67	30	238	13.22 (3.97)
Total	2,132	1,736	1,412	5,280	

Table 3. Mean collection (± SEM) of mosquitoes per trapping period by species in 6 traps in suburban neighborhoods in Gainesville, FL. Means within each row having the same letter are not significantly different (Ryan-Einot-Gabriel-Welsh Multiple Range Test). $n = 18$ trap periods (48 h).

Species	MM Pro	MM Liberty	MM-X	Fay-Prince	CDC trap	Wilton trap	*P* value
Ae. albopictus[1,2]	65.8 ± 8.4a	88.4 ± 13.9a	81.6 ± 11.9a	26.3 ± 3.9b	18.1 ± 3.2bc	13.2 ± 4c	0.0001
Cq. perturbans[1]	0.5 ± 0.2b	0.4 ± 0.2b	3.9 ± 1.3a	1.3 ± 0.4ab	3.7 ± 1.1a	0.3 ± 0.1b	0.0001
Cx. erraticus[2]	0.6 ± 0.2c	1.6 ± 0.8bc	2.6 ± 1.2bc	4.4 ± 2.3b	8.6 ± 1.8a	1.1 ± 0.8c	0.0001
Cx. nigripalpus[1,2,3]	27.8 ± 16.3c	148.8 ± 128.9b	477.9 ± 327.8b	327.4 ± 229.6b	417.3 ± 244a	67.2 ± 53.6bc	0.0001
Ae. atlanticus[2,4]	0.06 ± 0.06c	0.2 ± 0.1bc	4.2 ± 1.8a	1.5 ± 0.7bc	1.8 ± 0.7ab	0.2 ± 0.1bc	0.0001
Ae. infirmatus[2]	6.1 ± 2.7b	7.1 ± 2.4b	32.8 ± 10.8a	35.9 ± 16.8a	64 ± 28.3a	12.3 ± 6.4b	0.0001
Ae. triseriatus[1,2]	0.8 ± 0.3b	1.9 ± 0.8ab	2.8 ± 0.8a	2.3 ± 0.6ab	2.8 ± 0.8a	1.7 ± 0.5ab	0.03
Ps. ferox[1,2]	0.8 ± 0.3c	2.9 ± 1.3bc	8.1 ± 3ab	11.1 ± 4.6ab	23.6 ± 8.3a	14.6 ± 5.2a	0.0001
Wy. mitchellii[1]	0.6 ± 0.4b	1.2 ± 0.5ab	1.7 ± 0.6ab	1.3 ± 0.9ab	2.4 ± 1.2ab	6.1 ± 3.1a	0.003

[1] Significant position effect ($P < 0.05$).
[2] Significant period effect ($P < 0.05$).
[3] One or more trap means and REGW rankings differ due to extreme variation in trap capture.
[4] Adults could not be distinguished from *Ae. tormentor*.

MM-X (1:4.0), Wilton (1:5.4), CDC (1:20.7), and Fay-Prince (1:9.1).

Culex nigripalpus Theobald and *Ae. albopictus* were the 2 most abundant species, comprising 85.1% of all mosquitoes. Gainesville received approximately twice its average rainfall for August in 2004 (369 mm vs. 168 mm mean), and tremendous numbers of *Cx. nigripalpus* emerged at the beginning of September, 3 wk after Hurricane Charlie struck Gainesville (August 13, 2004). Two sites were particularly productive for *Cx. nigripalpus:* one was in proximity to a flood plain, and the other was heavily wooded with a plastic children's swimming pool that held water and leaves, providing an ideal breeding site for this mosquito. This was also our most productive *Ae. albopictus* site. The MM-X and CDC light traps collected the largest numbers of *Cx. nigripalpus:* 8,603 and 7,511, respectively. Species means (total from all traps/18 trap periods) were 1,466.50 for *Cx. nigripalpus* and 293.33 for *Ae. albopictus* (Table 1).

The 2 counterflow geometry commercial traps (MM Pro, MM Liberty) collected half of the *Ae. albopictus* catch (2,776 adults, 52.6%). Adding the third counterflow geometry (experimental) trap (MM-X) increased the total to 80.3%. Collection means of mosquitoes between both commercial traps (MM Pro = 65.8, MM Liberty = 88.4) and the experimental trap (MM-X = 81.6) were similar, and all counterflow geometry trap means (MM Pro, MM Liberty, and MM-X) were significantly higher than the means for the *Aedes*-specific traps (Wilton = 13.2, Fay-Prince = 26.3) and the CDC trap (CDC = 18.1; $t = 14.6$, $P < 0.0001$). Comparing noncommercial (and experimental) traps, the Fay-Prince trap caught significantly more *Ae. albopictus* than did the Wilton trap ($P < 0.0001$) and 31.3% more than the CDC light trap (not significant). The CDC light trap caught 26.8% more *Ae. albopictus* than the Wilton trap, but this difference was not significant (Table 3).

Site proved to be significant with respect to *Ae. albopictus* collections ($F = 14.89$, df = 5, $P < 0.0001$). Over half (53.5%) of all *Ae. albopictus* trapped in our study were collected from 2 of the 6 sites. One of these sites contained a large number of natural (tree holes) and artificial containers, and the other site was planted extensively in tank bromeliads. Both sites were heavily treed and well shaded. Of the remaining 4 sites, only one had small numbers of tank bromeliads, and all had few, if any, artificial containers found breeding *Ae. albopictus*.

Twenty-seven species of mosquitoes were captured in our study, representing 35% of all mosquito species (77) occurring in Florida (Darsie and Morris 2000). Other mosquito species trapped but not included in Table 1 were *Ae. vexans* (Meigen), *Anopheles crucians s.l.*, *An. quadrima-*

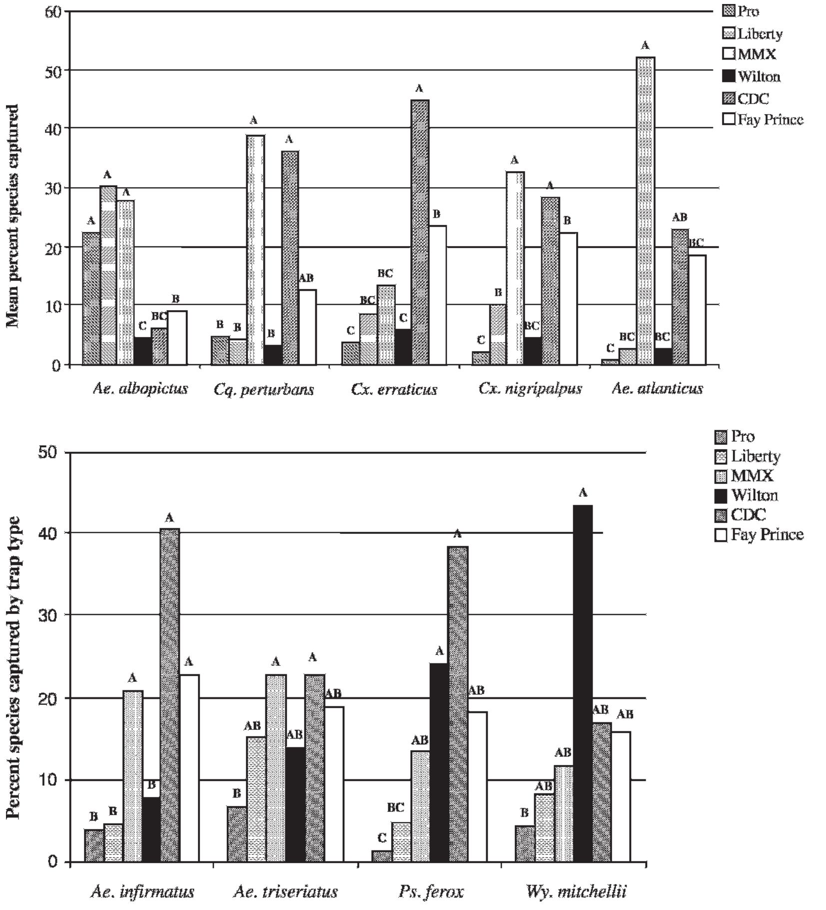

Fig. 2. Relative species composition (%) by trap from 18 trapping periods in suburban settings, Gainesville, FL. The number of mosquitoes collected within each trap with the same letter is not significantly different ($\alpha = 0.05$, Ryan-Einot-Gabriel-Welsh multiple range test).

culatus s.l., *An. perplexens* Ludlow, *Culiseta melanura* (Coquillett), *Cx. quinquefasciatus*, *Cx. salinarius* Coquillett, *Mansonia titillans* (Walker), *Ae. canadensis canadensis* (Theobald), *Ae. dupreei* (Theobald), *Ae. fulvus pallens* (Wiedemann), *Ae. taeniorhynchus* (Wiedemann), *Psorophora ciliata* (Fabricius), *Ps. columbiae* (Dyar and Knab), *Ps. cyanescens* (Coquillett), *Ps. howardii* Coquillett, *Uranotaenia lowii* Theobald, and *Ur. sapphirina* (Osten Sacken). The 9 most prevalent species collected in descending order were *Cx. nigripalpus*, *Ae. albopictus*, *Ae. infirmatus*, Dyar and Knab, *Ps. ferox*, Von Humboldt, *Cx. erraticus*, Dyar and Knab, *Wy. mitchellii*, *Ae. triseriatus* Say, *Cq. perturbans* Walker, and *Ae. atlanticus* s.l.

Relative species composition (%) of the 6 traps is presented in Fig. 2. *Culex erraticus* ($F = 14.42$, df $= 5$, $P < 0.0001$) and *Cx. nigripalpus* ($F = 8.11$, df $= 5$, $P < 0.0001$) were significantly higher in CDC light traps than in any other trap tested. Forty-five percent of all *Cx. erraticus* were captured in CDC light traps, almost twice the rate of the next most effective trap, the Fay-Prince trap (23%). Approximately 60% of all *Cx. nigripalpus* were collected in CDC and MM-X traps. Similarly high collections of *Ae. infirmatus* and *Ae. triseriatus* were obtained in CDC light traps (40% and 23%, respectively) followed by the MM-X and Fay-Prince traps. Over half of all *Ae. atlanticus* were collected in MM-X traps followed by CDC light traps (23%). *Coquillettidia perturbans* responded equally well to MM-X (38%) and CDC light traps (36%). Approximately 38% of all *Ps. ferox* were trapped in CDC light traps, followed by Wilton traps (24%). *Wyeomyia mitchellii* found the Wilton trap highly attractive (43% of the total) in preference to the CDC and Fay-Prince traps (17% and 16%, respectively), although these differences are not significant.

DISCUSSION

For collection of *Ae. albopictus*, both of the commercial mosquito traps tested (MM Pro, MM

Liberty) and the experimental trap (MM-X) performed very well. These traps caught significantly more *Ae. albopictus* (>80% of the total) than the other 3 traps, which included the commonly used CDC light trap and the 2 *Aedes*-specific traps (Fay-Prince and Wilton traps). All 3 top performers were optimally baited with lactic acid and octenol lures to increase the attraction of *Ae. albopictus* (Hoel et al. 2007). Octenol is known to be an attractant for most *Aedes* and some *Culex* mosquitoes (Kline et al. 1991a, 1991b; Kline 1994, Kline, and Mann 1998), and lactic acid in minute quantities is attractive to *Ae. aegypti* (Acree et al. 1968, Kline et al. 1990, Bernier et al. 2003). These 3 high-performing traps also utilize counterflow geometry and operate in an updraft mode, which may be beneficial for capture of *Ae. albopictus*, which tend to feed near the lower extremities of hosts and are weak fliers (Hawley 1988). The order of success in collection of *Ae. albopictus* was the MM Liberty > MM-X > MM Pro > Fay-Prince > CDC light trap > Wilton trap. Because all traps were approximately equivalent (500 ml/min) in CO_2 output, the updraft configuration and/or presence of chemical lures may have contributed to the success of commercial and experimental traps over the CDC, Fay-Prince, and Wilton traps.

Visual contrast is a factor that can contribute to trap collection of diurnal mosquitoes. The highly attractive visual target provided by the Fay-Prince trap makes use of contrasting black and white panels (Sippell and Brown 1953) and includes a glossy luster (reflective finish). Peterson and Brown (1951) found reflective black finishes to be more attractive to *Ae. aegypti* than nonglossy (flat) black surfaces. Likewise, the flat black color of the Wilton trap (Fay 1968) had minimal impact in collecting *Ae. albopictus*. The Wilton trap was designed in mimic tree holes for gravid mosquitoes seeking oviposition sites, consistent with the behavior of sylvatic African *Aedes* (*Stegomyia*) mosquitoes (Gubler 1997) and possibly peridomestic *Ae. albopictus*. However, collection totals between Fay-Prince and Wilton traps confirmed the visual advantage of the glossy, high-contrast Fay-Prince trap to the nonglossy, no-contrast appearance of the Wilton trap.

Incandescent light is known to be a poor attractant for *Aedes* (*Stegomyia*) mosquitoes (Thurman and Thurman 1955), and this finding served as the impetus for developing *Aedes*-specific traps (Service 1993). The CDC trap's incandescent light had little positive effect on *Ae. albopictus* collections, although it was seemingly more attractive to *Ae. albopictus* than was the flat black surface of the Wilton trap. The CDC light trap and Wilton trap were the 2 lowest-yielding *Ae. albopictus* collectors and did not differ significantly.

Mosquito Magnet commercial traps designed for home use have an advantage over older surveillance traps in that they can be set by the homeowner and left to run for 3 wk without maintenance. Propane provides power generation to operate Mosquito Magnet traps and produces attractants (CO_2, moisture, heat), unlike surveillance traps. Additionally, the MM Liberty and MM Pro have an advantage for *Ae. albopictus* surveillance in that they can be baited with octenol and lactic acid baits, which enhance overall collections (Hoel et al. 2007). The MM Pro is a standalone unit, capable of operating in remote locations independent of AC electricity. The MM Liberty was manufactured to operate with AC electricity and is thus limited in operation to locations with main line electricity. In our study, however, we used battery power to operate the trap. Nevertheless, both our MM traps produced CO_2, heat, and moisture independently of AC electricity, factors important in attraction of *Ae. albopictus*. The advantage of the MM Pro trap is that *Ae. albopictus*, a peridomestic species, can be surveyed in more remote areas where it often occurs, such as recreational parks, forest trails, and rural trash dumps.

Contrasting colored exhaust tubes (black) and flared intake tubes (white or gray) provide MM traps with color contrast, an important visual attraction component to host-seeking *Aedes* mosquitoes (Sippell and Brown 1953). On many occasions while setting the MM Liberty trap, and prior to starting it, *Ae. albopictus* were noticed swarming around the uptake tube, close to 2 black metal supporting arms located within 6 inches of this tube. We believe this was an important factor in collecting large numbers of adults and a key reason this trap was more successful than any other trap; the black metal support arms appear to mimic legs. Additionally, all ABC Corp. traps (MM Liberty, MM Pro, and MM-X) are updraft traps that take advantage of *Ae. albopictus* host-seeking behavior in that they tend to feed on the lower extremities of mammals (Watson 1967), closer to the ground where the uptake tubes of these traps are situated (approximately knee height on average-sized adults). The other 3 traps that caught significantly fewer *Ae. albopictus* were set at heights of 152 cm (CDC light trap) and 90 cm (Wilton trap and Fay-Prince trap). The updraft configuration seems advantageous for collecting near-ground, weak-flying, host-seeking insects such as *Ae. albopictus* and sand flies such as *Phlebotomus papatasi* Scopoli as compared to downdraft configurations (*P. papatasi* was collected in much larger numbers in southern Egypt with MM-X updraft traps compared to CDC light traps [downdraft]; D. Hoel, unpublished data). With respect to visual targets, the larger silhouette of the MM Liberty, MM Pro, and MM-X traps were probably advantageous to those of the much smaller CDC and Wilton traps.

Commercially formulated octenol and lactic acid baits would add an advantage to both commercial and experimental traps in that traps so baited have been shown to be much more attractive to *Ae. albopictus* than similarly unbaited traps (Hoel et al. 2007). Despite not producing the highly attractive factors of heat and moisture (for *Ae. aegypti*; Peterson and Brown 1951), the experimental MM-X trap collected the next largest number of *Ae. albopictus* adults, reinforcing the hypothesis that color contrast and updraft geometry contributed strongly in collecting this mosquito. The MM-X trap is particularly useful in *Aedes* surveillance efforts because it is more lightweight and portable and preserves captured mosquitoes better than commercial traps. This is an important feature in localities where *Ae. albopictus* and *Ae. aegypti* are both present. The MM Liberty and MM Pro traps kill adults through desiccation using high-volume airflow, greatly damaging specimens in the collecting process making species identification difficult. Mosquitoes trapped in MM-X traps are isolated from fast-flowing air, well preserved, and often alive when the trap is collected, a feature important in arbovirus surveillance work. Additionally, the MM-X trap caught more female *Ae. albopictus* (1173) than did the MM Liberty (1075), although these totals were not significantly different.

With respect to collecting *Ae. albopictus*, our results agree with those of Dennett et al. (2004). They tested the efficacy of 7 traps in collecting *Ae. aegypti and Ae. albopictus* at a tire repository in Houston, Texas, and found that the MM Liberty collected significantly more of both species than the remaining 6 traps. An experimental moving target trap and the omnidirectional Fay-Prince trap collected large numbers of both mosquitoes, with average results obtained by the propane-powered Mosquito Deleto and Dragonfly traps and poor results obtained by CDC light traps with and without light. The Mosquito Deleto trap (Coleman Co., Wichita, KS) combusts propane to produce heat, moisture, and CO_2 and uses an adhesive-coated paper strip to trap mosquitoes. The Dragonfly Biting Insect trap (BioSensory, Willimantic, CT) uses main line electricity to power an electrocution grid and produces CO_2 via a power-driven solenoid. Their study demonstrated the advantages of updraft traps (MM Liberty) and contrasting colors, especially black and white (Fay-Prince trap) over other type types (downdraft and single color traps) in collecting these 2 species.

Culex nigripalpus was the most abundant mosquito collected during our study, comprising 70.9% of the total trap collection, and together with *Ae. albopictus* accounted for 85.1% of all mosquitoes collected. Tremendous numbers of *Cx. nigripalpus* emerged 3 wk after Hurricane Charlie passed through the area. The largest collections of *Cx. nigripalpus* came from MM-X and CDC traps, with 8,603 and 7,511 mosquitoes, respectively.

Our results reinforce the general trend that *Culex* mosquitoes are strongly attracted to light and CO_2. Use of octenol-baited traps has resulted in mixed results in *Cx. nigripalpus* capture rates (Kline et al. 1990, Kline et al. 1991b), although most *Culex* mosquitoes do appear to respond positively to some extent (Kline 1994, Van Essen et al. 1994). Response of *Cx. nigripalpus* in our study was high for both octenol-baited MM-X traps and octenol-free CDC light traps. These results appear to indicate that light and octenol in the presence of CO_2 are 2 important factors in attracting *Cx. nigripalpus*. Fay-Prince and MM Liberty traps also produced favorable results; it appeared that visual qualities of the traps were an important factor in collecting *Cx. nigripalpus* because all 4 traps had either light or contrasting color as attractive components.

Overall, fewer numbers of *Cx. erraticus* were collected (339), with the highest collections from the CDC light trap followed by the Fay-Prince trap. Collections from the CDC light trap were significantly ($P = 0.05$) better than from other traps, and the Fay-Prince trap caught more than twice as many *Cx. erraticus* as the third best trap (MM-X). The lack of lactic acid and octenol bait in CDC light and Fay-Prince traps may have contributed to their relatively high capture rates. In a previous report *Cx. erraticus* were collected in higher numbers (not significant) in octenol- and CO_2-baited, unlit CDC traps than in CO_2-baited, unlit CDC traps in Arkansas rice fields (Kline et al. 1991a). Light traps appeared to be a good choice for collecting *Cx. erraticus*, whereas commercial baits (octenol + lactic acid used together in Mosquito Magnet traps) appeared to depress capture rates.

Although a small number of *Cq. perturbans* were collected during these trials, the MM-X and CDC light traps caught approximately equal numbers of this mosquito (71 and 66, respectively) and significantly more than the remaining 4 traps. Despite the small number captured, results indicated that light traps were a good surveillance tool for this species. Our MM-X results differed from those of Kline (1999), in which an MM-X caught significantly more *Cq. perturbans* than a light trap (ABC Pro trap), both of which were baited with CO_2 and octenol. Our MM-X trap was baited with octenol, unlike our light trap. Although octenol alone has been shown to be more attractive to this species than traps baited with CO_2 alone, a rare occurrence among Florida mosquitoes (Kline et al. 1990), incandescent light was as seemingly an important attractant factor as was octenol. Light traps and octenol-baited traps appear to be an excellent choice for collecting *Cq. perturbans*, and Campbell (2003) trapped more *Cq. perturbans* with MM-X and CDC light traps than with MM Pro and MM Liberty traps (no octenol).

Three species of *Aedes* were trapped in numbers worthy of review; they included *Ae. infirmatus*, *Ae. triseriatus*, and *Ae. atlanticus*. *Aedes infirmatus* was the third most abundant mosquito caught and is common throughout most of Florida. Significantly more *Ae. infirmatus* were caught in CDC light, Fay-Prince, and MM-X traps than the other 3 traps, with the CDC light trap accounting for 40.5% of all adults collected. Few published reports of mosquito trapping and/or attractants include data on *Ae. infirmatus* (Kline and Mann 1998, Kline 1999). Kline (1999) found no significant difference in capture means between MM-X and ABC Pro light traps; however, captures were very low (<2). Kline and Mann (1998) used different attractants with CDC light traps and obtained significantly more *Ae. infirmatus* in octenol + CO_2-baited traps than in CDC light traps baited with CO_2, butanone, CO_2 + butanone, or octenol; however, trap captures were relatively small (<5 for octenol + CO_2). Although our trap captures of *Ae. atlanticus* and *Ae. triseriatus* were also relatively low (<5), our highest trap captures where obtained from CDC light traps and MM-X traps.

Trapping of *Psorophora ferox* indicated significantly (P = 0.05) higher preference for CDC light and Wilton traps compared to MM Pro and MM Liberty traps. The Fay-Prince and MM-X traps produced intermediate results. Octenol, lactic acid, and octenol + lactic acid blends were previously shown to be repellent to this species (Hoel et al. 2007), and like-baited MM Pro, MM Liberty, and MM-X traps collected the smallest numbers in our study. Almost 40% of all *Ps. ferox* were collected from CDC light traps, indicating that this species is strongly attracted to light. The high collections of *Ps. ferox* in the Wilton trap may be owed to its black color and small size, mimicking reflected water, tree holes, or dark mud surfaces in which adult females seek to oviposit (Carpenter and LaCasse 1955).

Trap type appeared to influence collections of *Wyeomyia mitchellii*, although collections were generally low. Collection sites differed in production of *Wy. mitchellii*, with only 4 of the 6 test sites producing this species, including 1, the third site with a single specimen. The most productive site was extensively planted in tank bromeliads and accounted for 78.6% (202) of all adults; the second and third sites had fewer bromeliads. Wilton trap results were better than all other traps and accounted for 43.5% of the *Wy. mitchellii* catch. CDC light and Fay-Prince trap totals were approximately equal (44 and 41 adults, respectively). Surveillance traps (Wilton-, CDC light, and Fay-Prince traps) accounted for 76.2% of the total catch. It appears that this mosquito is highly attracted to black surfaces that mimic reflected water or tree holes. *Wyeomyia mitchellii* breeds primarily in bromeliads with minor breeding in tree holes and bamboo stumps (Carpenter and LaCasse 1955), possibly accounting for the good success of the Wilton trap with this species.

In summary, 2 commercial traps (MM Pro, MM Liberty) and 1 experimental trap (MM-X) baited with octenol + lactic acid outperformed *Aedes*-specific (Fay-Prince and Wilton) traps and a surveillance trap (CDC light trap) in collecting *Ae. albopictus*. The superior efficacy of counterflow geometry traps over traditional downdraft traps in this study supported previous findings by Dennett et al. (2004). In both trials the MM Liberty attained superior results among all traps tested for collecting *Ae. albopictus*. In our study both commercial traps and the MM-X trap performed about equally well. Ease of use, long-term operation (3 wk), and superior results of propane-powered counterflow geometry traps (MM Pro and MM Liberty) make them ideal candidates in long-term surveillance or trapping-reduction programs targeting *Ae. albopictus*.

When considering all species, the CDC light trap and the MM-X trap performed best overall. Trap rankings of our study for all mosquitoes were as follows: CDC light trap > MM-X > Fay-Prince trap > MM Liberty > Wilton trap > MM Pro. Results indicated that light was a very important attractant for most mosquito species collected from residential settings in north central Florida. Except for *Ae. albopictus* and *Wy. mitchellii*, all mosquito species collected were nocturnal biters. Incandescent light (from the CDC light trap) is apparently the most effective trap feature for collecting nocturnally active mosquitoes. The MM-X and Fay-Prince traps, which utilize visual contrast, performed well with all species. Traps using counterflow geometry performed well (MM-X, MM Pro, and MM Liberty) with weak fliers (*Ae. albopictus*) as well as strong fliers (*Cx. nigripalpus*). The MM-X trap appeared to be the most effective for protection and preservation of all mosquito species encountered in our study. Although the surveillance trap (CDC) performed well in trapping *Culex*, *Aedes*, and *Psorophora* mosquitoes, commercial traps (MM Pro, MM Liberty) also performed well and offer homeowners and public health personnel the advantage of long-term use with little attendance or maintenance required for operation. A primary advantage of commercial traps is the production of CO_2, the most effective of mosquito attractants, whereas surveillance and *Aedes* traps must be constantly resupplied with CO_2 and a power source (battery). In our opinion, these factors favor the newer, commercial mosquito traps for routine surveillance of *Ae. albopictus*. Continuing research into and development of effective mosquito lures will enhance the ability of commercial traps to increase catch and possibly trap select species in larger numbers (Bernier et al. 2003, Hoel et al. 2007).

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