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Research article

Sampling, Distribution, Dispersal

Field Comparisons of the Gravid *Aedes* Trap (GAT) and BG-Sentinel Trap for Monitoring *Aedes albopictus* (Diptera: Culicidae) Populations and Notes on Indoor GAT Collections in Vietnam

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Abstract

We report on the use of the Gravid *Aedes* Trap (GAT) as a surveillance device for *Aedes albopictus* (Skuse) relative to the BG-Sentinel (BGS) trap in field studies conducted in Trenton, NJ, and on Hammond Island, Queensland, Australia. A parallel study conducted in Nha Trang, Vietnam, assessed the use of the GAT as an indoor surveillance device as well as the use of canola oil as a noninsecticide killing agent. In Trenton and Hammond Island, the GAT collected fewer male (0.40 ± 0.12 and 0.43 ± 0.30, respectively) and female (3.05 ± 0.67 and 2.7 ± 2.3, respectively) *Ae. albopictus* than the BGS trap (males: 3.54 ± 1.26 and 3.75 ± 0.83; females: 4.66 ± 1.18 and 3.9 ± 0.23) over their respective sampling periods (i.e., 24 h for the BGS and 1 wk for the GAT). Despite differences in capture rates, the percentage of traps positive for female *Ae. albopictus* was similar between the BGS and GAT (Trenton: 60.1 ± 6.3% and 64.4 ± 4.1%; Hammond: 87.5 ± 6.9% and 80.0 ± 8.2%). In Nha Trang, the GAT was equally effective indoors and outdoors with (10 g hay or 3 g fish food) and without (water or empty) infusion. Additionally, no significant decrease in collections was observed between GATs set with canola oil or long-lasting insecticidal net. In summary, both traps were successful in monitoring female *Ae. albopictus* over their respective trapping intervals, but would be best used to complement each other to monitor both sexes and all physiological stages of female *Ae. albopictus*. However, the versatility and low-cost of the GAT makes it an attractive alternative to the more expensive BGS trap.

Key words: *Aedes albopictus*, *Aedes aegypti*, surveillance, Gravid *Aedes* Trap, Biogents-Sentinel Trap

Monitoring vector abundance is a key objective of local and global integrated vector management programs to reduce the risk of exposure to dengue virus (DENV), chikungunya virus (CHIKV), Zika virus (ZIKV), and other mosquito-borne pathogens (Regis et al. 2008, Semenza et al. 2013, Achee et al. 2015). Vector monitoring for container-inhabiting *Aedes* has traditionally relied on the sampling of immature stages, such as larvae or pupae, particularly for *Aedes aegypti* (L.) (Focks 2003, Morrison et al. 2004). These container-based indices, such as Breteau and House Index, have generally failed to correlate well with adult populations and risk of exposure to DENV risk (Focks et al. 2000, Bowman et al. 2014, Achee et al. 2015). A greater emphasis is now being put on monitoring adult populations, as it provides a more direct assessment of the impact of interventions than larval surveys regarding the risk of human DENV infection (Morrison et al. 2008, Bowman et al. 2014, Achee et al. 2015). This emphasis has extended to the Asian tiger mosquito, *Aedes albopictus* (Skuse), which is second only to *Ae. aegypti* in its vector importance in DENV, CHIKV, and ZIKV transmission (Delatte et al. 2008, Grard et al. 2014, Tsuda et al. 2015). Numerous types of traps are available to monitor adult host-seeking mosquitoes, including, but not limited to, the Center for Disease Control miniature light trap (Newhouse et al. 1966), Fay-Prince trap (Canyon and Hii 1997), and Encephalitis vector surveillance (EVS) trap (Rohe and Fall 1979). However, the majority of these traps are ineffective surveillance devices for diurnal *Ae. albopictus*. For this reason, many operators have adopted the Biogents-Sentinel trap (BGS) (Biogents AG, Regensburg, Germany) as their primary surveillance device due to its high efficacy in capturing *Ae. albopictus* (Kroeckel et al. 2006, Farajollahi et al. 2009).

The BGS trap attracts mosquitoes by visual cues and consists of a collapsible white or blue bucket with a white lid (gauze or plastic) covering its opening, while addition of lures, such as the BG lure (composed of ammonia, caproic acid, and lactic acid) or CO_2, can help increase attraction, especially for *Ae. albopictus* (Farajollahi et al. 2009). In the middle of the gauze cover, there is a black tube through which a down flow is created by a 12-V fan that causes any mosquito in the vicinity of the opening to be sucked into a catch bag. The use of the contrasting color scheme is highly attractive to adult *Ae. albopictus* and *Ae. aegypti* and is more effective at capturing adults compared with other light and fan traps (Kroeckel et al. 2006, Maciel-de-Freitas et al. 2006, Williams et al. 2006). Because the BGS trap captures adult mosquitoes searching for dark resting areas, it collects the full range of female physiological types as well as males (Ball and Ritchie 2010a). For these reasons the BGS trap has become the industry standard in adult *Ae. albopictus* surveillance (Farajollahi et al. 2009). Although an effective surveillance device for *Ae. albopictus*, the BGS trap is relatively expensive and requires power (electrical outlet or battery), which may not be appropriate or even available in many dengue-endemic areas. One alternative is the recently developed passive Gravid *Aedes* Trap (GAT) that captures gravid *Aedes* without the use of adhesives commonly used in lethal ovitraps or electrically powered fans and lights (Eiras et al. 2014, Ritchie et al. 2014).

The success of the GAT relies on its exploitation of the "fly to the light" strategy of capturing insects (Thomas et al. 2001, Díaz-Fleischer et al. 2009). This strategy has proven to be more efficient at capturing gravid *Ae. aegypti* than standard sticky ovitraps in North Queensland, AU (Ritchie et al. 2014). Because the GAT kills gravid females, it also acts as a lethal ovitrap with several advantages. Unlike most lethal ovitraps, particularly those reliant on the use of pesticide-treated ovistrips that do not capture adult females, the retained mosquitoes in the GAT can be tested for viruses or bacterial infections used to reduce vector competence such as *Wolbachia* (Hoffmann et al. 2011, Ritchie et al. 2014). Although the GAT is a practical and low cost trap, field studies assessing its effectiveness in capturing gravid *Ae. albopictus* mosquitoes have yet to be conducted. In the current article, we report on field studies comparing *Ae. albopictus* capture rates in the GAT and BGS trap in Trenton, NJ, and Hammond Island, Queensland, Australia. In a parallel study, we investigated the potential use of the GAT as an indoor surveillance device for *Ae. albopictus* in Nha Trang, Vietnam, due to its relatively high intradomicle abundance in areas with passive cooling housing styles, particularly those of developing countries located in tropical regions such as in Malaysia, Thailand, and Vietnam (Mogi et al. 1988, Tsuda et al. 2006, Dieng et al. 2010). This shift in the host-seeking and breeding behavior of *Ae. albopictus*, a competent vector of DENV and ZIKV (Grard et al. 2014, Tsuda et al. 2015), requires special attention and the development of traps that can effectively monitor intradomicle populations. Additionally, we investigated the incorporation of rain covers for both traps on Hammond Island and the use of canola oil as a noninsecticide killing agent in the GAT in Vietnam based on recent field reports highlighting its success as a killing agent for *Ae. aegypti* when used in the GAT (Heringer et al. 2016b).

Materials and Methods

Study Sites

Trenton, NJ

Trenton is the capital city of the U.S. state of New Jersey and is located in Mercer County in the central region of the state. The city has a land area of 8.16 km^2 and a population density of 4,286.5/km^2. Trenton has a temperate climate with four seasons of approximately equal length with precipitation evenly distributed throughout the year. Since its initial detection in New Jersey in 1995, *Ae. albopictus* has invaded all counties in New Jersey and is the major container-inhabiting *Aedes* species in urban and suburban areas, including Trenton and its surrounding suburbs (Farajollahi et al. 2009). The study areas (South Olden and South Clinton) have been described in detail elsewhere (Unlu et al. 2011); but briefly, South Olden (40° 22′ N, 74° 73′ W) is located in a densely urban neighborhood with 1,250 parcels (i.e., house and corresponding yard) divided into 24 city blocks of row homes, businesses, and a school. South Clinton (40° 20′ N, 74° 72′ W) consists of 1,064 parcels divided into 50 city blocks.

Hammond Island, Australia

Hammond (Keriri) Island is situated in the Torres Strait that encompasses 100 islands situated between the northern tip of Cape York, Queensland, and the southern border of Papua New Guinea. The Torres Strait region has experienced multiple dengue outbreaks as well as a Japanese Encephalitis outbreak that were vectored by *Ae. aegypti* (Hanna et al. 1998, Ritchie et al. 2007). *Aedes aegypti* has recently been displaced on several islands by *Ae. albopictus* after its initial detection in 2005, particularly on the southern islands including Hammond Is., Thursday Is., and Horn Is. (Ritchie et al. 2006). Hammond Is. is 14 km^2 in size with a population of ca. 226 people and experiences a distinct wet season (November–April) and dry season (May–October). The study environment of Hammond Island consists of low-density, mostly single story housing with sparse vegetation around homes and relatively large tracts of undisturbed vine forest and mangrove shrubland along the edges of the island.

Nha Trang, Vietnam

The Vietnam studies were conducted in 27 communes (8 periurban and 19 urban) in the city of Nha Trang, Vietnam. Nha Trang is a coastal city located in the central region of Vietnam with a metropolitan area of 251 km^2 and a population of ca. 400,000. Unlike the southern part of Vietnam, Nha Trang does not experience monsoon conditions during the summer. Therefore, the city has distinct hot-dry (May–October) and cool-wet (November–April) seasons. DENV is endemic in Vietnam and is vectored by both *Ae. aegypti* and *Ae. albopictus* that coexist throughout much of Vietnam, with *Ae. albopictus* dominating in the northern regions and *Ae. aegypti* dominating in the central and southern regions (Higa et al. 2010).

Experimental Design

Trenton GAT and BGS Study

The study incorporated 10 sets of paired traps (1 GAT and 1 BGS) placed at 10 individual residences within the study block and was conducted over a 16-wk period from July–October 2013. Each individual residence was separated by at least 100 m from other study residences. Traps were positioned in areas sheltered from direct wind and sunlight as well as from rain. Most of the traps were placed in the far back corner of the yard near vegetation, when possible. GATs were baited with standard infusion (10 g hay/3 liter tap water) and set with a single piece of long-lasting insecticidal net (LLIN, 4.8% alphacypermethrin, Biogents) supplied from the manufacturer. The LLIN was placed inside the clear upper compartment of the GAT on top of the mesh divider in a nested configuration described in detail elsewhere (Heringer et al. 2016). GAT collections were made weekly, with traps operated 24 h/d due to their passive nature (i.e. no electrical fans), whereas BGS were run continuously from a 12 V battery for 24 h (set between 0800 and 1000 hours EDST and collected between the same times) and were set with the proprietary BG lure, but not with CO_2 due to logistical limitations. All 10 trapping pairs were operated simultaneously and set on the same day of the week. The sampling intervals implemented represent the standard sampling periods for the BGS trap and GAT when used to monitor host-seeking (Farajollahi et al. 2009, Crepeau et al. 2013b, de Ázara et al. 2013, Degener et al. 2014) and gravid (Ritchie et al. 2014) *Aedes* spp. abundance, respectively. Collected female and male mosquitoes were identified to species by trained staff.

Hammond Island GAT and BGS Study

Because of the high amount of rainfall experienced in the Torres Strait islands (ca. 1,800 mm/yr), each trap type was tested with and without a rain cover (Fig. 1). The rain covers for the BGS trap and GAT were black plastic lids 45 cm and 40 cm in diameter, respectively, and were positioned 20 cm above each trap by affixing them to a wire (2- by 4-cm openings) cage support structure. Five 4 × 4 Latin squares (GAT-uncovered, GAT-covered, BGS-uncovered, and BGS-uncovered) were conducted over a 4-wk period from May–June 2013. Due to a lack of mains power, the BGS traps were operated on 12 V battery power for 24 h (set between 0800 and 1000 hours EDST and collected between the same times). The GATs were set in the field for 1 wk and were set with LLIN as stated above and baited with standard hay infusion at the beginning of each Latin square. To eliminate any position-specific effect, all traps were rotated (in a general clock-wise direction) to the next position within their respective squares after each trap interval. Traps were placed at individual residences and separated from neighboring trap sites by a distance of at least 50 m. Traps were positioned in areas sheltered from direct wind and sunlight as well as from rain and placed within close proximity of the residence (<5 m). Collected female and male mosquitoes were identified to species by trained staff.

Nha Trang Indoor and Outdoor GAT Study

We conducted an indoor and outdoor GAT comparison study to determine the feasibility of using the GAT indoors to monitor intradomicle *Ae. albopictus* populations. In addition to analyzing capture rates, the efficacy of two different infusions and a tap water and unbaited (empty) control were assessed. The infusions were either 10 g hay or 3 g of fish food (TetraMin Tropical Fish Flakes, Tetra Spectrum Brands, Blacksburg, VA) mixed in 3 liter of tap water. Unbaited and tap water GATs were "cured" prior to the start of the study by filling them water and leaving them outside for 1 wk to help eliminate the strong plastic odors present in new traps. Once cured, the GATs were emptied, rinsed clean, and left to air dry. Because a paired study design was not feasible due to the constraints of operating within a larger, previously established vector surveillance network, infusion types were distributed amongst 100 participating residences (53 outdoors and 47 indoors) across four trapping zones (each composed of five to seven communes), with staff members assigning treatments based on home-owner preference (i.e. some home-owners didn't want them indoors). The number of replicates per infusion per location (indoors or outdoors) ranged from 8 to 26. Each infusion was added to the trap at the start of each collection week and remade fortnightly. Captured mosquitoes were collected and identified weekly from March–June 2015.

Nha Trang GAT Canola Oil and LLIN Comparison

The efficacy of canola oil as a killing agent in the GAT was assessed against the standard LLIN in a large-scale field study based on a recent report highlighting its efficacy against gravid *Ae. aegypti* (Heringer et al. 2016). The study incorporated 48 GATs set with standard LLIN and 48 GATs treated with canola oil. The traps were distributed across 96 individual residences spread over the 17 wards of the city with each trap being separated from other traps by at least two residences. Trap placement and distribution was done as stated above and integrated into the pre-existing surveillance network based on home-owner participation. Canola oil was purchased as a bulk liquid and applied as a thin film to the entirety of the inside of the upper compartment of the GAT using a cloth rag. The oil is applied in this way because death is caused by an inability to fly after the wings become saturated with oil as they fly and make contact with the oiled wall of the GAT head. The LINN was set in the GAT in the nested position described above. All GATs were baited with standard infusion (10 g hay/3 liter water), and all captured mosquitoes were collected and identified weekly. The study was conducted over a 9-wk period from June–August 2015.

Statistical Analysis

Differences in the mean number of male and female *Ae. albopictus* collected per trap interval for each trap type in the Trenton and Hammond Island studies were compared by repeated measures analysis of variance (ANOVA) with Tukey HSD post hoc analysis on log $(n + 1)$ transformed data. Importantly, collections between the BGS trap and GAT were not statistically compared due to substantial differences in collection intervals (i.e., 24 h vs. 1 wk) and the fact that the BGS trap is a mechanical trap that collects the full range of female physiological types and is attractive to both sexes, whereas the GAT is designed solely to capture gravid females. Differences in collection totals observed among the infusion treatments during the indoor/outdoor GAT trial were analyzed by two-way ANOVA on aligned rank transformed trap means to account for uneven sample sizes (Wobbrock et al. 2011). Differences between the canola oil and LLIN treatments in Vietnam were analyzed by repeated measures two-way ANOVA with Tukey HSD post hoc analysis on log (n + 1) transformed data. Normality and equal variance assumptions for each dataset were confirmed by Shapiro–Wilk tests and visual inspections of residual plots. Statistical power analysis (Cohen 1992) was performed for each study using the G*Power Software (http://www.gpower.hhu.de/en.html, accessed 1 August 2016) with a chosen minimum power of $\pi \geq 0.65$ for inclusion. This power level was chosen due to the constraints of working within existing trapping networks and often with limited staff. All statistical analyses were performed using the R statistical software and related packages (http://www.r-project.org, accessed 1 June 2016).

Results

Trenton, NJ, GAT and BGS Paired GAT and BGS Study

Over their respective trapping intervals, the GAT consistently captured fewer female (Fig. 2A) and male (Fig. 2B) *Ae. albopictus* as compared with the BGS trap. The BGS trap captured 4.66 ± 1.20 (mean ± SE) female and 3.54 ± 1.26 male *Ae. albopictus* per trap

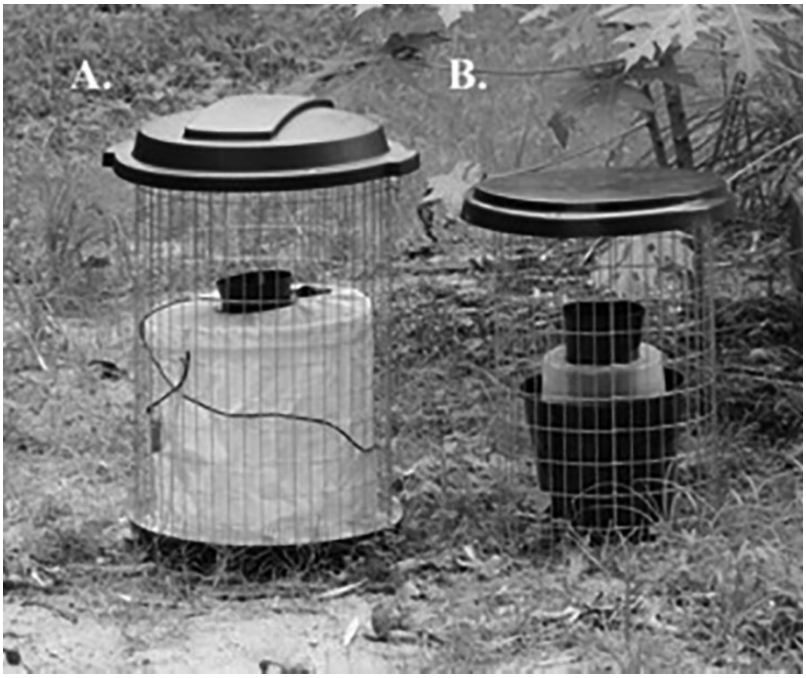

Fig. 1. Rain covers and support caging used in the (**A**) BGS trap and (**B**) GAT comparison studies conducted on Hammond Island, Queensland, Australia. The covers for the BGS trap and GAT were black plastic lids 45 and 40 cm in diameter, respectively, and were positioned 20 cm above the trap openings by affixing them to the wire support cage (2- by 4-cm openings).

interval, whereas the GAT captured 3.05 ± 0.67 and 0.41 ± 0.12, respectively. Despite these differences, the percentage of GAT and BGS traps positive for female *Ae. albopictus* were highly similar (Fig. 2C, 64.4 ± 4.1% and 60.1 ± 6.3%, respectively); however, the BGS trap had a much higher percentage of traps positive for male *Ae. albopictus* relative to the GAT (Fig. 2D, 18.8 ± 4.1% and 51.9 ± 5.9%, respectively). There was no significant difference ($F_{1,18}=0.64$, $P=0.43$) between female and male collections in the BGS trap, whereas significant ($F_{1,18}=8.8$, $P=0.01$) differences were observed between female and male collections in the GAT (Table 1).

Hammond Island, Australia, GAT and BGS Study

The GAT performed much the same relative to the BGS trap on Hammond Island as it did in Trenton. Specifically, the GAT collected fewer female and male *Ae. albopictus* relative to the BGS trap with and without a rain cover (Table 1 and Fig. 3). Overall, BGS traps averaged 4.2 ± 0.68 female and 3.8 ± 0.83 male *Ae. albopictus* per 24 h, whereas the GAT averaged 5.1 ± 1.1 female and 0.43 ± 0.30 male *Ae. albopictus* per week. Again, similar to the Trenton study, the percentage of BGS and GAT traps positive for female *Ae. albopictus* was highly similar while the BGS trap had a much greater percentage of traps positive for male *Ae. albopictus* (Table 1). Overall, the percentage of BGS traps positive for female and male *Ae. albopictus* was 80.3 ± 8.2% and 70.1 ± 9.9%, respectively, whereas the percentage of GAT traps positive for female and male *Ae. albopictus* was 89.4 ± 6.9% and 13.2 ± 9.7%, respectively. In regards to trap type and treatment, no significant ($F_{1,38}=0.18$, $P=0.67$) differences were observed between male and female collections in BGS traps with and without rain covers, whereas covered and uncovered GATs caught significantly ($F_{1,38}=2.7$, $P=0.11$) more females than males (Table 1).

Nha Trang, Vietnam, Indoor and Outdoor Infusion Comparisons

No significant differences ($F_{3,\ 92}=0.76$, $P=0.52$) in the number of female *Ae. albopictus* collected per week were observed between GATs placed indoors and outdoors across all infusion types (hay, fish food, water, and empty; Table 2, Fig. 4A). Overall, GATs placed indoors collected 0.66 ± 0.07 females per week, whereas GATs placed outdoors collected 0.62 ± 0.05 per week. Similarly, no significant differences were observed in the percentage of traps positive for *Ae. albopictus* (Table 2, Fig. 4B, $F3_{,78}=0.81$, $P<0.50$) across all infusion treatments and location (Table 2). The mean percentage of traps positive for *Ae. albopictus* indoors and outdoors across all treatments was 26.7 ± 3.4% and 25.8 ± 2.8%, respectively. Males comprised <5% of total collections across all treatments and thus not enough were collected to detect differences among the treatments or to establish patterns of male abundance.

Nha Trang, Vietnam, GAT LLIN and Canola Oil Comparison

No significant difference ($F_{1,195}=0.04$, $P=0.85$) in the number females captured per week was observed between GATs set with LLIN or canola oil (Table 2, Fig. 5A). The mean number collected per week in LLIN- and canola oil-treated GATs was 0.71 ± 0.18 and 0.57 ± 0.15, respectively. Additionally, no significant difference ($F_{1,196}=0.05$, $P=0.83$) was observed in the percentage of traps positive for *Ae. albopictus* between the two treatments (Table 2, Fig. 5B). The overall percentage of LLIN- and canola oil-treated traps positive for female *Ae. albopictus* was 26.7±3.4% and 25.8 ± 2.8%, respectively.

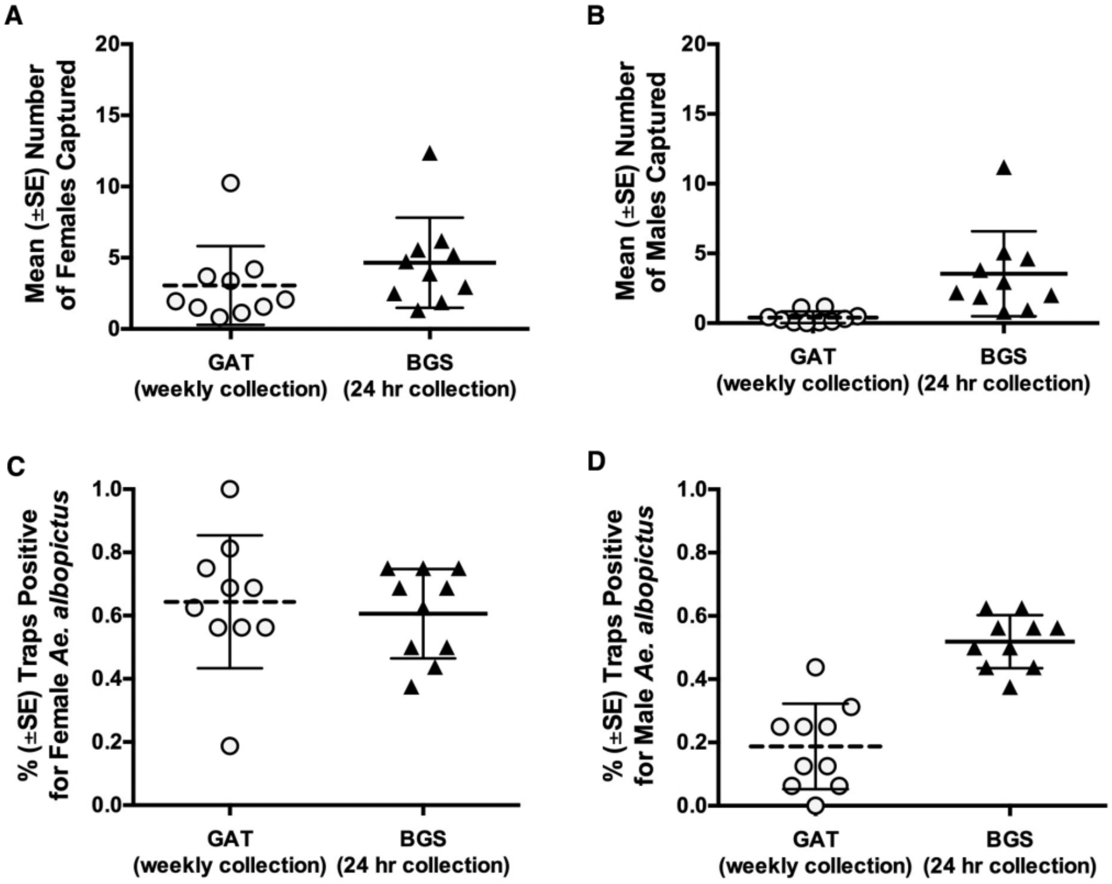

Fig. 2. (**A**) Female *Ae. albopictus* collections in GAT (set weekly) and BGS (set 1 d/wk) traps; (**B**) male *Ae. albopictus* collections in GAT and BGS traps; (**C**) weekly percentage of GAT and BGS traps positive for female *Ae. albopictus*; and (**D**) weekly percentage of GAT and BGS traps positive for male *Ae. albopictus* observed in Trenton, NJ. The figures present the overall study means ± SE and individual trap means for abundance and weekly means by trap type for percentage of traps positive per week.

Table 1. Summary of *Ae. albopictus* GAT (set weekly) and BGS (set 1 d/wk) field comparisons conducted on Hammond Is., Queensland, Australia

Sex	BGS		GAT	
	Female	Male	Female	Male
Abundance (Overall)	4.2 ± 0.68	3.8 ± 0.83	5.1 ± 1.1[a]	0.43 ± 0.30
Abundance: rain cover	3.6 ± 0.73	2.6 ± 0.44	4.4 ± 0.95[a]	0.0 ± 0.0
Abundance: no rain cover	4.8 ± 1.1	4.9 ± 1.5	5.7 ± 1.5[a]	0.85 ± 0.60
Trap positive % rain cover	85.0 ± 8.2	75.2 ± 9.9	83.7 ± 7.8[b]	0.0 ± 0.0
Trap positive % no rain cover	75.6 ± 10.1	65.3 ± 11.0	90.2 ± 6.9[b]	25.1 ± 9.9

Data are represented as trap means (±SE) observed across all Latin squares.

[a] Represents a significant difference between female and male collections in the same GAT treatment.

[b] Represents a significant difference in the percentage of traps positive for female and male *Ae. albopictus* in the same GAT treatment.

Discussion

Mosquito surveillance is a prerequisite to an effective and efficient mosquito control program. Surveillance is used to define the nature and extent of the mosquito problem and to evaluate the effectiveness of new and emerging control paradigms (Regis et al. 2008, Reiter 2014). Thus, operators and program managers need access to a diversity of effective surveillance devices to achieve their operational goals. The BGS trap is currently the "gold-standard" for monitoring host-seeking *Ae. albopictus* populations (Williams et al. 2006, Farajollahi et al. 2009), whereas the GAT is specifically designed to capture gravid *Aedes* females (Ritchie et al. 2014). Although the GAT is a practical, low cost trap, its efficacy in *Ae. albopictus* surveillance was unknown and field comparisons between the GAT and BGS trap were not previously available. In the current study, we have demonstrated that the GAT it is an effective surveillance device for gravid female *Ae. albopictus*, can be used effectively indoors and outdoors and, importantly, can incorporate a noninsecticide killing agent without decreasing collections. Although the GAT underperformed relative to the BGS trap in Trenton and on Hammond Is.

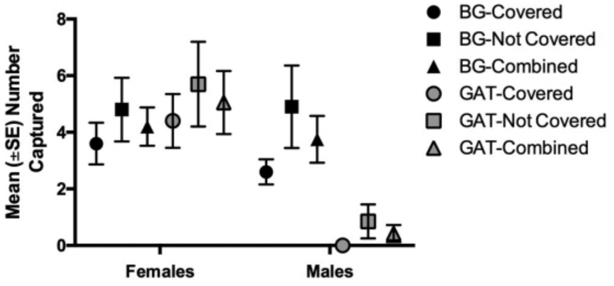

Fig. 3. Mean (± SE) *Ae. albopictus* collections in the GAT (set weekly) and BGS (set 1 d/wk) traps on Hammond Island, Queensland, Australia. Both traps were set with and without rain covers and combined data represents the overall average between traps with and without rain covers. A total of five 4 x 4 Latin squares (GAT-uncovered, GAT-covered, BGS-uncovered, and BGS-uncovered) were conducted over a 4-wk period ($n = 20$ for each treatment).

Table 2. Summary (mean ± SE) of outdoor and indoor female *Ae. albopictus* collections in GATs set with different infusions (hay, fish food, plain water, or no infusion/water) and in GATs set with long-lasting insecticidal net (LLIN, 5% alphacypermethrin) or canola oil killing agents in studies conducted in Nha Trang, Vietnam

Location	Infusion	Abundance	Trap positive %
Outdoors	Hay (10 g)	0.66 ± 0.10	31.5 ± 2.6
	Fish food (3 g)	0.46 ± 0.06	26.7 ± 3.7
	Water	0.71 ± 0.17	18.1 ± 4.3
	No infusion (empty)	0.50 ± 0.10	9.5 ± 2.7
Indoors	Hay (10 g)	0.61 ± 0.09	28.0 ± 3.1
	Fish food (3 g)	0.59 ± 0.09	30.1 ± 2.6
	Water	0.58 ± 0.12	13.5 ± 2.6
	No infusion (empty)	0.80 ± 0.11	21.7 ± 3.3
Location	**Killing agent**	**Abundance**	**Trap positive %**
Outdoors	LLIN	0.71 ± 0.16	26.7 ± 3.3
	Canola oil	0.57 ± 0.08	25.8 ± 2.8

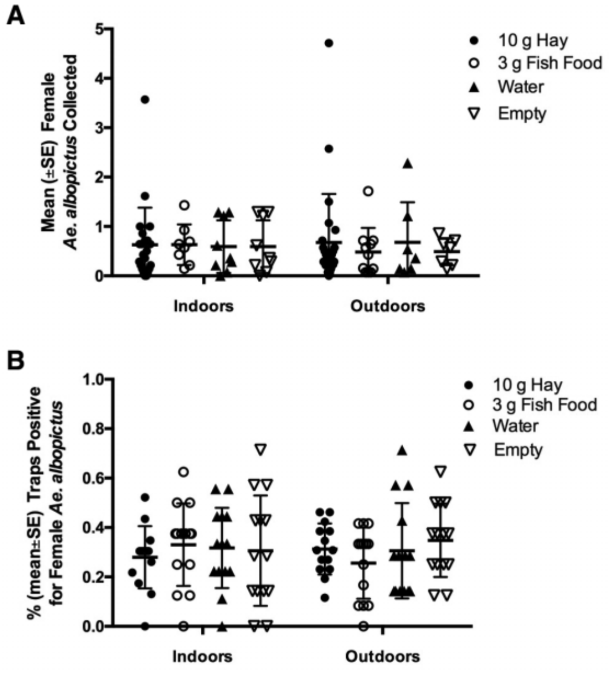

Fig. 4. (**A**) Mean (± SE) female *Ae. albopictus* collections per trap and (**B**) percentage of GATs positive for female *Ae. albopictus* set indoors and outdoors with different infusions from field trials conducted in Nha Trang, Vietnam. GATs were set with either a hay (10 g/3 liter water) infusion, fish food (3 g/3 liter of water) infusion, plain water (3 liter), or no infusion/water (empty) in Nha Trang, Vietnam. The figures present the overall study means ± SE and individual trap means for abundance and weekly means by trap type for percentage of traps positive per week.

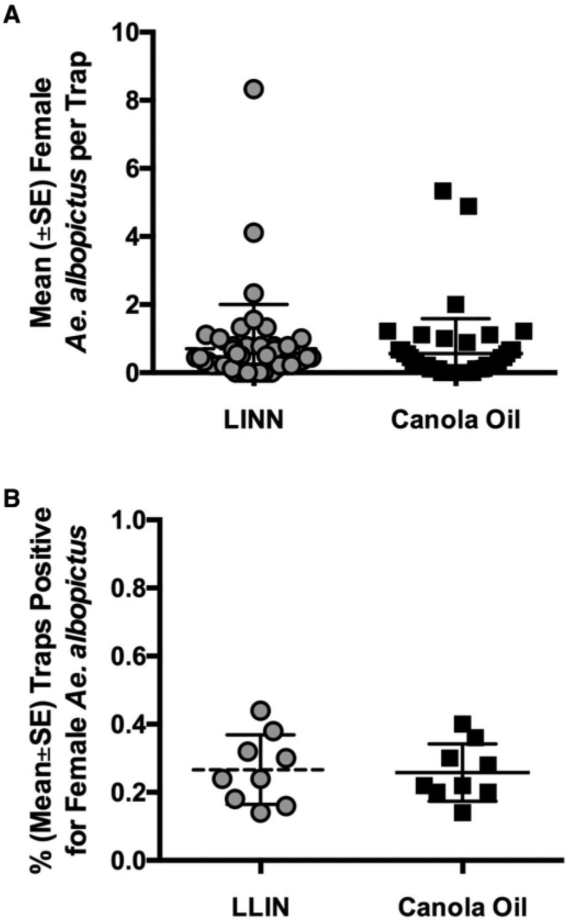

Fig. 5. (**A**) Mean (± SE) female *Ae. albopictus* collections per trap and (**B**) mean (± SE) weekly percentage of GATs positive for female *Ae. albopictus* per week when set with either long-lasting insecticidal net (LLIN, 5% alphacypermethrin) or canola oil in Nha Trang, Vietnam. The figures present the overall study means ± SE and individual trap means for abundance and weekly means by trap type for percentage of traps positive per week.

when considering 24 h BGS to weekly GAT collections, there was a high degree of similarity between the two trap types regarding the percentage of traps positive for female *Ae. albopictus* (presence/absence data). These results, combined with the substantially lower operational costs and ease-of-operation of the GAT compared with the BGS trap (Crepeau et al. 2013a), may offset the loss of general abundance data from an operational point of view. We acknowledge that these studies were performed without the addition of CO_2 for the BGS trap, which would have likely increased collections totals and trap positivity rates (Farajollahi et al. 2009, de Ázara et al. 2013). However, the BGS trap is commonly used without CO_2 for *Ae. aegypti* surveillance (Jeffery et al. 2009, Hoffmann et al. 2011), especially during large-scale field operations to reduce additional costs and logistical limitations imposed by CO_2 incorporation (Unlu et al. 2016). We also acknowledge that the conclusions being drawn for both traps are based on different sampling regimes (weekly vs. daily); however, these sampling protocols represent the standard sampling periods when monitoring *Ae. albopictus* populations with the BGS trap (Farajollahi et al. 2009, Crepeau et al. 2013b, de Ázara et al. 2013, Degener et al. 2014) and gravid *Aedes spp.* using the GAT (Ritchie et al. 2014).

The difference in total number of female mosquitoes collected between the two traps was largely expected given that the BGS trap collects the full range of female physiological types (Maciel-de-Freitas et al. 2006), whereas the GAT is designed solely to capture gravid females. This difference, combined with the generally greater abundance of young nulliparous females in mosquito populations (Gould et al. 1970, Scott et al. 2000), high adult mortality rates limiting the number of females becoming gravid (Harrington et al. 2001, Maciel-de-Freitas et al. 2007), and competition from natural oviposition sources, makes the two traps difficult to compare directly. Thus, interpreting gravid data requires caution because estimates from such data may not accurately reflect the abundance of gravid females under some conditions. These factors may be of greatest importance in densely populated areas harboring many competing oviposition sites, such as the study site in Trenton, NJ (4, 286.5 people/km^2), where past oviposition surveys have revealed many competing oviposition sources per land parcel (>12 oviposition sites per single home and surrounding yard; Fonseca et al. 2013). Such location-specific factors highlight the importance of understanding external environmental and socioeconomic factors that may inhibit surveillance efforts in a particular location (Tsuda et al. 2006, Unlu et al. 2011). However, we acknowledge that because we did not score the physiological status of captured females, further comparisons are needed to assess the complementarity of the two traps, as the BGS trap has been shown to have little bias in terms of collecting parous, gravid, and blood-fed *Ae. aegypti* mosquitoes (Ball and Ritchie 2010b), whereas the GAT predominantly captures gravid females (Ritchie et al. 2014).

The successful deployment of GATs indoors and outdoors with and without aromatic infusions (hay and fish food), or without water, supports previous observations that visual cues have a great influence on the selection of breeding sites by gravid *Stegomyia* mosquitoes (Clements 1992). The size of the GAT and its contrasting color scheme were chosen specifically due to their attractiveness to container-inhabiting *Aedes* (Eiras et al. 2014). Importantly, the strength of this visual attraction maintains its efficacy in capturing gravid *Ae. albopictus* in the absence of aromatic infusions or even water. This finding has particular relevance for *Ae. albopictus* in developing countries in tropical regions, such as Malaysia, Thailand, and Vietnam, where *Ae. albopictus* is adapting to indoor environments (Mogi et al. 1988, Tsuda et al. 2006, Dieng et al. 2010). The use of GATs set with plain water indoors may be of particular importance in these countries, as it provides them access to a low-cost, electricity-free alternative to the BGS trap by negating homeowner resistance to the strong aromatic infusions. Additionally, the successful incorporation of canola oil as an insecticide-free killing agent in the GAT will be attractive in areas with insecticide-resistant populations. It is also important to recognize the equal outdoor and indoor presence of *Ae. albopictus* in Nha Trang. Although *Ae. aegypti* is the dominant species in this region (Higa et al. 2010), these observations indicate that *Ae. albopictus* is adapting to indoor environments, and this may have implications for DENV transmission in this region (Dieng et al. 2010). Further studies are needed to address the potential adaptation of *Ae. albopictus* to indoor environments and their epidemiological consequences, particularly for DENV transmission, in central Vietnam. For example, Dieng et al. (2010) observed that domestic *Ae. albopictus* populations in Malaysia had a higher survival rate, greater fecundity, and increased night time biting activity relative to outdoor populations resulting in increased vectorial capacity (in terms of increased vector–host contacts and vector population density). If similar changes are occurring in central Vietnam, they could have a significant positive impact on DENV transmission in the region. It is important to acknowledge that there may have been a high Type II error rate (incorrectly retaining a false null hypothesis) in the nonsignificant findings among the different GAT treatments due to the very small effect sizes that occur with low collection totals. However, the generally high power of the tests ($\pi \geq 0.80$) and similarity in trap means indicates that the nonsignificant results are correct in this instance given the available data.

The one area where the BGS trap vastly outperformed the GAT was in capturing male *Ae. albopictus*. Although both traps attract males visually, the electric fan of the BGS trap is able to draw them in once they pass over the top of the trap, whereas little to no males are recorded in the passive GAT, as there is no way to force males inside the trap. However, a recent study has highlighted the successful capture of male *Ae. aegypti* in sound-baited GATs in which the female wing beat frequency is played back from a speaker resting on top of the collection mesh (Johnson and Ritchie 2016). Male capture rates in sound-baited GATs were comparable and often greater than the BGS trap (both set weekly). Similar results have recently been observed for *Ae. albopictus* in field trials conducted on the island of Mauritius, during which males were captured using female wing beat frequencies ranging from 500–650 Hz (Balestrino et al. 2016). Although the traps used in the Mauritius study incorporated electric fans, the results indicate that the use of sound stimuli is a promising prospect to increase the capture of male *Ae. albopictus* in GATs, especially if a cheap, reliable, and long-lasting sound lure can be produced.

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