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Mosquito vector abundance immediately before and after Tropical Storms Alma and Arthur, northern Belize, 2008

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ABSTRACT

Objective. *To monitor adult mosquito abundance in northern Belize before/after the first tropical storm of the wet season to estimate the time required for development/recovery of potential vector populations; determine which species predominate post-storm; and compare the effectiveness of two types of mosquito traps—octenol-baited Mosquito Magnets® and U.S. Centers for Disease Control and Prevention (CDC) light traps (with/without octenol).*

Methods. *Field experiments were conducted in Orange Walk Town, Belize, 21 May to 3 June 2008. Incidence rate ratios and exact binomial 95% confidence intervals were reported and trap-nights calculated to compare species abundance pre- and post-storm as well as trap-type effectiveness.*

Results. *Twice as many species and three times more* Anopheles *spp. were trapped pre-storm versus post-storm. However, greater numbers of* Aedes taeniorhynchus *and* Culex *(*Culex*) spp. were trapped post-storm. Mosquito Magnets® were consistently more effective than the CDC traps, obtaining twice as many* Anopheles *spp. and four times as many culicine species as the octenol-baited version (which collected 14 times more mosquitoes overall and 3.5 times more culicine species than the unbaited version). The unbaited CDC trap did not trap any* Anopheles *spp. during the study period.*

Conclusions. *Results indicated octenol is an effective attractant for* An. crucians *in northern Belize; malaria risk in Belize declines immediately post-storm (i.e., mosquito abundance drops); and arboviral risk associated with the rapid increase in culicine mosquitoes post-storm may represent a greater public health threat than malaria (although further research and active disease surveillance is necessary to validate this hypothesis).*

Key words Insect vectors; mosquito control; vector control; malaria; tropical storm; Belize.

Tropical storms and their effects on vector mosquito population dynamics are important factors in disease control and therefore should be considered in public health preparedness and disaster response. Data generated by studies of mosquito population dynamics in areas that receive significant rainfall during storm seasons can be used to estimate which species will predominate after tropical weather events and how quickly potential vector populations may develop and recover (1). These estimates can be useful to disaster response planners who must decide what disease control measures should be implemented and when they should begin (2–4).

This study attempted to record vector species abundance in northern Belize immediately before and after Tropical Storms Alma and Arthur, which occurred simultaneously at the end of the 2008 Belizean dry season. Tropical Storm Alma began on 27 May 2008 as an area of low

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pressure that strengthened into a tropical depression off the coast of Nicaragua. It was designated as the first tropical storm of the season on 29 May 2008 and reached peak winds of 104.6 km/h just before making landfall on the northwestern coast of Nicaragua near León (5, 6). Forming at 86.5°W, Alma developed further east than any other Pacific tropical cyclone on record and was also the first tropical storm to make landfall along the Pacific coast of Central America since 1949 (5, 7). Heavy rainfall across Central America (including Belize) caused flash flooding and landslides in Costa Rica and Nicaragua and left 42 000 people without power (6, 7). Damage was estimated at $33 million USD (7).

On 30 May 2008, Alma emerged into the Gulf of Honduras and fused with a tropical wave off the coast of Belize that became Tropical Storm Arthur one day before the official start of the 2008 Atlantic hurricane season (5). Tropical Storm Arthur was the first Atlantic tropical storm to form during the month of May since 1981 (5). It made landfall on the Yucatan Peninsula on 31 May 2008 and remained a tropical storm over land for nearly 24 hours before weakening to a tropical depression (5, 8). The rainfall from Arthur—approximately 25.4 cm in Belize over 36 hours—compounded the effects of flooding caused by Tropical Storm Alma (8). This heavy rainfall caused rivers in both southern and northern Belize to overflow, damaging bridges and highways and forcing evacuations in Orange Walk District in the north as well as parts of Corozal, Mexico (8). Flash flooding reportedly killed nine people in Belize and affected 100 000 more. Damage was estimated at $78 million USD (8).

The authors of the current study, who were working in the area where the early tropical storms occurred, designed and implemented the current research to take advantage of the opportunity to compare the mosquito vector abundance immediately before and after the first heavy rainfall of the wet season. This type of data may be useful in estimating the effect of tropical storms on local vector populations and subsequent changes in disease risks. A secondary goal of the study was to compare the efficacy of two types of mosquito traps in northern Belize: the commercially produced Mosquito Magnet® (Woodstream Corp., Lititz, PA, USA) and the U.S. Centers for Disease Control and Prevention (CDC) light trap (with and without octenol attractant).

MATERIALS AND METHODS

Mosquito abundances pre- and post-tropical storms

Field experiments were conducted on approximately 607 ha of cattle pasture bordered by mixed brush, marsh, and sugarcane habitat in a malarious area in northern Belize (Orange Walk Town). The first trial was conducted with four of the Mosquito Magnet® traps, which were used to monitor mosquito activity from 21 May to 3 June. As per manufacturer instructions, the traps were sheltered from rainfall—in this case inside two-person tents utilized by the U.S. military (National Stock Number 8340 01 026 6096). The distance from the tent opening to the Mosquito Magnet® was approximately 1 m. Although the tents had been treated with insecticides as part of another study, statistical analysis indicated the treatments were not effective (i.e., the trap catches from the treated tents did not differ from those of the control tent [P = 0.161]). The four Mosquito Magnet® traps were run nightly, 12 hours per sampling day (1800 to 0600 h), four nights before the first storm of the wet season (25–28 May) and four nights after (31 May–3 June), yielding 16 trap-nights (number of traps run [4] × number of nights [4] = 16) for each of the two comparison time periods (pre- and post-storm).

Each of the four Mosquito Magnet® traps utilized a 3.8-liter tank of 60% propane and 40% butane to produce heat and carbon dioxide (a by-product of the combustion process). The propane/butane mix was chosen because it was widely available in Central America and consistent with Mosquito Magnet® manufacturer's instructions. Each Mosquito Magnet® was baited with the 1 600-mg octenol cartridge included with each trap and operated according to manufacturer's instructions.

The tents were spaced 20 m apart and arranged in a line parallel to and approximately 100 m from a local marsh (a mosquito breeding site). The sides of the tents facing the marsh (60°NNE) were left open. The backs of the tents were staked to the ground but left unbuttoned to prevent overheating of the trap and avoid the repellent effect of excessive heat.

Octenol-baited Mosquito Magnets® versus octenol-baited CDC trap. Along with the tents used to house the four octenol-baited Mosquito Magnet® traps, an additional tent was set up to house one CDC light trap, which was baited with the same 1 600-mg octenol cartridge supplied with each Mosquito Magnet® and run for the same daily sampling period (1800 to 0600 h). No carbon dioxide was used. To evaluate the effectiveness of the two types of traps, Mosquito Magnet® trap data from 20–28 May (4 traps × 8 nights or 32 trap-nights) were compared with data from the single baited CDC light trap run from 20–27 May (1 trap × 7 nights or 7 trap-nights).

Octenol-baited CDC light trap housed inside tent versus unbaited CDC light traps outside tent. Two unbaited CDC light traps were also run, outside the tents. Data from these traps were compared with data from the single baited CDC light trap housed inside the tent to evaluate the effectiveness of octenol as an attractant. The two unbaited CDC light traps were run for five nights (28 May and 31 May–3 June), and the single octenol-baited CDC light trap was run for 10 nights (23–28 May, 31 May, and 1–3 June), generating a total of 10 trap-nights for each (2 traps × 5 nights and 1 trap × 10 nights respectively). Both traps were run for the same daily sampling period (1800 to 0600 h). As in the previous trial, no carbon dioxide was used.

All mosquitoes from the daily trap catches were counted and identified to species using a dichotomous key (9, 10). Voucher specimens were later deposited in the collections of the U.S. Army's Walter Reed Biosystematics Unit (WRBU) at the Smithsonian Institution National Museum of Natural History (NMNH).

Statistical analysis

The abundances of mosquitoes per trap-night were calculated to determine any notable differences pre- and post-storm (comparing the Mosquito Magnet® trap data before and after the rainfall) and to assess the effectiveness of the octenol attractant (comparing the data from the octenol-baited CDC trap inside the tent with data from the unbaited CDC traps outside the tent). Incidence rate ratios and exact binomial 95% confidence intervals (CIs) were calculated using Stata Statistical Software version 10.0 (StataCorp LP, College Station, TX, USA) (11).

RESULTS

Mosquito abundances pre- and post-tropical storms

There was a significant difference in the abundance of mosquitoes trapped by the octenol-baited Mosquito Magnets® run immediately before the storm versus those run immediately after the storm for all species except for *Anopheles vestitipennis* (Dyar and Knab, 1906), *Psorophora ferox* (Von Humboldt, 1819), and *Ps. albipes* (Theobald, 1907). The fact that the trap rates for these latter three species did not differ is most likely due to the low numbers of specimens obtained (Table 1). While the total number of culicine species collected by the traps did not change pre- versus post-storm, the species composition was altered, with increases in the number of *Aedes taeniorhynchus* (Wiedemann, 1958) and *Culex (Culex)* spp. post-storm. All *Culex* spp. were identified down to the subgenus *Culex*. As explained by J. Pecor (NMNH/WRBU, personal communication, 5 July 2007), the *Cx. (Cx.)* spp. could not be identified down to any of the 11 species found within this subgenus in Belize due to the lack of male specimens. Conversely, the total number of *Anopheles* spp. was three times higher before the storm compared to afterward. The total number of species caught post-storm decreased by half (pre-storm total = 1 137; post-storm total = 614).

An. crucians (Wiedemann, 1949) was the most abundant species before the storm, followed by *Coquillettidia nigricans* (Coquillet, 1904) and *Mansonia titillans* (Walker, 1848). No *Ae. taeniorhynchus* and only five *Culex* spp. specimens were trapped immediately before the storm. The species trapped most often post-storm was *Ma. titillans*, followed by *An. crucians*. *Ae. taeniorhynchus* and *Culex* spp. were trapped more often immediately following the storm.

Octenol-baited Mosquito Magnets® versus octenol-baited CDC trap. There was a significant difference in trap rates between the octenol-baited Mosquito Magnets® and CDC light trap housed in tents for all species except *Ps. ferox* and *Ps. albipes*. The small number of trapped specimens for these latter two species prevented reliable statistical analysis.

The octenol-baited Mosquito Magnets® produced an average of 54.7 mosquitoes per trap-night (total trapped = 1 750) whereas the octenol-baited CDC light trap caught an average of 20.4 mosquitoes per trap-night (total trapped = 143) (Table 2). However, the bulk of the trap rate from the CDC light trap was due to an abnormally high yield of *An. crucians* on a single night that was most likely due to the presence of livestock in the vicinity during that period (the CDC trap was closer to the livestock than the Mosquito Magnets® and was therefore more likely to capture any mosquitoes attracted by the presence of the animals). If the data for the abnormally high catchment of *An. crucians* during that one night are removed from the analysis, the mosquito abundance for the CDC light trap is reduced to 11.5 mosquitoes per trap-night (Table 2) and the Mosquito Magnet® trap rate becomes almost five times higher for all species versus the octenol-baited CDC light trap. If the data for the one night of abnormally high *An. crucians* catchment are included, the Mosquito Magnet® is almost three times more effective at trapping all species of mosquitoes and two times more effective at trapping *Anopheles* spp. In either scenario, the Mosquito Magnet® was four times more effective at trapping culicine species than the CDC trap.

An. crucians was the species trapped most often in the Mosquito Magnet®, followed by *Ma. titillans* and *Cq. nigricans*. While the total number of specimens collected per trap-night by the octenol-baited CDC trap was lower than that for the Mosquito Magnets®, the species distribution for both types of traps was the same.

Octenol-baited CDC light trap inside tent versus unbaited CDC light traps outside tent. The mosquito abundance per trap-night and associated *P*-values and 95% CIs for the octenol-baited CDC light trap housed inside the tent versus the unbaited CDC light traps outside the tents are presented in Table 3. There was a significant difference between the trap rates of the baited trap versus the unbaited traps for some species (*Anopeheles* spp., *An. crucians*, *Culicine* spp., and *Ma. titillans*) but no difference for others (*An. albimanus*, *An. vestitipennis*, *Cq. nigricans*, *Culex* spp., *Ae. taeniorhynchus*, *Ps. ferox*, and *Ps. albipes*), primarily due to the low trap rates of the latter group of species. However, the octenol-baited CDC trap (run inside the tent) was more effective overall than the unbaited traps (run outside the tent), obtaining 19.3 total mosquitoes per trap-night (total trapped = 193) versus only 1.4 total mosquitoes per trap-night (total trapped = 14) for the unbaited traps and thus almost 14 times more mosquitoes overall (and 3.5 times more culicine species). *An. crucians* was the species trapped most often in the baited CDC trap. The unbaited trap failed to collect any specimens from this species throughout the study period.

TABLE 1. Number of mosquitoes collected in four octenol-baited Mosquito Magnet® traps run inside tents for four nights before the first tropical storm of the wet season (25–28 May) and four nights after (31 May–3 June), Orange Walk Town, Belize, 2008

Species	Pre-storm (total)	Post-storm (total)	Pre-storm (per trap-night)[a]	Post-storm (per trap-night)	IRR[b]	95% CI[c]	*P*
Anopheles spp.	722	223	45.1	13.9	3.2	(2.8, 3.8)	<0.001
An. albimanus	128	30	8	1.9	4.2	(2.8, 6.6)	<0.001
An. crucians	587	183	36.7	11.4	3.2	(2.7, 3.8)	<0.001
An. vestitipennis	7	10	0.4	0.6	0.6	(0.2, 2.0)	0.48
Culicine spp.	415	391	25.9	24.4	1.1	(0.9, 1.2)	0.40
Coquillettidia nigricans	264	42	16.5	2.6	6.3	(4.5, 8.9)	<0.001
Mansonia titillans	146	204	9.1	12.8	0.7	(0.6, 0.9)	0.02
Culex spp.	5	56	0.3	3.5	0.1	(0.03, 0.2)	<0.001
Aedes taeniorhynchus	0	86	0	5.4	…[d]	(0, 0.04)	<0.001
Psorophora ferox	0	0	0	0	…	…	1.00
Ps. albipes	0	3	0	0.2	…	(0, 2.4)	0.13
Total	1 137	614	71.1	38.4	1.9	(1.7, 2.0)	<0.001

[a] Number of traps run (4) × number of nights (4) = 16 trap-nights per comparison period (pre- and post-storm).
[b] Internal rate of return.
[c] Confidence interval.
[d] Insufficient data for calculation.

TABLE 2. Number of mosquitoes collected in four octenol-baited Mosquito Magnet® traps and one CDC[a] light trap run inside tents for eight nights (20–28 May) and seven nights (20–27 May) respectively, Orange Walk Town, Belize, 2008

Species	Mosquito Magnet® traps (total)	CDC light trap (total)	Mosquito Magnet® traps (per trap-night)[b]	CDC light trap (per trap-night)[c]	IRR[d]	95% CI[e]	P
Anopheles spp.	945	100	29.5	14.3	2.1	(1.7, 2.6)	<0.001
An. albimanus	158	0	4.9	0	…[f]	(9.3, …)	<0.001
An. crucians	770	100	24.1	14.3[g]	1.7	(1.4, 2.1)	<0.001
An. vestitipennis	17	0	0.5	0	…	(0.9, …)	0.03
Culicine spp.	805	43	25.2	6.1	4.1	(3.0, 5.7)	<0.001
Coquillettidia nigricans	306	14	9.6	2.0	4.8	(2.8, 8.9)	<0.001
Mansonia titillans	350	26	10.9	3.7	2.9	(2.9, 2.0)	<0.001
Culex spp.	61	2	1.9	0.3	6.3	(1.8, 56.3)	<0.001
Aedes taeniorhynchus	86	0	2.7	0	…	(5.0, …)	<0.001
Psorophora ferox	0	1	0	0.1	…	(0, 8.5)	0.18
Ps. albipes	3	0	0.1	0	…	(0.09, …)	0.55
Total	1 750	143	54.7	20.4	2.7	(2.2, 3.2)	<0.001
Excluding abnormally high CDC trap rate recorded for one night of sampling							
An. crucian	770	26	24.1	4.3	5.6	(3.8, 8.5)	<0.001
All species	1 750	69	54.7	11.5	4.8	(3.7, 6.1)	<0.001

[a] Centers for Disease Control and Prevention (USA).
[b] Number of traps run (4) x number of nights (8) = 32 trap-nights.
[c] Number of traps run (1) x number of nights (7) = 7 trap-nights.
[d] Internal rate of return.
[e] Confidence interval.
[f] Insufficient data for calculation.
[g] Includes abnormally high trap rate recorded for one night (possibly attributable to the presence of livestock near the CDC trap during that period).

TABLE 3. Number of mosquitoes collected in one octenol-baited CDC[a] light trap run inside a tent for ten nights (23–28 May, 31 May, 1–3 June) and two unbaited CDC light traps run outside tents for five nights (28 May and 31 May–3 June), Orange Walk Town, Belize, 2008

Species	Octenol-baited trap (total)	Unbaited traps (total)	Octenol-baited trap (per trap-night)[b]	Unbaited traps (per trap-night)[c]	IRR[d]	95% CI[e]	P
Anopheles spp.	143	0	14.3	0	NA[f]	(38.3, …[g])	<0.001
An. albimanus	1	0	0.1	0	NA	(0.03, …)	0.50
An. crucians	142	0	14.2	0	NA	(38.0, …)	<0.001
An. vestitipennis	0	0	0	0	NA	…	1.00
Culicine spp.	50	14	5.0	1.4	3.6	(1.9, 7.0)	<0.001
Coquillettidia nigricans	18	11	1.8	1.1	1.6	(0.7, 3.8)	0.20
Mansonia titillans	29	3	2.9	0.3	9.6	(3.0, 49.6)	<0.001
Culex spp.	2	0	0.2	0	NA	(0.2, …)	0.25
Aedes taeniorhynchus	0	0	0	0	NA	…	1.00
Psorophora ferox	1	0	0.1	0	NA	(0.03, …)	0.50
Ps. albipes	0	0	0	0	NA	…	1.00
Total	193	14	19.3	1.4	13.8	(8.0, 25.7)	<0.001

[a] Centers for Disease Control and Prevention (USA).
[b] Number of traps run (1) × number of nights (10) = 10 trap-nights.
[c] Number of traps run (2) × number of nights (5) = 10 trap-nights.
[d] Internal rate of return.
[e] Confidence interval.
[f] Not applicable (IRRs were not estimable for species that were not collected in the unbaited traps).
[g] Insufficient data for calculation.

DISCUSSION

Because many mosquito-borne diseases are found in regions of the world at risk for hurricanes and tropical storms, understanding the effects of such events on local vector-borne disease epidemiology is important for directing appropriate public health responses (12). Caillouët et al. (2008) showed that after Hurricane Katrina there was a sharp increase in the number of reported cases of neuroinvasive West Nile virus disease in hurricane-affected regions (13). They also found a >2-fold increase in incidence of neuroinvasive West Nile virus disease in hurricane-affected areas for 2006 versus previous years (13). Many of these cases occurred among construction workers and other cleanup crew, underscoring the need to provide adequate shelter and mosquito control for disaster relief volunteers and workers as well as residents of affected areas in the days and weeks that follow the storm (12, 14, 15). During the post-storm cleanup of Hurricane Andrew, repair and cleanup crews were exposed to high densities of mosquitoes, which increased the potential for mosquito-borne disease transmission as well as bacterial infections from mosquito bites. Like the post-storm species composition in Belize found in the current study, the most common species collected post–Hurricane Andrew in both Florida and Louisiana were mainly *Culicine* spp. (15). It should be noted, however, that the studies cited above do not reliably link increased mosquito abundance with increased risk of disease because the increased disease incidence could have been due to increased human exposure to vectors rather than increased vector numbers.

In the current study, an increase in the variety of culicine species was noted as soon as four days post-storm. However, a drastic drop in *Anopheles* spp. was also noted post-storm, which may have implications for malaria prevention during storm seasons (16). In northern Belize, malaria is mesoendemic and moderately unstable, with seasonal epidemic exacerbations showing a fairly close correlation with alterations in rainfall (17). As documented in this study, habitat damage from tropical weather events can disturb *Anopheles* spp. populations enough to temporarily reduce their abundance and thus their role in malaria transmission (18). This finding suggests that public health interventions to prevent malaria immediately after a storm may not be as important as previously assumed (19), although this hypothesis is somewhat controversial in the literature because malaria transmission is not always directly correlated with number of mosquitoes or amount of rainfall (e.g., very low numbers of mosquitoes can also produce significant disease transmission) (20, 21)). Once the *Anopheles* vectors are reestablished in the environment, however, the increased rainfall provides a suitable breeding habitat, thus increasing the chance for a possible outbreak, as was seen after Hurricane Flora swept across the southern peninsula of Haiti (17). Conversely, this re-stabilization period can take many weeks to months, most likely depending on the strength of the storm and associated wind speed (17, 19). For this reason, natural disasters do not usually cause an immediate increase in vector-borne diseases. In areas that are heavily damaged, however, vector control may be inappropriately delayed during the most paramount of times—immediately after the storm—when most residents of the affected areas are still living in evacuation areas (4, 22).

The current study found that *Culex* spp. in Belize are able to increase rapidly following a storm and should potentially be regarded as a possible vector of interest immediately following heavy rainfall, especially at the end of the dry season. If hurricanes strike early in transmission season, there could be a late increase in risk after vector and host populations are reestablished. *Culex* spp. are able to transmit a number of pathogens to humans (e.g., West Nile virus and Venezuelan equine encephalitis virus) and therefore may require immediate control measures after heavy rainfall in northern Belize. It should be noted, however, that although these results indicate the abundance of certain vector species can increase rapidly after heavy rainfall, further studies and increased surveillance of diseases associated with these vector species are needed to ascertain whether or not this increase in species abundance leads to a direct increase in disease risk.

As mentioned above, based on the research results, the authors of the current study concluded that 1) the Mosquito Magnet® was more effective at trapping all species of mosquitoes (*Anopheles* spp. and culicines) than the octenol-baited CDC light trap, and 2) octenol is a reliable attractant for *An. crucians* in northern Belize (based on the observation that the unbaited CDC light traps failed to collect any specimens from this species whereas the octenol-baited CDC trap attracted a high number of them). These findings may prove useful for public health planners attempting to set up field surveillance programs after tropical weather has devastated an area.

Limitations

This study had several limitations. For example, in the trap comparison studies, there was an uneven number of replicates (due to the unpredictable nature of storms). If this type of study were attempted in the future, comparison of an equal number of trap-nights and trial nights would be preferable. In the pre- and post-storm study, the main weakness was the shortened temporal scope. A longer collection time (both pre- and post-storm) would improve the analysis and allow for consideration of the varying life cycles of potential vectors found in northern Belize. Although the current results indicating a parallel decrease in density of mosquitoes during the first 48 hours after storms are supported by studies conducted in 2000–2001 on the effect of tropical storms on adult mosquito abundance in Calcutta, India, it would be useful to determine how long this decrease in total species lasts and what factors play a role in rebuilding affected mosquito populations (23).

In addition, future studies examining mosquito populations before and after *several* tropical storms and hurricanes would further clarify how mosquito abundance is altered by these weather events and how it varies on an annual basis. Comparing mosquito populations during two or more different storm years could prove useful in determining how other climatic, temporal, and environmental factors facilitate breeding in certain species post-storm (21). After Tropical Storm Doreen hit California in 1977, Gordon et al. hypothesized that many breeding cycles are obligatory in nature and are modified primarily by temperature rather than precipitation (21). Comparing these results to those of the current study, it should be noted that the rains caused by Tropical Storm Doreen were not thought to have created favorable breeding habitats due to lack of vegetation and larval activity, whereas the current research site had profound vegetation in its water sources. In any case, it is clear that mosquito abundance and composition can vary tremendously in a region affected by tropical storms. This underscores the importance of species abundance research pre- and post-storms to facilitate and improve public health planning for devastated areas. It also further justifies the need for active disease surveillance during these time frames to identify any increases in certain species that may lead to a subsequent increase in disease risk or transmission.

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