A comparison of adult mosquito trapping regimes across seasons and ecosystems in Darwin, Australia

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ABSTRACT: Mosquitoes are problematic as vectors and pests in many tropical cities, including Darwin, the principal city in the Northern Territory of Australia. To monitor peaks in mosquito populations, the Medical Entomology unit of the Health Department sets overnight CO_2-baited traps weekly. Trap setting and retrieving, followed by mosquito counting and identification, are labor intensive. Aiming to reduce this workload, we tested the hypothesis that fortnightly trapping is as effective as weekly trapping across seasons and ecologically distinct systems in Darwin. We applied cross-sectional negative binomial mixed effects models, which adjusted for rain and calendar month, to existing historical data. *Culex annulirostris* peaks were effectively identified using fortnightly trapping across all three ecological systems, during wet/dry and build-up seasonal patterns. For *Aedes vigilax,* fortnightly trapping was adequate in identifying peaks during wet and dry season months, but inadequate during build-up months across all three ecological systems. Therefore, weekly trapping should continue during build-up months, but trapping could be reduced to fortnightly for wet and dry season months for all ecological systems. Trapping for *Cx. annulirostris* monitoring could be reduced to fortnightly in all areas and seasons. Evaluation of programs can maximize staff efficiency and improve service delivery by reducing the need for unnecessary tasks. ***Journal of Vector Ecology*** **37 (2): 284-288. 2012.**

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INTRODUCTION

Darwin, the principal city in the tropical north of the Northern Territory of Australia, has historically been associated with a high burden of endemic mosquito-borne diseases (Russell and Whelan 1986). Furthermore, residential development in Darwin since the 1970s has been concentrated in close proximity to major creeks, swamps, and wetland areas known to support mosquito breeding (Figure 1) (Russell and Whelan 1986). Creek systems and wetlands experience seasonal tidal inundation and wet season pooling of rainwater. This creates a flooding-desiccation cycle providing suitable seasonal larval habitats for the common banded mosquito *Culex annulirostris* (Skuse) and the northern salt-marsh mosquito *Aedes vigilax* (Skuse). *Culex annulirostris* is the most significant pest species in the Northern Territory. It is also a vector for Murray Valley encephalitis virus. The disease from this virus, previously called "Australian encephalitis," is potentially fatal (Doherty 1972). *Aedes vigilax* is also recognized as a major human pest species (Mackerras 1926, Marks 1967, Gislason and Russell 1997, Webb and Russell 1999) (Whelan 1989). Both mosquito species are established vectors for Ross River and Barmah Forest virus (Whelan et al. 1997, Russell 1998, Jacups et al. 2008), which constitute the majority of arbovirus infections in Australia (Russell 1994, Russell 1995).

Larval mosquito ecology varies across Darwin. Different wetland systems produce distinct peak periods of mosquito abundance in response to vegetation characteristics coupled with local weather conditions (Whelan 2007). Although habitats are in relatively close proximity to each other; their vast ecological differences result in locally specific vector prevalence and vector control requirements, and these require individual assessment (Whelan 2007). This is exemplified by the diversity of counts and species reported from adult mosquito traps located around the different wetlands, as populations respond to localized breeding conditions.

The Department of Health's Medical Entomology unit conducts overnight trapping of adult mosquitoes weekly at multiple sites in Darwin urban area using CO_2-baited EVS light traps (Whelan 2007). Traps are positioned between wetland breeding sites and urban areas to target mosquito densities in close proximity to residential areas (Figure 1). Trapping adult mosquitoes identifies peaks in mosquito populations and functions as a feedback mechanism for larvicidal controls conducted after rainfall or high tide events. Weekly trapping is labor intensive involving the employment of one staff member. Each week one staff member drives to trap sites, sets traps, and retrieves them the following day. Staff then count and identify mosquito samples and enter counts into a custom-designed database. These tasks are rotated among staff but occupy 40-50 h each week. The wet season months are especially busy, as mosquitoes are abundant in most habitats, resulting in greater time and personnel constraints

as mosquito reduction control operations are required.

Using existing data, we sought to test the hypothesis that an alternate, work-reduced mosquito trapping protocol (fortnightly) is as adequate at detecting peaks of *Ae. vigilax* and *Cx. annulirostris* as the current (weekly) trapping protocol across three ecologically distinct habitats in Darwin. If fortnightly trapping is as effective as weekly trapping in detecting the magnitude of vector mosquito peaks, then this laborious task could be reduced and staff re-allocated to other mosquito control tasks, thus maximizing the efficiency of the unit and enabling the staffing of mosquito control programs for Darwin's newly developed and expanding residential suburbs.

MATERIALS AND METHODS

Darwin is situated in the tropical zone of Australia (12° 28' S, 130° 51' E) and experiences a monsoon climate, with a high average annual rainfall of 1,708 mm. Most rainfall occurs during the wet season, from November to April. We defined the Darwin "wet season" as December to April inclusive, which differs from the Bureau of Meteorology (BOM) definition, which includes the hot and humid "build-up" months that rarely receive rain in its wet-season definition (Australian Bureau of Meteorology 2009). The build-up to the wet season is defined here as September to November inclusive, with the "dry season" defined as May to August inclusive. Daily rainfall data (Darwin airport rain gauge) was provided by the BOM for the study period (Australian Bureau of Meteorology 2010). Total rainfall by calendar month was used in the analysis.

Figure 1. Adult mosquito monitoring program-locations routine weekly adult mosquito CO_2-baited light trap sites in study analysis.

There are three major larval mosquito sites in the Darwin urban area (Figure 1). These are the tidal creek areas represented by the trap sites at Casuarina, Totem Road, and Coconut Grove (Red traps); the seasonally saline reed swamps around Leanyer and Holmes Jungle (White traps); and the non-tidal freshwater wetland at Marrara (Blue traps) (Figure 1). These three ecologically distinct systems provide suitable breeding habitats for *Cx. annulirostris* and *Ae. vigilax*.

Counts of *Ae. vigilax* and *Cx. annulirostris* females were collected from overnight EVS traps (manufactured by the Medical Entomology Department) set weekly in 11 locations, as indicated in Figure 1. Mosquito identifications were performed by the Medical Entomology Department in Darwin, with sub-samples of 300 mosquitoes identified to species level, after which the total was estimated by weight (Kurucz et al. 2005). Mosquito species were limited to include only the major vectors of endemic diseases in the region. Monthly averages, calculated from weekly mosquito counts between 1991 and 2005 (180 months), were compared with averages calculated using every second-week mosquito counts (fortnightly).

We compared weekly mosquito trapping protocol with fortnightly trapping using cross-sectional negative binomial models. Multiple models were required to clarify associations across ecological systems. All models included time (month) and rainfall as independent variables and some models included season (wet, dry, build-up). Models included mosquito species together (*Ae. vigilax* and *Cx. annulirostris,* Model 1); *Cx. annulirostris* only- by season (Model 2); and *Ae. vigilax* only modelled for each ecological system, by season (Model 3).

The best models were determined by Akaike's information criterion and maximum log-likelihood methods (Rabe-Hesketh and Skrondal 2005). As the data were counts, their means follow a gamma distribution. Poisson models or negative binomial models are traditionally used with negative binomial chosen in preference in cases of high over-dispersion, as the mean may not equal the variance. Cross-sectional models allow comparison of data across time periods that are not always equal in length (Beck 2004). Output coefficients indicate the strength and direction of variable association with the regressor. To control for time and seasonal (rainfall) variation, we applied a cross-sectional negative binomial mixed effects model to our count data. The model was in the form of:

$$\mathrm{Log}(y_{it}) = \beta_0 + X_{it}\beta + Z_i\gamma + \alpha_i + u_{it}$$

where y_{it} is the dependent variable observed for individual i at time t, X_{it} is the time-variant regressor, and Z_i is the time-invariant regressor. In the random-effects model, the dispersion varies randomly from group to group, such that the inverse of the dispersion has a Beta (r s) distribution. All analyses were performed using STATA version 11.0 (Stata Corp., College Station, TX, U.S.A.).

Table 1. Cross-sectional negative binomial mixed effects model. Weekly vs fortnightly adult mosquito trap sampling for *Ae. vigilax* and *Cx. annulirostris*.

Model 1	Coefficient	p	95% CI	
Total rainfall	0.000	0.145	0	0.001
Weekly vs fortnightly	0.051	0.059	-0.002	0.103
Calendar month	-0.077	0.000	-0.111	-0.044

RESULTS

Modelling results of both species combined, controlling for rain and month, indicated no difference between weekly vs fortnightly trapping (p= 0.059, Table 1). When the results were separated by mosquito species and season, a trend was observed between weekly vs fortnightly for *Cx. annulirostris* mosquito peaks during the wet, dry, and build-up seasons (p= 0.098, p= 0.959, p= 0.233, Table 2) respectively, across all three ecosystems combined. When modelling *Ae. vigilax* only, results indicate statistical differences between weekly vs fortnightly protocols for all three ecosystems during build-up months only. For tidal creeks at Casuarina and Coconut Grove (Red traps) (p= 0.001, Table 3, Model 3A), there were similar results for freshwater systems (Blue traps) (p= 0.001, Table 3, Model 3B), and mangrove/reed systems (White traps), (p= 0.010, Table 3, Model 3C).

DISCUSSION

The results indicate that fortnightly trapping, when conducted at the 11 sites adjoining Darwin's northern suburbs, is as effective for monitoring *Cx. annulirostris* species as weekly trapping. Additionally, fortnightly trapping was adequate for detecting peaks of *Ae. vigilax* at all three ecosystem locations during wet and dry season months. However, fortnightly trapping failed to detect the magnitude and timing of *Ae. vigilax* peaks during build-up months for all three ecological systems. Therefore, routine trapping could be reduced from weekly to fortnightly without a significant loss of information across ecological systems for most of the year.

As a rule, *Cx. annulirostris* breeds seasonally in temporary ground pools after rain. Eggs are laid in rafts on the water surface and each habitat may support a range of larval instars, which leads to relatively stable numbers of emerging mosquitoes. As rain-filled depressions exist throughout the wet season, and stormwater and waste water discharge can continue well into the dry season, *Cx. annulirostris* breeding is often continuous throughout the wet season and well into the dry season without obvious sharp population peaks. Nevertheless, breeding in seasonally extended wetlands during the late wet and early dry season generally produces some high population peaks. As *Cx. annulirostris* population peaks are usually greater than one week's duration, there was no significant difference between weekly and fortnightly trapping regimes; therefore the findings from this study are consistent with the mosquito species ecology.

In contrast to freshwater breeders, *Ae. vigilax* has a highly fluctuating cycle of population peaks that follow inundation by tides or rain (Kay et al. 1981). Wet season-flooded areas progressively recede until most of the area is dry. From the mid-dry season (July), spring tides inundate *Ae. vigilax* breeding habitat, increasing productivity. Tidal and /or rain inundation leads to high-density mosquito breeding until late in the wet season when the area becomes flooded, reducing oviposition sites and allowing predation by fish (Ritchie 1984, Jacups et al. 2009). This finding is congruent with other findings from this study site, documenting *Ae. vigilax* larval densities as highest between October and December each year (Jacups et al. 2009, Kurucz et al. 2009).

Maintaining rigid mosquito control for mosquito borne-disease reduction mandates adult trapping regimes that can provide timely feedback information on *Ae. vigilax* populations. This enables responses by the medical entomology unit to modify surveillance strategies or larvicide control to reduce mosquito population levels. This is essential for safeguarding against mosquito-borne disease transmission and public distress associated with biting at pest levels. To maximize the efficiency of adult mosquito control operations in Darwin, control should be concentrated on the build-up months between September and December each year. During these months, the medical entomology unit should trap weekly, but during the other months of the year a fortnightly

Table 2. Cross-sectional negative binomial mixed effects modelling results. Weekly vs fortnightly adult mosquito trap sampling for *Cx. annulirostris* females only.

Model 2		Coefficient	p	95% CI	
	Total rainfall	0.000	0.299	0.000	0.001
Wet season months	Weekly vs fortnightly	0.063	0.098	-0.012	0.137
	Calendar month	-0.132	0.000	-0.172	-0.092
	Total rainfall	-0.009	0.092	-0.019	0.001
Dry season months	Weekly vs fortnightly	-0.002	0.959	-0.063	0.060
	Calendar month	-0.154	0.062	-0.315	0.008
	Total rainfall	0.003	0.320	-0.003	0.008
Build-up months	Weekly vs fortnightly	0.052	0.233	-0.033	0.137
	Calendar month	-0.831	0.000	-1.276	-0.385

Table 3. Cross-sectional negative binomial mixed effects models. Weekly verses fortnightly adult mosquito trap sampling for *Ae. vigilax* females only.

		Coefficient	p	95% CI	
Model 3A **Tidal Creeks** **Red traps**					
Wet season months	Total rainfall	0.003	0.000	0.001	0.004
	Weekly vs fortnightly	0.004	0.939	-0.091	0.098
	Calendar month	0.128	0.001	0.053	0.203
Dry season months	Total rainfall	-0.006	0.455	-0.021	0.009
	Weekly vs fortnightly	0.114	0.173	-0.050	0.278
	Calendar month	-0.114	0.411	-0.386	0.158
Build-up months	Total rainfall	0.003	0.445	-0.004	0.009
	Weekly vs fortnightly	0.393	0.001	0.167	0.618
	Calendar month	0.253	0.378	-0.309	0.816
Model 3B **Freshwater wetland** **Blue traps**					
Wet season months	Total rainfall	0.002	0.053	0.000	0.003
	Weekly vs fortnightly	0.068	0.420	-0.098	0.234
	Calendar month	0.092	0.021	0.014	0.169
Dry season months	Total rainfall	0.007	0.589	-0.018	0.032
	Weekly vs fortnightly	-0.033	0.801	-0.287	0.222
	Calendar month	0.090	0.604	-0.250	0.429
Build-up months	Total rainfall	0.007	0.112	-0.002	0.015
	Weekly vs fortnightly	0.427	0.001	0.175	0.679
	Calendar month	0.085	0.811	-0.614	0.785
Model 3C **Mangrove/reed wetland** **White traps**					
Wet season months	Total rainfall	0.002	0.014	0.000	0.003
	Weekly vs fortnightly	0.054	0.363	-0.063	0.172
	Calendar month	0.069	0.088	-0.010	0.148
Dry season months	Total rainfall	-0.003	0.690	-0.020	0.013
	Weekly vs fortnightly	0.114	0.110	-0.026	0.253
	Calendar month	-0.054	0.730	-0.359	0.252
Build-up months	Total rainfall	0.009	0.041	<0.001	0.018
	Weekly vs fortnightly	0.280	0.010	0.068	0.492
	Calendar month	-0.199	0.569	-0.882	0.485

adult trapping program for the northern suburbs would offer a cost effective alternative, freeing up a staff member to assist with other mosquito control programs, and thus maximizing service delivery without the loss of valuable information.

This work bridges the fields of public health and ecology, and tests a management strategy to lower the workload within current programs aimed at pest and mosquito vector reduction. Evaluations such as this assist pest and disease management using existing and simulated data, without the need of additional field experiments. The methodologies developed here could be easily applied to many other areas of service delivery and best practice to ensure that only valuable data is collected and staff are utilized in areas of maximum need.

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