What is driving salt-marsh mosquito peaks in Darwin: tides or rainfall?
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Abstract
The northern salt-marsh mosquito Aedes vigilax (Skuse) is an established vector for Ross River and Barmah Forest viruses and an aggressive biter and an appreciable pest species in the Northern Territory (NT). Many of Darwin’s northern suburbs are adjacent to the coastal wetland of Leanyer swamp, which has an extensive breeding habitat for Ae. vigilax. Medical Entomology (ME) of the NT Department of Health conducts adult mosquito surveillance and larval mosquito control for Ae. vigilax in this wetland. One trap located near the residential suburb of Karama consistently reports some of the highest numbers of Ae. vigilax of the 7 local swamp trap locations. ME wish to clarify why it should indicate the highest numbers and what environmental variable triggers these peaks. The trap site is close to the residential area, and the results are used to trigger public warnings of mosquito pest or potential disease risks. This paper seeks to identify the most important environmental variables associated with peaks of ≥ 500 Ae. vigilax/trap/night, to better indicate the reasons for the peaks and the section of the swamp that is the source of these peaks, to reduce public pest problems and disease risks.

The results of the analysis using models indicated that calendar months September - November had significantly more peaks than January and in addition to rain in these months were more associated with high monthly tides coinciding with rain. The Karama trap site is relatively close to the flood plains and wet lands associated with the Holmes Jungle section of the wetland, and the large tidal influenced swamps to the east outside the 5 km control zone.

This suggests larval control should be implemented with increased emphasis in rain flooded tidal influenced areas of the Holmes jungle section of Leanyer swamp after high tides with rain events coinciding s during the build-up months between September and November. This study supports applying statistical methods to existing control programs can enable insights into solutions without the need for additional field experiments and may have applications for other mosquito control programs in other areas.

Background
The tropical region of northern Australia has a characteristic monsoonal climate with a ‘wet season’ from December to April and little or no rainfall during the ‘dry season’ months. Darwin, the capital of the Northern Territory (NT) receives an average annual rainfall of 1708 mm, with most of this falling in the wet season. The build-up season in Darwin occurs late in the dry season from September to November and features high humidity and occasional and random thunder storms.

Many of Darwin’s northern suburbs are adjacent to the extensive coastal reed and upper mangrove wetland of Leanyer swamp that has been recognized as an important larval habitat for Aedes vigilax (Skuse), the northern salt-marsh mosquito. There are a number of elements of the swamp including areas of constructed drains within the swamp, a former bomb target area with craters, a saline soil wet season flooded grassland, upper tidal mangrove areas and fresh, brackish and tidal influenced reed areas. The eggs of Ae. vigilax are laid in non-draining areas on salt affected damp soil or vegetation of relatively low height and density which allows the female mosquitoes access to the soil or plant base for oviposition. Hatching occurs when the eggs are inundated by either tides or rain.

Medical Entomology (ME) of the NT Department of Health conducts carbon dioxide baited adult mosquito trap surveillance and integrated mosquito control measures for Aedes vigilax breeding in the wetlands. This mosquito is an established vector for Ross River and Barmah Forest viruses and is also an aggressive biter and an appreciable pest species. Aerial control in the Leanyer
swamp area primarily involves large-volume water based *Bacillus thuringiensis var. israelensis* (B.t.i.) mist applications applied from the air by helicopter.\(^{13}\) Peaks in *Ae. vigilax* numbers have been historically associated with public complaints from residential areas in Darwin, (Figures 1).\(^{13}\) The majority of telephoned complaints are made from residents within 500 m of the Leanyer Swamp edge, (Figure 2). Appreciable mosquito peaks can occur each year, particularly from 1 trap location on the edge the residential suburb of Karama that consistently indicates some of the highest numbers of *Ae. vigilax* in the 7 swamp trap locations. The reasons for these peaks and at this location have always perplexed staff at the ME unit. The trap is not the closest to the swamp boundary or to the most extensive breeding sites, and insight is required as to why and when it indicates the highest numbers, and what environmental variable triggers these peaks. This trap site is important as it is closest to the residential area and the results are used to trigger public warnings of mosquito pest or potential disease risks.

Larval control is carried out routinely after high tide or rain events and there has been no discernable pattern of preceding tides or rains to elucidate the primary cause of the *Ae. vigilax* peaks. Clarification of the cause of the peaks would allow prioritisation for timing and location for aerial larval control. We therefore sought to identify what might be the most important environmental variables associated with peaks of \(\geq 500\) *Ae. vigilax*/trap/night that might aid predictions. Improved prediction of peaks of aggressive biting mosquitoes in residential areas could assist early control intervention, timely media warnings and thereby possibly reduce public pest or potential disease risks. Early prediction of peaks could assist planning of future mosquito surveys, control efforts and hence maximise the efficiency of the unit.

**Methods**

**Data**

All female *Ae. vigilax* mosquitoes collected from overnight encephalitis virus surveillance (EVS) CO\(_2\) baited-light traps\(^{14}\) trapped weekly at 1 location (Karama trap) between July 1998 to June 2009 were included (Table 2). Mosquito identifications were preformed by ME in Darwin, with subsamples of 300 mosquitoes identified to species level, after which the total was estimated by weight.\(^{15}\) Weekly counts of *Ae. vigilax* were analysed for the study period (419 weeks). Daily rainfall was provided by the Australian Bureau of Meteorology (BOM)\(^ {16}\) for the study period, from rain gauges located at: Karama, Leanyer, CSIRO Berrimah, Thorak cemetery, Shoal Bay Defence Base, and Royal Darwin Hospital, defined as ‘northern suburbs’ for this study.\(^ {16}\) Daily tide data were provided by BOM for Port Darwin for the study period.\(^ {16}\) Aerial mosquito control operations conducted by ME were included in the analysis as dates and areas (ha) sprayed.

**Statistics**

We identified the maximum tide during the 9 - 13 day period prior to each EVS collection date. Similarly the highest rainfall event and the cumulative rainfall were calculated for each 9 - 13 day period prior to trap collection. Chi square tests were used to test for associations between a peak in *Ae. vigilax* mosquitoes \(\geq 500\) and calendar month or season. Wet season was defined as December-April, dry season as May-August and build-up season September-November. Larval control categories were determined by percentile, with 20 ha at the 75th centile, and 100 ha at the 90th centile.

Following this, logistic regression models were applied, to determine explanatory variables fitted to weekly peaks of female *Ae. vigilax* mosquitoes \(\geq 500\) per trap. This was modelled controlling for calendar month, year, meteorological variables and larval control efforts.

**Results**

Overnight trap peaks of \(\geq 500\) female *Ae. vigilax* mosquitoes only occurred in months January, August-December (Table 1 and 2). There was a statistical difference between when peaks \(\geq 500\) occurred by calendar month (\(\chi^2 = 69.8, p<0.0001\)).

There was no difference between maximum tide (9-13 days) preceding trap collection, and *Ae. vigilax* mosquito \(\geq 500\) events (T-test, \(p=0.405\)). When the data were combined into a model, the maximum tide during the preceding 9-13 days prior to adult mosquito trapping was positively associated with peaks (\(\geq 500\)) OR=1.1 however this was not statistically significant (\(p=0.72\)).
Larval controls had a significant inverse effect on mosquito peaks. These effects were statistically significant and strongest when ≥100 ha were sprayed, OR 0.25, p=0.046. Calendar months September to November had significantly more peaks than January, with a trend for significance (p=0.09) in December. November had the highest association with mosquito peaks OR 45.4, p<0.0001. Year was not statistically associated with mosquito peaks but retained in the model to control for yearly variation.

Discussion

Findings from this study indicate that ‘build-up season months’, rather than intuitive ‘wet season months’ were more associated with peaks in *Ae. vigilax* in the Karama trap. Peaks mostly occurred in November with an increased risk OR of 45 associated with November versus January. Unseasonal rainfall during the build-up (September-November) rather than wet season months (December- April) was associated with peaks of *Ae. vigilax* over 500 in the Karama trap. These findings are supported by other published findings that *Ae. vigilax* larval densities are highest between October and December each year.2,3,17

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</tr>
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<td><strong>37</strong></td>
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Appreciable rain in Darwin usually commences in December with heavy rains in the months following. However, in some years, light to heavy rains commence earlier. Unlike tides, with clear demarcation lines, (Figure 4) rainfall is variable in intensity and less predictable, even
between suburbs adjacent to each other. With higher build-up season rainfall, rain added pooling in both currently tidal flooded areas as well as in tidally influenced areas can create a greater area of potential mosquito breeding habitat. Furthermore, unlike tides, rainfall can occur unpredictably from location to location. This creates a moving target for ME larval control teams who conduct the bulk of their surveys and control efforts with the aid of helicopters over a broad landscape. Although aerial larvae control efforts are conducted following tide or rainfall events the results of this study suggest that control efforts presently in place are sometimes inadequate at reducing \textit{Ae. vigilax} number peaks. This study suggests that these peaks are associated with tide and rain events coinciding, rather than rain or tide events alone. This could be due to all larval habitats not being adequately treated because of the difficulty in locating all pooling after tide plus rain events or that the Karama trap routinely captures an influx of adults from outside the 5 km control radius area from the northern suburb boundary. From the mid dry season, increasing spring tides progressively inundate potential \textit{Ae. vigilax} breeding habitat, thus progressively increasing \textit{Ae. vigilax} productivity, with rain in November to December further increasing \textit{Ae. vigilax} breeding. After inundation or swamp areas by tides or rain, the water does not drain and mosquito breeding can occur in very high densities until the area is seasonally flooded. Thus, no more egg laying habitat is available and larval predation by fish is enabled\textsuperscript{2,18}

Findings from this study indicate that maximum tide height was not associated with mosquito peaks in the crude or adjusted analysis. In the adjusted analysis, although tide had an OR 1.1, this was not statistically significant after adjusting for larval control efforts, which are routinely applied after high tides. These results also indicate that aerial larval control in the 2 to 4 days after high tides using \textit{B.t.i.} is adequate at reducing peaks, but not always adequate at controlling larvae 2 to 4 days after rainfall when coupled with high tides. This is understandable as rain events cause breeding over a much wider area than the prescribed areas following tide-only events. Additionally the rain prevents the timely (within 6 days) draining of tidal flooded areas and extending flooding into areas above the current tidal reach by direct rain addition to

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**Table 2, Weekly \textit{Aedes vigilax} counts from Karama EVS trap**

![Weekly \textit{Aedes vigilax} counts from Karama EVS trap](chart.png)
This expanded and less concentrated breeding is both harder to locate, especially at low concentrations, and harder to control over a much wider area in a limited time.

The Karama trap site is relatively close to the Holmes Jungle section of the swamp where these rain expanded areas of flooding can be very variable and more extensive (Figure 4), and thus is reasonably expected to better indicate the higher populations arising from rain and tide events together. In addition the Karama trap site is positioned in the lee of a hill among a relatively dense stand of eucalypts which would afford wind protection and increased harbourage for salt-marsh mosquitoes which would also lead to higher numbers in the trap.

To maximize the efficiency of adult salt-marsh mosquito control operations in Leanyer Swamp this study suggests aerial larval control should be implemented with increased coverage after rain or tide and rain events coinciding during the build-up months (September to November) on rain-flooded current tide and maximum tidal extremities, particularly in the Holmes Jungle section of the swamp. Whether this is the most cost effective measure needs further study.

This study reiterates the importance of applying statistical methods to service provider programs enabling insights into solutions without necessarily the need for additional field experiments. This method of evaluation may have applications for mosquito surveillance and control programs in other areas.

Acknowledgements
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References

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