Abstract

Large numbers of military personnel are based in northern Australia, generating risks to them from endemic tropical mosquito-borne diseases. In addition, posting of the military to Timor-Leste and other overseas locations poses a risk that mosquito-borne disease, notably malaria and dengue fever, will be imported back to Australia, a potential problem both for those personnel and the wider community. Robertson Barracks, near Palmerston in the Northern Territory (NT), lies adjacent to a seasonal freshwater wetland and 1.5 km from the seasonal fresh, brackish and saline habitats of Millner Swamp, and its mosquito incidence is consequently an issue of concern.

Here, we report weekly monitoring over 12 months from October 2005 to September 2006 at 2 sites, 1 in the Barracks area, and the other between the Barracks and Millner Swamp. 6 mosquito species of particular concern were common to abundant at both sites; Anopheles farauti s.l. and Anopheles bancroftii as potential vectors of malaria, Aedes vigilax and Culex annulirostris as vectors of prevalent arboviral diseases due to Ross River, Barmah Forest and Murray Valley encephalitis virus infection, and Coquillettidia xanthogaster and Mansonia uniformis as nuisance value. However, there was considerable fewer An. bancroftii and even less An. farauti s.l. and Ma. uniformis at the Barracks compared to Millner Swamp, An. farauti s.l., a key potential vector for malaria, and other disease vector species breed in Millner Swamp.

Maintenance of the buffer distance separation between the Barracks and Millner Swamp is an important part of the strategy to prevent local transmission of malaria, and to reduce the pest and vector-borne disease potential to Barracks personnel. Recommendations for management are made.

Keywords: wetlands; army; malaria; northern Australia; arbovirus; mosquitoes

Introduction

The incidence of Ross River virus (RRV), Barmah Forest virus (BFV) and Murray Valley encephalitis virus (MVEV) infection is a major public health concern in the monsoonal tropics of Australia.1 The concentration of the Australian military in northern Australia in recent decades, and in particularly the position of military establishments in the vicinity of tropical wetlands, means that disease management is an issue of concern to the military. Further, the posting of military personnel overseas and in particular to Timor-Leste, where malaria and various arboviral diseases are prevalent, exposes both these personnel and the wider community to the importation of diseases not currently endemic in the NT.2

Robertson Barracks is a major military establishment near Darwin in the NT. It lies adjacent to a seasonal freshwater wetland and 1.5km from the seasonally variable fresh, brackish and saline habitats of Millner Swamp. The latter is a known breeding area for An. farauti s.l. and An. bancroftii, with An. farauti s.l. being the major potential vector for malaria in the region and An. bancroftii being a potential secondary vector. Other mosquito species of prevalence and concern in the vicinity of the Barracks are Ae. vigilax and Cx. annulirostris, both vectors of endemic arboviral disease, and Coquillettidia xanthogaster and Mansonia uniformis, both nuisance species.3

Before the Barracks were established, Medical Entomology of the NT Centre for Disease Control (CDC) provided monitoring data and an assessment of vector borne disease risks and recommendations for management.4 In this report we provide an update on the incidence of these 6 key mosquito species based on intensive surveys conducted over 12 months in 2005-06, and provide further recommendations for reducing potential mosquito-borne disease in this and other military establishments in northern Australia.
Figure 1. Relative location of Robertson Barracks infrastructure, nearby swampland, and mosquito traps.

Table 1. Number of individuals of 6 mosquito species trapped over one year at Robertson Barracks (RB) and the nearby Millner Swamp (MS), 5 traps per site combined.

<table>
<thead>
<tr>
<th>Species</th>
<th>Robertson Barracks</th>
<th>Millner Swamp</th>
<th>Ratio (MS / RB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aedes vigilax</em></td>
<td>4,103</td>
<td>12,491</td>
<td>3.0</td>
</tr>
<tr>
<td><em>Anopheles bancroftii</em></td>
<td>1,515</td>
<td>8,282</td>
<td>5.5</td>
</tr>
<tr>
<td><em>Anopheles farauti s.l.</em></td>
<td>98</td>
<td>1,723</td>
<td>17.6</td>
</tr>
<tr>
<td><em>Coquillettidia xanthogaster</em></td>
<td>11,226</td>
<td>23,611</td>
<td>2.1</td>
</tr>
<tr>
<td><em>Culex annulirostris</em></td>
<td>21,402</td>
<td>62,605</td>
<td>2.9</td>
</tr>
<tr>
<td><em>Mansonina uniformis</em></td>
<td>632</td>
<td>6,949</td>
<td>11.0</td>
</tr>
</tbody>
</table>
Methods

The study area

Robertson Barracks (12° 26’ S, 130° 59’ E) is a major accommodation, service and training facility for troops from the Australian Army. It is 1 km north-east of the Pinelands industrial area and 3.5 km north of urban residential areas in Palmerston near Darwin in the NT. The facility extends over approximately 4 km² (Figure 1). It is situated immediately adjacent to a wetland and 1.5 km from the edge of Millner Swamp (Figure 1).

Rainfall at the nearby Darwin Airport during the study period (Oct. 2005 to Sept. 2006) was close to the average of 1700 mm except for very-much above average rainfall of 398 mm in April compared to the April mean of 100 mm.

Mosquito trapping

The abundance and diversity of adult female mosquitoes was monitored with standard EVS CO₂-baited traps. At each of 2 sites (Figure 1), 5 traps were set 1 night per week for each week from October 2005 to September 2006 inclusive. The 5 traps were arranged in a cross with a central trap; the 4 at the points of the cross being 50 m from the central trap. One site (hereafter Robertson Barracks) was in woodland surrounded by the Barracks, while the other (hereafter Millner Swamp) was in woodland 0.5 km from Millner Swamp between the Swamp and Robertson Barracks. The aim of the site design was to detect mosquitoes emanating from Millner Swamp, as well as those present in the Barracks area, and gauge the attrition, in particular, of the saltmarsh-breeding An. farauti s.l. with distance from Millner Swamp. The 5-trap design was part of a larger experiment, to be reported elsewhere, on the efficacy of a single trap in monitoring local site conditions.

Trapping around the proposed Roberson Barracks site in 1986-87 was conducted using the same type of traps, with mosquitoes sampled fortnightly at 4 dispersed points around the site.

Mosquito samples were killed by freezing prior to microscopic identification. Samples of less than 300 individuals were identified and counted fully. For larger samples, the full sample and a sub-sample of 300 specimens were weighed and the subsample fully identified and enumerated. The sample was checked for species absent from the subsample. The ratio of weights provided a conversion factor to estimate the number of individuals of each species in the sample. The abundance of species present in the sample but absent from the sub-sample was scored as the total number present in the sample.

Results

All 6 mosquito species occurred at both Robertson Barracks and Millner Swamp, and all were more abundant at Millner Swamp (Table 1). The attenuation at the Barracks was particularly marked for An. farauti s.l. and Ma. uniformis, which were 17 and 11 times more prevalent at Millner Swamp respectively, whereas the ratio for the other species ranged from 2.1 to 5.5.

Cx. annulirostris and Cq. xanthogaster were present throughout the year with limited seasonality but for generally lower numbers in the October to December period (Figure 2). Ae. vigilax was present for most of the year, although with low numbers in February and March and greatest abundance in October to January. An. bancroftii was most abundant from January to August, with low numbers in October to December. Ma. uniformis was present throughout most of the year with a peak in December to January and short periods of complete absence in July and late October. An. farauti s.l. exhibited the greatest seasonality, with a peak in April and May and near to complete absence from October to December.

Discussion

Patterns of mosquito abundance

Standardised comparisons (Table 2) of the current survey with the 1986-87 survey of mosquitoes in the then proposed Barracks area should be interpreted with great caution because:

- both are annual surveys which may not reflect long-term trends;
- trap sites are not matched; and
- the impact of positioning 5 traps in close proximity is unknown.

In addition, there has been some alterations to
Figure 2. Time series (Oct. 2006 to Sept. 2007) of abundance for 6 mosquito species of management concern in five traps set weekly at each of Robertson Barracks and nearby Millner Creek.
drainage with the development of the Barracks, with some minor drainage of the seasonal freshwater swamp possibly contributing to the reduced numbers of An. bancroftii currently at the Barracks (Table 2). However, the abundance of Cx. annulirostris and Ma. uniformis has not changed to a marked degree, suggesting that the majority of numbers arose from both swamp areas in a similar manner over the 2 periods. The variation in Ae. vigilax numbers is expected due to variable trap times in relation to days after tidal flooding. The apparent doubling of abundance of An. farauti and Cq. xanthogaster may be partly due to bias, with more traps in more favourable locations in the current survey compared with the wider dispersal of traps in the previous survey.

Table 2. Summary comparison of trap rates of 6 mosquito species in 1986-87 and this study (2005-06). Rates are annual mean totals per trap; those for 1986-87 have been doubled to standardise from fortnightly to weekly trapping.

<table>
<thead>
<tr>
<th>Species</th>
<th>1986-87</th>
<th>2005-06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeodes vigilax</td>
<td>618</td>
<td>1,659</td>
</tr>
<tr>
<td>Anopheles bancroftii</td>
<td>3,602</td>
<td>980</td>
</tr>
<tr>
<td>Anopheles farauti s.l.</td>
<td>94</td>
<td>182</td>
</tr>
<tr>
<td>Coquillettidia xanthogaster</td>
<td>1,771</td>
<td>3,484</td>
</tr>
<tr>
<td>Culex annulirostris</td>
<td>9,951</td>
<td>8,401</td>
</tr>
<tr>
<td>Mansonia uniformis</td>
<td>620</td>
<td>758</td>
</tr>
</tbody>
</table>

The observed seasonal patterns are consistent with those previously reported for the Darwin region, perhaps reflecting the relative constancy from year to year in the seasonal structure of the region’s mosquito assemblage. They therefore provide a good basis for consideration of seasonal management responses.

The lower numbers of mosquitoes at Robertson Barracks compared with the Millner Swamp trap site at least partly reflects an attenuation with distance from the swamp. This is likely to be particularly true of Ma. uniformis and An. farauti s.l. The latter is a complex of at least 3 species in the NT, with a key local species strongly associated with brackish wetlands such as Millner Swamp. While some freshwater breeding sites of this species possibly occur closer to the Barracks and may include the seasonal open freshwater swamp to the west, they are more likely to occur in isolated pools at the edge of the densely forested Millner Creek immediately to the east that feeds into Millner Swamp. These possible freshwater sites are not likely to be as productive as the brackish water species breeding sites associated with Millner Swamp.

Ma. uniformis is closely associated with aquatic and semi-aquatic plants and is likely to be breeding in the permanent to semi-permanent habitats in Millner Swamp rather than the closer densely forested creek areas. This species is known to have a relatively short flight range, which is supported by the reduction in numbers at the Barracks and an origin from the swamp itself.

While Cx. annulirostris and Ae. vigilax are known to have relatively long flight ranges of up to and in excess of 10 km, and An. bancroftii and Cq. xanthogaster have moderate flight ranges in excess of 2 km, they are also known to have reduced numbers with distance from point sources, depending on the nature of the intervening distance. This study has shown a considerable reduction of Cx. annulirostris, Cq. xanthogaster, An. bancroftii and Ae. vigilax at the 2 km distance between the 2 trap positions. Although part of this reduction is probably due to the buffer effect of lights, people and buildings in the intervening area in the north section of the Barracks between the 2 trap positions, it is clear that there has also been a considerable reduction in numbers of these species with distance from the swamp to the Barracks.

The deep-water pits of the quarry between the
Barracks and Millner Swamp are unlikely to be appreciable breeding sites for mosquitoes because of the lack of marginal vegetation and the presence of fish, so these features need not be regarded as potential sources of mosquitoes or requiring rectification to maintain a buffer distance from the Swamp.

**Mosquitoes as pests**

The time of year when mosquitoes are a pest (nuisance) does not necessarily or completely coincide with the time when they pose a major risk as disease vectors. *Cq. xanthogaster* and *Cx. annulirostris* can be present at pest levels at the Barracks from July to September, but during this period they are generally not vectors of disease due to reduced longevity.7 *Ae. vigilax* is an appreciable pest mosquito usually starting later in the dry season from September to the end of January, although primarily up to November, but in December and January the species more frequently acts as a vector of RRV and BFV.3 Pest problems may occur at the Barracks throughout the year. During the wet season from November to April, *Ae. vigilax* and *Cx. annulirostris* are the principal pest species. *Cx. annulirostris* can be a particular pest problem from December to February after appreciable rain floods the wetlands, and also from April to June as formerly upright grass and reeds topple over and intertwine in the water as water levels decrease. These latter conditions reduce fish access in the wetlands, thus reducing predation on mosquito larvae. Pest numbers continue until the swamps progressively dry up. *An. bancroftii* can be an additional and appreciable pest problem from January to February but can continue to May. *An. farauti* does not constitute a pest problem at the Barracks, as their numbers never reach pest proportions. *Cq. xanthogaster* can be a pest in January and February and re-emerge as a pest in April to June. *Ma. uniformis* may occasionally be a pest problem at the Barracks in January but this will be rare unless dwellings are built closer to the swamp breeding sites, as it has a relatively short flight range.

**Mosquitoes as vectors of disease**

The malaria parasite completes its life cycle in anopheline mosquitoes, of which *An. farauti* s.l. is the major potential vector in the Top End of the NT.7 Malaria was endemic in northern Australia, but is no longer so, with the last local case being at Roper River in 1962.13 At least 2 outbreaks in northern Australia were the result of troops returning from overseas during and after the 2 world wars, with the outbreak during and after the second world war being a major and sustained one.14 Given the relatively high prevalence of *An. farauti* s.l. near Millner Swamp, the potential for introduced cases of malaria at the Barracks (local transmission following transmission from an imported case) through interaction between the mosquito and persons returning from endemic malaria areas overseas is real and of considerable public health concern. Despite its importance as a malaria vector, the flight distance of *An. farauti* s.l. is not well documented and interpretation is doubtless complicated by taxonomic uncertainties. However, the attenuation with distance from Millner Swamp observed in our data is consistent with a previous assessment that the effective flight distance is about 1.6 km.4 The results of collections of *An. farauti* s.l. at the Barracks points to the presence of potential breeding sites of possibly both fresh and brackish water species in sites associated with the dense forested creek as well as the brackish swamp. Our results emphasize that the risk associated with military personnel returning to Robertson Barracks from overseas malaria areas can be minimised by maintaining the maximum possible separation between Barracks accommodation and the Millner Creek and Swamp complex.

Endemic arboviruses are also a matter of public health concern. The NT has the highest attack rate in Australia for both RRV and BFV,15 with areas in the Darwin rural area, which includes rural residential suburbs around the Barracks, having a much higher rate than Palmerston or urban Darwin.16 The principal vectors of RRV and BFV in the Top End of the NT are *Ae. vigilax* and *Cx. annulirostris*, which are both in relatively high numbers seasonally at Millner Swamp.

The serious diseases caused by infection with the MVEV and Kunjin virus (KUNV) are of particular concern. While human cases are relatively rare compared to RRV disease, MVEV disease has a 25% mortality rate, and any local case can cause considerable concern to the public. NT Department of Health (DoH) has a regular mosquito monitoring program around
urban Darwin and, based on results of this monitoring, analysis of environmental factors, and sentinel chickens to detect the presence of MVEV and KUNV, advises the public of high risk periods. In the event of high risk situations and human infection, NT DoH issues public health warnings for people to take precautions to prevent mosquito exposure. In 2010 there was a case of KUNV encephalitis in the Howard Springs locality which is not far from the Barracks.17

Exotic arboviruses including chikungunya, Japanese encephalitis and dengue are also of concern, with the risk of either troops or equipment returning from overseas importing the viruses or, in the case of dengue, the dengue mosquito *Ae. aegypti*. Chikungunya in particular can be vectored by *Ae. vigilax*,18 and *Cx. annulirostris* is a potential vector of Japanese encephalitis virus.19

The greatest vector-borne disease potentials at the Barracks are infection with RRV and BFV by *Ae. vigilax* from December to January inclusive and by *Cx. annulirostris* from January to April inclusive, and infection with MVEV and KUNV by *Cx. annulirostris* from March to June.

**Management of mosquitoes at Robertson Barracks**

Barrier protection by bifenthrin applications is best programmed from the start of November and repeated every 4 weeks to June to cope with at first RRV and then seasonal MVE risks, as well as the expected almost continual pest problems. Where people are exposed to mosquito attack at night by being outdoors, applications can be by hand held sprayers to outside walls, screens and nearby low vegetation. In key areas, hedges of vegetation can be established and subsequently treated.

If the Department of Defence wishes to control the pest and disease potential risks more efficiently than the barrier applications allow, this could be achieved by aerial spraying of the Millner Swamp system in a program that is carefully targeted in both time and space. The Millner Swamp system is not included in the routine aerial mosquito control program of the DoH. This control cannot be routine but must be based on monitoring of both adult numbers and the presence of larvae with the latter after initiating events such as rain or tides or both. Areas to be targeted can be deduced partly from the vegetation types identified in 3 recent publications.20,21,22 Aerial control methods are detailed in DoH publications, where control has been achieved by periodic application of either *Bti* or methoprene products.

At expected times of seasonal occurrence of mosquito problems at the Barracks, detailed personal protection measures could be publicised, ranging from protective clothing, including permethrin impregnated clothing, to the use of personal insect repellents. In addition, protection can be enhanced by the use of mosquito lanterns and other new mosquito repellent devices.

In the course of transport links with north Queensland and overseas, the exotic mosquito vectors of dengue may be imported as eggs in water-filled containers, as has happened previously in Darwin.23 Institutions such as Robertson Barracks appear particularly vulnerable to this importation. To reduce this risk, it is recommended that an exotic mosquito surveillance and precautionary control program be established at the Barracks. This would involve periodic inspection of water-filled receptacles, preventative spraying with alpha-cypermethrin or lambda-cyhalothrin, annual clean-up of receptacles, and the establishment of sentinel ovitraps or sentinel tyres, and/or insecticide-treated adult mosquito control tyre stations.2,23

**Conclusion**

Because of its position in the landscape and the pattern of human movements, Robertson Barracks faces significant problems from mosquitoes as pests and as vectors of disease throughout the year. These require substantive action, including mosquito surveillance, control and personal protection, and could include an extensive, seasonal program of aerial control of mosquitoes in the nearby Millner Swamp.

**Acknowledgements**

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References


