Australian Government
Department of Health

COMMUNICABLE DISEASES INTELLIGENCE
2019 Volume 43
https://doi.org/10.33321/cdi.2019.43.17

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Communicable Diseases Intelligence
ISSN: 2209-6051 Online

This journal is indexed by Index Medicus and Medline.

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Original article

Dominance of the tiger: The displacement of *Aedes aegypti* by *Aedes albopictus* in parts of the Torres Strait, Australia

Mutizwa Odwell Muzari, Joseph Davis, Rodney Bellwood, Bruce Crunkhorn, Ewan Gunn, Ursula Sabatino, Richard Gair

Abstract

Most of the inhabited islands in the Torres Strait region of Australia have experienced dengue outbreaks transmitted by *Aedes aegypti* at various times since at least the 1890s. However, another potential dengue vector, *Aedes albopictus*, the Asian tiger mosquito, was detected for the first time in 2005 and it expanded across most of the Torres Strait within a few years. In 2016, a survey of container-inhabiting mosquitoes was conducted in all island communities and *Ae. aegypti* was undetectable on most of the islands which the species had previously occupied, and had been replaced by *Ae. albopictus*. It is suspected that competitive displacement was responsible for the changes in species distribution. *Aedes aegypti* was only detected on Boigu Island and Thursday Island. Recent dengue outbreaks in the Torres Strait have apparently been driven by both *Ae. albopictus* and *Ae. aegypti.* The findings have major implications on management of dengue outbreaks in the region.

Keywords: *Aedes albopictus*, *Aedes aegypti*, Torres Strait, surveillance

Introduction

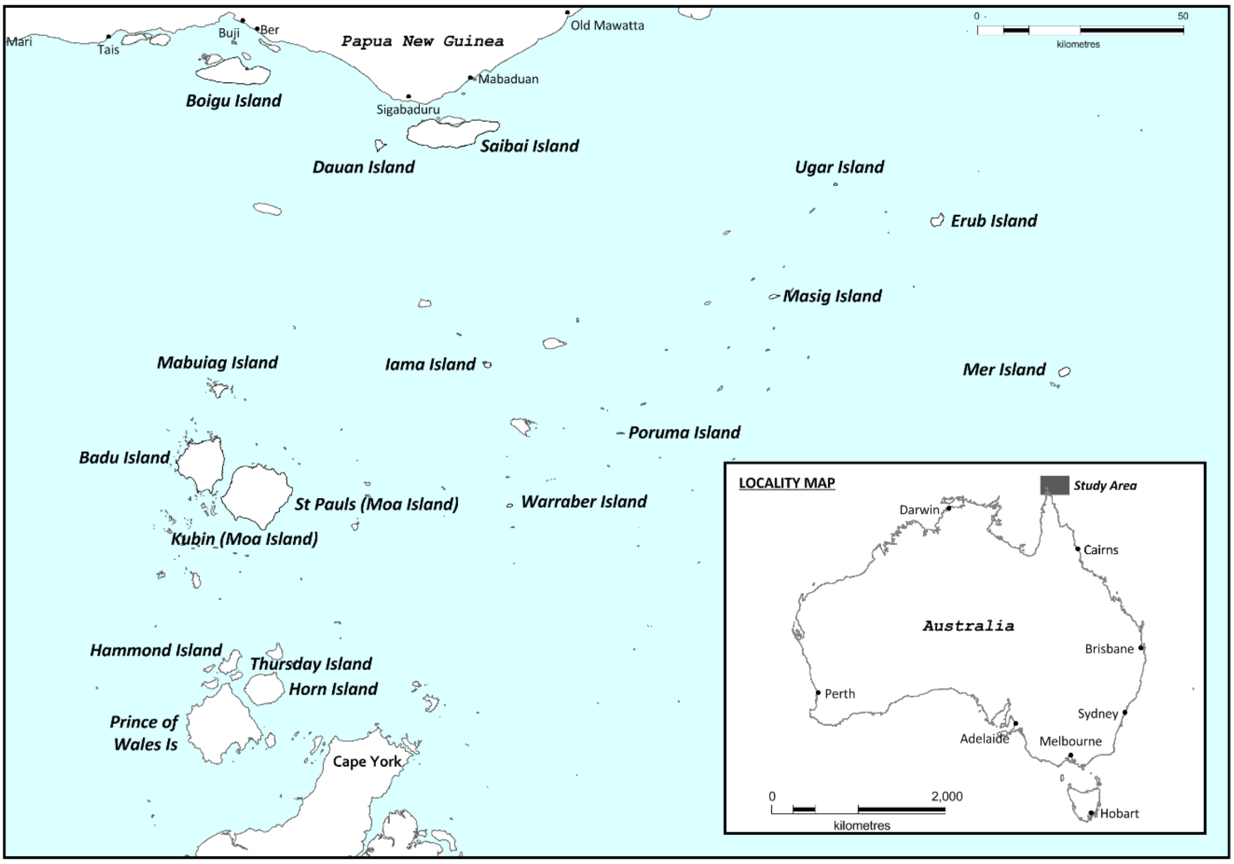
The Torres Strait in Queensland, Australia, separates the northernmost Australian mainland from the Western Province of Papua New Guinea (PNG) (Figure 1). The region has at least 100 islands of which 17 are inhabited, with a total population of approximately 8,000. Most of the islands have two names (Table 1) which can be used interchangeably.

Dengue outbreaks have been recorded in the Torres Strait since the 19th century, including many cases on Thursday Island in 1897[1] and on Mer and Erub islands in 1912.[2] In 1981-82 the islands of Masig, Iama, Badu and Thursday experienced a lengthy outbreak which also affected several cities on the Queensland mainland.[3] Other series of outbreaks occurred on various islands in 1996-97[4] and 2003-4.[5] Two Torres Strait residents died from the complications of severe dengue haemorrhagic fever in 2004.[6]All the dengue outbreaks during that time were attributed to the endemic vector *Aedes aegypti*.[2, 3,5,6]

In 2005 the Asian tiger mosquito, *Ae. albopictus,* was detected on Masig Island for the first time and this was followed by the discovery of a widespread infestation of this species on 10 of the 17 inhabited islands in the same year.[7] An eradication program was established but its impact was very limited.[8] *Aedes albopictus* spread rapidly across the Torres Strait, with subsequent detections on several more islands including Horn Island and Thursday Island by late 2010.[9]

Although *Ae. albopictus* was present in neighbouring Western Province of PNG,[10] genetic evidence suggested that the Torres Strait population may have originated from Indonesia, and the species' genetic structure in the region

Fig 1. The Torres Strait region showing the islands where surveys were conducted (bold letters).



tended to favour a dispersal pattern driven mostly by human movements.[11] *Aedes albopictus* is capable of transmitting dengue, Zika and Chikungunya[12-15] viruses among other viral infections.

As the proliferation of *Ae. albopictus* populations continued in the Torres Strait, there were suggestions, mostly based on anecdotal evidence, that *Ae. aegypti* was gradually disappearing from several of the outer islands.[16,17] However, there had been no comprehensive vector surveys on most of the outer islands since 2008 when the *Ae. albopictus* control program shifted focus to the 'inner islands' of Horn and Thursday as well as the Cape York Northern Peninsula Area on the mainland.[8] Meyer Steiger et al[18] briefly conducted adult mosquito trapping in 2013, but only covered four islands. Reliable information on the relative prevalence of *Ae. aegypti* and *Ae. albopictus* on the outer islands is essential when responding to disease outbreaks, because response strategies against *Ae. aegypti* and *Ae. albopictus* would have to be species-specific due to differences in behavioural ecology.[8]

To obtain this information, surveys of container-inhabiting mosquitoes were conducted in all Torres Strait island communities in March–May 2016 by the Cairns Tropical Public Health Services with support from Torres Strait Islands Regional Council and Torres & Cape Hospital and Health Services. This paper reports on those surveys and implications of the findings.

During the survey period in March 2016, there were dengue outbreaks simultaneously on Erub Island and Badu Island,[8] and later two more outbreaks in 2017 on Boigu and Masig islands. This paper also discusses the vector species incriminated in those outbreaks in relation to the findings from the vector prevalence surveys.

Table 1. Mosquito survey dates (2016) and demographic information of each island community in the Torres Strait[22]

Community	Population*	Number of dwellings*	Survey dates (2016)
Boigu	271	68	14 – 17 March
Dauan	191	44	22 March
Saibai	465	104	17 – 22 March
Mer / Murray	450	143	16 – 21 March
Erub/ Darnley	328	96	21 – 29 March
Moa (Kubin community)	198	73	4 – 9 April
Moa (St Pauls community)	248	71	2 – 7 April
Iama / Yam	319	80	10 – 13 May
Badu	813	223	22 March – 1 April
Ugar / Stephens	85	23	26 – 27 April
Warraber / Sue	245	62	25 – 29 April
Poruma / Coconut	167	59	27 – 30 April
Keriri / Hammond	268	78	14 – 15 April
Mabuiag	210	50	9 – 13 April
Masig / Yorke	270	73	18 – 25 April
Muralug / Prince of Wales	109	54	13 April
Ngurapai / Horn	531	178	11 – 12 April
Waiben / Thursday	2941	880	1 – 9 April

* 2016 Census data

Methods

Larval sampling

House to house yard inspections were conducted in all the island communities between March and May 2016 (Table 1) and all accessible potential larval habitats seen in the yard were checked for mosquito larvae. These included buckets, tyres, drums, tins, boats, plastic sheets, pot-plant bases, fallen palm fronds, coconut husks, garden tools and general rubbish items. Samples of 5-10 larvae were collected from each positive receptacle using a pipette or turkey baster and preserved in a vial with ethanol. To save time, larvae that were visually distinguishable as *Culex* spp. due to their characteristic movement pattern and distinctly long siphon, were not collected. Rainwater tanks were not inspected due to logistical considerations and the general abundance of alternative receptacles available in the wet season. Samples were transported to Cairns for identification.

Adult sampling

Sampling of adult mosquitoes was conducted with human-bait sweep-net collections[8] at selected sites on forest fringes along the edge of the community on Mer (11 sites), Erub (10 sites) and Saibai (11 sites). Selection of sites was targeted at the preferred habitats of adult *Ae. albopictus,* which are also the normal habitats of *Ae. scutellaris*. Adult sampling was not conducted on other islands due to time constraints.

Table 2. Number of receptacles with larvae of container-inhabiting *Aedes* mosquitoes identified from each island community in the Torres Strait during the surveys in March-May 2016.

Community	*Ae. aegypti*	*Ae. albopictus*	*Ae. scutellaris**	*Ae. notoscriptus*	*Ae. tremulus*
Boigu	26	0	9	0	0
Dauan	0	7	7	1	0
Saibai	0	0	4	0	1
Mer / Murray	0	146	27	0	0
Erub/ Darnley	0	62	3	0	0
Moa (Kubin community)	0	42	0	7	9
Moa (St Pauls community)	0	55	41	16	6
Iama / Yam	0	17	6	2	0
Badu	0	111	18	4	6
Ugar / Stephens	0	34	4	0	3
Warraber / Sue	0	86	5	0	4
Poruma / Coconut	1	84	6	0	1
Kiriri / Hammond	0	39	7	9	2
Mabuiag	0	40	5	4	4
Masig / Yorke	0	121	7	2	1
Muralug /Prince of Wales	0	15	2	4	6
Ngurapai / Horn	0	2	0	0	2
Waiben / Thursday	84	0	1	1	0

* Count of containers with Ae. scutellaris excludes any containers which may have had co-infestations with Ae. albopictus

Mosquito identification

Mosquitoes were identified by experienced officers using stereo microscopes. However, due to overlapping morphological features between larvae of *Ae. albopictus* and *Ae. scutellaris*,[19] larval samples suspected to be either of these species were submitted to Queensland Health Forensic and Scientific Services for identification using PCR methods.[20,21] Any such larvae originating from the same container in the field were homogenised together in the laboratory. However, the PCR molecular markers were set to detect the presence of *Ae. albopictus* only, as this was considered the main species of concern, and therefore any container in which *Ae. albopictus* was not detected in the test was inferred to be containing *Ae. scutellaris* only. On the other hand, a mixed larval sample would be classified as *Ae. albopictus*.

Results

The survey dates for each island are shown in Table 1, together with estimated size of each community. Results from larval sampling and identification are shown in Table 2.

Established populations of *Ae. aegypti* were only detected on Boigu and Thursday Island.

Aedes albopictus was detected on all the islands except Boigu, Saibai and Thursday Island, while *Ae. scutellaris* was found on all islands apart from Horn Island.

Adult mosquitoes collected with sweep-nets on Erub Island were identified as 179 *Ae. albopictus*, 4 *Ae. scutellaris*, 13 *Ae. vigilax* and 10 *Verrallina* sp. On Mer Island the collections had 93 *Ae. albopictus*, 29 *Ae. scutellaris*, 12 *Ae. vigilax* and 20 *Verrallina* sp. Saibai Island adult samples were 7 *Ae. vigilax*, 1 *Culex annulirostris* and 44 *Verallina* sp.

Discussion

Displacement of *Ae. aegypti* by *Ae. albopictus*

The surveys demonstrated that in 2016 *Ae. albopictus* was widespread and well-established among the Torres Strait islands, reflecting the species' progressive expansion since early detections in 2005-6. The results also confirmed the apparent disappearance of *Ae. aegypti* from most of the islands as the species was supposedly displaced by *Ae. albopictus*.

The widespread occurrence of the dengue vector *Ae. aegypti* in the Torres Strait was first documented by Taylor in 1912 after several epidemics of dengue were experienced on most of the islands in previous years,[2] and *Ae. aegypti* was reportedly still common on many islands as at 1980.[2]

In the 1990s, islands which had significant populations of *Ae. aegypti* include Erub, Masig, Poruma, Iama and Mer, all of which had "prolific breeding of *Ae. aegypti*" recorded during a dengue outbreak in 1996, with Breteau Indices of 73-219.[4] Samples of *Ae. aegypti* had also been collected on Mer Island in 2000 for vector competence studies[23] and again in 2002 during yard inspection surveys.[24] In the same year *Ae. aegypti* was detected in abundance during yard inspections on Erub Island.[24] Iama Island was also reported to have "large numbers of *Ae. aegypti* larvae" in 2003 during a dengue outbreak that resulted in 98 confirmed cases.[5] It is therefore interesting to note that by 2016 *Ae. aegypti* was undetectable on all these islands. The only confirmed disappearance of *Ae. aegypti* prior to the detection of *Ae. albopictus* in the Torres Strait was on Masig Island in 2002 where *Ae. aegypti* had been apparently displaced by *Ae. scutellaris*.[24] In contrast, the same year on Mer Island *Ae. aegypti* was prevalent in higher densities than *Ae. scutellaris*.[24] However, as at 2016, *Ae. albopictus* had become the most dominant container-inhabiting *Aedes* species on Masig and most other outer islands (Table 2).

It is unlikely that vector control interventions were responsible for the decimation of *Ae. aegypti* populations on any of these islands. Although vector control operations were conducted on the outer islands of the Torres Strait between 2005 and 2008 aiming to eliminate *Ae. albopictus*, the efforts had very limited impact and were eventually discontinued due to a wide range of logistical challenges including insufficient manpower to conduct adequate vector control.[8] The more plausible explanation for the widespread disappearance of *Ae. aegypti* could be the possible displacement by *Ae. albopictus* through inter-specific competition.

Similar cases of species displacement have occurred in parts of the United States of America, whereby a precipitous decline of *Ae. aegypti* population was observed after the arrival of *Ae. albopictus*.[25,26,27] Competition between the two species is said to occur primarily at the larval stage[28] where *Ae. albopictus* shows significantly greater survivorship especially in resource-limited conditions[29] and *Ae. aegypti* gets more severely affected when the larval density of *Ae. albopictus* increases.[30]

At the adult stage, the impact of *Ae. albopictus* on *Ae. aegypti* populations can occur through mating interference known as satyrization, whereby males of *Ae. albopictus* mate with females of *Ae. aegypti,* effectively sterilizing those females through the monogamizing actions of the male accessory gland products.[26,28] Therefore, the species displacement pattern noted in the Torres Strait may have been a result of a combination of processes in which *Ae. albopictus* was the superior competitor.

Presence of *Ae. aegypti* and *Ae. scutellaris*

During the 2016 survey, established populations of *Ae. aegypti* were found on only two islands, Thursday Island and Boigu Island, and it was interesting to note that both islands did not have detectable populations of *Ae. albopictus* at the time of the survey. The presence of *Ae. aegypti* on Boigu Island had been documented previously.[2,18]

On Thursday Island, the history of vector surveys and dengue outbreaks shows that the island has had high populations of *Ae. aegypti* for many years[3, 31] prior to the detections of *Ae. albopictus,* and still had notable densities recorded between 2010 and 2017.[8] Although Thursday Island was first invaded by *Ae. albopictus* in 2010-11, the population of this species was progressively suppressed to inconspicuous levels through an intensive and ongoing program targeting the adult resting sites and larval habitats of this species.[8] There would therefore have been no opportunity for the competitive displacement process to occur on Thursday Island in favour of *Ae. albopictus*. Surveys within the ongoing program on Thursday Island included adult mosquito sampling with sweep-nets.[8]

The intensive suppression program against *Ae. albopictus* on Thursday Island was also implemented concurrently on Horn Island since 2011, leading to very low levels of this species at the time of the April 2016 survey. Similarly, *Ae. aegypti* was at undetectable levels on Horn Island during the survey, although some detections have been recorded occasionally during ongoing regular surveys conducted there between 2010 and 2017.[8]

The non-detection of *Ae. aegypti* on Saibai Island was not surprising, given that the species had not been detected there in the various entomological surveys conducted in recent decades.[7,18,32,33] The island comprises largely of swampland and gets almost completely inundated with brackish water for lengthy periods during the spring tides and wet season. This possibly rules out ground-level and subterranean receptacles as potential breeding sites for *Ae. aegypti* as containers are contaminated by salt water that could kill or inhibit *Ae. aegypti* production. Similarly, *Ae. albopictus* had never been found on Saibai in any surveys after the initial invasion of other Torres Strait islands.[7,8] However, it is interesting that low populations of *Ae. scutellaris,* which is considered to exploit similar habitats as *Ae. albopictus,* appeared to have been thriving on the island for some time.[18,34] This may be due to *Ae. scutellaris* having a wider tolerance to salinity and water quality than *Ae. aegypti* [24] and possibly *Ae. albopictus*.

The surveys in 2016 showed that *Ae. scutellaris* was as widespread as *Ae. albopictus* across the Torres Strait (Table 2), albeit at lower densities. Despite the possible underestimation of *Ae. scutellaris* larval densities due to the molecular identification process, results of adult sampling on Erub and Mer islands confirmed that *Ae. albopictus* was by far the more dominant species. The two species are often found coexisting in larval habitats and as adults in their sylvatic habitats. *Aedes scutellaris* is endemic to the Torres Strait region, and it also occurs in northern parts of mainland Australia.[2, 35]

Aedes scutellaris was linked to dengue transmission at a locality in PNG in 1946[36] and, based on laboratory infection studies, *Ae. scutellaris* from the Torres Strait has been described as "a moderate vector" of dengue.[16] The species was suspected to have been responsible for at least one dengue case on Masig Island in 2004 (based on non-detection of other potential vectors on Masig at the time)[16] during a widespread outbreak that affected several islands in the Torres Strait.[5] However, retrospective molecular analysis of preserved mosquito specimens later suggested that *Ae. albopictus* may also have been present on Masig Island in 2004.[9] Consequently, not much is known about the importance of *Ae. scutellaris* in outbreaks of mosquito-borne diseases in Australia.[35]

The distribution pattern of *Aedes* species observed on the outer islands in this larval survey (Table 2) was comparable to the findings of Meyer Steiger *et al*[18] from adult mosquito surveys conducted on four islands with carbon dioxide-baited Passive Box Traps in January-April 2013. They found *Ae. aegypti* on Boigu Island but did not detect the species on Saibai, Badu and Moa. They also found *Ae. albopictus* on Badu and Moa but did not find it on Boigu and Saibai. Furthermore, *Ae. scutellaris* was detected on all four islands surveyed in 2013 just as it was detected in 2016. This suggests that the species distribution pattern observed in 2016 had probably persisted that way for several years prior.

Dengue outbreaks in the Torres Strait in 2016-2017

The Torres Strait region experienced a series of dengue outbreaks in 2016–2017 after absence of local transmission for at least a decade. There were 18 confirmed cases on Erub Island (Feb–March 2016), one case on Badu Island (March 2016), six cases on Boigu Island (Dec 2016–Jan 2017) and one case on Masig Island (March 2017).

Based on the vector species present (Table 2), the outbreaks on Erub, Badu and Masig islands were attributed to *Ae. albopictus*, whereas *Ae. aegypti* was incriminated for the outbreak on Boigu Island. Furthermore, intervention strategies targeting *Ae. albopictus* (i.e. residual spraying of fringing vegetation) resulted in immediate cessation of transmission on Erub, Badu and Masig islands.[8] On the other hand, interior residual spraying targeting *Ae. aegypti* on Boigu Island was equally successful in preventing further cases.

Based on the findings, it is now clear that any vector management efforts for prevention or control of dengue, Zika or Chikungunya in the Torres Strait should be targeting *Ae albopictus* with an emphasis on outdoor residual spraying, except on Boigu and Thursday Island where significant population of *Ae. aegypti* exist. However, periodic monitoring of the vector species prevalence is required since the situation may change over time.

Acknowledgements

We wish to thank all those involved in various ways to support, facilitate and conduct the surveys: the staff of Torres Strait Island Regional Council, Torres Shire Council, Torres Strait Regional Authority and Queensland Health. Thanks to Peter Horne for assistance with mapping.

Funding for the study was provided by Queensland Health as well as Commonwealth Department of Health through the National Partnership on the Torres Strait Health Protection Strategy.

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