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Ten years of the Tiger: *Aedes albopictus* presence in Australia since its discovery in the Torres Strait in 2005

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A B S T R A C T

The "Asian tiger mosquito", *Aedes albopictus*, is highly invasive, an aggressive biter and a major arbovirus vector. It is not currently present on mainland Australia despite being intercepted on numerous occasions at international ports and infesting the Torres Strait of Australia since at least 2004. In the current paper, we describe the invasion and current status of *Ae. albopictus* in the Torres Strait, as well as research conducted to assess the threat of this species becoming established in arbovirus transmission cycles on the Australian mainland. Genetic analysis of the invading population demonstrated that the Indonesian region was the likely origin of the invasion and not Papua New Guinea (PNG) as initially suspected. There was also intermixing between Torres Strait, PNG and Indonesian populations, indicating that the species could be re-introduced into the Torres Strait compromising any successful eradication programme. Vector competence experiments with endemic and exotic viruses revealed that *Ae. albopictus* from the Torres Strait are efficient alphavirus vectors, but less efficient flavivirus vectors. *Ae. albopictus* obtains blood meals from a range of vertebrate hosts (including humans), indicating that it could play a role in both zoonotic and human-mosquito arbovirus transmission cycles in Australia. Predictive models coupled with climate tolerance experiments suggest that a Torres Strait strain of *Ae. albopictus* could colonise southern Australia by overwintering in the egg stage before proliferating in the warmer months. Cohabitation experiments demonstrated that the presence of *Aedes notoscriptus* larvae in containers would not prevent the establishment of *Ae. albopictus*. Evidence from these studies, coupled with global experience suggests that we need to be prepared for the imminent invasion of Australia by *Ae. albopictus* by thoroughly understanding its biology and being willing to embrace emerging control technologies.

Contents

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Aedes albopictus as an invasive species

The "Asian tiger mosquito", *Aedes albopictus*, is a notorious pest mosquito that is a competent laboratory vector of at least 22 arboviruses and a major vector of dengue (DENVs) and chikungunya (CHIKV) viruses [1,2]. It is a highly invasive species, which has expanded its geographical range from Southeast Asia and India to include North and South America, Europe, Africa and the Pacific region in the past three decades [3]. *Ae. albopictus* lays desiccation resistant eggs in both natural and man-made containers, which has helped facilitate the rapid movement of this species both within and between countries [4]. An example of its ability to rapidly colonise new locations occurred in the USA where, within two years of its introduction into Texas in 1985, it had spread to 15 states [5]. There has been considerable research conducted on *Ae. albopictus*, both in its native region of Southeast Asia and in areas where it has recently colonized, such as the USA, Brazil and parts of Europe (reviewed by [1,6,7]).

The expansion of *Ae. albopictus* into Australia was first recognized in 2005, when established populations were identified in the Torres Strait, the region that separates mainland Australia from Papua New Guinea (PNG) [8]. Because *Ae. albopictus* is only a recent addition to the mosquito fauna of Australia, there had been no research conducted into the ecology and potential disease risk of this species in the Australian context. Thus, we have been in the unique position where we have been able to study an emerging arbovirus vector before it invades and colonises mainland Australia. In the current paper we outline the discovery and status of *Ae. albopictus*, as well as research that has been conducted in the last 10 years to assess the factors that may influence the colonization and proliferation of this species, and its potential role in arbovirus transmission cycles in Australia. It is important to note that research on *Ae. albopictus* in Australia is restricted in its scope by regulatory requirements necessitating high level containment facilities on the mainland. Field work is limited to the Torres Strait, where it can be prohibitively expensive and logistically difficult to conduct, due to its geographic isolation, being approximately 800 km from the nearest mainland city of Cairns.

Ae. albopictus invades Australia

The risk of introduction and establishment of *Ae. albopictus* in Australia has been recognized for a number of years and has resulted in the implementation of quarantine procedures to detect incursions [9]. Between 1997 and 2005, there were at least 28 detections of *Ae. albopictus* by the then Australian Quarantine and Inspection Service at international seaports including Darwin, Cairns, Townsville, Brisbane, Sydney and Melbourne [10], but there was no evidence that the species had become established. In April 2005, ovitrap collections were undertaken on Masig Island in the Torres Strait (Fig. 1) to collect *Aedes scutellaris* for DENV type 2 transmission experiments [11]. During the collection trip, Biogents sentinel traps (BGS) were opportunistically deployed on the island. Unexpectedly, 42 out of 44 adult mosquitoes collected using BGS were identified as *Ae. albopictus*, with the remaining two being *Ae. scutellaris* [8]. Furthermore, when the ovitrap collections were hatched, 69% of adults were identified as *Ae. albopictus*. This discovery was surprising, as this species had never been detected during previous surveys conducted on the island, including during a dengue outbreak in 2004 [12], or on any other Torres Strait island [13]. This was despite the species being present in the villages of the Fly River region of southern PNG since at least the late 1980s [9,14]. Retrospective analysis of the Masig Is specimens collected in 2004 using a newly developed molecular diagnostic assay [15] suggested that *Ae. albopictus* was present in low numbers [8]. A delimiting survey was subsequently conducted in 2005 across the 17 inhabited islands of the Torres Strait and communities of the Northern Peninsula Area (NPA), revealing that the incursion of *Ae. albopictus* was widespread, being present on 10 islands, although not in the mainland communities [8].

In response to this alarming discovery, a strategy was initiated during the 2005–2006 wet season, with the primary objective of eliminating *Ae. albopictus* from the Torres Strait. This *Ae. albopictus* Eradication Programme has cost approximately $750,000 per annum with the funding provided by the Commonwealth Government Department of Health and Ageing [16]. This programme initially consisted of a) a surveillance component, which utilized container surveys and human bait sweep net collections to characterise the *Ae. albopictus* populations; and b) a control component which relied on elimination of larval containers, by removing or treating them with λ-cyhalothrin, a residual pyrethroid insecticide, or treatment of fixed containers, such as rainwater tanks or wells, with *s*-methoprene, an insect growth regulator. The λ-cyhalothrin (25 g/L active ingredient (a.i.); Demand® Insecticide, Syngenta Crop Protection, North Ryde, Australia) was diluted at label rate of 16 ml/L of water and sprayed almost to the point of runoff on targeted surfaces. The *s*-methoprene was applied to smaller containers as pellets (40 g/kg a.i.; ProLink® Pellets Mosquito Growth Regulator, Wellmark International, USA), at a rate of 1 pellet/L of estimated container volume. Larger containers, such as rainwater tanks and wells, were treated with ProLink® XR Briquets (18 g/kg a.i.) applied at 1 briquet/5000 L water.

Although some success was achieved in reducing populations on some islands, a combination of logistical issues with operating in remote locations, and a demonstrated risk of re-invasion (see below), suggested that a change in strategy was required. Consequently, in 2008, the programme changed from a focus on eradication to one of containment, whereby a *cordon sanitaire* approach was enabled on the inner islands of Thursday (Waiben) Is and Horn (Ngurapai) Is. These islands represent the primary administrative centers and the transport hubs to both the outer islands and onto mainland Australia, which had up until that point, remained free of *Ae. albopictus*.

Intensive control activities mainly targeting larval habitats were unable to keep *Ae. albopictus* off these inner islands, as it was discovered on Horn and Thursday Islands in 2010. Consequently, the surveillance and control methodologies utilized on Thursday and Horn Islands were augmented with the deployment of lethal tyre piles and harbourage spraying. The lethal tyre pile consists of 7–9 water-filled tyres treated with λ-cyhalothrin and *s*-methoprene pellets at the rates described above, to which female *Ae. albopictus* are attracted and come into contact with the insecticide. Harbourage spraying involves treating foliage and leaf litter in shaded areas with λ-cyhalothrin as described above with the objective of killing *Ae. albopictus* adults where they preferentially rest [17]. This strategy appears to have been extremely successful, with the number of positive human bait collection sites reduced from >20 sites on each island per visit in the first year of discovery to <5 sites in later visits.

In addition to the programme on the inner islands of the Torres Strait, a comprehensive surveillance system was implemented on the Australian mainland. This involved regular surveys in the communities of the NPA (Fig. 1) and a network of adult surveillance traps focussing on high risk areas, such as the seaport and airport, in Cairns, the main destination of sea and air traffic from the Torres Strait. In March 2009, *Ae. albopictus* was detected in one larval site on the NPA, triggering intensive vector control operations. Subsequent surveys provided no