Mosquitoes and disease in Australia, what does the future hold?

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Australia has a history of mosquito-borne disease, with historic accounts of endemic malaria, filariasis and dengue during the 19th and early 20th centuries. Bancroftian filariasis, once relatively prevalent in Queensland, has been eliminated and malaria was declared eradicated from Australia in 1981. However, the endemic flaviruses Murray Valley encephalitis and Kunjin and the alphaviruses Ross River and Barmah Forest, which cause encephalitic and polyarthritic syndromes, respectively, continue to be active. Dengue, although no longer considered endemic, is an ongoing issue for Queensland and exotics such as Japanese encephalitis, chikungunya, West Nile and Rift Valley Fever viruses provide some cause for concern with respect to their possible introduction. Further, climate change has been proposed as likely to bring increased distribution and abundance of vectors and diseases, although regional, rural and residential development may be as much or more important. The various pathogens and the diseases they cause have to be viewed in their particular ecological contexts for a proper understanding of what the future might hold and how we will need to deal with the potential public health issues.

What risks do we face with regard to exotic mosquito-borne pathogens (the malarias and dengue, Rift Valley, chikungunya and West Nile viruses)?

Malaria activity may well increase in the future in the neighbouring countries of Southeast Asia and Melanesia, associated with breakdowns in anti-malaria programs, due to drug and insecticide resistance and logistical difficulties, and this could lead to increased importations of *Plasmodium* parasites in travellers. The essentially 'northern and northeastern coastal' distribution of *Anopheles farauti* (the 'so-called' Australia malaria

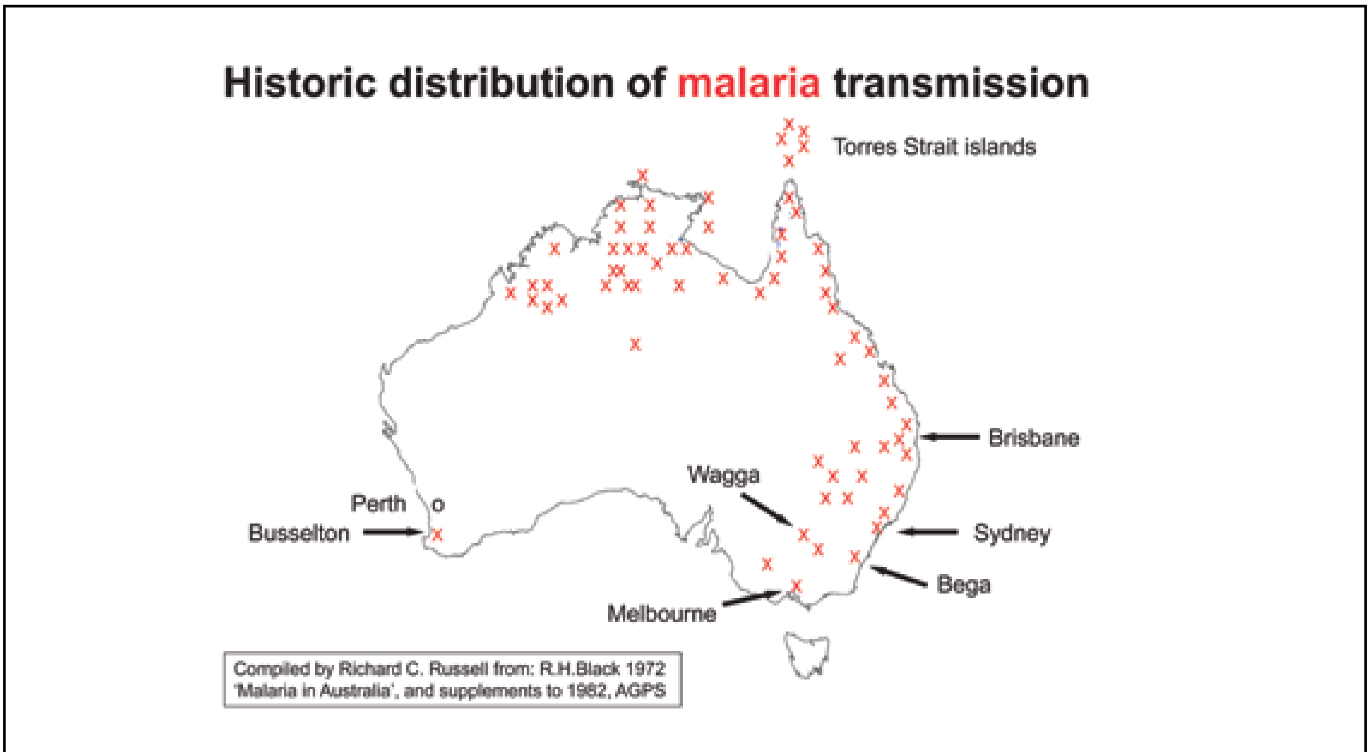

Figure 1. Approximate distribution of known cases of local transmission of malaria in Australia since 1900 and the vectors *Anopheles farauti* sl. and *An. annulipes* sl.

mosquito) may extend somewhat further south with climate change warming [1]. Historically, there has been widespread transmission of malaria in Australia as far south as Melbourne in the east and below Perth in the west (Figure 1), well beyond the current or projected distribution of *An. farauti* and demonstrating that other vectors exist (for example within the *Anopheles annulipes* complex), which could in the future transmit malaria widely in Australia [2]. More specifically, increased malaria transmission in Papua New Guinea is highly likely for various reasons and could bring a significantly increased risk for far northern Queensland and the Top End of the Northern Territory, where populations of *Anopheles* species vectors are relatively more abundant and in closer association with human communities. However, while such threats underline the need for continued vigilance on the part of health authorities, there is little chance that malaria could become re-established in Australia given the continuing effectiveness of our health services.

Dengue viruses have shown increased activity associated with increasing urbanisation and travel between developing countries, particularly in our neighbouring regions. In the future, we are likely to see an increase in imported cases to Australia and while local transmission can occur only in Queensland and only where the vector *Aedes aegypti* exists, those infected travellers arriving in Torres Strait communities and northern Queensland centres such as Cairns and Townsville (where there are substantial populations of *Ae. aegypti)* are likely to continue initiating outbreaks of disease (as have happened almost annually on a greater or lesser scale since 1990, despite improved disease management programs [3]), which have resulted in deaths [4]. The recurring question as to whether this will inevitably lead to endemicity might be considered somewhat academic, given that annual activity from imported infections occurs anyway, but there must be an increasing risk of the more severe haemorrhagic form of the disease occurring as antibodies to the different serotypes continue to become more prevalent in local communities. Additionally, the recent establishment of the secondary dengue vector *Aedes albopictus* in the Torres Strait islands and the consequent potential for introduction to the mainland, presents a serious risk for southern Australia as this exotic species has a demonstrated capacity to spread to cool temperate regions and thus provide a vector for dengue viruses in our major southern urban centres where none currently exists [5]. However, despite projections of increases in *Ae. aegypti* and dengue distribution as far south as Sydney associated with climate warming [6], since the current distribution of the vector in Queensland is seemingly not limited by current climate conditions, given the historic distribution of the vector in eastern and western Australia and transmission of dengue as far south as Carnarvon in WA and Gosford in NSW (Figure 2), there is nothing to indicate that there will be such an extension of these distributions in Australia directly related to increases in temperature [7].

Japanese encephalitis virus (JEV) appeared in Australian territory in 1995, with wide-ranging infections and two deaths in the Torres Strait islands. The virus presumably was introduced from New Guinea and there is evidence that it has remained annually active in the Torres Strait region, although the major

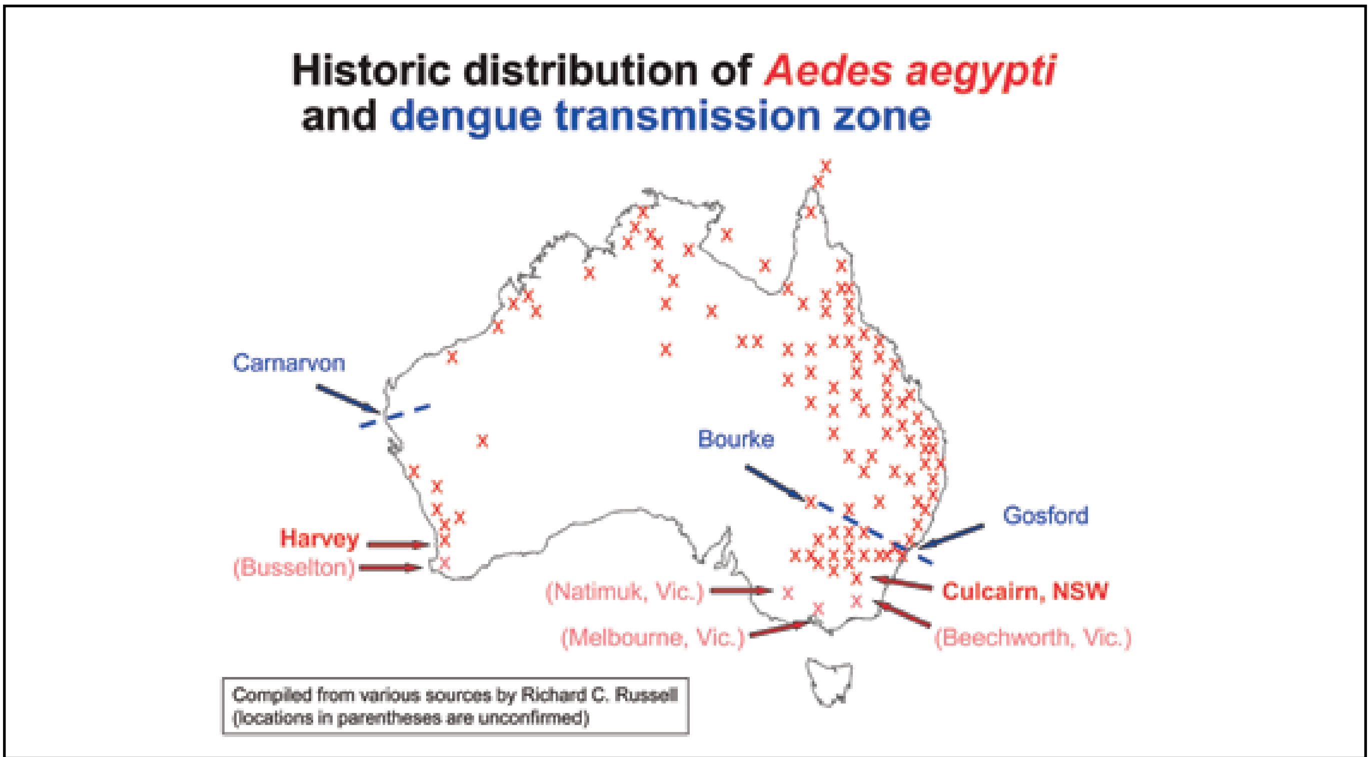

Figure 2. Approximate known distribution of *Aedes aegypti* from historic records (those in lighter colour and parentheses are unconfirmed reports for Vic. and WA).

vaccination campaign that followed its introduction appears to have prevented ongoing cases in the human populations [8]. While initially there was much concern that JEV would become established on the mainland and move south via the wading bird and feral pig populations to provide both veterinary and human health risks, this has not occurred and the reasons for this are unclear. There have been various speculations about the role of 'diversionary hosts' for the vectors (with local macropods being preferred to pigs as blood sources), 'protective immunity' in the vertebrate hosts (from other local flaviviruses such as Murray Valley encephalitis, Kunjin and Kokobera viruses) and 'variable infection competence' in vector populations (as some *Culex annulirostris* populations south of the Torres region are of a different genetic lineage and may not be able to maintain virus transmission [9]).

Rift Valley virus *(RVV)* is a zoonotic bunyavirus that primarily affects livestock animals, such as sheep, goats and cattle, but can affect humans and it can cause severe disease resulting in death in both livestock and humans. We know that a range of common local species (including *Aedes notoscriptus, Aedes vigilax, Culex annulirostris* and *Culex quinquefasciatus)* are susceptible to infection with and able to transmit RVV [10], so if the virus were to be imported from its endemic regions in east Africa, or via the occasional epidemics arising elsewhere, there would be a major concern for the animal husbandry industry and a lesser but significant concern for human health.

Chikungunya virus (CHIKV) is an alphavirus that causes symptoms that may be confused with dengue (fever, headache, arthralgia, myalgia and rash), but serious complications are uncommon except in elderly people. The virus has recently gained an increased profile with ongoing low-level activity in regions of Southeast Asia in recent years, following well-publicised major outbreaks in Indian Ocean islands off the coast of Africa and also in India during 2005-07 and an outbreak in Europe following an introduction to Italy in 2007 [11]. The risks for importation of this virus to Australia are seemingly greatest from Southeast Asia and are similar to those for the dengue viruses. The threats of local transmission relate to the presence of local mosquitoes that could act as vectors of CHIKV and recent research has shown that while Australian populations of *Ae. aegypti* and *Ae. albopictus* are highly susceptible to infection and readily transmit the virus, several other local species, particularly *Aedes vigilax, Aedes procax, Coquillettidia linealis* and perhaps *Aedes notoscriptus,* are competent laboratory vectors of CHIKV and possibly capable of facilitating an outbreak [12].

West Nile virus (WNV), which has become established in and across the USA since it was imported in 1999, has been touted as a potential exotic introduction to Australia and has therefore received some research attention as to potential local vertebrate reservoirs and mosquito vectors. Although research into likely local bird reservoirs has been limited, there is nothing to indicate a particularly high risk; however, some common Australian *Culex* mosquitoes (including *Culex annulirostris* and *Culex quinquefasciatus)* have been shown to be highly competent for transmitting WNV and some of our *Aedes* species (including *Aedes notoscriptus, Aedes procax* and *Aedes vigilax)* are also susceptible to infection, thus possibly being able to facilitate local transmission should WNV be introduced [13]. Questions on whether WNV could become established in Australian regions in the geographical presence of the closely related Kunjin virus (KUNV), whose antibodies can protect against WNV [14], have been asked but not yet fully answered and the greatest threat would be in eastern coastal regions where KUNV appears to be not active [15].

What is the likely future for activity of our endemic mosquito-borne pathogens (Ross River and Barmah Forest viruses, Murray Valley encephalitis and Kunjin viruses) and what of the possible impacts of the climate change scenarios projected for Australia?

Unfortunately, there is a widely-held and misinformed view within the general Australian community that climate change is necessarily going to bring an increased distribution and incidence of mosquito-borne disease. However, from a dispassionate recognition that projected climate change involving increases in temperature and sea-level, but either increased or decreased rainfall, will be significantly different in different parts of Australia[16, 17], it should be obvious that it is not possible to provide one-size-fits-all predictions, or other generalisations, regarding the future of mosquito-borne disease in Australia. Other than any possible impacts of climate change on mosquito populations, the potential influences on the various vertebrate hosts involved in the natural virus cycles must also be seriously considered. Further, future activity in many regions will be influenced, as much if not more, by issues related to rural and urban developments that bring people into greater contact with the vectors and zoonotic pathogens. For example, via mining and other industrial activities in northern Australia, the provision of irrigated agriculture in both northern and southern regions, the restoration of natural wetlands in major river systems, the construction of urban wetlands for storm- and waste-water management and the establishment of residential developments in coastal estuarine areas with extensive salt marsh habitats.

Ross River virus (RRV), an alphavirus that causes more morbidity than other arboviruses in Australia, with symptoms of fever, rash and polyarthritis, has a spectrum of ecological epidemiologies based around the nature of its different local vectors in the various tropical and temperate coastal and inland regions of Australia [18]. Related to its vertebrate macropod host distributions, there are differences in isolates and strains of RRV throughout Australia, possibly with different clinical pictures and outcomes and future environmental circumstances may favour some more than others.

Barmah Forest virus (BFV) is also an alphavirus, sharing many of its vector species with RRV, but with activity periods that do not necessarily coincide with those of RRV and thus indicative of differences in natural histories. That its native vertebrate hosts remain unknown has prevented a better understanding of what initiates and drives outbreaks of BFV. These two alphaviruses have such complicated epidemiologies, which are driven by different mosquito vector species in different ecological situations. The task of predicting the impact of changes in temperature, rainfall and sea-level is near to impossible – given also that the impact of these climatic changes on the populations of the vertebrate hosts has also to be considered; however, it's likely that the predicted year-round decreases in rainfall in southwest Western Australia may well reduce virus activity in that region, while predicted increases in summer rainfall in northeastern New South Wales and southeastern Queensland may result in increases in current activity of both viruses and hotter conditions with lower humidities in inland southeastern Australia may bring reduced activity by reducing adult mosquito longevity and thus transmission potential [2].

Murray Valley encephalitis virus (MVEV) is our most serious public health arbovirus, inasmuch as it has a high rate of mortality associated with clinical infection (although, fortunately, the clinical infection rate is very low). MVEV is associated with wetland wading birds and is endemic in northern Australia, particularly northern Western Australia, while occasional major epidemics have occurred in the Murray Darling River systems of the southeast [19]. However, the substantial adverse changes that have occurred in the wetlands in these southeastern systems may mean that river flood plains and associated habitats might never again provide for the bird and mosquito breeding that previously brought extensive activity of MVEV. KUNV, with a similar ecology to MVEV, is likely to be influenced by similar conditions pertaining to bird and mosquito populations in its endemic zone in northern Western Australia. However, KUNV is active more widely and more often than MVEV in southeastern Australia, although the above-mentioned concerns for the viability of local wetlands therein may be a limiting factor also for KUNV. It is difficult to assess the future climate-related risks related to MVEV and KUNV activity. For instance, predictions of wetter conditions in the northern endemic zones, particularly in northern Western Australia, could lead to enhanced activity of bird hosts and mosquito vectors in the Kimberley and greater risk of the virus extending south to the Pilbara and beyond (and those non-immune persons drawn to the region for employment or as tourists may encounter increased risks of infection) but, by the same token, predictions of drier conditions in the southeast of Australia (where greater human populations occur and previous major outbreaks have arisen), could be expected to militate against initiation and extension of such flavivirus activity [2].

Conclusion

Australia will have to continue to deal with mosquito-borne disease, at least in the foreseeable future and particularly with regard to DENV, RRV and BFV. What impacts new rural and urban developments, as well as any changes in climatic conditions, will have on the interactions between hosts, vectors and humans that lead to infection and potentially disease, will govern the outcomes for individual and public health, but the health services authorities will have to remain vigilant and responsive if major outbreaks are to be prevented or contained.

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