

## Chikungunya Virus: A Novel and Potentially Serious Threat to New Zealand and the South Pacific Islands

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**Abstract.** There has never been a locally transmitted outbreak of mosquito-borne disease in New Zealand, but the risk of an outbreak occurring is increasing with on-going interceptions of exotic mosquito vectors across its border, increasing traffic of goods and passengers, higher numbers of viremic travelers arriving, and local, regional, and global environmental change. The risk posed to New Zealand by chikungunya virus is potentially high because of the transmissibility of this virus in subtropical climates, compounded by a population that is predominantly immunologically naive to exotic arboviruses. However, risk reduction in New Zealand should not be considered in isolation but must be viewed within a wider South Pacific context. In this report, we discuss the potential threat posed by chikungunya to the region, focusing in particular on New Zealand, and re-emphasizing the need for a South Pacific-wide approach towards mosquito-borne disease prevention.

### INTRODUCTION

Chikungunya virus (CHIKV) (family *Togaviridae*, genus *Alphavirus*) is an arbovirus that appears to be endemic to several countries in Africa and in India and parts of Southeast Asia.<sup>1</sup> It was first described in Tanganyika (now Tanzania) in the 1950s, but it has recently been re-emerging and emerging as an infectious disease of increasing international concern,<sup>2</sup> particularly since the large outbreak on the Island of La Réunion in 2006, which had more than 250,000 reported cases that affected more than one-third of the population.<sup>3,4</sup>

Chikungunya has been primarily transmitted by *Aedes* spp. mosquitoes,<sup>5</sup> but the Asian tiger mosquito *Aedes albopictus* was the main vector involved in the La Réunion outbreak. *Aedes albopictus* mosquitoes have since been shown to be highly competent vectors of CHIKV,<sup>1,6</sup> and it appears that the virus has mutated and consequently adapted to *Ae. albopictus* mosquitoes resulting in improved viral replication and transmission efficiency.<sup>7–9</sup> It was shown that a single mutation can increase the range of vectors and hosts of this virus, resulting in greater geographic distribution and establishment in new areas.<sup>9</sup>

In 2007, Italy registered the first CHIKV outbreak autochthonously transmitted in Europe.<sup>10</sup> One of the striking factors of this outbreak was that it seemed to have started with a viremic traveler who spent only a few hours in a village with an immunologically naive population.<sup>10</sup> Since the epidemic in La Réunion and the subsequent outbreak in Italy, there is greater interest in CHIKV in Europe and the United States.<sup>2</sup> In France, a major shift in interest occurred when it was realized that the risk to metropolitan France was real, as opposed to confined to its tropical departments (former colonies).<sup>11</sup> In official reports about the epidemic, the concept of a protective metropolitan French climate was abandoned, the need for whole-of-society involvement in control measures became accepted, and symptoms were increasingly described in terms more accessible to the public.<sup>11</sup> The abundance of *Ae. albopictus* mosquitoes in Europe and the United States, together with the evidence for CHIKV adaptation to

this new vector, has considerably extended the number of areas around the globe at risk from CHIKV outbreaks. Many other countries, including those in the South Pacific, should thus heed the lessons learned in France and respond to the risk posed by CHIKV with proactive rather than reactive public health interventions.

With the global toll of CHIKV nearly two million cases in 2006 alone,<sup>4</sup> CHIKV has gained notoriety as one of the emerging pathogens of greatest concern,<sup>2,4</sup> particularly because it poses a threat to temperate regions. Furthermore, concern has recently arisen because of severe forms of CHIKV infection that were previously unrecorded, including encephalopathy and numerous deaths.<sup>12,13</sup> Studies have also shown that CHIKV can be vertically transmitted from mother to fetus, leading to severe neonatal infection,<sup>3,14</sup> and likely fetal death in early gestation.<sup>15</sup>

### NEW ZEALAND

New Zealand has a relatively poor mosquito fauna, with only 12 native and 4 introduced mosquito species (Table 1).<sup>16</sup> One of the latter being targeted by a current eradication program. All introduced mosquitoes are potential disease vectors, and at least 30 other exotic culicid species have been intercepted at national entry ports.<sup>16,17</sup> Although to date there has not been a confirmed indigenously acquired arboviral infection in humans in New Zealand,<sup>18</sup> it is predicted that it is just a matter of time before an arboviral outbreak occurs.<sup>19</sup> Fortunately, neither *Ae. aegypti* nor *Ae. albopictus* mosquitoes (the two main vectors of CHIKV worldwide) are present in the country, and based on the published literature, few of the established species are of potential concern (Table 1).

As a result of the evolutionary history of New Zealand and the consequent absence of indigenous terrestrial mammals (other than three bat species), native mosquitoes appear to be primarily ornithophilic (bird feeders). There is little experimental evidence on their feeding preferences,<sup>20</sup> although some species have been reported to bite humans (Table 1).<sup>21</sup> Overall, however, most native species would unlikely be of concern as vectors for CHIKV, but an exception may be *Coquillettidia iracunda* mosquitoes (Table 1), which are aggressive biters that are readily attracted to humans.<sup>21</sup> This species is known to produce high densities seasonally, and is abundant throughout

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TABLE 1  
Mosquito species present in New Zealand and their potential significance as vectors of chikungunya virus on the basis of available evidence

Species	Potential chikungunya virus vector status*	Comments
Native		
<i>Aedes antipodensis</i>	1	Widespread, and although it may bite humans, it does not appear to be anthropophilic.
<i>Aedes chatamensis</i>	0	Recorded indoors and appears to bite humans. However, it seems to be restricted to the Chatham Islands, <sup>41</sup> where the cooler climate and its breeding habitats (probably saline pools) likely rules it out as a species of concern.
<i>Aedes subalbirostris</i>	0	Its distribution is restricted to southeastern South Island, <sup>42</sup> and it seems to only rarely bite humans.
<i>Coquillettidia iracunda</i>	10	Aggressive biter that is common in and around native forests, and it is closely related to an efficient laboratory vector of chikungunya virus.
<i>Coquillettidia tenuipalpis</i>	1	Although widespread, this species is rarely recorded biting humans. <sup>43</sup>
<i>Culex astelliae</i>	0	Adults have only recently been collected in the field, <sup>44</sup> and it most likely feeds only on birds.
<i>Culex pervigilans</i>	1	The most common and widespread mosquito in New Zealand, but which seems to be primarily ornithophilic and is rarely recorded biting humans. In addition, <i>Culex</i> spp. are poor vectors for chikungunya virus. <sup>5</sup>
<i>Culex rotoruae</i>	0	It has a restricted distribution (geothermal pools), and its host range is unknown. <sup>45</sup>
<i>Culiseta novaezelandiae</i>	0	It is a rare species, whose hosts are still unknown and most likely to be birds. <sup>45</sup>
<i>Culiseta tonnoiri</i>	5	This species is a vector of Whataroa virus that infects birds, <sup>46</sup> and it appears to have a wide range of mammalian hosts, including humans. <sup>45,47</sup>
<i>Maorigoeldia argyropus</i>	0	This species does not seem to take blood meals. There are no records of this species in CO <sub>2</sub> -baited traps or actively biting a host, and attempts to induce blood feeding in laboratory conditions have failed. <sup>48,49</sup>
<i>Opifex fuscus</i>	1	Although it seems to readily bite humans, it occupies primarily saline rock pools on coastal habitats <sup>43</sup> and is unlikely to play a significant role in the epidemiology of human diseases.
Introduced		
<i>Aedes australis</i>	1	Although a laboratory vector of dengue and Ross River virus, <sup>50</sup> it is mostly restricted to saline rock pools on the southern coasts of the South Island. <sup>51</sup>
<i>Aedes camptorhynchus</i>	10	Although rare in New Zealand because of the eradication program, it is a highly anthropophilic species, <sup>52</sup> and a major <i>Alphavirus</i> vector in Australia. <sup>23</sup>
<i>Aedes notoscriptus</i>	10	Highly infective for chikungunya virus (87%) but low transmission rates (20%). <sup>5</sup> However, it is widespread and abundant in northern New Zealand and it is highly anthropophilic thriving in close association with human habitats.
<i>Culex quinquefasciatus</i>	1	Despite viral isolations in the field, it is refractory to chikungunya virus infection. <sup>5,6</sup>

\*0 = negligible; 1 = unlikely; 5 = possibly; 10 = likely.

the country, including forest fringes in suburban areas, where it will readily move into houses. Although there is virtually no information on its vector competence for any arbovirus, *Cq. iracunda* mosquitoes are closely related to mosquito species in Australia, such as *Coquillettidia linealis*, which is an efficient laboratory vector of CHIKV.<sup>5</sup> Thus, vector competence studies should be carried out to help shed light on the potential role of this and other relevant New Zealand species as CHIKV vectors.

Three of the four exotic mosquitoes present in New Zealand require close scrutiny (Table 1). *Culex quinquefasciatus* mosquitoes, from which CHIKV has been isolated in the field,<sup>22</sup> are vectors of a number of arboviruses,<sup>16</sup> but are unlikely to be of concern because they are refractory to CHIKV infection.<sup>5,6</sup> *Aedes camptorhynchus* mosquitoes were previously reported in a number of sites in New Zealand, but a multi-million dollar program has been in place for approximately 10 years that aims to eradicate it from the country. *Aedes camptorhynchus* mosquitoes are a highly anthropophilic species regarded as a vicious biter, and they are one of the most important *Alphavirus* vectors in Australia.<sup>23</sup>

In contrast, *Aedes notoscriptus* mosquitoes are abundant (and often dominant) in urban and suburban areas in northern New Zealand, particularly in the Auckland region.<sup>20</sup> Furthermore, the species appears to be favored by anthropogenic environmental change and it is therefore likely to continue to spread into previously unoccupied habitats such as

human-modified native forests.<sup>24</sup> *Aedes notoscriptus* mosquitoes are not only highly anthropophilic but also a vector of *Alphavirus* in Australia, where they are believed to be important vectors of Ross River virus (RRV) in urban areas.<sup>25</sup> A recent laboratory study found *Ae. notoscriptus* mosquitoes to be highly infective for CHIKV (87%), but they showed a low transmission rate (20%).<sup>5</sup> However, this relatively low transmission rate is likely to be countered by high densities in habitats closely associated with humans and because these mosquitoes are highly anthropophilic.

A major barrier for an appropriate assessment of the current likelihood of CHIKV transmission within the country is that the vector competence of New Zealand native species is unknown. In addition, results for the mosquito populations in Australia must be interpreted with caution because it remains unclear whether the mosquitoes in Australia established in New Zealand represent subpopulations with identical physiology to their parent populations.

The recognition of CHIKV as a threat to temperate areas<sup>26</sup> is reason for concern to New Zealand, Australia, and the South Pacific. This concern is particularly important in view of CHIKV outbreaks in parts of Asia, a source of frequent travelers who could be viremic. Furthermore, as previously pointed out, New Zealand has benefited from a species-poor mosquito fauna, but the risk of CHIKV transmission would be considerably compounded by the establishment of *Ae. albopictus* mosquitoes, a species regularly intercepted at New Zealand

borders.<sup>16,19</sup> *Aedes albopictus* mosquitoes would likely find a favorable environment for establishment and spread in the Auckland region,<sup>17</sup> the largest city in New Zealand and main port of arrival for incoming travelers. Mean summer temperatures in Auckland vary between approximately 17°C and 21°C, and daily minimum and maximum were of 11.7°C and 23.8°C for 2007–2008 (National Institute of Water and Atmospheric Research, unpublished data).

Under laboratory conditions at 20°C, *Ae. albopictus* mosquitoes showed two days as the minimum time between emergence and first blood meal and a mean life span of approximately 33 days, during which females may have four gonadotrophic cycles and lay an average of 250 eggs.<sup>27</sup> *Aedes albopictus* mosquitoes can transmit CHIKV within two days of biting a viremic host, and once infected, the mosquito is able to transmit the arbovirus for life.<sup>7</sup> Because this species is an aggressive biter and can take four blood meals during its life span at 20°C,<sup>27</sup> conditions in Auckland would be ideal for a CHIKV outbreak. In addition, it has been previously established that this area of the country could be receptive to dengue.<sup>28</sup> Furthermore, the possibility of local mosquitoes transmitting CHIKV cannot be entirely disregarded because the virus could rapidly adapt to available vectors, as has occurred with *Ae. albopictus* mosquitoes in La Réunion.<sup>9</sup>

In the event of an outbreak in New Zealand, the long-term forecast for the transmission, spread, and possible establishment of the disease in the country is unclear. The pattern of CHIKV re-emergence is unpredictable, but it seems to occur every 7–8 years.<sup>1</sup> As is the case with dengue, outbreaks of CHIKV can occur by the human-mosquito-human cycle, which does not require a non-human reservoir host.<sup>4</sup> However, because of the temperate climate of New Zealand, mosquitoes may reach high densities only over a relatively short period, primarily January–March, and throughout the rest of the year virus replication and transmission would be unlikely to occur. However, this scenario may alter under the influence of global climate change. Vertical transmission is one mechanism in which a virus can remain in the mosquito populations when climate is unfavorable for adult mosquito survival, because the virus may persist in desiccation-tolerant eggs.<sup>1</sup> However, vertical transmission of CHIKV within mosquito vectors has not been demonstrated in laboratory conditions.<sup>29,30</sup>

The range of vertebrate reservoir hosts in areas where CHIKV is endemic is also poorly known.<sup>31</sup> Primary reservoirs for the virus in Africa are likely to be human and non-human primates,<sup>31,32</sup> but the latter primates are not found in New Zealand except for those captive in zoologic parks. However, CHIKV isolations in the field have also been obtained from bats and rodents.<sup>32</sup> In addition, antibodies specific for CHIKV have been detected in birds and rodents, indicating a possible secondary virus cycle.<sup>32</sup> Chikungunya virus has also been isolated from cattle in central Africa, and although these animals were considered to have a negligible role in the virus cycle in the area,<sup>33</sup> this may not necessarily apply to New Zealand.

It should be noted that New Zealand would be particularly vulnerable to an arboviral outbreak because there are no recognized alphaviruses known to affect humans in New Zealand, and it is therefore unlikely that any immunity exists among the general population.<sup>19</sup> As a result, there would be little or no natural resistance to CHIKV if it were to arrive in New Zealand. As it has been the case in a number of other countries,<sup>34</sup> there is the potential of CHIKV importation into New

Zealand by infected humans. Asymptomatic viremic travelers could arrive in New Zealand, and once in the country be exposed to local vectors so that a locally acquired epidemic occurs. With the ever-increasing rate of international travel (as well as migration), there is therefore an increasing flux of people arriving in New Zealand from areas where CHIKV is endemic. As CHIKV continues to re-emerge and emerge in new areas, it is likely that the number of viremic travelers arriving will increase.

Although such cases appear to be rare in New Zealand, with only one reported case of imported CHIKV infection per year, a single infected person may be enough to initiate an outbreak in the presence of an efficient vector in large-enough density, as occurred in the outbreak in Italy.<sup>10</sup> A challenging issue is that, as pointed out by Druce and others for Australia,<sup>34</sup> accurate serologic diagnosis of foreign alphavirus infections is not likely because of the lack of specific assays. In the case of New Zealand, this situation is compounded by the paucity of confirmatory arboviral testing ability.<sup>19,35</sup>

A further issue in New Zealand is its population's apparent ignorance of the need for basic mosquito control and avoidance measures.<sup>19</sup> In urban areas in particular, backyard breeding of mosquitoes in artificial containers is a common unrecognized problem in northern New Zealand, the area most at risk. *Aedes notoscriptus* mosquitoes have greatly benefited from such artificial breeding grounds, where they now thrive.<sup>20,36</sup> Invading *Ae. albopictus* mosquitoes would similarly profit from such habitats,<sup>17</sup> whose close proximity to human inhabitations would obviously maximize likelihood of transmission in the event of a CHIKV outbreak.

Finally, there is the growing issue of global climate change to add to the mix. It is widely acknowledged that climate change may have an effect on vector biology and thus alter vector seasonality, abundance, and distributions. Likewise, climate change may affect hosts and pathogens and influence human behavior and thus exposure risk. In this complex scenario, it is difficult to predict how climate change will affect vector-borne disease risk in the region. However, it is likely that arboviruses, such as CHIKV, will continue to emerge in new areas and be associated with a changing global climate. Epstein recently suggested that the explosive re-emergence of CHIK fever in 2004 was associated with intensifying extreme weather patterns affecting Africa.<sup>37</sup>

In the case of New Zealand, under current climatic conditions, *Ae. aegypti* mosquitoes are unlikely to become established. For *Ae. albopictus* mosquitoes, they are predicted to have a potential distribution covering the northern region of the North Island of New Zealand,<sup>20</sup> which contains more than 25% of the population of New Zealand. In the future, changing climate and weather patterns may facilitate the establishment of these vectors, consequently maximizing the likelihood of a CHIKV outbreak, and possibly other arboviruses.

## SOUTH PACIFIC

The public health threat in association with arboviral outbreaks would likely be intertwined in New Zealand and other South Pacific islands. Nations in the region are geographically proximal and closely linked culturally and economically, with a regular flow of travelers among them. Therefore, a CHIKV outbreak in one nation could potentially escalate to a region-wide event. In 2007, dengue outbreaks in the South Pacific led

to a significant increase in the number of imported dengue cases reported in New Zealand, most of which originated in the Cook Islands and Samoa. For most South Pacific nations, the risk of a CHIKV outbreak is considerably greater because of *Ae. aegypti* and *Ae. albopictus* mosquitoes in the region and another vector (*Ae. polynesiensis* mosquitoes).

The scenario for an outbreak of CHIKV could resemble the RRV epidemic that occurred in the South Pacific in 1979,<sup>38,39</sup> which appears to have started with the arrival of an infected human in Fiji,<sup>39</sup> as happened in the CHIKV outbreak in Italy.<sup>10</sup> There were an estimated 50,000 clinical cases of RRV in Fiji, and more than 300,000 human infections affecting nearly half of the population, and the epidemic eventually spread to other South Pacific nations such as Samoa, Cook Islands, New Caledonia, and Wallis and Futuna Islands.<sup>39</sup> The explosive nature of the outbreak in Fiji was a likely result of low levels of antibodies to RRV in the community,<sup>38</sup> which would also occur in the event of CHIKV outbreak. In New Zealand, this would likely occur in the case of any arbovirus outbreak.

Early detection of any sentinel cases is fundamental to prevent an outbreak from occurring. However, this would be hindered by the paucity of confirmatory arboviral testing ability in New Zealand.<sup>19,35</sup> Currently, arboviral testing for much of the South Pacific is mostly restricted to Australia, although some limited screening capability exists in some nations for specific viruses, and New Zealand is also working towards developing confirmatory assays for some arboviruses. However, much greater capacity is needed to address not only the testing requirements of this country, but also to provide support for South Pacific nations that are much less able to afford it.<sup>35</sup>

Nonetheless, to manage adequately the risk of a CHIKV outbreak or to contain such an event if it occurs, it is necessary to develop a regional approach to public health. In the case of New Zealand, to minimize the risk associated with mosquito-borne diseases among its own people, it is necessary to assist with public health prevention in more vulnerable populations in poorer nations in the South Pacific that could act as sources of emerging infectious diseases.<sup>35</sup> A recent report from the United Kingdom recognized the importance of multinational collaborations to deal with infectious diseases,<sup>40</sup> stressing that although the World Health Organization operates a competent international surveillance network, many developing countries are seriously deficient in this respect. Because a chain is as strong as its weakest link, it is therefore necessary to “direct greater investment into this vital area of global disease control” (page 5).<sup>40</sup> Because New Zealand and other South Pacific nations are tightly knit cultural and economic communities, a regional approach would likely strengthen the ability to reduce potential morbidity and mortality from vector-borne disease across the region to a large extent.<sup>35</sup>

Furthermore, the perception of public health risk (e.g., mosquitoes) within a specific population is highly subjective, and may be mentally scaled from negligible to catastrophic on the basis of a number of factors intrinsic to a particular community. As a result, it is not possible to adopt a single approach to prevent or mitigate a CHIKV outbreak across the whole of the South Pacific. In fact, this is applicable also within an individual nation, where considerably different ethnic and cultural groups exist. In the case of the CHIKV epidemic in the Island of La Réunion in 2005, different groups of distinct backgrounds and experience had varied perceptions of the risk posed by mosquito-borne diseases.<sup>11</sup> Residents of

European origin were concerned about being bitten by mosquitoes, as reflected in the media by their complaints about the inadequacy of mosquito control efforts.<sup>11</sup> Their feelings of lack of control were exacerbated by feelings of abandonment (inequity), which led to a heightened perceptions of risk.<sup>11</sup> In contrast, the non-white Créole community perceived the mosquitoes only as a nuisance, against which herbal repellents provided adequate protection. Thus, they believed they were in control and, in any case, often questioned whether the mosquitoes were causing the disease.<sup>11</sup> It is likely that similar if not greater differences in perception of the risk posed by mosquitoes would be present in the South Pacific, including New Zealand, where a complex historic mixture of ethnicities and belief systems are prevalent. To be effective, public health education and intervention against mosquito-borne disease would need to take such differences into account, as has already been implemented in community-specific public health messages for such issues as smoking and exercise.

Finally, it is important to highlight that the costs of programs to prevent mosquito-borne diseases are relatively small compared with the effects on human health and the human, political, and financial costs of the epidemics, as well as the costs of attendant vector control and other public health measures a CHIKV epidemic would require in the region. Therefore, in view of the increasing threat of a CHIKV outbreak in the South Pacific, we strongly recommend the support and expansion of preventive action by appropriate authorities in the region.

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