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Concurrent outbreaks of dengue, chikungunya and Zika virus infections – an unprecedented epidemic wave of mosquito-borne viruses in the Pacific 2012–2014

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Since January 2012, the Pacific Region has experienced 28 new documented outbreaks and circulation of dengue, chikungunya and Zika virus. These mosquito-borne disease epidemics seem to become more frequent and diverse, and it is likely that this is only the early stages of a wave that will continue for several years. Improved surveillance and response measures are needed to mitigate the already heavy burden on island health systems and limit further spread to other parts of the world.

Since January 2012, the Pacific is experiencing a high burden of mosquito-borne disease due to concurrent epidemics of dengue, chikungunya and Zika virus infections. So far over 120,000 people have been reported to be affected, a figure that is likely to substantially underestimate the real numbers due to underreporting. For as long as there has been data available from the Region (i.e. 40 years), this epidemic wave of mosquito-borne viruses with 28 new mosquito-borne viral outbreaks (n=25) and circulation (n=3) documented since January 2012 (18 Dengue virus (DENV) serotype 1–4, 7 chikungunya virus and 3 Zika virus infection outbreaks, respectively) is unprecedented (Table) [1–3]. We here present an overview of the surveillance and epidemiology of these mosquito-borne disease epidemics in the Pacific Region, to help facilitate response measures that are needed to mitigate the already heavy burden on island health systems and to limit further spread to other parts of the world.

Surveillance of mosquito-borne viruses in the Pacific Region

The Pacific Public Health Surveillance Network (PPHSN) is a voluntary network of countries, territories and organisations created in 1996. It is dedicated to the promotion of public health surveillance and response to health emergencies in the Pacific Region. It covers 22 Pacific Island countries and territories (hereafter referred to as the Pacific Region) with a population of 10.6 million inhabitants [4]. The network services

include the timely exchange of information on outbreak-prone disease through PacNet, an email list with around 680 health professionals, and diagnostic support through a network of laboratories for identification and verification of pathogens.

In 2010, the Pacific Syndromic Surveillance System was introduced in the PPHSN. It monitors four syndromes and aims at improved early warning to complement routine notifiable disease notification systems that generally are not timely and seldom used for regional surveillance purposes in the Pacific Region. The Syndromic Surveillance system is under development and currently includes sentinel reporting from primary healthcare or hospital sites in all countries [5]. Manifest dengue, chikungunya and Zika virus infections have a similar initial clinical presentation and may be reported as any of the first three of the following four monitored syndromes: (i) acute fever and rash, (ii) prolonged fever, (iii) influenza-like illness and (iv) diarrhoea. Due to similar initial clinical features to the three mosquito-borne diseases, concurrent measles epidemics and leptospirosis pose diagnostic challenges in the Region.

There is a need for timely, reliable and detailed data on mosquito-borne virus outbreaks and circulation of the viruses in the Pacific Region. To obtain a comprehensible overview of the present epidemiological picture, several sources of information are used. Further to PacNet, syndromic and laboratory-based surveillance, event-based surveillance (mainly media and personal communications with health professionals) and surveillance by-proxy (reports of exported cases to neighbouring countries) [6] are also important. To facilitate better risk assessments and efficiency of data dissemination, this data is visualized in a recently launched interactive map available from: www.spc.int/phd/epidemics. The map, updated weekly, provides the region for the first time with a dynamic real-time picture of the current epidemic situation.

TABLE
 Characteristics of new dengue, chikungunya and Zika virus infection outbreaks and circulation^{ab}, Pacific Region, January 2012–17 September 2014^c (n=28)

	Country	Month of onset	Latest information	Implicated mosquito borne virus	Summary	Sources
Dengue						
●	Tuvalu	Mar-14	10/07/2014	DENV-2	408 suspected cases with 195 cases positive in rapid tests (NS1/IgM).	[32]
●	Nauru	Mar-14	7/08/2014	DENV-3	251 suspected cases with 91 confirmed using IgM ELISA and/or rapid test. Samples sent for confirmatory serotyping.	[32, 33]
●	Tonga	Feb-14	21/08/2014	DENV-3	Outbreak ongoing; 2 cases of dengue imported into New Zealand since 12 July 2014.	[32–34]
●	New Caledonia	Feb-14	17/09/2014	DENV-3	In 2014, 338 cases of dengue recorded of which 55% were DENV-3. Virus circulation ongoing, with latest reported dengue case on 12 September 2014.	[35]
●	Fiji	15/01/2014 ^c	23/06/2014	DENV-2	Circulation of virus, no outbreak declared; 6 confirmed cases of DENV-2 imported into Queensland Australia from January to June 2014.	[33]
●	Vanuatu	Dec-13	20/04/2014	DENV-3	1,561 dengue cases reported; 5 imported cases in Queensland Australia since January 2014 and 10 imported cases in New Caledonia from January to March 2014; 4 cases of DENV with serotype unknown imported into New Zealand since April 2014, of which 1 in July 2014.	[32–35]
●	Kiribati	Nov-13	24/01/2014	DENV-3	As of 16 Jan 2014, 198 suspected dengue cases of which 85 were laboratory-confirmed. Outbreak over, only sporadic cases of fever.	[32], media: Radio New Zealand International
●	Vanuatu	27/10/2012 ^c	20/04/2014	DENV-1	Circulation of virus, no outbreak declared; 2 confirmed cases imported into Queensland Australia (1 case in 2013 and 1 case in 2014) and 6 cases into New Caledonia (5 cases in 2013 and 1 case in 2014); 4 cases of dengue serotype unknown imported into New Zealand since April 2014, of which 1 in July 2014.	[33, 35]
●	Fiji	Oct-13	5/06/2014	DENV-3	25,300 suspected cases, 15 deaths. Outbreak is ongoing; 15 confirmed cases imported into Queensland Australia from December 2013 to May 2014.	[33], media: Radio Australia, Fiji Broadcasting Corporation
●	French Polynesia	Feb-13	6/09/2014	DENV-1 DENV-3	As of 23 May 2014, 2188 positive cases since February 2013, and between 16 400 and 34 000 clinical visits estimated. 11 severe cases in March 2014 and 5 severe cases requiring hospitalisation in July 2014. DENV1 outbreak is still ongoing, but there are no cases of DENV3 reported since April 2014.	[36]
●	Wallis & Futuna	Jan-13	28/03/2013	DENV-1	88 suspected cases and 16 confirmed of which 11 imported cases from New Caledonia.	[37]
●	Solomon Islands	Dec-12	15/08/2014	DENV-3	7,697 reported cases as of 31 December 2013. As of June 2014, 1,762 suspected cases since January 2014, and 282 out of 1,500 samples tested positive in rapid tests. In March 2014 DENV-3 confirmed. Outbreak still ongoing.	[32, 33], media: Solomon Star
●	Kosrae, Federated States of Micronesia	Sep-12	19/07/2013	DENV-4	729 reported clinical cases; 206 cases laboratory confirmed by rapid diagnostic tests. No deaths reported.	[9, 37]
●	New Caledonia	Sep-12	17/09/2014	DENV-1	Largest ever recorded outbreak of dengue in New Caledonia with 10,978 cases and 5 deaths from September 2012 to September 2013; 338 cases of dengue recorded in 2014 of which 45% were DENV-1. Virus circulation ongoing, with latest reported dengue case on 128 September 2014.	[35]
●	Fiji	15/07/2012 ^c	31/12/2012	DENV-2	Circulation of virus, no outbreak declared. 2 imported cases in Queensland Australia;	[33]
●	Kiribati	Mar-12	4/05/2012	DENV-1	243 clinical cases.	[32]
●	Niue	Feb-12	20/07/2012	DENV-1	More than 100 cases.	Media: Radio New Zealand International

	Country	Month of onset	Latest information	Implicated mosquito borne virus	Summary	Sources
Chikungunya						
●	Tokelau	Jul-14	11/09/2014	CHIKV	164 suspected cases reported. CHIKV confirmed.	[32]
●	Samoa	Jul-14	1/09/2014	CHIKV	433 cases reported over 4 weeks. 21 RT-PCR positives out of 59 samples (as of 28 Aug 2014).	[37], media: Samoa Observer
●	American Samoa	Jun-14	17/09/2014	CHIKV	823 probable cases reported, with 15 hospitalisations. CHIKV confirmed.	[37], media Radio New Zealand International
●	Tonga	Feb-14	11/09/2014	CHIKV	Over 10,000 suspected cases reported. Ongoing circulation of CHIKV confirmed.	[32–34]
●	Yap, Federated States of Micronesia	Aug-13	10/09/2014	CHIKV	A total of 1,711 suspected cases identified in Yap State. Circulation of CHIKV reconfirmed.	[37]
●	New Caledonia	Jan-13	2/06/2014	CHIKV	A total of 32 confirmed cases from January to May 2013.	[35]
●	Papua New Guinea	Jun-12	25/11/2013	CHIKV	A major outbreak spread over Papua New Guinea in 2013. Number of cases not reported, but estimated in media to be tens of thousands of cases.	[2], media: Australia Network News, Pacnews
Zika virus infections^d						
●	Cook Islands	Feb-14	29/05/2014	ZIKV	Outbreak is over. 932 suspected and 50 confirmed cases.	[32], media: Radio New Zealand International
●	New Caledonia	Jan-14	17/09/2014	ZIKV	Imported cases reported in November 2013, first autochthonous case reported in January 2014; 1,400 confirmed cases of which 35 imported cases. Outbreak peaked in April 2014. Last case reported on 2nd August 2014.	[35]
●	French Polynesia	Oct-13	4/05/2014	ZIKV	8,723 suspected cases reported and more than 30,000 estimated clinical visits due to Zika. Outbreak declared over but virus circulation may be ongoing.	[36]

● Cases reported are increasing or peaking

● Cases reported are decreasing or viral circulation is ongoing

● Outbreak is reported to be over and/or no cases have been reported for one year.

CHIKV: chikungunya virus; DENV: dengue virus serotype 1-4; RT-PCR: reverse-transcriptase polymerase chain reaction; ZIKV: Zika virus.

^a Only incident outbreaks and circulation notified during the reported period. Outbreaks first reported in 2011 (DENV-4 in Marshal Islands, DENV-2 in Yap and circulation of DENV in Papua New Guinea and Fiji) and still ongoing in 2012 are not presented.

^b An outbreak is considered an outbreak when reported as such or when the first autochthonous cases are reported, and new circulation if there have been no events reported during one year.

^c Month of start equals the month of first report, as this reflects circulation of virus.

^d Easter Island experienced a Zika virus infection outbreak starting February 2014, but is not presented in the table as it is not part of the 22 countries and territories of the Pacific Public Health Surveillance Network.

The epidemiology of mosquito-borne viruses in the Pacific Region

Mosquito-borne virus diseases in the Pacific Region have a distinct epidemiology due to small populations scattered over thousands of tropical and sub-tropical islands on both sides of the equator in relative geographic isolation, together with (nowadays) significant people's mobility and thereby exposure to circulating arboviruses through the airline networks of the Asia-Pacific region (Figure 1).

Between January 2012 and 17 September 2014, a total of 28 new mosquito-borne viral outbreaks (n=25) and circulation (n=3) were documented: 18 DENV 1–4 outbreaks (2012: 7; 2013: 6; 2014: 5), 7 chikungunya virus (CHIKV) (2012: 1; 2013: 2; 2014: 4) and 3 Zika virus infection outbreaks (2012: 0; 2013: 1; 2014: 2), respectively.

Looking at the first semester of 2014, the number of outbreaks and circulating mosquito-borne viruses seem to be increasing (Figure 2). During the same period, DENV-3 became the dominating dengue virus, and since Zika virus started to spread in the end of 2013, there was concurrent circulation of DENV-1,-2 and -3, CHIKV and Zika virus (Table, Figure 2)

Dengue

The epidemic pattern of dengue in the Pacific Region has typically presented in form of sporadic or rare epidemics rather than a hyperepidemic/endemic pattern, with one dominating serotype sweeping across the islands every 3 to 5 years, and with varying duration of circulation in different islands largely depending on population size [1,7–8]. During 2012, there were outbreaks of all four serotypes of DENV documented for the first time during one year (Figure 2) [1]. DENV-1 was the dominating serotype in 2012 and beginning 2013, causing the largest documented dengue outbreak ever in New Caledonia, with 10,978 confirmed cases and 5 deaths from September 2012 to September 2013. Since 2012 there have only been reports of one outbreak with DENV-2 and -4 respectively: DENV-2 recently caused an outbreak in Tuvalu with 408 suspected cases (4% of the population) and DENV-4 caused a large outbreak in Kosrae in September 2012 to March 2013 with 729 clinical cases (11% of the population) (Table) [9]. Furthermore there have been reports of new circulation of DENV-2 in Fiji. (Table) After having been absent in the region for 18 years, DENV-3 has after the reintroduction in 2012, become the dominating DENV in the region with five ongoing outbreaks, one of them in Fiji, with 25,300 suspected cases and 15 deaths (Table, Figure 1) [1,10].

FIGURE 1

Map of newly reported dengue, chikungunya and Zika virus infection outbreaks or new virus circulation^a, Pacific Region^b, January 2012–17 September 2014^c (n=28)



CHIKV: chikungunya virus; DENV: dengue virus serotype 1-4; ZIKV: Zika virus.

^a Only incident outbreaks and virus circulation reported during the period. Outbreaks first reported in 2011 (DENV-4 in Marshall Islands, DENV-2 in Yap and circulation of DENV in Papua New Guinea and Fiji) and still ongoing in 2012 are not presented.

^b The 22 Pacific Island countries and territories that are core members of the Pacific Public Health Surveillance Network and referred to as the Pacific Region.

^c Real-time interactive map with current epidemiological situation and alerts is available from: www.spc.int?phd/epidemics

Chikungunya

After being reported in the Pacific for the first time in a small tightly controlled outbreak in New Caledonia in 2011 [11], CHIKV is currently becoming established in the Region (Figure 1, Table) [2]. In Papua New-Guinea in 2012-13, the largest epidemic in the Region so far with estimated (though poorly documented) tens of thousands of cases, was caused by the East Central South African (ECSA) lineage of the virus [2]. The Asian lineage of the virus was responsible for the outbreak in Yap State (2013-14) [12] and also in New Caledonia (2013) where CHIKV re-emerged in the middle of a large DENV-1 epidemic and caused a small outbreak, similar to the 2011 outbreak (Table) [13]. Phylogenetic analyses of the CHIKV involved in the outbreaks in Tonga, Samoa and American Samoa are not yet available. Due to the on-going geographic expansion of *Aedes albopictus* in the Pacific region (Figure 3), virus genotype monitoring is a crucial aspect of surveillance.

Zika virus infections

After the first documented Pacific Zika outbreak in Yap in 2007 [14], the Asian lineage of the virus reappeared in French Polynesia in October 2013, and has since caused large outbreaks in New Caledonia (1,400 confirmed cases), Cook Islands (over 900 cases) and Easter Island that is not part of the PPHSN (Figure 1,

Table) [3]. In French Polynesia, extrapolation of the 8,746 suspect cases reported by the sentinel surveillance network allows to infer that over 30,000 medical consultations were due to the spread of Zika virus throughout the archipelago. Between November 2013 and February 2014, increased incidence of neurological complications, including 42 cases of Guillain-Barré syndrome, was a unique and worrying feature of the French Polynesia outbreak that warrants further studies [3].

Discussion and Conclusions

Burden on the Pacific countries and territories

Mosquito-borne outbreaks are greatly exacerbating the pre-existing burden that Pacific Island primary health-care systems face. If not managed well, the epidemic wave may threaten societies broadly, affecting trade, tourism and work force beyond the direct morbidity and mortality toll [2]. During the chikungunya outbreak in Reunion Island, one third of the around 800,000 inhabitants were infected, peaking at more than 47,000 estimated cases in one week, with estimated productivity loss of €17.4 million (range €6 to €28.9 million) and medical costs of €43.9 million that were met by the French state [15-17]. Much of the burden on the Pacific Region of the concurrent epidemics of all three diseases covered here is unknown and further studies are warranted, especially on co-infection and the effect of sequential infection with different viruses.

Zika virus disease, generally reported to have a mild clinical presentation, was associated with neurological complications during concurrent Zika virus disease and dengue epidemics in French Polynesia [3,18]. The Pacific Region may be particularly vulnerable to communicable diseases due to isolation and immunologically naive populations, but also due to rates of non-communicable disease, such as obesity, diabetes and cardiovascular disease, that are among the world's highest on some islands [19].

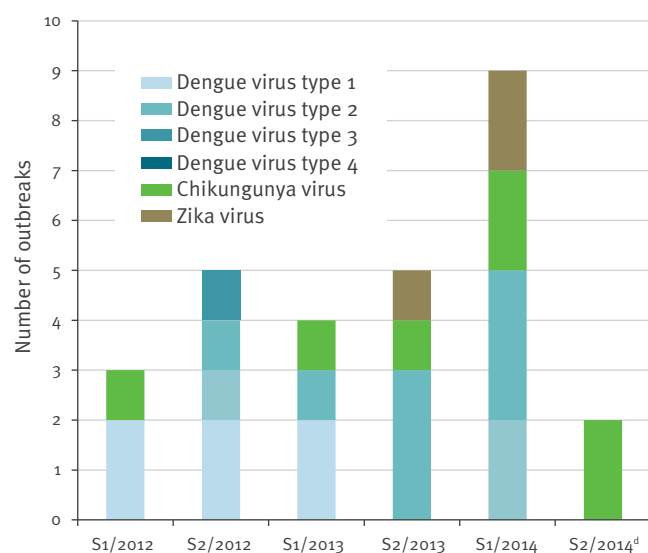
The risk for further spread

While there have been efforts to improve surveillance in the Pacific over the past two decades, it is not likely that the extent of the current increase in diversity and frequency of mosquito-borne virus outbreaks in the Pacific can be explained solely by improved surveillance systems. In the island setting of the Indian Ocean, the largest documented CHIKV outbreak lasted four years (2004–2007) [15]. Therefore, considering also the previous dengue outbreaks in the Pacific Region [1-2] and the diversity of the current outbreaks, it seems likely that the Pacific Region is in the early stages of an epidemic wave for the three mosquito-borne viruses that started in 2012 and is likely to continue for several years.

The risk for further spread in the Pacific Region is high for several reasons. Firstly, it is likely that there is little immunity to these diseases, as DENV-3 had not been

FIGURE 2

Incidence and aetiology of newly reported mosquito-borne virus outbreaks and circulation^a by semester^b, Pacific Region, January 2012–17 September 2014^c (n=28)



S: semester.

^a An outbreak is considered an outbreak when reported as such, and new circulation of virus if there has been no event with the same virus reported during one year previously.

^b S1 includes the months from January to June and S2 the months from July to December.

^c Outbreaks or circulation that started before January 2012 or after 17 September 2014 are not presented in this graph to allow observation of a possible trend over time.

^d Semester 2 in 2014 is not complete, and only includes reports from two full months out of six.

circulating in the Region since 1995 [1] and prior to the current wave, CHIKV and Zika virus occurrence in the Pacific was limited to two documented outbreaks [11, 14]. Secondly, competent vectors present in the Region, mainly *Ae. aegypti* and *Ae. albopictus*, but also other local mosquitoes such as *Ae. polynesiensis* or *Ae. hensilli* are known to transmit these viruses (Figure 3) [20]. These species have been incriminated in DENV transmission on epidemiological and/or experimental (laboratory infections) grounds. Several of them are confirmed or strongly suspected vectors of CHIKV and Zika viruses [21]. Thirdly, large population mobility and airline travel facilitate the spread [22].

Vector control capacity in the Pacific Region is often limited or insufficient [11]. At present, there is no ongoing entomological surveillance system targeting vectors of dengue and other arboviruses established in

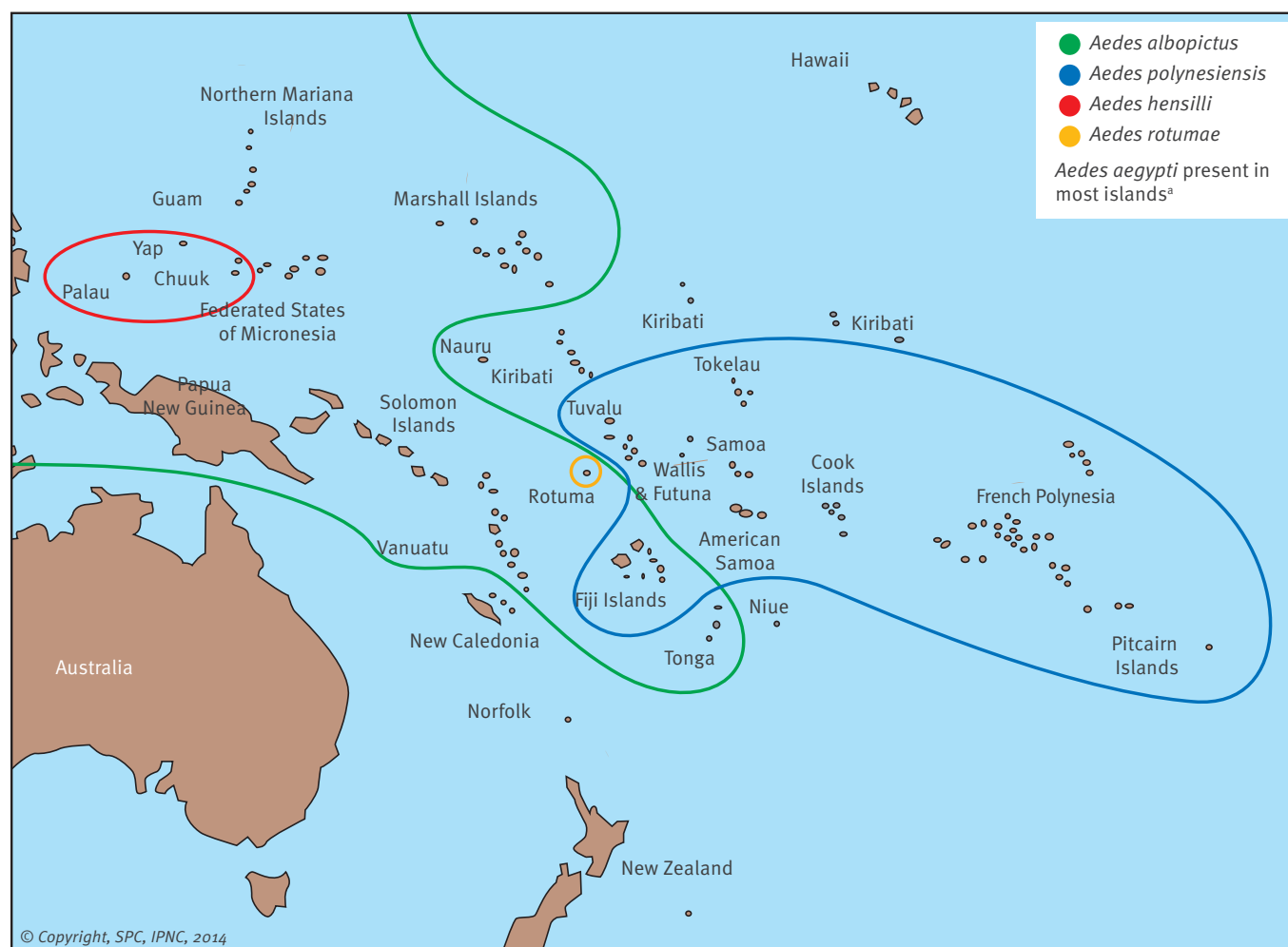
the Region except in New Caledonia, Fiji and French Polynesia. The current knowledge about mosquito distribution in the other countries and territories is based on data collected during entomological investigations in surveys from the second half of the 20th century and from some more recent surveys [20]. Interestingly, the three viruses involved in this epidemic wave are not broadly mosquito-borne, but specifically *Aedes* (*Stegomyia*)-borne.

The cause of the recent increase in mosquito-borne disease in the Pacific Region is largely unknown, but is in line with a global increase of emerging diseases, and likely driven by a combination of socio-economic, environmental and ecological factors [23].

The continuous challenges of dengue and chikungunya [24] and more recently Zika virus infections [25]

FIGURE 3

Map of the known distribution of *Aedes* (*Stegomyia*) mosquitoes, vectors of dengue and possible vectors of chikungunya and Zika viruses, Pacific Region as of beginning October 2014



^a *Aedes aegypti* (not represented on the map) is present throughout most of the region including North Queensland. It is absent from the rest of Australia, New Zealand, Hawaii, Futuna and some other remote islands, and it seems to be currently displaced by *Ae. albopictus* in many locations (e.g. Papua New Guinea and Solomon Islands). The known or strongly suspected distributions of other vectors are as follows (not exhaustive): *Ae. scutellaris* (Indonesia; Northern Australia, Papua New Guinea); *Ae. marshallensis* (Marshall Islands; Western Kiribati; Kosrae; Pohnpei); *Ae. hebrideus* (Papua New Guinea; Solomon Islands; Vanuatu); *Ae. cooki* (Niue, Vava'u Group, Tonga); *Ae. tongae* (Ha'apai Group, Tonga); *Ae. tabu* (Tongatapu group, Tonga); *Ae. kesseli* (Niua group, Tonga); *Ae. pseudoscutellaris* (Fiji). [25]

for Europe, the re-emergence of dengue in Japan [26], and the first-time chikungunya transmission in the Americas [27], show that these viruses pose a threat to any country with competent vectors. The epidemiology of mosquito-borne viruses in the Pacific may be changing. There are close links between the several European overseas countries and territories in the Pacific Region and Europe and the United States [28]. Considering the extensive airline travel between the Pacific Region and other parts of the world where the viruses have not yet been established e.g. Europe and the United States, it should be of international interest to stay informed of the spread of the current Pacific Region wave of mosquito-borne viruses and to support surveillance and control efforts [2,23,29].

Examples of response from PPHSN partners to the epidemic situation include the provision of support and capacity building to Pacific Islands in surveillance, outbreak investigation and response, and mass-gathering surveillance. The Pacific Outbreak Manual is also being updated to include specific response guidelines for the three viruses [30].

To further enhance surveillance and response measures, Pacific Directors and Ministers of Health have shared the current risk assessment, and the upcoming Pacific International Health Regulations meeting will focus on mosquito-borne diseases. Island primary healthcare-based systems have difficulties to cope with high caseloads and there is a need for early multi-disciplinary preparedness and response to face larger outbreaks adequately [2].

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Conflict of interest

None declared.

Authors' contributions

AR, YS, CL, DH conceived the idea of the paper. AR, AM, CL, SD and EB contributed to data gathering and cleaning. AR, CL and AM conducted the analysis. LG gathered and compiled all vector data and analysis. AR and AM drafted the first draft, and all authors commented and agreed upon the final manuscript.

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