Mosquito vectors of arboviruses in French Polynesia

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Abstract

The circulation of arthropod-borne viruses (arboviruses) throughout the Pacific is no exception in French Polynesia (FP). We review here the mosquito vectors involved or potentially involved in the transmission of arboviruses in FP. We highlight *Aedes aegypti* and *Aedes polynesiensis*; species that are widely distributed in FP and whose ability to transmit dengue, zika and chikungunya viruses is well known. In addition, we discuss the contribution of those species and the abundant *Culex annulirostris* to the silent circulation of Ross River virus in FP. As these mosquito species and others present in FP are known to be vectors of a large panel of arboviruses, there is a high risk for new emergences. © 2019 The Authors. Published by Elsevier Ltd.

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French Polynesia (FP) is a French overseas territory located in the south-east Pacific and consists in 80 inhabited islands divided into five archipelagos: the Society, Tuamotu, Gambier, Austral and Marquesas Islands. Several arthropod-borne viruses (arboviruses) have been described in FP. Dengue virus (DENV) has been circulating in FP since the nineteenth century with clinical descriptions of epidemics mentioned in old written works [1]. Zika virus (ZIKV) and chikungunya virus (CHIKV) were introduced in 2013 and 2014, respectively, causing massive outbreaks [2,3]. Furthermore, silent circulation of Ross River virus (RRV) has been demonstrated [4]. Local transmission leading to the spread of these arboviruses in FP is inherent to the presence of competent mosquito vectors.

Vector-borne transmission of DENV, ZIKV and CHIKV in FP

Two diurnal species belonging to the genus *Aedes*, sub-genus *Stegomyia*, are incriminated in the transmission of DENV, ZIKV and CHIKV in FP: the indigenous *Aedes polynesiensis* and the worldwide distributed *Aedes aegypti* [5–11]. *Aedes polynesiensis* Marks 1951, a member of the *scutellaris* group, probably derived from an original species that arrived together with the first human migrations in the Pacific a thousand years ago [12]. *Aedes aegypti* Linnaeus 1762 (*aegypti* group), originally from African forests, is one of the most primitive members of the sub-genus *Stegomyia*. This species was introduced into the Pacific islands through commercial trade with European and Asian countries in the late nineteenth and early twentieth centuries [12,13]. Today, *A. aegypti* and *A. polynesiensis* are found on all the inhabited islands of FP. Breeding sites of *A. aegypti* are artificial containers associated with human habitations whereas *A. polynesiensis* is typical of natural breeding niches specific to these island environments, such as crab holes and open coconuts.

In laboratory experiments, *A. aegypti* populations have usually shown higher vector competence for arboviruses than *A. polynesiensis* [5,6,11]. Nevertheless, *A. polynesiensis* may be a good vector, able to sustain an epidemic by itself, as illustrated by the occurrence of dengue outbreaks in the Marquesas Islands several years before the appearance of *A. aegypti* in the archipelago [1,12,14]. Heterogeneous susceptibility to arboviruses observed in FP between *A. aegypti* and *A. polynesiensis*, and also observed between different *A. aegypti* populations [8], results from different genetic backgrounds [15,16] determined by

several factors such as ecological characteristics of mosquito habitats, human population density and intensity of insecticide spraying [8,17]. Expansion of sea and air connections between the islands of FP tends to increase the gene flow between mosquito populations [16,18].

Differences in viral genotypes, such as the occurrence of specific changes in the viral genome, can also result in the heterogeneous ability for a given FP *A. aegypti* population to transmit the virus [9,10,19]. For example, ZIKV isolates collected from the explosive outbreaks that occurred from 2013 in FP and elsewhere were shown to have an alanine-to-valine amino acid substitution in the non-structural protein 1 compared with previous isolates of the same lineage [19]. This mutation was found to facilitate viral acquisition by *A. aegypti* mosquitoes and subsequently to enhance viral prevalence in mosquitoes [19]. This may have facilitated the spread of ZIKV during the outbreak in FP.

There is worldwide disagreement about the potential ability of the mosquito species *Culex quinquefasciatus* to transmit DENV and ZIKV [20,21]. Although no investigation with any FP population of *C. quinquefasciatus* has been conducted for DENV, laboratory experiments found no evidence for FP populations to be able to transmit ZIKV, in accordance with the majority of published studies [22]. Nevertheless, the controversial results found for the ability of *Culex* species from various countries to transmit DENV or ZIKV, and the unexpected slowness of ZIKV dissemination in experiments conducted in laboratory conditions on *Aedes* populations, particularly *A. polynesiensis*, raised questions about the possibility that field conditions may significantly impact the ability of these species to sustain viral propagation [20,22–25].

Silent circulation of RRV in FP

Several mosquito species may have contributed to the silent circulation of RRV in FP. One of the most probable vectors is *Culex annulirostris* Skuse 1889 (*sitiens* group), known to be a major vector of RRV in Australia where the virus is endemic [26]. *C. annulirostris* was initially considered as having been introduced into FP with the settlement of the first Polynesians, but it may be a native species [12,27]. *C. annulirostris* is abundant and distributed in most of the FP archipelagos, mostly in rural areas. The larvae of this nocturnal species grow more particularly in marshes and river mouths [28]. Two other members of the *Culex* genus were suspected of being potential vectors of RRV in FP [4]. *C. quinquefasciatus* Say 1823, a member of the *pipiens* group, was undoubtedly introduced through commerce by Europeans in the nineteenth century. Suited to urban environments, this species is now widely distributed in the five FP

archipelagos [12,27]. *Culex sitiens* Wiedemann 1828, a member of the *sitiens* group, was described in the late twentieth century in FP [27]. Wastewaters and brackish waters are preferred sites for the larval development of *C. quinquefasciatus* and *C. sitiens*, respectively [28]. After RRV was isolated from wild-caught specimens, these two nocturnal species were suspected as possible vectors of RRV [26]. However, experimental oral infections of Australian and American populations of *C. quinquefasciatus* found either poor susceptibility or refractoriness to RRV infection [29,30]. In the same manner, *C. sitiens* showed low susceptibility to RRV infection [31]. Nevertheless, field conditions and particularly substantial densities of mosquitoes may compensate for poor viral susceptibilities and initiate an outbreak [20,25,32].

A. aegypti and more particularly *A. polynesiensis* may be efficient vectors of RRV in FP. Vector competence for RRV has been demonstrated for several populations of these two species, including an FP population of *A. polynesiensis* [26,30,33]. An additional argument for *A. aegypti* and *A. polynesiensis* to have sustained RRV transmission in FP is the observation that among all FP archipelagos, RRV antibody prevalence was higher for the inhabitants of Austral-Gambier and Marquesas Islands [34], despite *C. annulirostris* never having been indexed in the latter archipelago [27].

A new potential vector introduced in FP

In recent decades, a new potential vector for arboviruses was recorded for the first time in FP: *Aedes vexans* [35]. *Aedes vexans* Meigen 1830, commonly known as *A. nocturnus* Theobald 1903 in the Pacific region, is a member of the *vexans* group belonging to the genus *Aedes*, sub-genus *Aedimorphus*. This species lays its eggs at the base of plants, on blades of grass or on the ground in land subjected to periodic flooding such as floodplains, grassy ponds and marshes, where they are frequently associated with *C. annulirostris* [36]. Breeding sites may also be ditches along roads, particularly those rich in leaves and twigs, which keep the soil moist, but also in artificial containers and coconut shells [36]. *Aedes nocturnus* was first described as a probable separate species from *A. vexans* in the Pacific, although the differences from typical *vexans* appeared very limited [12]. Due to the lack of biological, behavioural and genetic data on the Pacific populations of *vexans*, the species was formally synonymized with *A. vexans* [37]. The distribution of this species in the Pacific in the middle of the twentieth century suggested that it may have been originally brought into the South Pacific by natives or Europeans [12]. The presence of *A. vexans* in FP was discovered in 2004 on the island of Moorea (Society Islands) during sampling of mosquitoes [35]. Its introduction in FP has been

suggested as probably related to horticultural imports from Hawaii, where the species has been described since 1962 and with which regular commercial air flights operate [38].

A Tongan population of *A. vexans* was shown to be able to transmit RRV despite poor susceptibility [39] and an Italian population of the species was demonstrated to be susceptible to CHIKV [40]. Recently, experimental infections in wild-caught American mosquitoes showed moderate to high susceptibility to ZIKV and low ability to transmit the virus [41,42]. The authors also highlighted the importance of field factors, arguing that high mosquito population densities may counterbalance weak vector competence. In FP, the current distribution and abundance of *A. vexans* are not known and its propagation is not monitored. The role of *A. vexans* as a potential vector at risk for arboviruses in FP is especially important because the adults are known to be able to fly long distances [36,43].

Vector control in FP

There is currently no approved vaccine and no specific treatment for the arboviruses circulating in FP, so vector control remains essential. The population is strongly encouraged to clear domestic mosquito-breeding sites. Perifocal insecticide treatments are sprayed around initial cases of confirmed human infections by newly introduced arboviruses to prevent outbreaks.

Considerable research progress was made in recent years for developing non-insecticidal vector control strategies [44]. Several of these strategies rest on the maternally inherited endosymbiotic *Wolbachia pipientis* (commonly shortened to *Wolbachia*), which is a common bacterium in a broad range of arthropods, including many mosquito species. *Wolbachia* types isolated from mosquitoes are divided into two supergroups referred as A and B [45]. Experimental strains of mosquitoes were developed by manipulating *Wolbachia* to induce infertility between a *Wolbachia*-infected male mosquito and an uninfected female mosquito or one having a natural *Wolbachia* from a different supergroup, through an early arrest of mosquito embryonic development by cytoplasmic incompatibility. Release in the field of both male and female *Wolbachia*-modified mosquitoes intends to replace the wild population with these mosquitoes that are more resistant to arbovirus infections [45]. Indeed, transfer of *Wolbachia* into *A. aegypti*, which is naturally uninfected with the bacteria, has been shown to limit the ability of the mosquito to become infected and to transmit DENV, CHIKV and ZIKV [44,46]. In the same manner, replacement in *A. polynesiensis* of its natural *Wolbachia* type (A supergroup) by an exogenous one (B supergroup) has been shown to reduce the susceptibility of the vector for DENV infection [46].

Another strategy consists of releasing only *Wolbachia*-modified male mosquitoes to reduce or suppress the wild mosquito population, with the supplementary benefit of also suppressing the nuisance of mosquito bites.

In FP, experimental field trials have been conducted with a strain of *A. polynesiensis* called 'CP' strain, which is stably modified with an alternate *Wolbachia* type (B supergroup) originated from a closely related mosquito species, *Aedes riversi*. Under semi-field cage conditions on Tahiti (Society Islands), CP males were demonstrated to have a mating competitiveness with wild females that was indistinguishable from that of wild males [47]. An open release trial was performed on Toamaro, an islet of Raiatea (Society Islands), selected for its small size, its high density of *A. polynesiensis* and the absence of inhabitants. Despite only relatively small numbers of CP males being released over 30 weeks (compared with the large wild population size on the islet), a significant decrease in the number of wild females able to produce viable embryos was obtained [48]. Another pilot study started in 2015 on Onetahi, the main islet of Tetiaroa (Society Islands), to evaluate the feasibility and sustainability of releasing incompatible male *A. polynesiensis* on a larger scale. The mass production of *A. polynesiensis* mosquitoes, also modified with B-*Wolbachia* from *A. riversi*, enabled the release of more than one million incompatible male mosquitoes on the islet through repeated weekly releases [49,50]. As early as 6 months after the project began, *A. polynesiensis* mosquitoes were almost eradicated from the islet with a 100-fold drop in the wild population [49,50]. The successful reduction of *A. polynesiensis* on Onetahi is all the more promising because it lasted over a year after the end of releases with the mosquito population density remaining one-tenth of what it was before the project [49].

The mosquito vectors described in this review are known to be able to transmit several arboviruses that have never been detected in FP. For example, *C. annulirostris*, *C. sitiens* and *C. quinquefasciatus* may transmit Japanese encephalitis virus [51] and, with *A. vexans*, West Nile virus [43,52]. *Aedes aegypti* is a vector of yellow fever virus [53]. Consequently, these arboviruses are a risk for FP. Mosquitoes are vectors of infectious diseases but the role of humans remains central in the introduction of viruses to the region. Vector control remains inseparable from increased surveillance of human transport flows at the international points of entry of FP (i.e. port and airport).

Conflicts of interest

The authors declare no conflicts of interest.

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