

Research Report

A preliminary assessment of the distribution of mosquitoes in the kingdom of Tonga: potential threats to biodiversity through invasive pathogens

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School of Biological Sciences
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A preliminary assessment of the distribution of mosquitoes in the kingdom of Tonga: potential threats to biodiversity through invasive pathogens

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Executive summary

1. Mosquitoes can be significant vectors of wildlife diseases and although most species endemic to the South Pacific have not been recognised as carriers of disease the occurrence of exotic mosquito species has markedly increased the risk of disease introduction and transmission.
2. Several outbreaks of human arbo-viruses in the kingdom of Tonga have highlighted the potential risk to the diversity of indigenous wildlife from mosquito borne diseases.
3. This preliminary study was undertaken to investigate the occurrence and distribution of mosquito species in Tonga, and to determine habitat preferences of mosquito larvae which might be targeted in mosquito control programs.
4. A survey of 42 sites, 22 town and 20 farm plantation, on the six islands of Tongatapu, Pangaimotu (Tongatapu group), Vava'u, Pangaimotu (Vava'u group), 'Utungake, and Nuku resulted in the collection of larvae of eight species, *Aedes aegypti*, *A. horrescens*, *A. nocturnus*, *A. tongae*, *Culex albinervis*, *C. annulirostris*, *C. quinquefasciatus* and *C. sitiens*.
5. Several species were widespread, particularly *A. aegypti* and *A. nocturnus* on the main island of Tongatapu, while *A. aegypti* dominated sites on Vava'u. Of these eight species, seven are known vectors of diseases contractible by animals and humans.
6. The wide distribution of disease vector species (particularly *A. aegypti*) poses a significant risk to tongan wildlife.
7. Quantitative sampling in 17 town and 17 farm sites showed that mosquito larval habitat was more abundant in towns than in the country. Mosquito larvae were found in a wide range of habitats. However, markedly more larvae habitats were found in human-related structures, particularly disused concrete water tanks, 44-gallon drums and car tyres.
8. In country sites, larval habitats were generally sparse, except in giant taro plantations where rain-filled branch axils provided frequently used habitat.
9. Mosquito larval habitat could be markedly reduced by managing artificial habitats, in particular introducing predatory freshwater invertebrates (e.g., waterboatmen and dragonflies) and fish into disused water tanks, using fine mesh nets over 44-gallon drums and drilling holes in car tyres.

Introduction

Mosquitoes are one of the largest vectors of disease globally. Currently, over 2000 species of mosquitoes have been identified worldwide, a number of which are known animal and human disease vectors. Mosquito-borne diseases pose a major threat both to the diversity of indigenous fauna and to human populations throughout the world. Studies assessing the possible threats to endemic wildlife in south Pacific nations are limited.

One group of viruses that can be introduced and spread by blood-sucking insects are part of a group of pathogens known as arboviruses (**arthropod-borne viruses**). There are over 100 arboviruses that can cause human disease and many more that cause disease in wildlife, although the latter are poorly known. Some of the better known examples of arboviruses include the West Nile virus, Dengue Fever, Ross River Fever, Yellow Fever and numerous forms of encephalitis. The occurrence of these diseases in animals is receiving increasing attention and as more studies are conducted our understanding of the potential threat to indigenous species improves. For example, recent outbreaks of West Nile virus in the United States have now documented the virus in over 130 species of birds and scores of mammals. West Nile is primarily an avian disease but it occasionally jumps species barriers and infects humans and other mammals. It is believed to have been introduced to the United States from Africa either through the importation of birds or via the translocation of a new species of mosquito.

Many types of arboviruses are harboured in animal populations where they can be held in “wildlife reservoirs” and then transported into a human host via infected mosquitoes. Although there has been little published research examining the influence of mosquito-borne diseases on the population dynamics of wild bird populations, it is well known that pathogens can have a marked effect on individual fitness and in many cases are known to act as a density dependent control of wild populations.

Various arbo-viruses and diseases and protozoan parasites such as malaria have been widely reported around the Pacific. In Hawaii, avian malaria has been responsible for the decline of numerous endemic species, while in Tonga no mosquito-borne diseases have yet been reported in endemic wildlife. However, several outbreaks of Dengue fever in humans have occurred in within the last 10 years, and several mosquito species known to be vectors of this disease (e.g., *Aedes aegypti*) have been previously reported in Tonga (Belkin 1968).

The occurrence and distribution of mosquitoes has been widely documented worldwide, particularly due to the importance of this organism as a vector for human diseases. Despite the profusion of literature on mosquito ecology and control, many countries still have major mosquito populations and poorly developed control programmes. The Kingdom of Tonga has a reputation as a nation with a significant mosquito problem. Historically, the Tongan authorities have instituted limited adult spray programmes associated with human mosquito-borne disease outbreaks, however to our knowledge little information exists on the distribution and habitat preferences of mosquito taxa across the Kingdom.

In this study we conducted a preliminary survey of mosquito species and larval habitat preferences in the kingdom of Tonga in order to assess the possible risk to indigenous wildlife from mosquito-borne diseases.

Specifically we wished to;

- a) determine the distribution of different mosquito species on selected islands,
- b) compare the occurrence of mosquito larvae and habitat in urban and rural areas,
- c) characterise the relative importance of differing artificial and natural habitats for mosquito larvae,
- d) identify possible practices which might be used by local authorities and residents to reduce mosquitoes and their habitat.

A longer term aim that we were not able to complete is this survey due to time and limited resources;

- e) Collect blood samples from both female mosquitoes for analysis of blood parasites.

Methods

Study sites

Located in the South Pacific Ocean, Tonga lies about 2/3 of the way between Hawaii and New Zealand (between latitude 15° and 23°30'S and longitude 173° and 177°W). The kingdom includes three main groups of islands (Tongatapu, Ha'apai and Vava'u) that comprise 170 islands, giving Tonga a collective landmass of 718 km². The capital of Tonga is the small city of Nuku'alofa situated on the island of Tongatapu. The majority of the islands are of volcanic and raised coral origin and support a unique diversity of flora and fauna. The kingdom has a tropical climate, and warm temperatures and high rainfall occur year round.

Six islands were surveyed; the main island Tongatapu and a smaller off-shore island Pangaimotu. Within the Vava'u island group, four islands; Vava'u, Pangaimotu, 'Utungake, and Nuku were surveyed. The urban areas of Tonga, consist of the capital city of Nuku'alofa and a large number of markedly smaller towns and villages (e.g. Tongatapu has approximately 45 small villages). The towns generally consist of 100-200 residents and are almost entirely residential with no business (except one or two small shops) or industry. The rural areas are dominated by fields of coconut trees frequently with ground crops such as giant taro (*Alocasia macrorrhiza*).

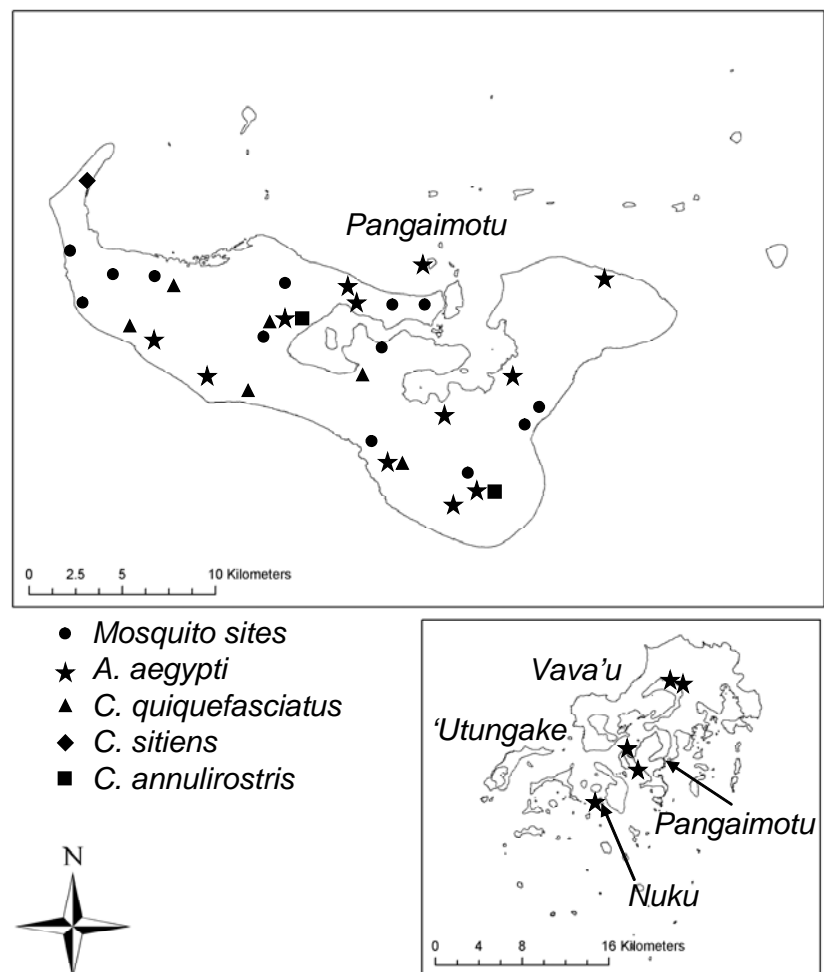


Figure 1. The Tongatapu and Vava'u island groups showing the location of 42 sampling sites on six islands sampled in May 2006. The distribution of the main mosquito species known to be disease vectors are shown.

Mosquito distribution

In order to determine the distribution of species, 42 sites were sampled on six islands. Of these, 22 were town and village sites (each with a grid of approximately 100m²). At each site local residents were asked about known and possible mosquito habitats. A further 20 sites were selected in rural areas, at these sites fields (approximately 100m²) were surveyed for all larval habitats. Where present mosquito larvae were collected from all habitats detected at each grid.

Urban v. rural comparison

To compare the relative frequency of habitats between urban and rural areas a further survey was conducted. A total of 34 quadrats (25m x 25m) were surveyed, 17 in towns and 17 in rural plantations. All larval habitats were identified in every quadrats and the type of habitat described.

Representative larvae were collected at each habitat with a pipette or hand net, preserved in the field in 70% ethanol and returned to the laboratory for identification. Larvae were identified using the key of Belkin (1965).

Results

A total of 8 mosquito species were identified, of which *Aedes aegypti* was the most widespread (Table 1). *A. aegypti* was collected on all six islands and was the only species found in Pangiamotu (in the Tongatapu Island group) and on Vava'u, 'Utungake, and Nuku. Tongatapu had all eight species, while the only other island with more than one species was Pangiamotu (in the Vava'u Island group).

Table 1. Mosquito species collected from 42 sites across six islands.

| | Tongatapu Islands | | Vava'u Islands | | | |
|----------------------------|-------------------|------------|----------------|------------|-----------|------|
| | Tongatapu | Pangiamotu | Vava'u | Pangiamotu | 'Utungake | Nuku |
| <i>Aedes aegypti</i> | X | X | X | X | X | X |
| <i>A. horrescens</i> | X | | | | | |
| <i>A. nocturnus</i> | X | | | | | |
| <i>A. tongae</i> | X | | | | | |
| <i>Culex albinervis</i> | X | | | | | |
| <i>C. annulirostris</i> | X | | | | | |
| <i>C. quinquefasciatus</i> | X | | | X | | |
| <i>C. sitiens</i> | X | | | | | |

A. aegypti was the most commonly collected species occurring in 21 sites (50% of all sites sampled), while *A. nocturnus* was found in 11 sites (26%), and *C. quinquefasciatus* at seven (17%), *A. horrescens*, *A. tongae*, and *C. sitiens* were only found at one site each.

The eight species recorded were distributed relatively evenly across both town and rural sites, with the three most common species, *A. aegypti*, *A. nocturnus*, and *C. quinquefasciatus* occurring frequently in both land uses.

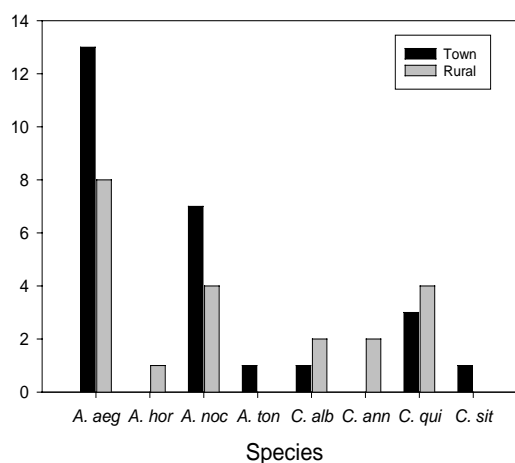


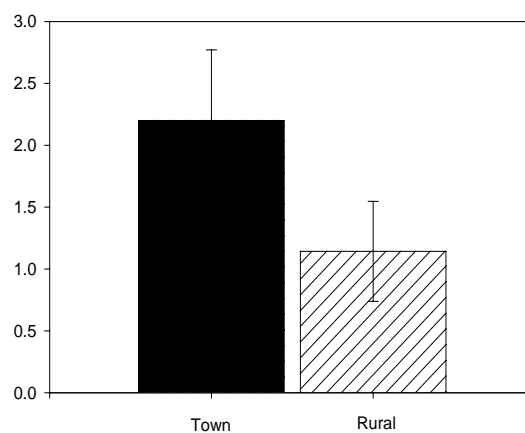
Figure 2. The occurrence of eight species of mosquito larvae inside towns and in country plantations.

Of these eight species, seven are known vectors of animal and human diseases (Table 2).

Table 2. Diseases known to be transmitted by the mosquito species found in Tonga in this survey.

| Species | Disease |
|----------------------------|--|
| <i>Aedes aegypti</i> | Lumpy skin disease in cattle Dengue fever Yellow fever West Nile virus Malaria |
| <i>A. horrescens</i> | Dengue fever filariasis |
| <i>A. nocturnus</i> | West Nile virus Japanese encephalitis |
| <i>A. tongae</i> | Filariasis |
| <i>C. annulirostris</i> | Murray Valley encephalitis Kunjin virus Japanese encephalitis Ross River Fever Barmah Forest Virus |
| <i>C. quinquefasciatus</i> | Filariasis Avian malaria Murray encephalitis Lymphatic disease |
| <i>C. sitiens</i> | Murray River encephalitis Japanese encephalitis Ross River virus (suspected) |

A comparison of the occurrence of mosquito larvae in towns and rural areas showed that more larvae habitats occurred in urban areas than in rural areas (Fig. 3). Within these two land uses larvae were found primarily in artificial habitats in towns, while in rural areas mosquitoes used natural and artificial habitats equally (Fig. 3).



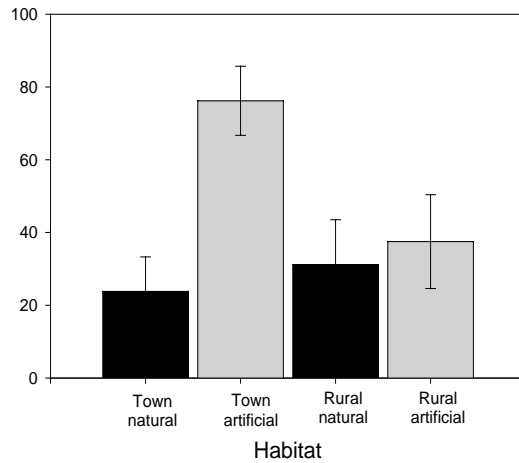


Figure 3. Occurrence of mosquito habitat in town and rural sites in both natural habitats and artificial man-made habitats (mean \pm SE).

The occurrence of artificial habitats in rural plantations, therefore, markedly increased the number of habitats available for mosquitoes. A notable exception to this occurred in Giant taro plantations where larvae were found in taro branch axils. The main artificial habitats colonised in villages and towns were pools (formed by tyre tracks), discarded car tyres, disused concrete water tanks and 44-gallon drums (Fig. 4, 5). While in farm plantations mosquito larvae were commonly found in giant taro (and to a lesser extent in Mango and Fig tree roots), as well as pools and 44-gallon drums. No mosquito larvae were found in banana, coconut, palm or fan palm trees.





Figure 4. Common artificial and natural habitats (old concrete water tanks, pools formed by car tracks, abandoned car tyres, 44-gal drums and giant taro plants) in which mosquito larvae were collected.

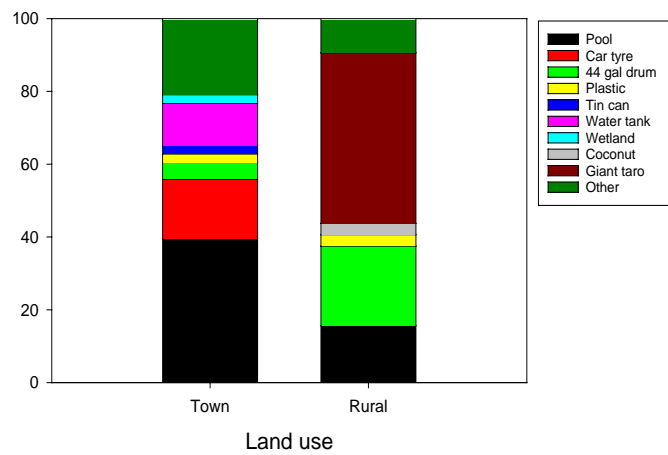


Figure 5. Micro-habitats colonised by mosquito larvae in town and rural sites.

Nine sites (almost all disused concrete water tanks) were sampled which had fish, dragonfly and/or waterboatmen larvae present. Of these sites only two contained mosquito larvae and larvae were in very low abundances.

Discussion

Mosquitoes are widely recognised as a major pest for humans in the kingdom of Tonga, however, relatively little is known about the occurrence and distribution of mosquitoes within the kingdom. Belkin (1965) reported ten species from Tonga, three of which *A. horrcscens*, *C. albinervis* and *C. roseni* were considered questionable records. While Ramalingam (1976) suggested there were eight species, including two endemics *C. annulirostris* and *C. sitiens*. All eight species collected in our study were included in Belkin's list, and we have confirmed the presence of *A. horrcscens* and *C. albinervis* although they were only collected at one and three sites, respectively. These later two species have been recorded by the Tongan Medical Department (1952, 1957), however Ramalingam (1976) suggested these might be misidentifications. To our knowledge, no previous data exists on the distribution of mosquito species throughout Tonga and the results of this study clearly show the ubiquitous distribution of the exotic species *A. aegypti* and *A. nocturnus* on the main Island group.

Anthropogenic impacts have altered all inhabited ecosystems in Tonga both directly (e.g. through land use changes) and indirectly (e.g. via introduced species). Nevertheless, Tonga still supports a number of unique wildlife species that are found no-where else on earth. The bird life on the islands are diverse and like the rest of the flora and fauna, includes a number of threatened endemic species such as the Tongan whistler (*Pachycephala jacquinoti*), red shining parrot (*Prosopaea tabuensis*), blue-crowned lorikeet (*Vini australis*) and the Niuafu'ou megapode (*Megapodius pritchardii*). The aim of this study was to provide baseline data on the distribution and occurrence of mosquitoes in several important islands throughout the kingdom. Our longer term goal is to assess the possible threat to Tongan biodiversity by taking blood samples from bird life. In this initial survey we were unable to carry out blood collections due to time and logistical limitations. However, our distributional data clearly shows that several exotic mosquito species are now entrenched in Tonga, of particular concern is the widespread occurrence of *Aedes aegypti*, which was found on all six islands and was the most common species encountered. This species is a known vector for several diseases (including avian malaria), and its wide distribution poses a significant risk for the diversity of indigenous tongan wildlife species which might be susceptible to introduced diseases.

C. quinquefasciatus was also among the most common species collected, and this mosquito has been attributed to the spread of avian malaria in Hawaii (Warner 1968). Furthermore, several of the rarer mosquito species collected in our study may have recently been introduced and will probably spread given time. Therefore, there is a need for longer term studies of distributions to monitor the spread of these species.

A number of diseases can be introduced to new locations by the introduction of the vector species (in many cases mosquitoes). For example, the accidental introduction of *Culex* mosquitoes in the early 19th century, and the importation and widespread release of domestic fowl, game birds, and cage birds (with their accompanying diseases), are believed to be responsible for the establishment of avian pox virus and malaria (*Plasmodium relictum*) in Hawaiian forest bird populations (Warner 1968; van Riper *et al.* 1986). Research into avian malaria suggests that it represents the single greatest threat to endemic bird species in Hawaii. The disease has been found in around 8% of the birds tested and it is evident that native birds are more susceptible to the disease and have a significantly poorer survival rate than introduced birds (Van Riper *et al.* 1986; Atkinson *et al.* 1995). This has serious implications for native bird faunas elsewhere in the world where the mosquito and the pathogen may have been recently introduced.

Despite the threat that mosquito-borne diseases pose to Pacific Island bird species, there have been very few rigorous epidemiological surveys of disease vectors in the Pacific. Recent surveys in New Zealand suggest that arboviruses may be widespread and implicated in the demise of several captive and wild populations of endangered bird species (New Zealand dotterel, yellowheads, yellow eyed-penguins; Derraik & Calisher 2004). Jarvi *et al.* (2003) found 59% of American Samoan birds were infected with avian malaria, but suggested that it likely that the *Plasmodium* responsible was indigenous. There may well be indigenous pathogens already in Tonga that have yet to be identified along with a raft of non-endemic pathogens. The introduction of a new species of mosquitoes could well impact on any such existing bird/parasite dynamics.

Any introduction of mosquito borne disease into Tonga is liable to occur through a limited number of paths. The greatest risk is probably likely to be posed by an infected human arriving in Tonga. Our data indicate that *A. aegypti* is abundant in the vicinity of the three main ports of entry i.e. Fua'amotu International Airport, Nuku'alofa (the capital and major sea port), and Neiafu (the major port of Vava'u), and it is likely that these exotic species originally arrived in Tonga at these points of entry. No mechanisms exist to detect the arrival of an infected human at these points of entry. Another

potential source of disease arrival is via migratory wildlife. Although this is possible we are not aware of significant migratory species using Tonga and compared to the risk of arrival via human hosts this threat is probably relatively minor. A third potential source of disease is via legal importation of infected animals. Tonga is relatively self-sufficient in domestic livestock and to our knowledge there is no imported pet bird or animal market. Many Tongans own dogs and chickens and the local population of these animals are widespread and self-sustaining. However, people frequently move food between islands, probably including live animal and so the risk of spread of diseases is probably high. If a mosquito borne disease did arrive in Tonga which was able to be spread via dogs and poultry then it would be virtually impossible to control.

The results of this survey clearly indicate that larval habitats are widespread throughout Tonga, and eradication of mosquitoes would require considerable resources that may be beyond those available to the Tongan Government. However, the number and availability of larval habitats have been substantially increased by the creation of artificial habitats. In particular, disused concrete water tanks, 44-gallon drums and used car tyres. Active management by removal or control of these artificial habitats would markedly reduce mosquito habitats and could significantly reduce mosquito numbers and the threat of mosquito borne disease transmission.

Recommendations

1. A widespread education program needs to be instituted to inform the general public about the mosquito life history, that larvae live in standing water and what they can do about it.
2. We recommend that a policy of **active management** of artificial standing water bodies occur in Tonga. This management strategy might include;
 - Burying or destroying disused containers so that they no longer hold water.
 - Placing mesh net covers over 44-gal drums and any containers which are used to collect rainwater.
 - Drilling or cutting holes in the bottom of all disused car tyres
 - Drilling holes in disused concrete water tanks, or stocking them with fish, dragonfly and/or waterboatmen larvae.
3. Further studies more intensive monitoring needs to be conducted on the distribution and possible mechanisms for mosquito control.
4. The occurrence of mosquito borne disease within Tongan wildlife populations needs to be investigated.

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