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Mosquitoes of Rarotonga, Cook Islands: a survey of breeding sites

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Abstract Two surveys of Rarotonga, Cook Islands (21°20′S, 160°16′W) were made to determine the mosquito fauna of the island, and to identify the habitats required for breeding by searching for larvae. The first survey was made during the "dry season" in May 2001, the second during the "wet season" in February 2002. The mosquito fauna comprised four species *Culex* (*Culex*) *quinquefasciatus* Say, *Culex* (*Culex*) *annulirostris* Skuse, *Aedes* (*Stegomyia*) *aegypti* (Linnaeus) and *Aedes* (*Stegomyia*) *polynesiensis* Marks. Larvae of the *Culex* species were most often found in larger natural and artificial water bodies. The *Aedes* species bred in both natural and artificial containers of all sizes. *Ae. polynesiensis* was the most widespread species, using natural holes in all regions as well as artificial containers in the urban areas. Most larvae of *Ae. aegypti* were located in small artificial containers. The two *Aedes* species are the vectors of dengue fever on the island. Mosquito control during outbreaks should specifically target the artificial containers preferred by *Aedes* sp. for breeding habitats.

Keywords *Culex quinquefasciatus*; *Culex annulirostris*; *Aedes aegypti*; *Aedes polynesiensis*; mosquito larval habitats; mosquito breeding sites; mosquito distribution

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INTRODUCTION

Recurrent outbreaks of dengue fever (causative agent, *Flavivirus* transmitted by *Aedes* mosquitoes) in Rarotonga, Cook Islands (21°20′S, 160°16′W) (McCormack 2002) have highlighted the need for better information on the distribution and ecology of mosquitoes on the island. A key aim of this research was to distinguish the breeding habitats of the two *Aedes* species from those of *Culex*, which do not transmit dengue fever. Two surveys of breeding habitats were made in May/June 2001 (dry season) and February 2002 (wet season), extending the work of Keenan (1994).

STUDY AREA AND METHODS

Rarotonga is the largest island of the Southern Cook Islands group. It is a volcanic island of roughly circular outline with an area of 6880 ha and perimeter of 32 km. There are broadly three habitat zones on the island: a narrow coastal sand strip and lagoon islets (motu), a fertile agricultural and urban zone extending inland for 1–1.5 km and a central, forested, hilly interior covering over 70% of the land area and rising to 653 m. Housing is almost continuous around the coast but is sparse through the agricultural lands and in the inland valleys. The central highlands are unoccupied. The main town of Avarua extends for 4 km around the coast, and to a kilometre inland.

Extensive searches were made within each of the three zones to ensure that the full range of habitats was surveyed. The first survey took place between 23 May and 6 June 2001 during an island-wide clean-up of larval breeding habitats, and the second between 18 and 28 February 2002. In neither survey was it possible to search within houses or other buildings. The collections were thus made entirely in breeding places in the grounds of houses and public buildings, in agricultural areas, in parks, and in the forests. The range of breeding habitats used was the same in both surveys, and the collections are considered together in this account.

Collections of larvae and pupae were made using fine-mesh nets, syringes, and dippers. Trees were searched for water-filled holes and depressions from ground level to a height of 2.5 m. It was not possible to sample crab burrows.

Collections of adults were made during daylight by placing a tube wetted with alcohol over them when feeding on a human bait. Adults were not collected during the dengue epidemic at the time of the second survey.

Identifications were made from Belkin (1962). Trees were identified from McCormack & Künzlé (1995). Mosquito breeding habitats were assigned to the categories defined by Laird (1988). The categories represented in this study are listed in Table 1.

RESULTS

The mosquito fauna of Rarotonga

Four species were identified in the adult and larval collections: *Culex* (*Culex*) *quinquefasciatus* Say, *Culex* (*Culex*) *annulirostris* Skuse, *Aedes* (*Stegomyia*) *aegypti* (Linnaeus), and *Aedes* (*Stegomyia*) *polynesiensis* Marks.

Distribution of mosquito larvae by habitat

In the 2001 survey, 1835 larvae were collected from 44 sample sites representing *x* up to nine habitats, and 766 adults were trapped at 12 locations around the margin of the central forest and on the lagoon islets. In the 2002 survey, 2150 larvae were collected from 84 sample sites.

Table 1 records the distribution of larvae in each of the nine habitat categories. No larvae were found in four extensive hillside terraces for taro (*Colocasia esculenta*) irrigated with stream flows, nor were any found in four streams searched (Laird categories 1 and 2, flowing and ponded streams). There are no lakes (category 3) on the island, and only 12 shallow temporary pools (categories 6 and 7) were discovered, none of which contained mosquito larvae. All other above-ground categories yielded larvae.

Laird's category 4 (swamps and marshes) is well represented on the island by the lowland taro swamps that lie in the depression immediately inland of the coastal fringe. These are, in contrast to the hillside terraces, potentially an immense breeding habitat, with hundreds of metres of ditches filled with stagnant water. During both surveys these all (with one exception) contained gambusids (*Gambusia affinis*) and lacked mosquito larvae. The exception was a large swamp near the airport, which in 2001 had gambusids and no larvae, but in 2002 had no gambusids and myriad larvae of *Cx. quinquefasciatus* and *Cx. annulirostris*.

There were few category 5 habitats (shallow ponds). Four ponds holding water leaking from stock troughs, with adjacent puddling in pig wallows, plus one ornamental pool, all contained many thousand *Cx. quinquefasciatus* and *Cx. annulirostris* larvae.

Rarotonga has an almost complete forest cover, with palms and an understorey on the islets and

Table 1 Number of times each species was found in each larval habitat category (surveys pooled).

Habitat category	*Ae. polynesiensis*	*Ae. aegypti*	*Cx. quinquefasciatus*	*Cx. annulirostris*
4. Swamps and marshes	–	–	7	7
5. Shallow ponds				
(i) Ornamental ponds	–	–	1	1
(ii) From leaking pipes	–	–	4	4
Totals			5	5
8. Natural containers				
(i) Leaf axils	1	–	–	–
(ii) Tree holes	33	3	6	–
(iii) Fallen coconuts	9	–	–	–
Totals	43	3	6	
9. Artificial containers				
(i) Urban areas	13	14	2	–
(ii) Urban fringe	18	7	7	1
(iii) Agricultural zone	15	8	5	2
Totals	46	29	14	3
Totals for each species	89	34	32	16

coastal fringe, extensive tree and plant cover in the agricultural zone, and dense forest inland. These trees, ornamental plantings and food crops potentially provide an abundance of category 8, natural container breeding sites.

At first sight the coastal fringe zone and lagoon islets of coral rubble and sand appeared quite unsuitable as mosquito breeding areas, but almost every fully-grown tree in them supported tree-holes and other potential breeding places. The tree hibiscus (*Hibiscus tilieaceus*) and barringtonia (*Barringtonia asiatica*) were the dominant species in this zone. Searches in 123 of these trees on the islets and within the beach parks yielded 15 breeding sites with larvae, predominantly *Ae. polynesiensis*. These tree holes could, however, harbour a mix of species. The complex ecology of rich water over rotting leaves and fruits in some *barringtonia* holes attracted the widest range of species (three of the possible four, with only *Cx. annulirostris* missing) of any single category of breeding site discovered on the island. In addition, the islets were carpeted in places with fallen coconuts, many of which had been opened by rats. A small proportion contained *Ae. polynesiensis* larvae: 0.8% of 485 nuts in the first survey, 1.03% of 482 in the second.

In the mature forest of the central zone, almost all mosquito breeding sites were in cavities and depressions in mato (*Homalium acuminatum*) and Polynesian chestnut (*Inocarpus fagifer*). Of 127 fully-grown trees surveyed, 33 had water-filled holes, of which 22 had *Ae. polynesiensis* larvae.

Lengthy searching turned up few larvae of any species in the axils of crop and ornamental plants. The surveys found minimal breeding in giant taro (*Alocasia macrorrhiza*) and none in taro, crinum lilies (*Crinum asiaticum*) or traveller palms (*Ravenala madagascarensis*). It must be only under exceptionally wet conditions that mosquitoes breed to any significant extent in these plants on Rarotonga.

Laird's category 9, artificial containers, provided the most rewarding collecting in the urban and agricultural zone. Containers included small tins, jars, used car tyres, drums, abandoned stoves and refrigerators, stock troughs, stored boats; indeed anything holding more than a few millilitres of water. Many containers had little water, and few larvae, but the larger containers supported very large populations. All four species were found in these habitats but, significantly, the two *Aedes* species were the most common.

Collections of adult mosquitoes (in May 2001 only)

There were numerous mosquitoes at all sites within the central forest; four collections totalled 289 *Ae. polynesiensis*. Six collections were made along the forest edge at the upper limit of agriculture. Five found only *Ae. polynesiensis*, 211 in total, and the sixth one contained 76 *Ae. polynesiensis* and two *Cx. quinquefasciatus*. Collections beneath coconut palms on the islets within Muri Lagoon found only *Ae. polynesiensis* biting adults, of which 107 were taken on Motutapu, and 83 on Oneroa.

Associations among the species

The two surveys comprised a total of 116 separate collections of larvae, of which 76 recorded a single species (65.5%), 36 recorded two species (31.0%), and 4 recorded three species (3.5%). Associations among the species are shown in Table 2 for all collections of more than a single larva. In both natural and

Table 2 The number of times the larvae of each species were taken alone or with another species.

	Ae. polynesiensis	*Ae. aegypti*	*Cx. quinquefasciatus*	*Cx. annulirostris*
All collections				
Ae. polynesiensis	62	21	14	0
Ae. aegypti	21	6	2	2
Cx. quinquefasciatus	14	2	11	10
Cx. annulirostris	0	2	10	6
In category 9 habitats only, artificial containers				
Ae. polynesiensis	22	18	10	0
Ae. aegypti	18	6	2	2
Cx. quinquefasciatus	10	2	8	1
Cx. annulirostris	0	2	1	0

artificial habitats *Ae. polynesiensis* and *Ae. aegypti* are the most often associated, *Cx. quinquefasciatus* is equally often associated with *Ae. polynesiensis* and with *Ae. aegypti*, and *Cx. annulirostris* is commonly found only with *Cx. quinquefasciatus*.

DISCUSSION

The mosquito fauna

The species list for 2001/02 comprised the same four species that were recorded by Davis (1949), Belkin (1962) and Keenan (1994). No other species were identified, suggesting that there have been no additional colonisations since the mid-twentieth century. Compared with the faunas of neighbouring South Pacific territories this is a small number of species. Belkin (1962) and Debenham (1987, 1989) list 18 species for Fiji, 13 for Samoa, 8 each for Tonga and the Society Islands. The Southern Cooks as a whole may well be characterised by a small range of species. Laird (1954) found only three species on Aitutaki: *Ae. polynesiensis*, *Culex pipiens fatigans* (= *Cx. quinquefasciatus*, Belkin, 1962) and *Cx. annulirostris*.

Aedes polynesiensis was the most abundant species throughout the island, and occupies the highest number of individual breeding sites, as found also by Davis (1949) and Keenan (1994). Of greater interest is the apparent recent increase in abundance of *Ae. aegypti*. Davis (1949) omitted this species from his experiments "owing to its rarity". In the current surveys *Ae. aegypti* was far from rare, recorded in 11 (37%) of 30 artificial habitats containing larvae in the first survey, and in 18 (51%) of 35 in the second.

The association between species and habitat category

The preferred breeding habitat of the species recorded in these surveys conforms to previous accounts (as reviewed by Debenham 1987, 1989; Laird 1956, 1988), except that we failed to establish any significant breeding in the leaf axils of any of the plant species surveyed. As indicated in the literature, *Ae. aegypti* and *Cx. quinquefasciatus* are considered commensal species. On Rarotonga, *Ae. aegypti* was the more restricted, with *Cx. quinquefasciatus* being more abundant in natural breeding places, especially in swamps and marshes, in the ditches of the taro beds, and in the shallow pools from leaking water, than in artificial containers. *Ae. polynesiensis* was the only species taken in tree holes in the central forest and on the islets, but it was also common in artificial containers in urban areas, sharing the same habitats as *Ae. aegypti*. The fourth species, *Cx. annulirostris*, was found in the ditches of the taro swamps and was uncommon in small containers whether natural or artificial but, as Laird (1956) had noted previously, it may also be found in large, simple, artificial containers. On Rarotonga we found it in stock troughs, in the pooled water inside stored canoes and yachts, and in the concrete ponds of an ornamental pond and stream system.

Implications for mosquito control

The habitat distribution records demonstrate a nice dichotomy in the mosquito fauna on the island. According to Debenham (1987, 1989) the two *Culex* species are essentially nuisance mosquitoes, biting mainly at night but not usually implicated in the transmission of disease. By contrast, the two day-biting *Aedes* species are vectors of dengue fever, and *Ae. polynesiensis* transmits filariasis as well. On Rarotonga the two groups tend to breed in different places. The *Culex* species are most likely to be found breeding in the larger natural habitats, in swamps, lakes, pools, and marshes, and in the larger artificial water bodies. The *Aedes* species flourish in smaller natural and artificial containers. Habitat differences, therefore, provide some guidance for control operations aiming to ameliorate the impact of dengue fever, and most effort should be directed at eradicating small natural and artificial containers in the urban and agricultural areas.

The high densities of *Ae. polynesiensis* in the central forest, inland valleys, and on the islets present a high risk of dengue virus infection to visitors and agricultural workers. On the lagoon islets, tree holes could be filled, but this would not be a feasible option for the central forest.

The special case of the lowland taro swamps

Keenan (1994) found the lowland taro swamps to be potent breeding sites. With a single exception, all such sites included in these surveys were found to have been colonised by gambusids, and no mosquitoes survived long enough there to breed. The exception which proved the rule was the large swamp near the airport in which every ditch checked in February 2002 was infested with extraordinarily high densities of mosquito larvae, both *Cx. quinquefasciatus* and *Cx annulirostris*. No gambusids were caught or seen

there in 2002, but in 2001 the same ditches supported abundant gambusids and no larvae. The difference since the 2001 survey arose because drought over the intervening months had caused the ditches to dry, killing off the fish. With returning wetter conditions mosquitoes again found ideal breeding conditions here in the absence of this predator. The recurrent cycle of wet and dry conditions on the island requires that swamp and marsh habitats that are usually protected from mosquito breeding by gambusids must be regularly monitored, and gambusids or other controls re-introduced when any such habitats are re-filled after drying out.

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