Mosquitoes breeding in phytotelmata in native forests in the Wellington region, New Zealand

José G. B. Derraik

Ecology & Health Research Centre, Department of Public Health, Wellington School of Medicine & Health Sciences, University of Otago, P.O. Box 7343, Wellington, New Zealand.
(E-mail: jderraik@ihug.co.nz)

Abstract: This study assessed the level of utilization by mosquitoes of the available phytotelm habitats in indigenous forests in the Wellington region (New Zealand). The native epiphyte *Collospermum hastatum* was found to be the most abundant source of larval mosquito habitats in local native forests, but no mosquito larvae were recorded in the plants' leaf axils. Apart from these epiphytes, the local forests were found to have few natural breeding containers, and the only other relevant type of phytotelm habitat for mosquitoes was tree holes. The single mosquito species recorded was the exotic *Ochlerotatus notoscriptus*, whose larvae occurred in 23% (9/39) of the water-bearing tree holes in the region. The results provided some evidence that larval mosquito habitats in the region are underutilized.

Keywords: mosquitoes; phytotelmata; native forests; Wellington; *Ochlerotatus notoscriptus*.

Introduction

The term phytotelmata ('plant-waters') was coined by Varga (1928) to describe bodies of water impounded by plants. According to Fish (1983) over 1500 different plant species from at least 26 families have been reported to impound water. Leaf axils seem to be the most common type of phytotelmata (Greeney, 2001), with the Bromeliaceae alone believed to have more than 1000 species capable of impounding water (Frank, 1983).

The literature on mosquitoes inhabiting phytotelmata is relatively extensive, particularly due to bromeliad-breeding species and their public health significance in tropical regions (e.g. Olano *et al.*, 1997; Forattini *et al.*, 1998; Cunha *et al.*, 2002). Due to the nature of New Zealand's native flora, phytotelm-forming plants seem to be relatively rare, and, considering the amount of information available overseas, the records of mosquitoes in phytotelmata in this country are scarce. Mosquitoes in New Zealand have been recorded from at least three phytotelm habitats: leaf axils, tree holes and fallen plant parts (e.g. Belkin, 1968). Two endemic species in particular, *Culex asteliae* Belkin and *Maorigoeldia argyropus* (Walker), seem adapted to such breeding habitats (Belkin, 1968).

There is, however, evidence that larval breeding containers in native ecosystems in New Zealand are underutilized (Laird, 1990). Laird (1990) suggested that such underutilization of larval mosquito habitats in northern New Zealand has aided in the establishment of the exotic *Ochlerotatus notoscriptus* (Skuse) and *Culex quinquefasciatus* Say. New Zealand is at risk of an arbovirus outbreak (Weinstein, 1996; Derraik & Calisher, 2004), and this situation could be aggravated by the establishment of other exotic vectors such as *Aedes albopictus* (Skuse), which might be able to exploit available larval habitats not utilized by native mosquitoes (Derraik, 2005b). *Aedes albopictus* and at least 26 other exotic mosquito species have been intercepted in New Zealand in the past 75 years (Derraik 2004b). This study therefore aimed to assess the level of utilization by mosquitoes of the available phytotelm habitats in indigenous forests in the Wellington region, New Zealand.

Methods

This study was carried out in the Wellington region, North Island, New Zealand. The area has a mean annual rainfall of 1249 mm with 123 wet days per annum, and a mean average annual temperature of 12.8°C (NIWA, 2004). Five sites were surveyed between January and March 2002, including four native forests, Otari-Wilton's Bush, Karori Wildlife Sanctuary, Kaitoke Regional Park and Nga Manu Reserve (Waikanae), and the Wellington Zoo. The native forest sites examined were reserves and, with the exception of Nga Manu, were mostly made up of native conifer-broadleaf forests dominated by angiosperms, with emerging podocarp trees. The sampled area at Kaitoke consisted of a pristine mature forest, while at Otari and Karori the studied areas were a mixture of primary and secondary growth forests. Nga Manu consisted of a relatively small but pristine remnant of primary swamp forest. The Wellington Zoo contained a belt of highly modified native vegetation, and numerous exotic mammals that seem to benefit mosquitoes in New Zealand (Derraik, 2004a; 2004c).

All sites but the Wellington Zoo undergo regular animal control programmes to cull exotic pests such as rats (*Rattus* spp.) and brushtail possums (*Trichosurus vulpecula* Kerr). With the exception of Kaitoke, all sites were located near urban areas. The survey was carried out during a one-off search route along the main tracks within the sites. All plants within five metres on each side of the track (with a search height restricted to c. 2.5 m) were carefully examined for any phytotelm habitats.

In the early stages of the investigation it became clear that native forests in Wellington had a limited availability of phytotelm habitats. The major exception was the native epiphyte *Collospermum hastatum* (Liliaceae) (Fig. 1), which is commonly found in coastal and lowland forests throughout the North Island (Dawson and Lucas, 2000). Individual plants are capable of harbouring mosquito larvae within leaf axils, and *C. hastatum* is the main breeding habitat for the endemic *C. asteliae* (Belkin, 1968; Derraik, 2005a), but larvae of the exotic *O. notoscriptus* have also been recorded in its leaf axils (Dumbleton, 1968; Derraik, 2004a). As an epiphyte, *C. hastatum* is abundant in the canopy of native trees, and therefore more commonly found above the height limit established for the general survey.

Figure 1. Leaf axils of the native epiphyte *Collospermum hastatum* being checked for mosquito larvae with endoscopic sampling tool, on the top of a rimu tree.

A second investigation consequently focused on *C. hastatum*, at Otari-Wilton's Bush. Two *C. hastatum* plants on each of six native rimu trees (*Dacrydium cupressinum*; Podocarpaceae) were accessed via climbing ropes and regularly checked for the presence of mosquito larvae. The 12 plants were checked fortnightly for mosquito larvae on eight occasions from January to April 2002. Although *C. hastatum* are most abundant in the tree canopy, specimens are occasionally present in the forest understorey. Four such plants that were large and healthy were also included in the fortnightly survey for mosquito larvae.

In order to extract the water contents from *C. hastatum* leaf axils and other phytotelm habitats, a sampling tool made of an endoscopic tube 5 mm wide and 550 mm long, attached to a 50 mL syringe was used (Fig. 1). Larger phytotelmata such as basal tree holes were sampled using a turkey baster. Water contents of leaf axils and other phytotelm habitats were transferred into plastic containers and transported to the laboratory, where they were inspected for the presence of mosquito larvae. All larvae collected were counted and identified to species.

Results

A total of 2577 trees (excluding seedlings) were carefully examined in this survey. Only 33 water-filled tree holes were recorded in all native forest sites investigated, while a further six were recorded in native and exotic trees at the Wellington Zoo (Table 1). The number of water-filled tree holes varied considerably between the sites. Although only 6% (141) of all trees were surveyed at the Zoo, there were six water-filled tree holes (15%; Table 1). In contrast, a single water-filled tree hole (3%) was recorded at Kaitoke Regional Park where 21% of the surveyed trees (529) were located (Table 1). The native mahoe (*Melicytus ramiflorus*; Violaceae) was the most abundant species recorded (477 trees, 19% of total) and the source of 20 water-filled tree holes (51%; Table 2).

Overall, the Wellington Region was found to have a very low mosquito occupancy rate of tree holes, with 9 out of 39 water-filled tree holes (23%) having mosquito larvae (Table 1). When only the data from native forest habitats were taken into account, this rate dropped to 15% (5/33); this is because the occupancy rate at the Zoo was proportionally higher than in all other sites with four out of six tree holes (67%) having larvae (Table 1).

The only mosquito species recorded in tree holes was the exotic *O. notoscriptus*, whose larvae were found in six different tree species (Table 2): the exotic *Acacia* sp. (Fabaceae) and *Rhododendron* sp.

Table 1. Results from tree hole survey in the Wellington region during summer 2001/2.

Locality	Approximate coordinates	No. trees examined	No. water-filled tree holes	Tree holes with larvae	Percent with larvae
Kaitoke Regional Park	41° 03' S 175° 11' E	529	1	0	0%
Karori Wildlife Sanctuary	41° 17' S 174° 44' E	633	10	1	10%
Nga Manu Reserve	40° 51' S 175° 03' E	425	3	0	0%
Otari-Wilton's Bush	41° 16' S 174° 45' E	849	19	4	21%
Native Forests Total		2436	33	5	15%
Wellington Zoo	41° 19' S 174° 47' E	141	6	4	67%
Wellington Region Total		2577	39	9	23%

Table 2. List of tree species, the water content of tree holes and respective numbers of mosquito larvae found in a survey of five different localities in the Wellington region during summer 2001/2. The exotic tree species are indicated. All larvae were of the exotic mosquito *Ochlerotatus notoscriptus*.

Locality	Tree species	Vol. (mL)	No. mosquito larvae
Kaitoke Regional Park	*Nothofagus truncata*	34	0
Karori Wildlife Sanctuary	*Hoheria populnea*	6	0
	Melicytus ramiflorus	50	10
		59	0
		85	0
		101	0
		132	0
		220	0
		254	0
		526	0
		669	0
Nga Manu Reserve	*Dacrycarpus dacrydioides*	228	0
	Laurelia novae-zelandiae	117	0
	Melicytus ramiflorus	65	0
Otari-Wilton's Bush	*Dacrydium cupressinum*	100	0
		159	0
	Dysoxylum spectabile	127	0
		178	0
	Hedycarya arborea	421	30
	Melicytus ramiflorus	14	0
		19	0
		63	0
		84	0
		116	0
		170	15
		229	0
		301	0
		340	0
		342	22
	Myoporum laetum	27	0
	Nothofagus solandri var. *cliffortioides*	6	5
		17	0
		111	0
Wellington Zoo	*Acacia* sp. [exotic]	30	2
	Griselinia littoralis	5	8
	Pittosporum eugenioides	13	0
	Plagianthus regius	3	0
	Rhododendron sp. [exotic]	6	7
		10	9

(Ericaceae), and the native broadleaf (*Griselinia littoralis*; Cornaceae), pigeonwood (*Hedycarya arborea*; Monimiaceae), mahoe and mountain beech. Three out of the nine tree holes containing larvae were in mahoe (Table 2). Larvae of other Diptera families were occasionally recorded, including Empididae, Syrphidae and Tipulidae (Derraik and Heath, 2005).

The volume of water impounded by a particular tree hole did not appear to determine the presence of mosquito larvae (Table 2). Two tree holes on mahoe at Otari contained more than 0.5 L of water, but yielded no larvae, while mosquito larvae in some instances were collected from minute amounts of water (Table 2). Three particular tree holes (in *G. littoralis*, *Rhododendron* sp. and mountain beech) contained 5–6 mL of water with 5–8 larvae each, equating to 0.8–1.6 larvae per mL of water. The highest abundance of mosquito larvae recorded was 30 specimens in 421 mL of water from a *H. arborea* tree hole at Otari (Table 2).

Despite the extensive survey, no fallen plant parts impounding water were found. Leaf axils suitable for mosquito breeding, apart from those of *C. hastatum*, were also practically absent. Several inspected flax bushes (*Phormium tenax*; Agavaceae) yielded between 26 and 98 mL of water per axil, but yielded no mosquito larvae. Flax leaf axils however, harboured larvae of other Diptera, specifically Ceratopogonidae, Chironomidae and Syrphidae (Derraik and Heath, 2005).

The monitoring of *C. hastatum* equated to 128 plant-visitations and more than 2000 examinations of leaf axil samples. No mosquito larvae were recorded, even though 24 other *C. hastatum* plants on the surveyed tree canopies were also inspected once, as were a further five plants on the ground at Kaitoke and 11 at Otari. Although no mosquito larvae were recorded in any of these plants, numerous other Diptera larvae were recorded, including Ceratopogonidae, Chironomidae, Psychodidae and Tipulidae (Derraik and Heath, 2005).

Discussion

Availability of tree holes

It is possible that Wellington region's windy climate might have affected the outcome of this survey, so that many tree holes capable of holding water for a significant period of time were dry. Since at the time of the survey the Wellington region experienced the third highest summer rainfall average for the season since records began (NIWA, 2002), the level of water-filled tree holes was not likely to have been uncommonly low.

The age of a particular forest stand plays an important part in the availability of tree hole habitats. The extremely gnarled morphology in mahoe, for instance, substantially develops as the tree gets older and larger. Basal tree circumference can be positively associated with number of tree holes per tree (Beier & Trpis, 1981). Preliminary investigations in the Lewis Pass National Reserve (central South Island) and the Orikaka Ecological District (Westland) have provided similar results for red, mountain and silver beech trees (*Nothofagus* spp.) sampled to full canopy height (T. Blakely and R. Didham, University of Canterbury, Christchurch, unpubl. data). Nonetheless, the investigation of primary forest at Kaitoke yielded a single water-filled tree hole, indicating that the age of forest stand was not the main factor accounting for the low availability of tree hole habitats in the region.

The only native tree species that was an important source of tree hole habitats in the Wellington region was mahoe, which is one of the most common lowland native trees in New Zealand in both forests and scrublands (Salmon, 1996). The few mountain beech trees inspected suggested that this species may be also a common source of tree holes. The investigation at Lewis Pass National Reserve has indicated that mature trees of mountain, red and silver beech do form large numbers of tree holes, but they seem to occur mostly above 15 m (T. Blakely and R. Didham, University of Canterbury, Christchurch, unpubl. data). It is not known whether tree holes are also more common in the canopy of other mature native trees, but it is possible that many tree holes might have been missed due to the height limit (c. 2.5 m) imposed in this study. However, mosquitoes are known to display oviposition height preferences and many species clearly favour particular forest strata (e.g. Corbet 1961; Scholl and DeFoliart 1977; Tikasingh *et al.* 1987). It is therefore uncertain whether New Zealand mosquitoes oviposit in canopy tree holes. *Culex asteliae* larvae have been collected from *C. hastatum* plants at 18 m and *O. notoscriptus* adults were also recorded biting at the same height (Derraik, 2005a), but *C. asteliae* has never been recorded in tree holes.

In addition, other authors have also noted that native forests in New Zealand have a very limited availability of tree holes. Hayes (1974) surveyed forests in the Waitakere Ranges (Auckland) and observed that tree-hole-forming types of timber were very rare. Dumbleton (1965) investigated Westland forests (West Coast, South Island) and concluded that water-filled tree holes were also rare, despite the region averaging one of the highest rainfalls in New Zealand. In contrast, many tree species overseas form large number of tree holes (e.g. Beier & Trpis 1981; Welch and Long, 1984), and in New Zealand, certain exotic species, such as Moreton Bay figs (*Ficus macrophylla*; Moreaceae) and coral trees (*Erythrina sykesii*; Fabaceae), stand out as very abundant sources of tree hole habitats for mosquitoes in the Auckland region (J. Derraik, unpubl. data).

There have been few comprehensive investigations on the distribution of mosquitoes and their occupancy rate of tree hole habitats. However, tree hole utilization by mosquitoes in the Wellington region was substantially lower than that of overseas studies. The rate obtained in this investigation was only 15% in native forests, in comparison to 86% in Nigeria (Dunn, 1927), 84% in Uganda (Haddow, 1945), and >50% in the U.S.A. (Sinsko and Craig, 1981). Sinsko & Craig (1979, 1981) found that the frequency of water-filled tree holes sometimes dropped from 66% to 42% within a week, indicating that temporal variation can be considerable at small scales. Moreover, they mentioned that, according to their observations, short periods of heavy rainfall may not be as productive for filling tree holes as longer periods of light rainfall. Since this investigation was carried out over a relatively short period of time, it is possible that wider temporal sampling might have yielded a higher frequency of *O. notoscriptus* in tree holes. However, an oviposition study carried out in the Auckland region in the following year indicated that the population numbers of *O. notoscriptus* were positively associated with the highest mean air temperature (Derraik and Slaney 2005). Because February is New Zealand's warmest month (NIWA 2004) this investigation is likely to have coincided with the population peak of *O. notoscriptus*. In addition, 57% (17/30) of water-filled tree holes with no immature mosquitoes occurred in mahoe, which was the tree species that yielded the most larvae. Therefore, it is very unlikely that any chemical factors such as leachates were inhibiting mosquito oviposition or larval development.

Species present

The only mosquito species found breeding in any natural containers in Wellington forests was the exotic *Ochlerotatus notoscriptus*. Based on historical records, the only native mosquito that may also occupy tree holes in Wellington forests is *Maorigoeldia argyropus*. This species seems to have become restricted to relatively pristine and large native forest areas (Pillai 1965; Hayes, 1974), so it is not known whether *M. argyropus* is still present in areas such as Otari and Kaitoke. There is, nonetheless, increasing evidence that *O. notoscriptus* is now the most common mosquito utilizing container habitats in anthropic environments and disturbed native forests in the North Island (e.g. Derraik, 2004a; Derraik and Slaney, 2005), although it has yet to invade the interior of pristine forests (Derraik; unpubl. data).

The original breeding habitats of *O. notoscriptus* in its native Australia were tree holes (Russell, 1986), and in New Zealand it seems to be occupying a niche in indigenous forests highly underutilized by native mosquitoes. It is possible that the relatively recent arrival of *O. notoscriptus* in the Wellington region (c. 1970) (Laird and Easton, 1994) accounts for its low abundance (of both larvae and adults) in local native forests, with colonization of these habitats being at an early stage. It is common amongst biological invaders to experience long lag times, sometimes for many years, during which the population is maintained at low numbers, until environmental conditions are favourable and population explosion occurs (Enserink, 1999). Although the first known record of *O. notoscriptus* in New Zealand dates back to at least 1920 (Laird and Easton, 1994), the last comprehensive mosquito survey carried out in the North Island in 1993 and 1994 indicated that the species was still expanding its distribution southwards (Laird, 1995). The spread of *O. notoscriptus* is reason for concern, as it is a vector of human diseases (Derraik, 2004b). In Australia, *O. notoscriptus* has been implicated as an urban vector of Ross River virus (Russell, 1995; Watson and Kay, 1997), which is the mosquito-borne virus most likely to cause a disease outbreak in New Zealand (Derraik and Calisher, 2004).

Collospermum hastatum

Despite the large number of leaf axils examined no mosquito larvae were encountered in *C. hastatum*. The average water yield from individual *C. hastatum* leaf axils was 8.0 ml (based on 1000 axils) and the largest maximum storage capacity of a single leaf axil was 78 ml. These figures are relatively high compared to phytotelm-forming plants known to harbour several mosquito species in Africa (Gibbins, 1942; Haddow, 1948) and North America (Mogi and Mokry, 1980).

The only mosquito species in New Zealand that regularly utilizes the leaf axils of *C. hastatum* is the endemic *C. asteliae*, a species that has been found only from Auckland northwards (Belkin 1968). Leaf axils are rather specialized habitats, which could explain why *Ochlerotatus notoscriptus* seldom utilize *C. hastatum* plants in native forests. However, *O. notoscriptus* larvae were considerably more common in *C. hastatum* in the Auckland Zoo (Derraik, 2004a), which might be a result of higher mosquito density and increased competition for larval habitats.

Conclusions

The evidence from Wellington suggests that an invading cold-tolerant exotic species would find abundant breeding habitats to exploit, in particular the leaf axils of *C. hastatum*. *Aedes albopictus*, which has been intercepted at least 12 times in New Zealand (Derraik, 2004b), is a species that fits the profile of an ideal invader to occupy such habitats (Derraik, 2005b). The local climate may be suitable for cold-tolerant strains from Japan, and conditions may become significantly more favourable for the species under a climate change scenario (de Wet *et al*., 2001; Laird *et al.*, 1994).

The results from this field study also indicated that, apart from the numerous large clumps of *C. hastatum* plants on the tree canopy and some sporadic tree holes, native forest habitats in the Wellington Region seem to have few phytotelm habitats. However, in areas where mahoe and beech trees are present in large numbers there may be enough tree holes to sustain a viable breeding population of mosquitoes. Nonetheless, the low number of larva-containing tree holes and the absence of mosquito larvae in the *C. hastatum* plants surveyed support the hypothesis that natural breeding containers in indigenous forests in the Wellington region are underutilized by mosquitoes. This study therefore corroborated Laird's proposition of the underutilization of mosquito breeding habitats in New Zealand's indigenous ecosystems (Laird, 1990), at least for the studied region.

Acknowledgements

I would like to thank: Mauritz Basson (Wellington Zoo); Eleanor Burton, Jane Wright and John Dawson (Otari-Wilton's Bush); the staff from the Nga Manu Reserve and Karori Wildlife Sanctuary. Thanks to Cathy Rufaut, Phil Sirvid, Kay Clapperton, Duane Peltzer, and two anonymous reviewers for valuable comments on previous versions of this manuscript; to Raphael Didham for his input; and to Dave Slaney for his encouragement and assistance. Neil Price has kindly given permission to use his photograph. The University of Otago provided funding support.

References

Beier, J.C.; Trpis, M. 1981. Local distribution of *Aedes triseriatus* (Diptera: Culicidae) at the Baltimore Zoo. *Mosquito News 41:* 447-455.

Belkin, J.N. 1968. Mosquito Studies (Diptera: Culicidae) VII. The Culicidae of New Zealand. *Contributions of the American Entomological Institute 3:* 1-182.

Corbet, P.S. 1961. Entomological studies form a high tower in Mpanga Forest, Uganda IV. Mosquito-breeding at different levels in and above the forest. *Transactions of the Royal Entomological Society of London 113:* 275-283.

Cunha, S.P.; Alves, J.R.C.; Lima, M.M.; Duarte, J.R.; Barros, L.C.V.; Silva, J.L.; Gammaro, A.T.; Filho, O.S.M.; Wanzeler, A.R. 2002. Presence of *Aedes aegypti* in Bromeliaceae and plant breeding places in Brazil. *Revista de Saúde Pública 36:* 244-245.

Dawson, J.; Lucas, R. 2000. *Nature guide to the New Zealand forest*. Godwit, Auckland, N.Z., 312 pp.

Derraik, J.G.B. 2004a. A survey of the mosquito (Diptera: Culicidae) fauna of the Auckland Zoological Park. *New Zealand Entomologist 27:* 51-55.

Derraik, J.G.B. 2004b. Exotic mosquitoes in New Zealand: a review of species intercepted, their pathways and ports of entry. *Australian and New Zealand Journal of Public Health 28:* 433-444.

Derraik, J.G.B. 2004c. Mosquitoes (Diptera: Culicidae) breeding in artificial habitats at the Wellington Zoo. *The Weta 28:* 28-31.

Derraik, J.G.B. 2005a. Presence of *Culex asteliae* larvae and *Ochlerotatus notoscriptus* adults (Diptera: Culicidae) in native tree canopy in the Auckland region. *The Weta 29:* 9-11.

Derraik, J.G.B. 2005b. A scenario for invasion and dispersal of *Aedes albopictus* (Diptera: Culicidae) in New Zealand. *Journal of Medical Entomology 42:* in press.

Derraik, J.G.B.; Calisher, C.H. 2004. Is New Zealand prepared to deal with arboviral diseases? *Australian and New Zealand Journal of Public Health 28:* 27-30.

Derraik, J.G.B.; Heath, A.C.G. 2005. Immature Diptera (excluding Culicidae) inhabiting phytotelmata in the Auckland and Wellington regions. *New Zealand Journal of Marine and Freshwater Research 39:* 981-987.

Derraik, J.G.B.; Slaney, D. 2005. Container aperture size and nutrient preferences of mosquitoes (Diptera: Culicidae) in the Auckland region, New Zealand. *Journal of Vector Ecology 30:* 73-82.

de Wet, N.; Ye, W.; Hales, S.; Warrick, R.; Woodward, A.; Weinstein, P. 2001. Use of a computer model to identify potential hotspots for dengue fever in New Zealand. *New Zealand Medical Journal 114:* 420-422.

Dumbleton, L.J. 1965. Developmental stages and biology of *Culiseta tonnoiri* (Edwards) and a note on *Culex pervigilans* Bergroth (Diptera: Culicidae). *New Zealand Journal of Science 8:* 137-143.

Dumbleton, L.J. 1968. A synopsis of the New Zealand mosquitoes (Diptera: Culicidae) and a key to the larvae. *Tuatara 16:* 167-179.

Dunn, L.H. 1927. Tree-holes and mosquito breeding in West Africa. *Bulletin of Entomological Research 18:* 139-144.

Enserink, M. 1999. Predicting invasions: biological invaders sweep in. *Science 285:* 1834-1836.

Fish, D. 1983. Phytotelmata: flora and fauna. *In*: Frank, J.H.; Lounibos, L.P. (Editors), *Phytotelmata: terrestrial plants as hosts for aquatic insect communities*, pp. 1-27. Plexus Publishing, Medford, U.S.A., 293 pp.

Forattini, O.P.; Marques, G.R.A.M.; Kakitani, I.; Brito, M.; Sallum, M.A.M. 1998. Significado epidemiológico dos criadouros de *Aedes albopictus* em bromélias. *Revista de Saúde Pública 32:* 186-188.

Frank, J.H. 1983. Bromeliad phytotelmata and their biota, especially mosquitoes. *In*: Frank, J.H.; Lounibos, L.P. (Editors), *Phytotelmata: terrestrial plants as hosts for aquatic insect communities*, pp. 101-128. Plexus Publishing, Medford, U.S.A., 293 pp.

Gibbins, E.G. 1942. On the habits and breeding-places of *Aedes (Stegomyia) simpsoni* Theobald in Uganda. *Annals of Tropical Medicine and Parasitology 36:* 151-160.

Greeney, H.F. 2001. The insects of plant-held waters: a review and bibliography. *Journal of Tropical Ecology 17:* 241-260.

Haddow, A.J. 1945. On the mosquitoes of Bwamba County, Uganda. I. Description of Bwamba, with special reference to Mosquito Ecology. *Proceedings of the Zoological Society of London 115:* 1-13.

Haddow, A.J. 1948. The mosquitoes of Bwamba County, Uganda. VI. Mosquito breeding in plant axils. *Bulletin of Entomological Research 39:* 185-213.

Hayes, J.C. 1974 (unpublished). *Biology of* Maorigoeldia argyropus *(Walker) (Diptera, Culicidae).* M.Sc. thesis, University of Auckland, Auckland, N.Z.

Laird, M. 1990. New Zealand's Northern Mosquito Survey, 1988-89. *Journal of the American Mosquito Control Association 6:* 287-299.

Laird, M. 1995. Background and findings of the 1993-94 New Zealand mosquito survey. *New Zealand Entomologist 18:* 77-90.

Laird, M.; Calder, L.; Thornton, R.C.; Syme, R.; Holder, P.W.; Mogi, M. 1994. Japanese *Aedes albopictus* among four mosquito species reaching New Zealand in used tires. *Journal of the American Mosquito Control Association 10:* 14-23.

Laird, M.; Easton, J.M. 1994. *Aedes notoscriptus* (Diptera: Culicidae) in Wellington Province. *New Zealand Entomologist 17:* 14-17.

Mogi, M.; Mokry, J. 1980. Distribution of *Wyeomyia smithii* (Diptera: Culicidae) eggs in pitcher plants in Newfoundland, Canada. *Tropical Medicine 22:* 1-12.

NIWA. 2002. *Climate summary for summer 2001-02*. National Institute of Water and Atmospheric Research (NIWA). URL: http://www.niwa.co.nz/ncc/cs/sclimsum_02_1_summer. Accessed 5 July 2004.

NIWA. 2004. *Climate Data*. National Institute of Water and Atmospheric Research (NIWA). URL: http://www.niwa.co.nz/edu/resources/climate/. Accessed 5 July 2004.

Olano, V.; Carrasquilla, G.; Méndez, F. 1997. Transmisión de la malaria urbana en Buenaventura, Colombia: aspectos entomológicos. *Revista Panamerica de Salud Publica 1:* 287-294.

Pillai, J.S. 1965. Notes on mosquitoes of New Zealand I. *Maorigoeldia argyropus* Walker (Diptera, Culicidae, Sabethini). *New Zealand Entomologist 3:* 25-35.

Russell, R.C. 1986. Larval competition between the introduced vector of dengue fever in Australia, *Aedes aegypti* (L.), and a native container-breeding mosquito, *Aedes notoscriptus* (Skuse) (Diptera: Culicidae). *Australian Journal of Zoology 34:* 527-534.

Russell, R.C. 1995. Arboviruses and their vectors in Australia: an update on the ecology and epidemiology of some mosquito-borne arboviruses. *Review of Medical and Veterinary Entomology 83:* 141-158.

Salmon, J.T. 1996. *The native trees of New Zealand*. Reed Books, Auckland, N.Z., 384 pp.

Scholl, P.J.; DeFoliart, G.R. 1977. *Aedes triseriatus* and *Aedes hendersoni*: vertical and temporal distribution as measured by oviposition. *Environmental Entomology 6:* 355-358.

Sinsko, M.J.; Craig, G.B. 1979. Dynamics of an isolated population of *Aedes triseriatus* (Diptera: Culicidae) I. Population size. *Journal of Medical Entomology 15:* 89–98.

Sinsko, M.J.; Craig, G.B. 1981. Dynamics of an isolated population of *Aedes triseriatus* (Diptera: Culicidae) II. Factors affecting productivity of immature stages. *Journal of Medical Entomology 18:* 279-283.

Tikasingh, E.S.; Martinez, R.; Guerra, A. 1987. Vertical distribution of ovipositing *Toxorhynchites moctezuma* in Trinidad. *Journal of the American Mosquito Control Association 3:* 319-321.

Varga, L. 1928. Ein interessanter Biotop der Bioconöse von Wasserorganismen. *Biologisches Zentralblatt 48:* 143-162.

Watson, T.M.; Kay, B.H. 1997. Is *Aedes notoscriptus* (Skuse) an urban vector of Ross River virus in Southeast Queensland? *Arbovirus Research in Australia 7:* 305-307.

Weinstein, P. 1996. When will mosquitoes strike? *New Zealand Science Monthly 7:* 6-7.

Welch, J.B.; Long, J.D. 1984. *Aedes aegypti* collections in rural southeast Texas. *Mosquito News 44:* 544-547.

Editorial Board member: Kay Clapperton