EXOTIC AND ENDEMIC MOSQUITOES IN NEW ZEALAND AS POTENTIAL ARBOVIRUS VECTORS

Occasional paper, Ministry of Health, Wellington

Philip Weinstein,[1] Marshall Laird [2] and Gene Browne [2]

[1] Department of Public Health, Wellington School of Medicine, University of Otago, PO Box 7343, Wellington South.
[2] School of Biological Sciences, University of Auckland, Private Bag, Auckland.

ISBN 0-478-09498-1 (Booklet)
ISBN 0-478-20807-3 (Internet)

ABSTRACT

Three accidentally imported mosquito species, now established in New Zealand, are potential arbovirus vectors. *Culex quinquefasciatus*, native to warmer parts of the Americas, was collected here prior to 1848. The water supplies of American whaling vessels that made heavy use of the Bay of Islands in the mid-1830s were the likely source, Australia's stock doubtless being similarly derived. Predominantly a utiliser of polluted surface-water larval habitats, its immature stages also abound in a wide range of artificial containers, from gully traps in stormwater drains through discarded water barrels and drums to used tyres. When shaded, such containers also harbour *Aedes notoscriptus*, originally a natural container utiliser from rock pools to tree holes and leaf axils. First collected in Auckland in 1916, this species had initially been described from Sydney, New South Wales, in 1889. It has since been reported from all Australian states (although rarely in Tasmania), as well as from much of Melanesia, Polynesia and Indonesia's Moluccas. There is evidence of recent dispersal of both mosquitoes from their original entry points in the northern North Island southwards, with a 1930 report of the presence of both in Nelson (in the relatively mild north-east of the South Island). Stewart Island and the southernmost parts of the South Island were the first areas from which *Aedes australis* was collected in New Zealand just over three decades ago. It has since shown northward dispersal as far as Timaru. All three species could possibly transmit Ross River virus in New Zealand. *A. notoscriptus* and *A. australis* are potential vectors of dengue fever too, and *C. quinquefasciatus* is a possible vector of encephalitis viruses.

A simplified larval key to the mosquitoes of New Zealand is provided on page 9.

INTRODUCTION

Three potential arbovirus vectors are currently well established in New Zealand: *Aedes (Finlaya) notoscriptus* (Skuse), *A. (Halaedes) australis* (Erichson) and *Culex (Culex) quinquefasciatus* Say. The last mentioned arrived in the early years of European settlement. *A. notoscriptus* was first noticed here during World War I (Miller 1920), and *A. australis* only three decades ago (Nye 1962). These imported species are the only ones thus far to have demonstrated vector competence for human arboviruses in New Zealand. Their potential involvement in local disease transmission has been recently highlighted (Laird 1990, 1995; Calder and Laird 1994; Maguire 1994; Weinstein 1994, 1995; Weinstein et al 1995). The present paper aims to provide an up-to-date training document for Health Protection Officers by briefly reviewing entomological data and presenting a simplified larval key for rapid identification.

SYNOPSIS

Aedes notoscriptus

Incidence First described from Sydney, Australia, in 1889 (Lee et al 1982), this species has been introduced repeatedly from Australia since early this century. The British Museum holds specimens taken around Auckland in 1918 and 1919 (Belkin 1968), and the species was recorded on several occasions before World War II on vessels arriving at Auckland from Sydney (Graham 1939). *A. notoscriptus* was originally confined to seaports in the North Island north of Gisborne, but it has lately begun a rapid move southwards to become well established in the Wellington region (Laird and Easton 1994; Laird 1995). Its larvae were the second most frequently recorded in New Zealand's Northern Mosquito Surveys (Laird 1990, 1995). Its presence in Nelson was reported by Graham (1939) and lately confirmed by Browne (1995).

Biology The natural Australian habitats of the larval *A. notoscriptus* are tree holes and rock pool environments. However, the species is now more commonly found in shaded artificial containers (Russell 1993). Roof gutters, tyres, tins, tanks and pot-plant bases are all readily invaded, indicating that the species is able to shift from a category 8 (natural containers) to a category 9 (artificial containers) habitat (Laird 1988). In becoming established in New Zealand, *A. notoscriptus* has made the opposite shift, moving from category 9 habitats around seaports into pools, marshes, tree holes, rock pools and leaf axils of asteliads and palms (Belkin 1968). The establishment of *A. notoscriptus* in such environments was facilitated by the lack of competition from native species, because New Zealand's larval mosquito habitats were (and remain) considerably underutilised (Laird 1990).

Like most aedines, *A. notoscriptus* lays its eggs at the waterline of containers, whether natural or artificial. The eggs can tolerate desiccation for several months (an adaptation to ephemeral habitats). The adult is a silent flier and diurnal biter of man.

Public health significance

Contrary to what is generally believed in New Zealand, the country does have an endemic and actively circulating arbovirus – Whataroa virus – in the wild bird populations of Westland, vectored by the native mosquitoes *Culiseta (Climacura) tonnoiri* (Edwards) and *Culex (Culex) pervigilans* Bergroth (Miles 1973). *A. notoscriptus* is capable of harbouring this virus under laboratory conditions (Taylor 1967, in Lee et al 1982), but has not reached as far south as Westland. Although no human cases of infection with Whataroa virus have been recorded, human infection is likely to result in mild flu-like disease similar to that caused by Ockelbo virus in Sweden (Lundström et al 1991). With global warming (see 'Discussion'), the distribution of *A. notoscriptus* may well spread further southwards (Weinstein 1994), possibly bringing the mosquito into contact with reservoir hosts for Whataroa virus.

The vector competence of *A. notoscriptus* for other arboviruses (yellow fever, dengue fever, Murray Valley encephalitis) is generally held to be poor (Lee et al 1982 and references therein). However, recent evidence is likely to lead to a re-examination of this opinion. *A. notoscriptus* is likely to play a major role in the transmission of Ross River virus in northern Queensland, Australia, where up to 10 percent of wild-caught females carry the virus (BH Kay, personal communication, Dec. 1996). Laboratory studies with New Zealand *A. notoscriptus* failed to achieve transmission of Ross River virus to mice, but showed the mosquito to be a competent experimental vector of dengue virus (Maguire 1994).

In addition to arboviruses, *A. notoscriptus* is a known vector of dog heartworm (*Dirofilaria immitis*) in Australia (Russell and Geary 1992), where the spread of canine dirofilariasis has paralleled increasing adaptation of *A. notoscriptus* to category 9 habitats. The Australian experience and the recent spread of *A. notoscriptus* in New Zealand speak strongly for the tightening of New Zealand border controls for dogs originating in Australia (McSporran 1994).

Aedes australis

Incidence

First described from Tasmania in 1844 (Lee et al 1984), *A. australis* was first identified from New Zealand (Stewart Island) in 1961 (Belkin 1968). It has since dispersed northward to the South Island provinces of Southland, Otago and Westland (Nye 1962; Nye and McGregor 1964). With early records coming from the ports of Bluff and Dunedin (Nye 1962), *A. australis* is most likely to have been introduced to southern New Zealand ports by timber vessels (Pillai and Ramalingam 1984; Laird 1990). However, Belkin (1968) felt that the mosquito was introduced by natural wind dispersal of eggs, as hypothesised for the earlier introduction of *Aedes (Nothoskusea) chathamicus* Dumbleton. Although generally not in high densities in areas of New Zealand where it can be a nuisance to humans, *A. australis* does reach pest proportions in eastern Tasmania (Lee et al 1984).

Biology

The natural Australian habitat of *A. australis* larvae is in coastal rock pools above the high-tide mark (category 6 habitats, Laird 1988). The larvae are halophilic and extremely tolerant of changes in salinity: their wave-filled pools may be diluted by rainwater or become hypersaline through evaporation (Lee et al 1984). Their tolerance can be considered to have facilitated dispersal to New Zealand, where they occupy similar shallow rock pool habitats (Laird 1990).

Adult females are autogenous (capable of oviposition without a blood meal), and oviposit at the waterline. They do not generally disperse far from their larval habitats, and so are rarely found in close association with large numbers of people. However, when in high densities in eastern Tasmania, they have been observed to enter domestic environments and bite man (Russell 1993).

Public health significance

Other than as a potential vector of Ross River virus in Tasmania, *A. australis* has not been considered significant in a public health context because it does not have a sufficiently close relationship with man (see above). However, this species is capable of harbouring Whataroa virus under laboratory conditions (Taylor 1967, in Lee et al 1984); and Maguire (1994) has demonstrated that New Zealand *A. australis* is a competent laboratory vector of both Ross River virus and dengue virus. There is no scientific reason why *A. australis* could not be involved in epidemic transmission of Ross River virus in the South Island (Weinstein et al 1995).

Culex quinquefasciatus

Incidence

Unlike the previous two mosquitoes, *C. quinquefasciatus* is not native to Australia, but is a pantropical/subtropical mosquito believed to originate in the Americas. It is likely to have been dispersed originally by slave-trading vessels returning to Africa from the Americas, the same sailing vessels that spread *Aedes (Stegomyia) aegypti* (Linnaeus) in the opposite direction by means of open-barrel storage of fresh water on deck (Calder and Laird 1994). The oldest New Zealand specimen is at the British Museum and dates from 1848 (Belkin 1968). By this time, American high-seas whaling had undergone a vigorous expansion into the Pacific. Following the opening of Australian ports to American whalers in 1831, ship visits to northern New Zealand saw a dramatic upturn (Calder and Laird 1994). It is therefore not unreasonable to suspect that *C. quinquefasciatus* may have been spread to New Zealand from Australian stock in the first third of last century, although a direct eastward arrival across the Pacific is feasible too.

The species is now found in coastal areas in the vicinity of the larger ports of the North Island, but with suggestions of the beginnings of a recent move both inland and southwards (Laird 1995; Browne 1996). Browne (1996) confirmed Graham's (1930) report of this species from Nelson, and extended the known South Island distribution of the species to Picton, Marlborough. Browne (1996) also identified this species from Taranaki and the Waikato. It is the third most frequently recorded larva in recent New Zealand mosquito surveys (Laird 1990, 1995; Browne 1995, 1996).

Biology

The preferred habitat of larval *C. quinquefasciatus* in New Zealand is for artificial containers (category 9, Laird 1988, 1990), particularly when these have a high nutrient content (gully traps, used tyres, discarded metal drums, etc). Larval records from New Zealand are from similar habitats, including (importantly) gully traps (Laird 1990). Elsewhere, the species also exploits many of the same larval habitats utilised by *Aedes aegypti*. Unlike *A. aegypti*, however, *C. quinquefasciatus* is capable of tolerating the lower temperatures of New Zealand (but see Christophers 1960 and Weinstein 1994 on the risk of *A. aegypti* establishment). As for *A. notoscriptus*, the establishment of *C. quinquefasciatus* in New Zealand would have been facilitated by the underutilisation of these habitats by native mosquitoes (Laird 1990).

The eggs of *Culex* are not desiccation-tolerant, and are laid as small rafts directly onto the water surface. *C. quinquefasciatus* is consequently more dependent on water availability than is *A. notoscriptus*, possibly accounting for the more limited dispersal of the former in New Zealand. The months of July to September are too cold for adult survival in New Zealand, and the larvae overwinter during this time (Belkin 1968). Adult females are intensely anthropophilic, readily biting man (and poultry) both indoors and outdoors, chiefly at night (Lee et al 1989).

Public health significance

C. quinquefasciatus is a proven laboratory vector of Murray Valley encephalitis virus (McLean 1953). Isolates are readily obtained from field-collected specimens. Isolates of Ross River virus have also been obtained from field-collected specimens (Lindsay et al 1993), but laboratory transmission has not been successful. However, the isolation of Ross River virus from *C. quinquefasciatus* taken in New Caledonia during the 1979 to 1980 Pacific outbreak is noteworthy (Fauran et al 1984, in Lee et al 1989), because it suggests that the species is capable of transmitting Ross River virus in 'virgin soil' outbreaks independently of traditional reservoir hosts (Weinstein 1994). The occurrence of large populations of *C. quinquefasciatus* in gully traps near international airports in New Zealand is particularly worrisome in this context (Laird 1990), because females would have ready access to viraemic tourists arriving at these terminals (Weinstein 1994). The situation speaks strongly for the stringent elimination of all standing water within 400 m of such ports (Weinstein 1994; Weinstein et al 1995), as is recommended by the WHO (1983). Like *A. notoscriptus*, *C. quinquefasciatus* is a known vector of dog heartworm, but is probably less efficient than the former (Lee et al 1989).

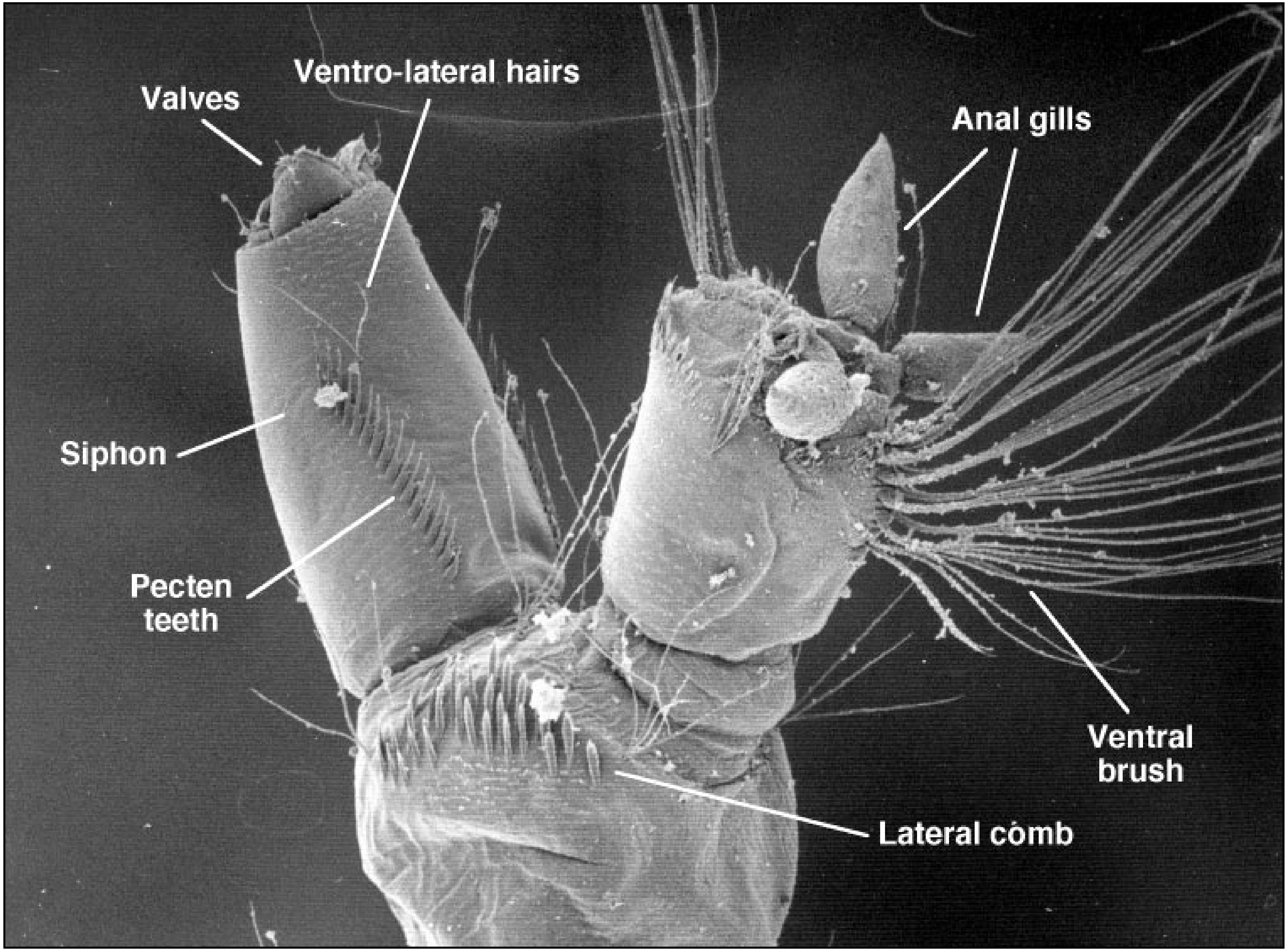
Larval key to exotic and endemic mosquitoes of New Zealand

A simplified key is presented on the following pages to allow rapid identification of larval forms by non-specialists. The key is based on a typical specimen for each species, and the morphological terms that have been used are clearly illustrated in the accompanying diagram. Users should be wary of the possibility of additional exotic species, the presence of which could invalidate the key. Expert advice remains essential when there is any doubt.

For additional details, descriptions of adults, and synonymies, see Pillai (1966), Belkin (1968), Lee et al (1982 to 1989) and Russell (1993). Belkin (1968) also provides distribution maps. Any significant extensions of range (other than as described above) or possible introductions of new exotic species should be *promptly* reported to health authorities.

For this key, only the distal end of mosquito larvae need be examined, as illustrated in Figure 1. Species of *Mansonia* have not been included because these are cryptic, attaching to the undersides of aquatic plants, and are unlikely to be encountered. A full list of species present in New Zealand is given in Appendix 1.

Figure 1. The distal (tail) end of a mosquito larva (*Aedes notoscriptus*), illustrating the morphological terms used in the larval key.



KEY

1. Pecten teeth present → 2
   No pecten teeth; lateral comb scales in single row; siphon and valves fused .... *Coquillettidia* species

2. Anal gills scarcely evident (small) → 3
   Anal gills longer than they are wide, usually tapering to apex → 5

3. Pecten with many teeth in a row → 4
   Pecten with only two or three teeth; middle siphon valve with single long hair .... *Opifex fuscus* Hutton

4. Pecten teeth in a continuous series; ventral brush with nine pairs of hairs .... *Aedes chathamicus* Dumbleton
   Basal pecten teeth separate, distal teeth with bases adjoining; ventral brush with seven pairs of hairs .... *Aedes australis* Erichson

5. Siphon with one pair of ventro-lateral hairs → 6
   Siphon with more than one pair of ventro-lateral hairs → 8

6. Pecten series continuous → 7
   Pecten teeth extending in series then having isolated teeth under ventro-lateral hair .... *Aedes subalbirostris* Klein and Marks

7. Dorsal gill longer than ventral .... *Aedes notoscriptus* Skuse
   Dorsal and ventral gills about even in length .... *Aedes antipodeus* Edwards

8. Ventral brush with at least five pairs of hairs → 9
   Ventral brush with one pair of hairs; more than six pairs of longer ventro-lateral siphon hairs with an equal number of long dorso-lateral siphon hairs .... *Maorigoeldia argyropus* Walker

9. Scales of lateral comb in single row → 10
   Scales of lateral comb in triangular patch → 11

10. Lateral comb with 18 to 20 scales .... *Culiseta tonnoiri* Edwards
    Lateral comb with 25 to 29 scales .... *Culiseta novaezealandiae* Pillai

11. Ventral brush has six pairs of hairs → 12
    Ventral brush has seven pairs of hairs; five pairs of ventro-lateral siphon hairs in alignment .... *Culex rotoruae* Belkin

12. Ventro-lateral hairs not in alignment with pecten; slender siphon .... *Culex asteliae* Belkin
    Ventro-lateral hairs mostly in alignment with pecten → 13

13. Siphon curved with penultimate hair tuft indented; dorsal anal gill longer than ventral; pecten teeth broad .... *Culex quinquefasciatus* Say
    Four pairs of ventro-lateral hairs mostly in straight line; anal gills equal length; siphon straight .... *Culex pervigilans* Bergroth

DISCUSSION

The radiation of Gondwanan relicts (eg, *Maorigoeldia argyropus*) in New Zealand is of fairly recent origin, consistent with the creation of a depauperate fauna by Pleistocene extinctions (Rowe 1987). The affinities of New Zealand Culicidae are also predominantly Australian, and represent an ancient continental fauna (Belkin 1968; Dumbleton 1969). Of Mesozoic origin, this fauna had differentiated in isolation without addition from external sources until the arrival of the three exotic species detailed in this paper. *Culex asteliae* and *C. rotoruae* represent a northern component of the fauna, and *A. subalbirostris* and two species of *Culiseta* a southern component (Belkin 1968; Dumbleton 1969). The remaining seven of the 12 endemic species are more or less universal in distribution, except for *A. chathamicus* which is restricted to the Chatham Islands. The last-mentioned mosquito is believed to be derived from the same stock as *Opifex fuscus*, both species having retained a number of features considered by Belkin (1968) to be primitive, and possibly representing post-Pleistocene radiation as discussed above.

The more recently arrived *A. australis* also has clear affinities with *A. chathamicus* and *O. fuscus* (Belkin 1968). The close relationship between recently imported arbovirus vectors and native species whose vector competence remains largely unstudied, highlights an interesting area of potential research on New Zealand mosquitoes (Weinstein 1994). Vector competence studies of endemic species may, with the advent of global warming and increased rainfall (see below), prove to be of greater public health significance than is currently appreciated. Four native species are closely enough associated with man to achieve pest status, and should perhaps be the first species targeted by such studies (*Culex pervigilans, Opifex fuscus, Culiseta tonnoiri,* and *Aedes antipodeus*; see Appendix 1).

Several factors have facilitated the establishment of exotic mosquitoes imported into New Zealand (see Laird 1990, 1995; Laird et al 1994; Weinstein 1994; Weinstein et al 1995). Firstly, Laird (1990) has estimated non-utilisation of potential larval habitats in New Zealand at over 40 percent in summer and close to 50 percent in winter (includes larvae of the three introduced species). In Australia and the Pacific, non-utilisation of larval habitats was less than 20 percent when estimated by the same methods (Laird 1956). Larval habitats are thus readily available to imported mosquitoes both to establish themselves and to disperse rapidly at the local level.

In water-containing tyres in New Zealand, a second factor facilitating establishment is the lack of effective larval predators. Micro-predators, notably cyclopoid copepods which attack mosquito eggs and the earliest larval instars, are sometimes present. However, from the high incidence of *Aedes notoscriptus* and other exotic and endemic larvae in the 1993 to 1994 New Zealand Mosquito Survey (particularly in silage heap/pit tyres used as cover weights, Laird 1995), such predators fall far short of results that have been claimed elsewhere (Laird 1988). Much larger invertebrate predators such as notonectid and corixid hemipterans and dysticid water beetles are (other than accidentally) absent from 'wet' tyres (Laird 1990), as of course are the best of all larval mosquito predators – fish – especially those of the genera *Gambusia* and *Lebistes* (McDowall 1990). Because discarded tyres are prime oviposition sites of such major arboviral vectors as *Aedes albopictus* (the Asian tiger mosquito which threatened New Zealand in 1993, Laird et al 1994), the establishment of focal populations of this and other category 9 larval habitat utilisers is likely once they are introduced into this country. Once so established, such mosquitoes could spread to adjacent category 8 larval habitats (eg, tree holes, rock pools), thereby becoming very much more difficult to eliminate.

While container utilisers rather seldom spread to surface waters, other potential arboviral vector imports and malaria-carrying anophelines too, utilise surface waters of categories 4B (marshes), 5 and 6 (shallow permanent ponds and temporary pools respectively) and 7 (intermittent ephemeral puddles) as oviposition sites. The first three of these habitat categories are quite rich in the larger invertebrate predators (notonectids, corixids, dysticids, dragonfly and damselfly larvae, etc), in New Zealand as elsewhere. Prospective mosquito colonists of these habitats thus face much higher predator hazards in New Zealand than do container-utilisers, and the chances of colonists of the former habitats establishing focal populations is thus correspondingly limited.

There is currently no serological evidence from humans to suggest that *A. notoscriptus* or *A. australis* have been responsible for local transmission of either Ross River virus or dengue virus, which are the arboviruses most frequently imported into New Zealand (Maguire 1994; Weinstein 1995). This situation appears to be entirely fortuitous; there is nothing special about New Zealand that makes it intrinsically refractory to the local transmission of arboviral diseases (Weinstein 1994).

The risk of such transmission occurring is therefore compounding with time. It will increase further as a result of the climatic changes predicted for New Zealand by the year 2050. A temperature rise of between 1.5 and 3°C and increased rainfall (particularly in the west, Wratt 1991) will decrease mosquito development times as well as increase the availability of larval habitats. A projected 30 to 50 cm rise in sea levels is likely to flood low-lying areas around river mouths, estuaries and behind sandy beaches (Wratt 1991), leading to a significant increase in availability of the larval habitat of *A. australis*. Clearly, the abundance, distribution and pest status of many mosquitoes is likely to increase in New Zealand with the onset of these environmental changes. Further, the time required for arboviruses to become infective in mosquitoes (extrinsic incubation period) decreases with rising temperature, increasing the probability of competent vectors becoming involved in outbreak situations.

Overall, a southward shift in New Zealand's isotherms, isohyets and vegetation zones is likely to favour established mosquitoes as well as new imports. More mosquitoes, increased travel (virus and mosquito importation, particularly if aircraft disinsection continues to diminish) and urbanisation (susceptible populations) must eventually lead to the local transmission of human arboviral diseases in New Zealand (Weinstein 1994; Weinstein et al 1995), an event that would be consistent with the current resurgence of arboviral diseases as a major public health problem worldwide (Gubler 1993; Weinstein 1993). As might be expected, control measures aimed at decreasing the morbidity and mortality from arboviral disease are entirely dependent on an intimate knowledge of the ecology of the vectors concerned (Service 1992). It is timely therefore to study the local ecologies of *A. notoscriptus, A. australis* and *C. quinquefasciatus* in New Zealand in greater depth.

ACKNOWLEDGEMENTS

This study is an extension of work originally supported by the ESR: Communicable Disease Centre, the Public Health Commission and the Ministry of Health; the authors thank those people involved as well as Agnes Weinstein for typing the manuscript.

REFERENCES

Belkin JN. 1968. Mosquito studies (Diptera: Culicidae) VII. The Culicidae of New Zealand. *Contributions to the American Entomology Institute* 3: 1–182.

Browne G. 1995. *Report to the Ministry of Health on the New Zealand Mosquito Check 1994-1995*. Auckland: University of Auckland.

Browne G. 1996. *Report on the New Zealand 1995-1996 Mosquito Survey in Waikato and Taranaki*. Auckland: University of Auckland.

Calder L and Laird M. 1994. Mosquito travellers, arbovirus vectors and the used tyre trade. *Travel Medicine International* 12: 3–12.

Christophers SR. 1960. *Aedes aegypti (L): The yellow fever mosquito*. England: Cambridge University Press.

Dumbleton LJ. 1969. Pleistocene climates and insect distributions. *New Zealand Entomologist* 4: 3–23.

Graham DW. 1939. Mosquito life in the Auckland district. *Transactions and Proceedings of the Royal Society of New Zealand* 69: 210–54.

Gubler DJ. 1993. Epidemic arbovirus diseases: an emergent public health problem. *Arbovirus research in Australia* 6: 299–300.

Laird M. 1956. Studies of mosquitoes and freshwater ecology in the South Pacific. *Royal Society of New Zealand Bulletin* 6: 1–213.

Laird M. 1988. *The natural history of larval mosquito habitats*. London: Academic Press.

Laird M. 1990. New Zealand's Northern Mosquito Survey 1988-89. *Journal of the American Mosquito Control Association* 6: 287–99.

Laird M. 1995. Background and findings of the 1993-1994 New Zealand Mosquito Survey. *New Zealand Entomologist* 18: 77–90.

Laird M and Easton JM. 1994. *Aedes notoscriptus* (Diptera: Culicidae) in Wellington Province. *New Zealand Entomologist* 17: 14–17.

Laird M, Calder L, Thornton RC et al. 1994. Japanese *Aedes albopictus* among four mosquito species reaching New Zealand in used tyres. *Journal of the American Mosquito Control Association* 10: 14–23.

Lee DJ, Hicks MM, Griffiths M et al. 1982. *The Culicidae of the Australasian Region*, Vol 2. Canberra: Australian Government Publishing Service.

Lee DJ, Hicks MM, Griffiths M et al. 1984. *The Culicidae of the Australasian Region*, Vol 3. Canberra: Australian Government Publishing Service.

Lee DJ, Hicks MM, Griffiths M et al. 1989. *The Culicidae of the Australasian Region*, Vol 7. Canberra: Australian Government Publishing Service.

Lee DJ, Hicks MM, Griffiths M et al. 1982 to 1989. *The Culicidae of the Australasian Region*, Vols 1–12. Canberra: Australian Government Publishing Service.

Lindsay MD, Broom AK, Wright AE et al. 1993. Ross River virus isolation from mosquitoes in arid regions of Western Australia: implication of vertical transmission as a means of persistence of the virus. *American Journal of Tropical Medicine and Hygiene* 49: 686–96.

Lundström J, Vene S, Espmark Å et al. 1991. Geographic and temporal distribution of Ockelbo disease in Sweden. *Epidemiology and Infection* 106: 567–74.

Maguire T. 1994. Do Ross River and dengue viruses pose a threat to New Zealand? *New Zealand Medical Journal* 107: 448–50.

McDowall RM. 1990. *New Zealand fresh water fishes: A natural history and guide*. Auckland: Heinemann Reed/MAF Publishing Group.

McLean DM. 1953. Transmission of Murray Valley encephalitis virus by mosquitoes. *Australian Journal of Experimental Biology and Medical Science* 31: 481–90.

McSporran KD. 1994. Canine dirofilariasis: the case for the intoduction of import controls on Australian dogs entering New Zealand. *Surveillance* (MAF Wellington) 21: 17–21.

Miles JAR. 1973. The ecology of Whataroa virus, an alphavirus, in South Westland, New Zealand. *Journal of Hygiene* (Camb.) 71: 701–13.

Miller D. 1920. *Report on the mosquito investigation carried out in the North Auckland peninsula of New Zealand during the summer of 1918-19*. Part 1. Wellington: Government Printer, Department of Health Publication No. 3.

Nye ER. 1962. *Aedes (Pseudoskusea) australis* Erichson (Diptera: Culicidae) in New Zealand. *Transactions of the Royal Society of New Zealand Zoology* 3: 33–4.

Nye ER and McGregor DD. 1964. Mosquitoes of Otago. *Otago Museum Records of Zoology* 1: 1–23.

Pillai JS. 1966. *Culiseta novaezealandiae,* a new species of the subgenus *Climacura* Felt (Diptera: Culicidae: Culisetini), with notes on its ecology and development. *Transactions of the Royal Society of New Zealand* 8: 125–33.

Pillai JS and Ramalingam S. 1984. Recent introductions of some medically important Diptera in the northwest, central and south Pacific (including New Zealand). In: M. Laird (ed). *Commerce and the Spread of Pests and Disease Vectors*. New York: Praeger, pp 81–101.

Rowe R. 1987. *The Dragonflies of New Zealand*. Auckland: Auckland University Press.

Russell RC. 1993. *Mosquitoes and mosquito-borne disease in south eastern Australia*. Sydney: University of Sydney.

Russell RC and Geary MJ. 1992. The susceptibility of the mosquitoes *Aedes notoscriptus* and *Culex annulirostris* to infection with dog heartworm *Dirofilaria immitis* and their vector efficiency. *Medical and Veterinary Entomology* 6: 154–8.

Service MW. 1992. Importance of ecology in *Aedes aegypti* control. *Southeast Asian Journal of Tropical Medicine and Public Health* 23: 681–90.

Weinstein P. 1993. Full circle: public health entomology resurfaces. *Snow's Field*, Royal Australian College of Physicians (AFPHM), June: 6.

Weinstein P. 1994. *The real and potential risks of human arboviral disease in New Zealand*. Report to the Communicable Disease Centre, Institute of Environmental Science and Research Limited, Porirua, New Zealand.

Weinstein P. 1995. Arboviral diseases: an increasing threat to New Zealand. *New Zealand Public Health Report* 2: 33–5.

Weinstein P, Laird M and Calder L. 1995. Australian arboviruses: at what risk New Zealand? *Australian and New Zealand Journal of Medicine* 25: 666–9

WHO. 1983. *International Health Regulations 1969*, 3rd edn. Geneva: World Health Organization.

Wratt DS. 1991. *Climate Change*. Wellington: New Zealand Climate Change Programme, New Zealand Meteorological Service and Ministry of the Environment.

Appendix 1

New Zealand Mosquitoes

Exotic mosquitoes now established in New Zealand

(known vector competence)

Aedes notoscriptus

Aedes australis

Culex quinquefasciatus

Endemic mosquitoes

(nuisance mosquitoes, vector competence studies recommended)

Culex pervigilans

Opifex fuscus

Culiseta tonnoiri

Aedes antipodeus

Other endemic mosquitoes

(unlikely to play significant role in arboviral disease epidemiology)

Aedes subalbirostris

Aedes chathamicus

Culex asteliae

Culex rotoruae

Culiseta novaezealandiae

Mansonia tenuipalpis

Mansonia iracunda

Maorigoeldia argyropus