NEW ZEALAND'S NORTHERN MOSQUITO SURVEY, 1988–89[1]

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ABSTRACT. The latest mosquito survey of the warmer regions of New Zealand (NZ) sampled 2,304 larval mosquito habitats of all major categories. While revealing no evidence of new establishments of exotic mosquitoes, it produced important data revealing the underutilization of types of habitats that could be invaded now or in the future (especially if the "greenhouse effect" eventually causes even quite small rises in average temperatures and sea levels). Although long feared additions of malaria vectors to a fauna still lacking any species of *Anopheles*, or of essentially tropical arbovirus vectors from neighboring countries to the north and northeast, may not materialize failing climatic amelioration, a new danger appeared at the beginning of the 1988–89 Northern Mosquito Survey when *Aedes albopictus* was reported for the first time from Fiji. This vector of dengue hemorrhagic fever and Ross River virus has since been spreading widely on the archipelago's main island, Viti Levu, whence much air and sea traffic reaches NZ. Information presented and discussed herein strongly supports the continuance and improvement of international aircraft disinsection and other insect quarantine measures.

INTRODUCTION

On the basis of his 1918–19 North Auckland mosquito survey, Miller (1920) reported 2 of New Zealand's (NZ's) 3 exotic species believed to have been established since the European rediscovery. These were *Culex quinquefasciatus* Say [listed as *Taeniorhynchus acer* (Walker) see Lee et al. (1989)], and *Aedes notoscriptus* (Skuse) [reported as a member of subgenus *Ochlerotatus*—see Lee et al. (1982)]. The latter, actually a *Finlaya*, is otherwise found from Indonesia through Papua New Guinea to Australia and the New Caledonian area. A Category 8 larval habitat[3] utilizer in nature, it readily disperses to Category 9 sites, as do many other members of its subgenus (Horsfall 1955, Laird 1988). This behavioral trait rendered *Ae. notoscriptus* as transportable aboard sailing vessels as the now virtually pantropical (and to a large extent pansubtropical, bearing in mind their American dispersal) *Cx. quinquefasciatus* and *Aedes aegypti* (Linn.). Despite the view of Christophers (1960) that the latter could establish northward from just south of Auckland City where the 10°C winter isotherm line coincides with the Bombay Hills, northern NZ may still be a shade too cool for the latter species. Notwithstanding, *Ae. notoscriptus*—having proved rather more successful than *Cx. quinquefasciatus* in colonizing NZ, where there are North Island east coast and northern South Island port foci (Belkin 1968)—exhibits a dispersal pattern fully supporting the statement (Lee et al. 1982): "It seems reasonable to assume that *Ae. notoscriptus* has been introduced to New Zealand."

New Zealand's third and latest presumed exotic is *Ae. australis* (Erichson). Its synonomy is fully discussed by Lee et al. (1984), who accept its (Belkin 1962) subgeneric designation as one of 2 otherwise uniquely Australian members of the subgenus *Halaedes*. Only known from southernmost provinces of the South Island and Stewart Island (Nye 1962, Nye and McGregor 1964, Belkin 1968), this brackish water, rock pool-utilizer may well be a Tasmanian strain imported by timber vessels to southern NZ ports by the 1960s (Pillai and Ramalingam 1984). These authors disagreed with Belkin's (1968) speculation about a natural (windborne carriage of eggs) arrival from Australia, and I agree with them. In southern parts of the South Island, *Ae. australis* occupies Category 6 and 8 larval habitats of brackish splashpool and seepage types, "similar to those occupied by *O. fuscus*" (Belkin 1968). As yet, the former is unrecorded from the North Island, and need not concern us further here.

Miller (1920) and Graham (1929, 1939) recognized the danger posed to NZ by possible introductions of *Anopheles* spp. to a temperate country lacking malaria and its vectors. The latter author (1939) actually reported "*Anopheles maculipennis* Meigen" from vessels reaching Auckland from Indonesia in May and September 1929. As shown by Belkin (1962) and Lee et al. (1987b), this identification of a continental European/SW Asian/northern Siberian mosquito must have been wrong. Perhaps Graham was misled by one of the few source books that would then have been available to him, i.e., Tidswell (1910), which refers to *An. maculipen-*

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3 Larval mosquito habitat classification herein follows the rational 11-category system (Table 3) proposed as an international standard by Laird (1988). Some New Zealand examples of these categories are illustrated in Figs. 1–12.

nis somewhat ambiguously but not specifically to the South Pacific. If indeed Graham's identification of the genus was correct (which Belkin doubted in favor of indigenous forest-stream backwater—Category 1—larval habitat utilizer, *Culiseta tonnoiri* Edwards, a largely South Island species so rarely reported from Auckland Province that its presence in a city dockland setting would have been as unlikely as that of *Anopheles*), some Indonesian or Melanesian anopheline was surely involved.

At all events, no *Anopheles* spp. imagines, whether alive or dead, were discovered aboard any of the many aircraft that reached NZ from abroad during or in the aftermath of World War II, although the closest possible insect quarantine surveillance was maintained in those years (Laird 1951, 1952, 1956a). By 1977–78, when a North Island Mosquito Survey (Pillai 1979[4]) resulted in 438 field samples, *Cx. quinquefasciatus* and *Ae. notoscriptus* still remained the only exotic Culicidae known from NZ's warmest sector.

1988–89 SURVEY METHODOLOGY

Field sampling was conducted by Health Protection Officers of the Northland Area Health Board (NAHB), Whangarei, and the Health Development Units (HDUs) of Takapuna, Auckland Central, South Auckland and Hamilton. This provided for coverage of northernmost NZ from North Cape (34°23′S) to approximately 38°40′S near the most southerly point of Auckland Province, which has several large and many small harbors, some of which were being visited by European sailing vessels as early as the late-18th century. So as to include the period of maximum mosquito production, the project ran from early spring through late summer, October 1, 1988–April 15, 1989. During the previous summer the author had visited all 5 of the groups which were to collaborate, traveling with their Health Protection Officers to a wide range of prospective urban and rural sampling sites, including the major and minor airports and seaports. With the assistance of technical staff from the University of Auckland, he conducted a preliminary Mosquito Workshop for survey participants, and also designed and procured appropriate collecting kits and data sheets.

Metal soup ladles with the interior of the 100-ml bowl white-enameled (Fig. 9) were provided as larval dippers. It was left to the ingenuity of the field teams to improvise suitable alternatives (Fig. 6) for sampling the smaller surface waters. Rubber bulbs (55-ml) attached to lengths of pliable polythene tubing served for collecting from phytotelmata, etc. Squashable wire-gauze tea strainers were included in the kits for insertion into the narrow aperture (Fig. 8) of off-rim tires where draining was impracticable. Prelabeled, leakproof plastic tubes (50-ml) were used for storage and mailing, 70% alcohol being the preservative, with a pledget of facial tissue serving to immobilize the specimens in transit. Wherever larvae were reasonably plentiful in a habitat, the sample was expected to include about 20 of the largest present.

The field data sheets called for precise information on the larval habitat category (see Footnote 3 and Figs. 1–12) and location (specific address of street, farm, etc., and 6-fig. cadastral map reference if rural), supported by photographs or sketches to aid in relocation in the event of anything unusual being found during laboratory examination. The latter was undertaken in the author's laboratory at the University of Auckland, where weekly consignments of material were delivered throughout the survey. All larval identifications were checked against Belkin (1962, 1968). However, I did not choose to follow that author (1968) in relegating the Dixidae (well represented in NZ) and Chaobor-

Fig. 1. Slowly flowing farm ditch (Category 1). *Culex pervigilans* in marginal vegetation.

[4] Pillai, J. S. 1979. A report on the North Island mosquito survey. Unpublished report to New Zealand Department of Health, Wellington.

Fig. 2. Ponded stream (Category 2). *Culex pervigilans.*

Fig. 3. Lake edge (Category 3). *Culex pervigilans.*

idae to the status of subfamilies of the Culicidae.

Other larval habitat details requested on the data sheets included notes on the presence or absence of predators (examples to be preserved in the same collecting tubes as larval mosquitoes, but separated from these by the pledget). An estimate of larval abundance was asked for too (*abundant*, 20+ per dip; *common*, less than 20 per dip; *rare*, most dips without larvae).

RESULTS

Larval mosquito habitat utilization: Of the 2,304 sites sampled, 971 (42%) were negative for Culicidae (Table 3). This overall figure did not mask any dramatic seasonal fluctuations. Thus, nonutilization of potential larval habitats of all categories averaged 48% for the cooler and generally wetter months of October/November, 39% each for the warmer and generally drier ones of December/January and February/March, and 43% for the first half of April as late summer merged into autumn.

Fig. 4. Marsh, i.e., inundated savanna (Category 4). *Culex pervigilans.*

Fig. 5. Mangrove swamp, i.e., inundated forest (Category 4) at rear, merging with shallow seepage-fed permanent pond (Category 5) bordering garbage dump. Pond with *Culex pervigilans,* also present in discarded tires, cans, etc. (Category 9); swamp negative.

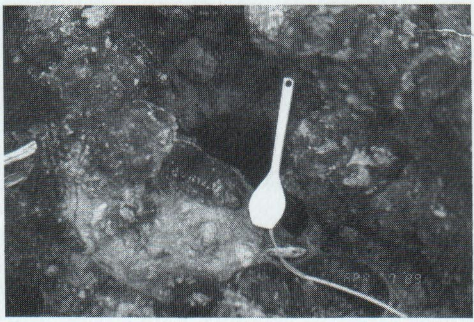

Fig. 6. Coastal brackish rockhole (Category 8), *Opifex fuscus.*

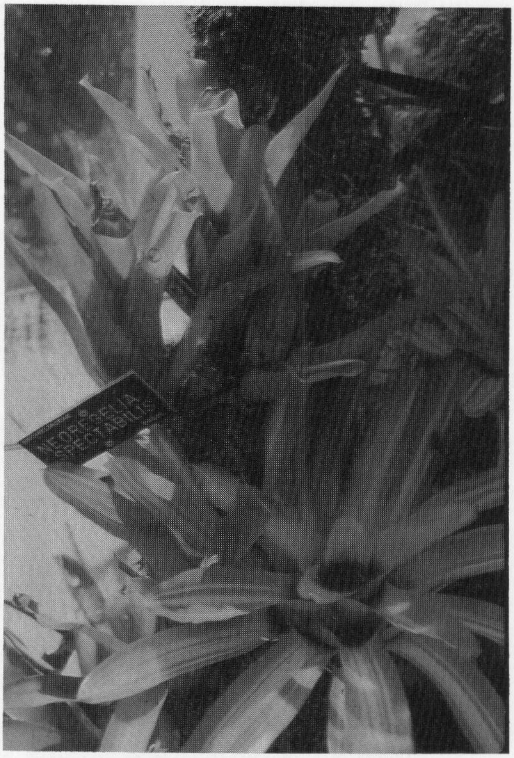

Fig. 7. Neotropical bromeliads (Category 8). These negative for larvae but others utilized by *Aedes notoscriptus.*

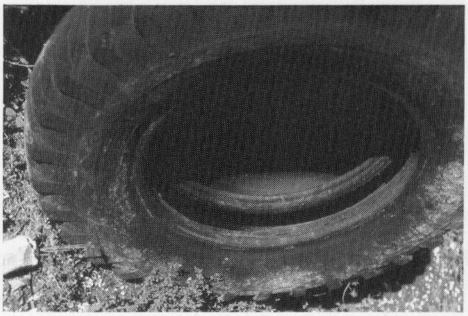

Fig. 8. Off-rim tire (Category 9). Water contents partially shaded by incurving lips, despite exposure to sunlight. *Culex pervigilans* and *Aedes notoscriptus.*

Category 9 habitats (artificial containers) were utilized more frequently than any of the others, with 65% larva-positive (Table 3). They were also by far the most plentiful group, accounting for 1,493 (i.e., again 65%) of the entire sample. The level for nonutilization of artificial containers of all types (35%) and the relevant levels for October/November (45%), December/January (28%), February/March (35%) and early April (34%) were all distinctly below the overall figures, too.

Moreover, the 212 double and 5 triple infestations recorded (Table 4) were mostly (204 doubles and all triples) from Category 9 sites—especially disused tires from automobiles, aircraft and farm equipment, of which 197 harbored 105, or just over half, of the double infestations. Significantly, too, 23 (11%) of the latter were recorded in October/November, 57 (27%) in December/January and 107 (50%) in February/March; with a decline to 25% in early April, while 4 of the triples were discovered in February/March and the other in April.

Occurrence of predators: There were only occasional records of larvivorous fish. These mostly concerned the introduced *Gambusia affinis* (Baird and Girard). New Zealand has a very limited native freshwater fish fauna, and exotics established for sporting purposes have little relevance to larval mosquito habitats. While many of the latter, notably those of Categories 1–6 and stock drinking troughs of Category 9 (Fig. 10), often exhibited cyclopoid copepods, there were no observations of these attacking mosquito eggs or early instar larvae. Neither was there any evidence of correlation between presence of large numbers of copepods and absence

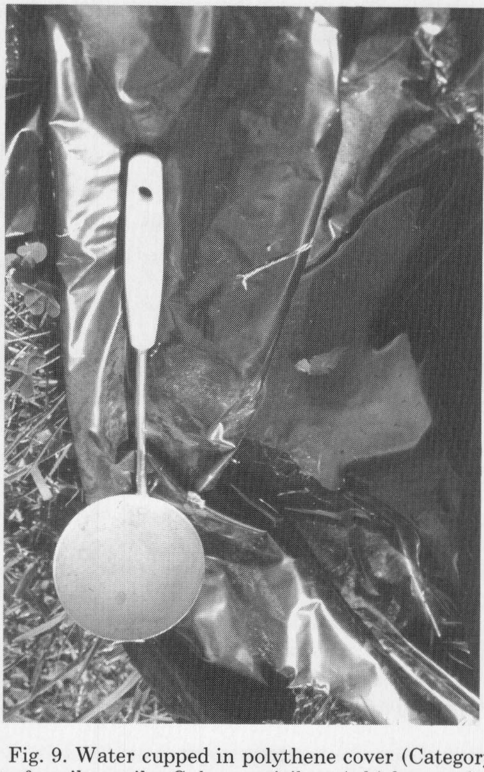

Fig. 9. Water cupped in polythene cover (Category 9) of ensilage pile. *Culex pervigilans* (which was also present with *Aedes notoscriptus* in tires weighing down the cover).

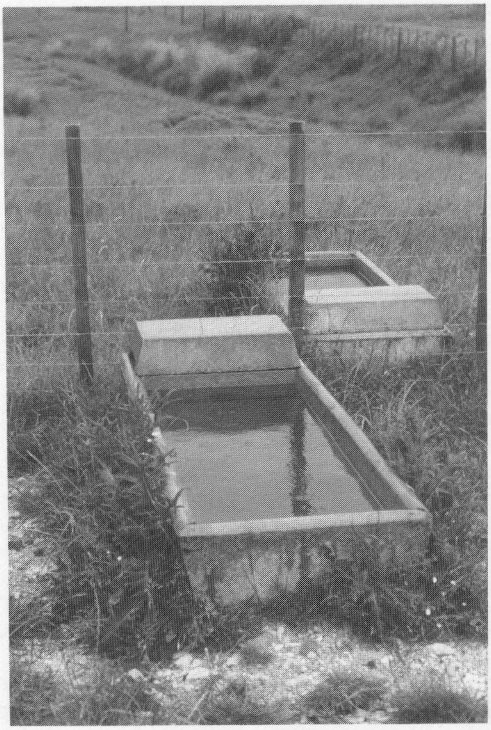

Fig. 10. Stock drinking troughs (Category 9). Full exposure to sunlight and only *Culex pervigilans* present.

of larvae. Indeed, they thrived in association. As no identification of any microcrustaceans could be obtained in the time available, nothing of substance can be offered concerning the current advocacy of certain cyclopoid copepods as candidate biocontrol agents.

The only actual observations of aquatic invertebrates attacking mosquito larvae involved the backswimmer, *Anisops assimilis* White, and the water beetle, *Rhantus pulverosus* Stephens. Relevant correlations between their presence, and that of immature mosquitoes in stock drinking troughs, are considered in the Discussion.

Occurrence of epibionts, parasites and pathogens: Three cosmopolitan epibionts significant as "biological indicators" of high levels of organic enrichment of aquatic habitats, but of little if any importance as population limiting factors with respect to their hosts, were identified during this project. Two of these were Protista, the ciliate protozoans *Vorticella microstoma* Ehrenberg and *Epistylis lacustris* Imhoff. Both were, as always (Laird, 1956a, 1959, 1988), prevalent on pollution-tolerant culicines; in this instance, on larvae of *Cx. quinquefasciatus,* already know as a host worldwide, and on those of *Cx. pervigilans. Vorticella microstoma,* "the overwhelmingly dominant protozoan of polysaprobic situations" (Laird 1988; and see, Liebmann 1962, Bick 1972) was almost incredibly abundant on still-viable 4th instar larvae of both these species in drains and gutters of Parnell,

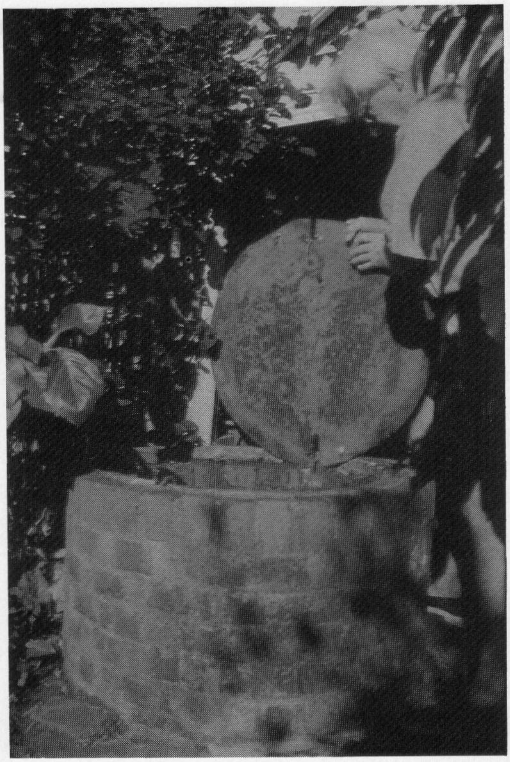

Fig. 11. Deep covered well (Category 11). *Culex pervigilans.*

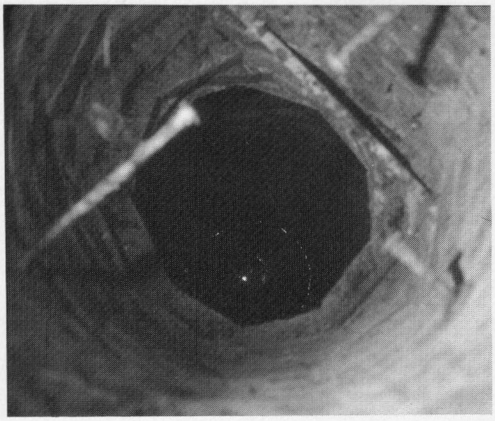

Fig. 12. Deep covered well (Category 11). *Culex pervigilans.* Such sites (this one in Parnell, Auckland City, dates from the 1850s), like larval habitats of categories 3 and 10, were not characteristic of the project area and only exceptionally sampled in the (random) survey.

Auckland, in the first week of April, 1989. There and elsewhere under similarly heavily polluted circumstances, the sheathed bacterium, *Sphaerotilus natans* Kützing (see Laird 1959, 1988) added to the larval vestiture together with unidentified Cyanobacteria and Fungi.

Table 1. Regional coverage of survey.

Region	Samples
Northland Area Health Board	853
South Auckland HDU	599
Hamilton HDU	513
Auckland Central HDU	183
Takapuna HDU	156
Total	2,304

Table 2. Mosquito species identified.

Species	Collections
* *Culex pervigilans* Bergroth	931
** *Aedes notoscriptus* (Skuse)	426
** *Culex quinquefasciatus* Say	156
* *Opifex fuscus* Hutton	32
* *Culex asteliae* Belkin	2
* *Maorigoeldia argyropus* (Walker)	2
Total	1,549***

* Indigenous.
** Exotic.
*** This total exceeds the number of mosquito-positive larval habitats reported (1,333, Table 3) because many of the latter exhibited mixed-species infestations (Table 4).

Interestingly, all 3 of the above epibionts were present on the cuticle of the largest-stage larvae of one of Belkin's NZ "Culicidae," *Paradixa neozelandica* (Tonnoir), collected from a highly polluted stream (Category 1) in South Auckland (late November). The site was not far from the Mangere Sewage Treatment Plant, from which Belkin (1968) reported both larvae and adults in early March 1965. Almost 2 decades earlier, in the immediate aftermath of World War II and in my then capacity of Royal New Zealand Air Force Entomologist, I made an urgent flight from Wellington to Auckland to investigate a report from an airman who had served in the South Pacific forward zone. Having learnt to recognize anopheline larvae on Guadalcanal, Solomon Islands, and in Papua New Guinea, he had noticed what he took to be these in the surroundings of NZ's then only international airport. Upon arrival, they turned out to be the surface-haunting larvae of *P. neozelandica.* The incident serves as a fine example of what would nowadays be termed "community participation" and good public relations in vector awareness and control.

In view of the frequency of association of *Ae. notoscriptus* with *Cx. pervigilans* and/or *Cx. quinquefasciatus* (Table 4), it is of interest that larvae of the first-mentioned species never bore *Vorticella* nor *Epistylis.* This might be supposed due to the fact that such associations were mostly in the relatively clean water of Category 9 larval habitats. However, although *V. microstoma* and *E. lacustris* populations peak under polysaprobic and mesosaprobic conditions re-

Table 3. The 11 major categories of larval mosquito habitats, showing their utilization by Culicidae in the 1988–89 Northern Mosquito Survey.

Categories	Total no. samples	Number larva-positive	Percentage positive	Number larva-negative	Percentage negative
Above-ground waters					
1. (Flowing streams—Fig. 1)	85	32	38	53	62
2. (Ponded streams—Fig. 2)	172	97	56	75	44
3. (Lake edges—Fig. 3)	13	6	46	7	54
4. (Marshes—Fig. 4; and swamps—Fig. 5)	97	47	48	50	52
5. (Shallow permanent ponds)	89	38	43	51	57
6. (Shallow temporary pools)	114	75	66	39	34
7. (Intermittent ephemeral puddles)	84	27	32	57	68
8. (Natural containers—Figs. 6, 7)	155	46	30	109	70
9. (Artificial containers—Figs. 8–10)	1,493	963	65	530	35
Subterranean waters					
10. (Natural)	1	1	100	0	—
11. (Artificial—Figs. 11, 12)	1	1	100	0	—
Totals	2,304	1,333	58	971	42

Table 4. Mixed species infestations of individual larval habitats (species listed in decreasing order of associations, read from left to right; figures below each taxon show the number of sites involved in each association).

	Aedes notoscriptus	*Culex pervigilans*	*Culex quinquefasciatus*	*Culex asteliae*	*Opifex fuscus*	*Maorigoeldia argyropus*	Total associations
	142	142	—	—	—	—	142
	32	—	32	—	—	—	32
	5	5	5	—	—	—	5
	1	—	—	1	—	—	1
	1	—	—	—	—	1	1
	—	35	35	—	—	—	35
	—	1	—	—	1	—	1
Overall totals	181	183	72	1	1	1	217

spectively (Laird 1988), both can tolerate far less organic enrichment; and as Bick (1972) states with respect to the former, "Small colonies may occur under mesosaprobic conditions, solitary specimens even being found in the oligosaprobic zone." While as already mentioned just over half of the double infestations encountered occurred in tires, most of which were so positioned as to be charged with rainwater initially, some other Category 9 larval habitats in which *Ae. notoscriptus* was associated with one or both of the 2 species of *Culex* held foul water—for example, meat cans that still bore traces of their original contents when thrown into open garbage dumps. One such can exhibited *Cx. pervigilans* larvae, all with a heavy vestiture of *V. microstoma,* together with many perfectly clean larval *Ae. notoscriptus.* The latter species was similarly free from epibionts in a horse trough organically rich enough to have attracted *Cx. quinquefasciatus* similarly heavily infested with *V. microstoma.* Again, in a plastic bucket containing quite clean water, there was a scattering of *Epistylis* over the cuticle of *Cx. pervigilans* larvae in association with uninfested *Ae. notoscriptus,* while a similar situation involving either *E. lacustris* or *V. microstoma* was noted for a number of tires.

Perhaps, just as most cladocerans suffer far less from epibionts than do copepods (due to the former's hydrofuge qualities as opposed to the latter's hydrophilic ones?—Hutchinson, 1975), similar physical phenomena may apply within the Culicidae. Although the matter merits experimental study, the environmental preferences of *Op. fuscus* suffice to account for the general freedom of larvae of this species from ciliate epibionts. For while it proved free from such infestation in 31 of the 32 sites from which it was identified, these were as usual decidedly brackish, a circumstance inimical to *V. microstoma* and *E. lacustris,* both of which were equally scattered over larvae of *Opifex* and those of *Cx. pervigilans* in an atypical Category 2 site (ponded stream) which was spring-fed in the immediate vicinity of several normal *Opifex* larval habitats at Mangonui, Northland.

Turning to parasites and pathogens, with just 2 exceptions these were conspicuous by their absence. In the light of wide field experience elsewhere in the world, it was particularly surprising to find no trace of mermithid nematodes, microsporidian Protista or Blastocladiidea of the genus *Coelomomyces,* in so large a sample of material—the more so, as J. S. Pillai and his colleagues have described microsporidians from *Maorigoeldia argyropus* and the apparently introduced *Ae. australis,* besides *Coelomomyces* in the latter and *Op. fuscus,* in the South Island.

Ovoidal bodies plentiful throughout the hemocoel of all *Op. fuscus* late-instar larvae collected from a brackish rockpool in Te Karo Bay, eastern Coromandel Peninsula, on April 7, 1989, appeared at first sight to be resting sporangia of a species of *Coelomomyces.* More detailed examination in collaboration with J. S. Pillai suggests that the organism is really a eugregarine protozoan.

Finally, fungal hyphae and conidiophores—as yet unidentified—were noted on the thorax and anal segment of larvae from 2 Category 9 habitats. The species concerned were *Ae. notoscriptus* (Orua Bay, South Auckland, November 21, 1988—in water tank), and *Cx. pervigilans,* in association with uninfected *Ae. notoscriptus* (Point Chevalier, Auckland, December 5, 1988—in tire).

DISCUSSION

Occurrence and prevalence of Culicidae in northern NZ: The 4 native and 2 (long since) accidentally imported species recorded tallied with earlier findings, apart from minor details of distribution and incidence. The latter could reflect seasonal variables (e.g., summer rainfall vs. drought) and survey coverage; the project took place in rather a wet period offering optimum larval habitat availability, but had it been conducted a year later a sustained summer drought would have resulted in a substantially reduced total of collections. And until recently, I would have accepted the opinions of Belkin (1968) and Pillai (1979[4]) on the comparative rarity and low frequency of *Cx. quinquefasciatus*, which according to the former author is "largely confined to coastal areas in the vicinity of the larger ports on North Island." This is indeed so, but it was not until early April that attention to the "gully traps" of the stormwater drainage system of Parnell, Auckland City, revealed a great abundance of this species there. As the barred covers of these sumps were raised one by one from the gutters, huge assemblages of adult and larval *Cx. quinquefasciatus*, often in association with *Cx. pervigilans* and occasionally with *Ae. notoscriptus* were revealed beneath, amply accounting for many complaints of a serious biting problem from local residents. In the final days of the survey, a similar situation was revealed in parts of South Auckland, where "gully traps" near the airport's International Terminal at Mangere were sustaining large populations of both *Cx. quinquefasciatus* and *Cx. pervigilans* and thereby furnishing sources of both to aircraft departing for foreign destinations, and at the same time serving as potential oviposition sites for pollution-tolerant foreign mosquitoes should these evade on-arrival disinsection.

Still on the matter of international arrival/departure places, other *Cx. quinquefasciatus* collections were made from a variety of Category 9 sites on Auckland's container wharf and the Devonport Naval Base. Positive samples were also taken on the nearby Hauraki Gulf islands of Waiheke and Rakino. Further afield, Belkin's (1968) first record of this species from the old port of Coromandel was confirmed. New Coromandel Peninsula locality records were obtained a little further north, at Koputauaki Bay, and from the old port city of Thames (in the latter case from a Category 1 habitat, backwaters of a foul streamlet). Perhaps the most interesting new finding of *Cx. quinquefasciatus* was the first inland one, from a school swimming pool in the city of Hamilton, Waikato. The species was not collected elsewhere there, and the finding could easily have been due to road, rail or air transportation from Auckland; in which connection, it is pertinent that an unusual Category 9 larval habitat, a pool on the metal floor of a railway wagon on an Auckland siding, yielded *Cx. pervigilans* and *Ae. notoscriptus*.

The last-mentioned exotic, now North Auckland's second most plentiful and widespread mosquito, has spread inland throughout the farming districts. It has been aided in its dispersal by the practice of piling many discarded tires (sometimes up to 100 or more) to weigh down the plastic covers of rural ensilage piles, to mention only one example of the diversity of Category 9 larval habitats characteristic of today's throwaway society. Via artificial containers *Ae. notoscriptus* had already radiated into other types of NZ larval habitats characteristic of those of its countries of origin [i.e., such Category 8 sites as tree holes and rock potholes (Lee et al. 1982)], long ago. Thus Graham (1929) reported it from rock hollows, "especially those occurring in caves" (i.e., Category 10) as well as from rot-holes in various species of native trees, the leaf axils of nikau palms and *Astelia* spp., and exceptionally even from "drains, swamps and water-holes." In the present survey it was commonly collected from the leaf-base tanks of neotropical Bromeliaceae (Fig. 7) grown as greenhouse ornamentals. An interesting Northland finding concerned Waipoua Forest, where a marginal zone investigated in late March 1989 yielded several Category 9 sites ranging from a "gully trap" at a camp mess hall, through steel drums, tires, buckets and ubiquitous beer cans and bottles, to many Category 8 (natural containers) ones. The former group had opened entry to the latter, in which *Ae. notoscriptus* was identified from slits in prostrate logs and standing trees, as well as from Bush Flax, *Astelia nervosa*, leaf axils. In this center of concentration of an exotic peridomestic mosquito reverting to its original natural larval sites, *Ae. notoscriptus* larvae were not only also found in a Category 2 habitat (ponded stream), but in a stream backwater (Category 1), too.

No intensive sampling of leaf axil, tree hole and other Category 8 habitats was undertaken in dense forest. Had this been done, there would certainly have been many more records of the indigenous *Cx. asteliae* and *Mg. argyropus*; but it was felt more important for the purposes of the survey to concentrate on the surroundings of airports and seaports and the rural hinterland that further mosquito arrivals would have to traverse before reaching major forests. Coastal areas were searched wherever feasible, though, and this resulted in findings of *Op. fuscus* wherever suitable larval habitats existed.

The only other mosquitoes known to occur in the northern parts of Auckland Province but not reported in the 1988–89 larval survey are: *Ae. antipodeus* (Edwards), *Coquillettidia tenuipalpis* (Edwards) and *Cq. iracunda* (Walker). Like other members of the tribe Mansoniini, *Coquillettidia* spp. have larvae which "rely on air within the underwater roots of emergent plants and all have the siphon highly modified for piercing plant tissue" (Wood et al. 1979). Larvae of neither of the NZ species are known from the field, although according to Belkin (1968) 1st instars were obtained from egg rafts by L. J. Dumbleton (unpublished). Adults have been obtained from Northland since the pioneer survey of Miller (1920; and see Belkin 1968), there being a strong association with marshlands rich in sedges, reeds and other aquatic vegetation. Typical NZ Raupo (a bullrush, *Typha orientalis*) and *Carex* spp. are central to the aquatic complex within which both NZ species of *Coquillettidia* might be expected to be found. So far, the manual uprooting of much such vegetation, with care to divert the underwater parts into a submerged drum without breaking the water-film and so dislodging larvae, has proved fruitless.

Aedes antipodeus is a winter floodwater utilizer, larvae of which were collected in 6 of Pillai's (1979[4]) July–September 1978 samples from the vicinity of Whangarei. Although the females are active year-round (Belkin 1968), the timing of the present survey would have made it rather unlikely to come across immature stages, the more so as populations of this member of the subgenus *Ochlerotatus* seem characteristically small.

Factors relevant to possible future establishments of foreign mosquitoes in NZ: Offering a temperate climate and an adequate range of environments for Culicidae, NZ nevertheless still has an unusually limited mosquito fauna (14 species, only 11 of them indigenous) for a country of 269,063 km^2 (103,886 mi.^{2}). It is thus pertinent to consider how this may affect the question of vulnerability to new introductions of pests and vectors paralleling those of arthropods of agricultural and forestry importance that continue to take place despite quarantine measures as expanding trade and tourism break down former isolation.

The proportion of 1988–89 collecting sites actually positive for larval mosquitoes (58%; Table 3) was appreciably less than has been found characteristic of NZ's nearer and warmer neighbors. Thus widespread surveys in many tropical South Pacific island groups and Queensland, Australia (Laird 1956a), revealed that overall, 372 (81%) of 457 actual and potential larval mosquito habitats sampled exhibited larvae. Moreover, 131 (35%)—by comparison with 217 (16%) in the present project—harbored more than one culicid species. Thus 85 (25%) held 2 species, 33 (9%) 3, 9 (2%) 4, 3 (1%) 5 and 1 (<1%) 6. As already indicated, there were no multiple infestations beyond 3 in this Northern Mosquito Survey, all but 5 of them involving only 2 species (Table 4). Furthermore, while *Cx. pervigilans* and *Ae. notoscriptus* headed the list for mixed infestations in almost equal numbers (Table 4), the species-proportions of each were 20% and 42%, respectively. As 46% of all *Cx. quinquefasciatus* samples were mixed ones, too, these figures are evidence of the success of both exotics in competing for available larval habitats in the NZ environment.

A general underutilization of potential larval mosquito sites in northern NZ has thus been turned to account by both exotic immigrants, although distinctly more so by *Ae. notoscriptus* than by *Cx. pervigilans*. The former, having adapted better to local conditions, has radiated into varied and widely dispersed larval niches (both near the likely ports of entry and deep inland) to become the region's most plentiful culicid after the indigenous *Cx. pervigilans*. This highly adaptable species was obviously largely free from mosquito competition prior to the arrival of the 2 foreign species. It has a remarkably wide range of tolerances in oviposition site selection, having been collected from all 11 larval habitat categories (positive examples of 6 of which are illustrated in Figs. 1–5, 8–12), and dominating in all but one of them (Category 8) in Table 5.

While natural containers were the only larval habitats where *Cx. pervigilans* was subordinate to other species, one of these was *Cx. asteliae*, a derivative of the former. Belkin (1968) suggested "that *asteliae* was formed from a founder population of the *pervigilans* stock on an isolated volcanic island where the only available fresh water was in astelia axils" (probably those of the Perching Lily, *Collospermum hastatum*, a conspicuous epiphyte on forest trees which is also a pioneer on bare volcanic rock). Such axils and forest tree holes are commonly negative for native mosquitoes, and although *Ae. notoscriptus* was quick to take advantage of the circumstance and was the species most often collected from Category 8 habitats—being present in 18 (39%) of the 46 found positive—the proportion of such habitats that proved negative (70%; Table 3) was the highest for all categories. Originally clearly a utilizer of surface and cave waters

Table 5. *Culex pervigilans* occurrences (percentages derived from overall larva-positive habitat figures in Table 3).

Category	Collection(s)	% of occurrence
1	30	94
2	92	95
3	5	83
4	44	94
5	36	95
6	73	97
7	26	96
8	3	7
9	620	64
10	1	100
11	1	100

(Categories 1–7, 10), *Cx. pervigilans* must have begun to have access to artificial containers in pre-European times. For the Moriori made water containers, *hakana*, of wood and perhaps of pumice also (Skinner 1923), and the Maori manufactured both types while their beached dugout canoes would have afforded similar larval habitat prospects to mosquitoes as those of many tropical Pacific islanders still do today. Contrary to the experience of Belkin (1968), but in agreement with that of Pillai (1979[4]), most (620, 67%) of the present survey's 931 collections of larval *Cx. pervigilans* were from Category 9 habitats. The comparable figure for *Ae. notoscriptus* was 95%.

Of 37 different types of Category 9 habitats dominated by these 2 species, discarded tires (613) and stock drinking troughs (210) were by far the most numerous and widespread. Both abound throughout rural areas; the former were larva-positive at airports and seaports, and a number of the latter yielded *Cx. pervigilans* adjacent to the perimeters of both Auckland International Airport, Mangere, and Royal New Zealand Air Force Base, Auckland, at Whenuapai. Both are clearly dangerous as potential oviposition sites for newly imported Culicidae, and neither proved anything like fully utilized. For 190 (31%) of the tires and 119 (57%) of the stock drinking troughs altogether lacked Culicidae, a fact that when added to the multiple-occupancy data presented earlier points to a prevailing availability of oviposition sites awaiting Category 9 larval habitat utilizers that might in future be accidentally imported into NZ. Whether or not such exotics have direct sunlight tolerance is a factor here, for most water held by tires is shaded by the rims (Fig. 8), while most gravity-filled stock troughs (Fig. 10) are in open fields and unshaded. Now the tire/trough occupancy rates exhibited by *Cx. pervigilans*, with its exceptionally "wide tolerance of environmental conditions" (Belkin 1968), were 40 and 34%, respectively, while those of *Ae. notoscriptus*, which is as intolerant of direct sunlight in NZ (Graham 1929) as in all possible source countries (Lee et al. 1982), were 41 and 4%, respectively.

Another factor to be considered on the chances of success of future mosquito invasions of NZ is predation. In that connection, field data sheets for 63 (53%) of the 119 troughs negative for Culicidae mentioned that predators were common to abundant. Relevant samples occasionally contained Corixidae, but the dysticid beetle, *Rhantus pulverosus*, was more common, and the backswimmer, *Anisops assimilis*, most common of all. The last-mentioned were frequently flightless morphs. Being unable to fly from the habitat as winged notonectids can, these are well-suited to keeping stock troughs relatively or totally free from larvae (their efficacy of course being subject to the frequency of emptying for cleaning). There is presumptive evidence here that the phenomena of notonectid flightlessness and environmentally determined polymorphism (Young 1970) might have some practical value in limiting mosquito populations in these clearly necessary water bodies, besides diminishing the chances of successful establishment by invading exotics.

The best consequences of such predation, however, would be offset by the prevalence of discarded tires (from which notonectids, dytiscids and corixids were never collected) near airport and seaport likely reception areas and throughout the urban and rural north. Until now, NZ's greatest threat from a Category 9 utilizer has been assumed to be the cosmotropical or tropicopolitan (see Lee et al., 1987a) *Ae. aegypti*. This species was established in eastern Australia (Skuse 1889) by December 1887 according to Lee et al. (1987a). By the early 1900s (and possibly long before) it was in Fiji (Theobald 1903) and Samoa (Grunberg 1913). Perhaps *Ae. aegypti* is just a little too tropical for NZ? After all, *Cx. quinquefasciatus* has achieved a greater latitudinal dispersion; yet it seems from data herein to be only just sufficiently tolerant of NZ's temperate conditions to have maintained itself (with a high summer population peak) at and around the original ports of entry in the warmer northern districts. Yet, *Ae. aegypti* is still on the move, having only extended its range to NZ's tropical neighbors of Tokelau and Niue as recently as the late 1960s, apparently in consequence of importations during hurricane-relief operations (Pillai and Ramalingam 1984, Dale and Maddison 1984).

Latterly, though, the prime threat has switched to the Asian tiger mosquito, a *Stegomyia* second only to *Ae. aegypti* as a dengue hemorrhagic fever virus vector and also able to transmit Ross River virus. For although of SE Asian origin and until recent years regarded as a purely tropical species, this insect, following its 1985 appearance in the United States via the used tire trade, has dispersed to far from tropical regions of that country (Hawley 1988, Anonymous 1989). This suggests that *Ae. albopictus* (Skuse) might indeed become established in the warmer sector of NZ's North Island, once introduced. Having done so, and differing from *Ae. aegypti* in its well-known although not exclusive (Laird and Mokry 1983) predilection for peridomestic Category 9 larval sites, it would be well placed for following such local paths as those already blazed by *Ae. notoscriptus* back to the diversity of Category 8 larval habitats that it favors in nature in SE Asia (references in

Hawley 1988), thus becoming so deeply entrenched in northern rural and forest country as to preclude eradication and render effective control very difficult and extremely expensive. In this connection, the writing on the wall was furnished when tree hole colonization by *Ae. albopictus* was recognized in the United States (Foster 1989).

The above is no idle speculation. As the 1988–89 Northern Mosquito Survey was beginning, word was received of this mosquito's first introduction into Fiji in the proximity of Nadi International Airport (Fauran and Laille 1988). By the second half of 1989, the Asian tiger mosquito had become entrenched around the main island of Viti Levu (J. S. Pillai, personal communication, August 21, 1989), from which shipping and aviation maintain constant links with NZ. These links are far closer than those with the previous nearest vicinity of *Ae. albopictus* to NZ, the Solomon and Santa Cruz islands, where it had first been recognized in 1978 (Elliott 1980), perhaps as a result of a seaborne introduction from Papua New Guinea. The species must therefore be regarded as posing an immediate threat to at least Auckland Province. This threat includes a potential pest problem as well as a possible vector-borne arbovirus component. The same holds good for 2 other arbovirus vectors resident in Fiji, *Ae. vigilax* (Skuse) and *Cx. annulirostris* Skuse, these being on epidemiological grounds the chief Australian vectors of Ross River virus (Miles 1984).

By 1954 the former mosquito was not yet established in Fiji (Laird 1956a), although there is believed to have been an apprehended introduction in 1940 (R.J.A.W. Lever, in Paine 1943). It had arrived, though, by late 1957, perhaps via Nadi International Airport (Burnett 1960). Both species are also present elsewhere in NZ's near vicinity, in New Caledonia and eastern Australia. As in the case of *Ae. albopictus*, both would pose pest problems as well as health ones, once established in northern NZ, where *Cx. annulirostris* might be expected to invade underutilized categories 1–7 and 9 larval habitats. Graham (1939) reported the discovery 10 years earlier of larvae of the last-mentioned species in the hold of a ship reaching Auckland from Suva, Fiji, and his later destruction of more larvae in a barrel on the nearby waterfront, while Laird (1951) detailed the finding of adult *Cx. annulirostris* in routine disinsection collections from 5 aircraft following arrival at RNZAF Station Whenuapai (then Auckland's only airport receiving civilian as well as military aircraft from abroad) from Fiji, Norfolk Island and Australia. In the last instance a female example was alive when collected from a luggage bay of a plane from Sydney on April 20, 1950. Another live female *Cx. annulirostris* was found a year later in the passenger compartment of an aircraft from Fiji (Laird 1952). World War II collections from Whenuapai flights subsequently worked through were found to have twice included examples of *Ae. vigilax* from New Caledonia (Laird 1956b).

Since those days NZ has maintained efficient routine disinsection aboard arriving international flights, and despite the enormous growth of aviation over the intervening period, no further foreign mosquitoes have become introduced into the northern regions of Auckland, as earlier comprehensive surveys and the present one have shown. Meanwhile this area has acquired major tourist significance, compounding the problem in terms of ever-increasing numbers of daily arrivals of loaded jumbo jets, and adding a new dimension to the likely consequences of establishments of such species as those named in the previous paragraph—that of a pest problem of hitherto unexperienced dimensions, which might prejudice tourism. One could be the establishment of *Ae. vigilax*, a brackish water utilizer thriving at the landward margin of mangrove swamps and in pools on associated *Salicornia* flats (Lee et al. 1984). Such larval habitats are characteristic of much of the Auckland area, Northland and Coromandel Peninsula coasts (all prime recreational areas). Of the 97 Category 4 habitats (marshes and swamps) sampled there, 20 were mangrove swamps (*Avicennia resinifera*), of which 15 (75%) lacked any Culicidae. Four of the others harbored *Cx. pervigilans*, incidence being heavy only once. In the remaining site, the sample being taken at a point on the perimeter of Auckland International Airport where a culvert discharged drainage water into the swamp, a few *Cx. quinquefasciatus* larvae were found. That site was within convenient flight range of both international and domestic terminals for parous mosquitoes chancing to elude disinsection measures, and thus could conceivably serve as a bridgehead, concentration point and source of internal NZ dispersal for accidentally imported *Ae. vigilax.*

Carrying speculation a stage further, at a time when possible consequences of the "greenhouse effect" are the subject of much discussion and controversy, it is worth noting that the 10°C winter isotherm line lies just south of Auckland City. Christophers (1960) held that the area north of that line might be considered suitable for *Ae. aegypti.* Whether or not this is so, the 1.5°C temperature rise over the next half century that is being forecast by advocates of the above hypothesis would certainly enhance the establishment opportunities for this species, others discussed herein and perhaps such malaria vectors as the Melanesian/northern Australian *Anopheles farauti* Laveran. This might occur if sea levels were raised significantly to influence the water table, thereby enlarging marshlands and enhancing floodwater availability in low-lying areas. The consequences of the "greenhouse effect" would also enhance the production of some mosquito species already present, and the ameliorated climate at the same time would encourage the southward and inland spread of *Ae. notoscriptus* and *Cx. quinquefasciatus* (Pillai and Laird 1989[5]; Mogi 1990[6]).

To conclude, source reduction—with particular attention to off-rim tires—would be a wise precaution and useful contribution to the limitation of present mosquito populations in northern NZ at this time. Both now and in the foreseeable future, though, as in the past, port inspections (above all with respect to arriving tires) and effective disinsection of aircraft (Laird 1989) will comprise the essential first defense against economically and medically dangerous mosquito importations into NZ.

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