Scientific Note

Vertical distribution of adult mosquitoes in native forest in Auckland, New Zealand

José G. B. Derraik✉[1], Amy E. Snell[1], and David Slaney[2]

[1]*Ecology and Health Research Centre, Department of Public Health, Wellington School of Medicine and Health Sciences, University of Otago, P.O. Box 7343, Wellington, New Zealand*
[2]*Institute of Environmental Science & Research Ltd, P.O. Box 50348, Porirua, New Zealand*

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Mosquitoes have been shown to be active over a wide vertical range within the forest column (e.g. Haddow 1947), and their vertical stratification appears to be related to feeding or oviposition habits. Some mosquito species are active throughout the vertical forest strata from ground level to the top of the canopy, while others may display a marked preference for host-seeking high into the forest canopy or close to the ground (e.g. Snow 1974, Braack et al. 1994).

There are 12 native and four established exotic mosquito species in New Zealand (Derraik 2004), and although there are no records of indigenously acquired cases of mosquito-borne disease in this country (Derraik and Calisher 2004), the vector status of most indigenous species is unknown. A comprehensive investigation of Culicidae in New Zealand is necessary, and large numbers of specimens should be collected and processed for virus isolation. However, one difficulty in collecting adults of many indigenous species could be a result of their vertical distribution within native forest habitats, and adults of *Culex (Culex) asteliae* Belkin, for instance, have never been collected in nature. Although there are isolated records describing the presence of some native species in the tree canopy (Pillai 1968), there is overall very little information on their vertical distribution in New Zealand forests. A study was therefore set up to assess the vertical stratification of adult mosquito activity within an area of native forest in northern New Zealand.

This investigation was carried out in a relatively pristine native coniferous-broadleaved forest in the Cascade-Kauri Park (36° 53' 35'' S, 174° 30' 30'' E), located within the Waitakere Ranges Regional Park, West Auckland, New Zealand. The area is protected and undergoes regular pest control against introduced mammals, in particular brushtail possums (*Trichosurus vulpecula*). Four dry ice-baited light traps were used for sampling, and two native rimu trees (*Dacrydium cupressinum*; Podocarpaceae) located approximately 200 m apart and at least 20 m away from a walking track were selected for simultaneous placement of traps. On each tree, one trap was set as close to the ground as possible, while the other was set at a height of 10 m. The traps were set over five non-consecutive dry and relatively windless nights in April, 2003 (early austral autumn). Adult trap catches between ground level and 10 m were compared using non-parametric tests (Kruskal-Wallis), and significance level used was $P < 0.05$. Note that although the statistical analyses were calculated at a per trap basis, the results are given at a per night basis for the sake of clarity.

The total number of mosquitoes collected from both trees was very similar, with 516 and 507 mosquitoes recorded from trees 1 and 2, respectively (a total of 1,023 specimens in the 20 traps set up). The relative abundance was also similar for all individual species from both trees, and there were consequently no location effects on the community as a whole or on any individual species (all *P*-values were > 0.703).

Overall, there were significantly more mosquitoes ($P = 0.002$) collected overnight at ground level than at a height of 10 m. At the species level however, this particular pattern was only observed for the endemic *Ochlerotatus (Ochlerotatus) antipodeus* (Edwards), which was over five times more abundant at ground level (623, mean = 124.6, SE = 7.9) than at 10 m (175, mean = 35.0, SE = 6.8) ($P < 0.001$; Figure 1). *Ochlerotatus antipodeus* largely dominated the community, making up 78% (798) of all mosquitoes recorded, and excluding this species from the overall yield there were significantly more mosquitoes caught at 10 m ($P = 0.001$).

The only exotic species recorded at the site was *Ochlerotatus (Finlaya) notoscriptus* (Skuse), of which 22 specimens were recorded. The mean number of *Oc. notoscriptus* specimens collected overnight at ground level and at 10 m was small (2.8 and 2.4, respectively) and not significantly different ($P = 0.342$, Figure 1).

No specimens of the endemic *Cx. asteliae* and *Culex (Culex) pervigilans* Bergroth were recorded at ground level, but both were found at 10 m (Figure 1) with the *P*-values for height differences being < 0.001 and 0.031, respectively. Only 18 *Cx. pervigilans* were recorded (mean = 3.4, SE = 1.8), while *Cx. asteliae* had 86 specimens (mean = 15.6, SE = 4.9) recorded in all but one of the 10 canopy traps set. *Culiseta (Climacura) tonnoiri* (Edwards) was another endemic species that was significantly more abundant at 10 m than at ground level ($P = 0.024$), with 41 (mean = 8.2, SE = 1.5) and 18 (mean = 3.6, SE = 1.6) specimens recorded, respectively (Figure 1). The only native species for which there was no significant difference between the two heights was *Coquillettidia (Coquillettidia) iracunda* (Walker) ($P = 0.259$),

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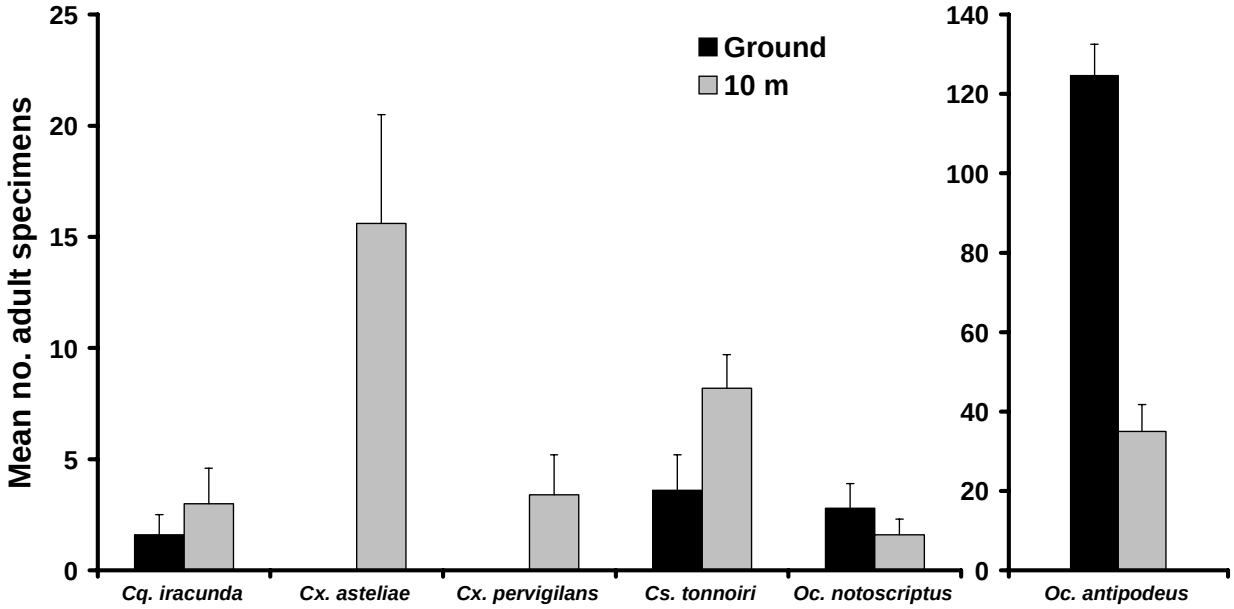

Figure 1. Mean number of adult mosquitoes collected from two traps at each of 5 nights in native forest at ground level and 10 m. Error bars represent the standard error for the mean.

for which 8 and 15 specimens were collected at ground level and 10 m, respectively (Figure 1).

The exotic *Oc. notoscriptus* was recorded both at ground level and 10 m (Figure 1), and similar results were obtained in a small investigation in the Wellington region (Derraik et al. 2003). This species was also caught in biting catches from a height of 18 m in native forest canopy, at a site where the species was also viciously biting at ground level (Derraik 2005). Therefore, there is no doubt that this species is active over a relatively large vertical stratum within native forests in New Zealand. In its native Australia, *Oc. notoscriptus* seems to feed almost entirely on mammals, although poultry is also included among its potential hosts (Lee and Bugledish 1999). Whether this species feeds on native birds in New Zeland is unknown, but its presence at Cascade-Kauri Park could be an indication that it does.

Among the native species, no *Cx. pervigilans* were collected in this study from ground traps, in comparison to the 17 specimens recorded within the forest canopy (Figure 1). In contrast, this species was recorded at the Wellington Zoo in both ground level and 10 m traps (Derraik et al. 2003). *Culex pervigilans* is New Zealand's most abundant and widespread mosquito species (Laird 1990), and it seems to thrive particularly well in urban and rural areas, typically away from forest covers. It is possible that *Cx. pervigilans* may display heterogeneous patterns of activity as a result of phenotypic or genotypic variation. Populations from modified environments may have adapted to feeding near the ground to exploit the abundant blood meals provided by the numerous animals present at ground level (e.g. humans, cattle, and other domestic animals), in contrast to canopy feeding within areas of native forest.

Culiseta tonnoiri was the other native New Zealand species for which published height distribution data were available, and Pillai (1968) frequently captured females in traps baited with bantam fowl (*Gallus domesticus*) in native forest canopy as high as 33 m. The results from this study support the idea that this species is active in various forest strata but seems to prefer feeding within the tree canopy (Figure 1). This pattern of activity seems to reflect the wide range of hosts on which the *Cs. tonnoiri* may feed including humans, many domesticated animals, and both canopy-frequenting and ground-dwelling birds (Pillai 1968, Crosby 1978).

One interesting pattern was found in the native mosquito *Cx. asteliae*, whose adults were collected in nature for the first time in this study. This species was entirely absent from ground traps but was relatively common within the tree canopy (Figure 1). The absence of previous collection records of *Cx. asteliae* adults is most likely a result of this species' marked preference for canopy activity. Interestingly however, larvae of *Cx. asteliae* are widespread and abundant in the leaf axils of the native plant *Collospermum hastatum* (Liliaceae) on the ground and in the forest canopy, where they have been collected as high as 18 m (Derraik 2005). As pointed out by Woodward et al. (1996), the vertical stratification of oviposition preferences may not necessarily be correlated with that of adult mosquito activity.

Unlike the other native mosquito species observed, *Oc. antipodeus* was predominantly found at ground level and *Cq. iracunda* showed no preference for a particular stratum (Figure 1). Apart from the fact that both species bite man (Derraik and Snell 2004, Holder et al. 1999), no information is available regarding their natural hosts, and for *Oc. antipodeus* at least, according to Belkin (1968) there are no records of the species biting cattle or other animals.

The results indicated that mosquitoes seem to be vertically stratified in the native forest site studied. The nature of New Zealand's pre-human fauna (no native land mammals apart from three bat species) means that mosquito species in native

forests would have adapted to feeding on birds. The latter seem to be now mostly restricted to the forest canopy as anthropogenic impacts have led to the displacement of the majority of New Zealand's ground-dwelling bird fauna and the extinction of 40% of all avian species (Holdaway et al. 2001).

Although some mosquito species are opportunistic and will feed on a variety of hosts, blood-feeding preferences of other species can be very host-specific (Service 1971). As a result, the apparent canopy-feeding habits of many native mosquitoes might be a result of avian host availability occurring mostly in the forest canopy. Unfortunately, as with other aspects regarding the ecology of New Zealand mosquitoes, very limited information is available on their host preferences (Belkin 1968, Holder et al. 1999). It is possible therefore, that in other patches of native forest where introduced mammals are abundant (in particular, brushtail possums), these may also become hosts to native mosquitoes.

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