Short Communication

An investigation into the circadian response of adult mosquitoes (Diptera: Culicidae) to host-cues in West Auckland

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.
[*] E-mail: jderraik@ihug.co.nz
[2] Institute of Environmental Science & Research Ltd, P.O. Box 50348, Porirua, New Zealand.

Mosquitoes display circadian rhythms, and under natural conditions their activity periods correspond to a 24-hour cycle (Clements 2000). Although microclimatic conditions such as wind speed, relative humidity and rainfall directly influence the activity of adult Culicidae (Bates 1945, Clements 2000, Haddow 1945, 1947), mosquitoes can usually be classified as diurnal, crepuscular or nocturnal, being commonly active either within the hours of daylight, twilight or darkness, respectively (Bates 1949).

Despite New Zealand's relatively species-poor mosquito fauna with 12 endemic and 4 exotic species (Derraik 2004a, Snell 2005), little is known of their ecology. For example, adults of the endemic *Culex asteliae* Belkin have been recently recorded in nature for the first time, in overnight traps set within the forest canopy at the Waitakere Ranges (Derraik *et al*. 2005). Most published data on the host-seeking activity of New Zealand mosquitoes are anecdotal (Table 1), and suggest that most species are crepuscular (mostly active at dawn and dusk) and/or nocturnal. There seems to be no published information on adult activity for a couple of species (Table 1), including the exotic *Ochlerotatus australis* (Erichson), which is not anthropophilic (Lee *et al*. 1984). We consequently carried out a pilot study to obtain some experimental data on adult mosquito activity, and to determine whether there was a change in species composition and/or relative abundance of mosquitoes seeking host-cues between daytime and overnight periods in particular habitats.

Materials and Methods

Sampling was carried out in West Auckland in late spring/early summer 2003, in three distinct habitat types: urban, native wetland and native forest. The urban site was located in a house backyard in Kelston (36° 53' 40'' S, 174° 38' 35'' E), in which a few native and exotic trees were present. The native wetland was located along Whatipu Beach (37° 02' 30'' S, 174° 29' 30'' E), while the remaining site was a relatively undisturbed native coniferous-broadleaved forest in the Cascade-Kauri Park (36° 53' 35'' S, 174° 30' 30'' E). The wetland and native forest are protected areas located within the Waitakere Ranges Regional Park.

A battery powered CO_2-baited light trap was used for sampling due to its effectiveness in collecting adult mosquitoes (e.g. Newhouse *et al*. 1966). Carbon dioxide (from dry ice) is the main attractant (Newhouse *et al*. 1966), while a minute lamp serves primarily for orientation within a metre or so of the trap (Rohe & Fall 1979). Due to the very small lamp and its rather inconspicuous placement by the point-source of CO_2, it was considered unlikely that the trap would cause significant bias in night time versus daytime catches. It should be noted however, that some species are not particularly attracted to CO_2-baited light traps (e.g. Russell 2004), and therefore could be under-represented in this study.

A single trap was set at each site during dry and relatively windless conditions, as wind speed is also an important factor inhibiting mosquito biting activity (Clements 2000, Snow 1979). Traps were placed in sheltered locations to maximize the attractiveness to mosquitoes and to hide them from vandals. At the urban site the trap was set underneath a rimu tree (*Dacrydium cupressinum*), at the wetland site it was located beneath two native

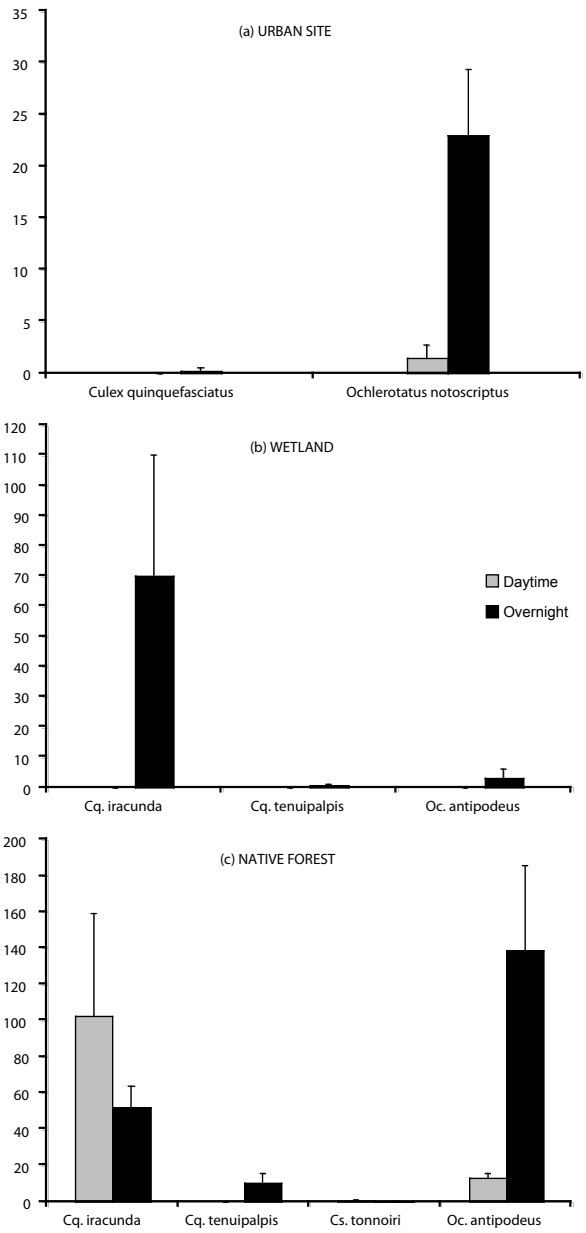

Fig. 1. Mean number of adult mosquitoes per trap collected overnight and in the daytime in West Auckland: at an urban site, wetland and native forest. Error bars indicate the standard error of the means.

shrubs, and at the native forest site the trap was under the canopy of a group of rimu trees. Adult mosquitoes were collected at each site over four 24-hour periods of sampling (between 15 December 2002 and 17 January 2003), with traps being set for 12 hours at a time. During this period, when mosquitoes are most active and abundant, darkness lasted for approximately 9 hours. Overnight traps were set up approximately 1.5 hours before sunset and taken down 1.5 hours after sunrise, to include any crepuscular activity. Daytime trapping started 1.5 hours after sunrise and lasted for 12 hours. All mosquitoes were identified to species using a key to the New Zealand Culicidae (Snell 2005). Overnight and daytime catches were compared using non-parametric tests (Kruskal-Wallis).

Results

The number of species and specimens caught varied between the different sites, with two, three and four species, and 99, 231 and 1285 specimens recorded at the urban, wetland and native forest sites, respectively (Fig. 1). Native mosquitoes were absent from the traps at the urban site, whereas exotic species were absent from those at the indigenous ecosystems (Fig. 1).

At the urban site all specimens were *Ochlerotatus notoscriptus* (Skuse), except for a single *Culex quinquefasciatus* Say collected overnight (Fig. 1a). *Ochlerotatus notoscriptus* appeared to be a nocturnal and/or crepuscular species ($P = 0.019$), as daytime catches were rare, but overnight catches were relatively abundant (Fig. 1a).

All three species collected from the wetland were crepuscular and/or nocturnal ($P = 0.019$; Fig. 1b). Unfortunately, data from one overnight trap were lost due to trap malfunction. *Coquillettidia iracunda* (Walker) was most abundant, while *Coquillettidia tenuipalpis* (Edwards) and *Ochlerotatus antipodeus* (Edwards) were somewhat rare (Fig. 1b).

Four endemic species were recorded from the indigenous forest (Fig. 1c), where 470 (mean per trap = 117.5, SE = 56.1) and 815 (mean per trap = 203.8, SE = 56.5) mosquitoes were collected during daytime and overnight trapping periods, respectively. At the individual species level, *O. antipodeus* and *C. tenuipalpis* were crepuscular/

nocturnal (P = 0.021 and 0.014, respectively); *C. iracunda* was more abundant in daytime traps, but the difference was not statistically different (P = 0.773); while *Culiseta tonnoiri* (Edwards) was rare (two specimens in the daytime, and one overnight) and no conclusions could be made about its activity (Fig. 1c).

Discussion

Irrespective of the habitat, overnight trapping was the best indicator of the mosquito species present at the West Auckland sites in late spring/early summer. In the three habitat types (urban, wetland and native forest), all species recorded during the study were found in overnight traps, with a few species absent from the daytime catches (Fig. 1). However, the trapping regime could not separate crepuscular from nocturnal activity.

Foot (1970) showed that *O. notoscriptus* was typically crepuscular, and a similar pattern was recently found in a study in South Australia (Snell and Williams, unpublished data). In contrast, Belkin (1968), Baber (1934), Miller (1920) and Graham (1939) described *O. notoscriptus* as a diurnal species, and the senior author has also been bitten by numerous *O. notoscriptus* in the daytime in native forest fragments in the Auckland region (Derraik & Snell 2004). Since mosquito host-seeking activity is affected by microclimate (Bates 1945, Clements 2000, Haddow 1945, 1947), crepuscular/nocturnal species for instance, may bite during the day in cool, shaded, humid forest habitat, and this may apply to *O. notoscriptus* in forest areas.

Our results seem to confirm *C. tenuipalpis* as a nocturnal/crespuscular species, as described by Baber (1934) and Graham (1939). *Coquillettidia iracunda* was described by Graham (1939) as a nocturnal species', while Baber (1934) stated that the species was active during the day and night. The species time of activity in this study varied between habitats and supports the previous anecdotal statements, as *C. iracunda* is possibly nocturnal in a wetland, but it may be active during the day and night within native forest environments. *Ochlerotatus antipodeus*, described by Baber (1934) and Graham (1939) as being active during the day and night, was ten times more abundant in overnight traps, but still collected in relatively large numbers during the daytime. Although only three *C. tonnoiri* were trapped, this species was relatively numerous in overnight traps in another study carried three months later (Derraik *et al.* 2005), supporting Dumbleton (1965) and Pillai (1968) who described it as being mostly nocturnal and crepuscular/nocturnal, respectively.

We believe this study probably provides the first experimental data on the time of adult activity of New Zealand mosquitoes, as the previous publications appear to rely on anecdotal evidence. Even though it is possible to determine a species' main period of activity, microclimatic influences may lead to significant variation between different environments, which may affect sampling results over a short period of time.

It is also important to highlight that although recent studies have indicated that the exotic *O. notoscriptus* is the dominant species in urban areas and highly modified native forests in the Auckland region (e.g. Derraik 2004b, Derraik & Slaney 2005, Stone & Mackereth 2003), this investigation provides further evidence that this species has yet to invade relatively undisturbed native ecosystems. A similar pattern was observed in the Wellington region, where *O. notoscriptus* is invading native forest remnants, but so far it has not invaded relatively undisturbed native forest habitats (Derraik 2005, Snell unpublished data).

The observed absence of native mosquitoes at the urban site and absence of exotic culicids at the relatively undisturbed indigenous ecosystems support the occurrence of a mosquito species replacement for the Auckland region. This is not unexpected as anthropogenic environmental change, in particular urbanization, is known to displace certain mosquito species often favouring invading vector species (e.g. Easton 1994, Forattini & Massad 1998, Póvoa *et al.* 2003). Such replacement has wider implications for New Zealand, as *O. notoscriptus* is a known vector of human and animal diseases (Derraik 2004a).

Table 1. Time of host-seeking activity in New Zealand mosquitoes according to the available literature. A dash (-) indicates where information is not available, and a question mark (?) where it is uncertain.

Origin	Species	Time of Host-Seeking Activity	Reference
Endemic	***Culex (Culex) asteliae* Belkin**	crepuscular/nocturnal (?)	Derraik *et al*. (2005)
	***Culex (Culex) pervigilans* Bergroth**	nocturnal	Baber (1934); Graham (1939)
	***Culex (Culex) rotoruae* Belkin**	–	–
	***Culiseta (Climacura) novaezelandiae* Pillai**	crepuscular/nocturnal (?)	Pillai (1966)
	***Culiseta (Climacura) tonnoiri* (Edwards)**	nocturnal	Dumbleton (1965)
		dusk & night, occasional daytime	Pillai (1968)
	***Coquillettidia (Coquillettidia) iracunda* (Walker)**	nocturnal	Graham (1939)
		daytime & night time	Baber (1934)
	***Coquillettidia (Austromansonia) tenuipalpis* (Edwards)**	nocturnal	Baber (1934); Graham (1939)
	***Maorigoeldia argyropus* (Walker)**	nocturnal	Baber (1934); Graham (1939)
	***Ochlerotatus (Nothoskusea) chathamicus* (Dumbleton)**	nocturnal	Snell & Sirvid (2005)
	***Ochlerotatus (Ochlerotatus) antipodeus* (Edwards)**	daytime & nighttime	Baber (1934); Graham (1939)
	***Ochlerotatus (Ochlerotatus) subalbirostris* (Klein & Marks)**	crepuscular/nocturnal (?)	Mark Disbury, pers. comm. 2005
	***Opifex fuscus* Hutton**	nocturnal	Graham (1939)
		mostly nocturnal	Baber (1934)
Exotic	***Culex (Culex) quinquefasciatus* Say**	nocturnal	Baber (1934); Graham (1939)
	***Ochlerotatus (Finlaya) notoscriptus* (Skuse)**	diurnal	Belkin (1968); Baber (1934); Graham (1939); Miller (1920); Derraik & Snell (2004)
		crepuscular	Foot (1970)
	***Ochlerotatus (Halaedes) australis* (Erichson)**	–	–
	***Ochlerotatus (Ochlerotatus) camptorhynchus* (Thomson)**	diurnal & crepuscular	Dobrotworsky (1965)

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