Adult Diptera trapped at two heights in two native forests and an urban environment in New Zealand

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Abstract
Traps designed primarily to attract adult mosquitoes were set at two different heights (ground level and 10 m) in three sites in the Wellington and Auckland regions; one trap in an urban area and two in native forest environments. In all, 405 adult Diptera were caught, comprising 13 families and approximately 55 taxa, many of which were represented by one specimen each. These data provided indications, in some taxa, of vertical stratification, with some found only at ground level or only in the canopy.

Introduction
Arboreal arthropod communities have been studied for many reasons, principally to improve understanding of ecology and biodiversity (McWilliam & Death 1998, Basset *et al.* 2003a), but also as a means of identifying important food sources for insectivorous birds (Moeed & Meads 1984). Numerous arthropods, including Diptera, and in particular mosquitoes (Culicidae), have been shown to occupy a wide vertical range within the forest column (e.g., Haddow 1945, 1947, Basset *et al.* 2003b). While some species may be active from ground level to the top of the canopy, the activity of others may be somewhat restricted to more circumscribed parts within the vertical forest strata (Goma 1965, Snow 1974, Braack *et al.* 1994, Basset *et al.* 2003b). These preferences are presumably related to the ecological requirements of individual species (Schowalter & Ganio 1998, Basset *et al.* 2003a), such as microclimate, vertical light gradients, and availability of food or hosts.

During an extensive research project into the Culicidae of New Zealand, trapping of adult Diptera was carried out at two different heights in the Wellington and Auckland regions (Derraik *et al.* 2003, 2005). The primary purpose of the study, from which the results reported here arose, was to discern the distribution and stratification of mosquitoes within both modified and relatively unmodified ecosystems. Here, records of other Diptera, collected during a portion of the trapping operations are presented, and aspects of their stratification discussed.

Substantial studies on arthropod stratification have been undertaken in both tropical (Basset *et al.* 2003b) and southern temperate (Didham 1997) rainforests, and the study reported here is small by comparison, but does offer its own individual insight, albeit indicative, into stratification of Diptera in two environments not previously studied.

Methods

Sampling was carried out at three different sites. Two of these were native coniferous-broadleaved forests: Otari-Wilton's Bush (41° 16' S, 174° 45' E; 90 ha) in Wellington City, and Cascade-Kauri Park (36° 54' S, 174° 30' E; >1,000 ha) located within the Waitakere Ranges Regional Park, West Auckland. The third site was the Wellington Zoo (41° 19' 20'' S, 174° 47' 00'' E; ca 2.0 ha), an urban habitat located within Wellington city, surrounded by narrow belts of exotic *Pinus* forest and highly modified secondary native forest.

At each of the Wellington sites, three trees were selected for placement of traps, being pohutukawa (*Metrosideros excelsa*) at the Zoo and rimu (*Dacrydium cupressinum*) at Otari. Two CO_2-baited light traps (primarily to attract mosquitoes; Rohe & Fall 1979) were set overnight at each selected tree, with one trap installed as close to the ground as possible, and another at 10 m above ground. Diptera were collected over three nights in March 2002. At the Cascade-Kauri Park in Auckland, Diptera were collected in four dry ice-baited light traps set up once (out of a total of 5 nights for the mosquito study) for overnight sampling in early April 2003. Two *D. cupressinum* were selected for simultaneous placement of traps, which were positioned as in the Wellington study.

At all sites, trapping was carried out in dry and relatively windless conditions, as insect trap catches decrease with rainfall and increasing wind speed (Strickman *et al.* 1995, Southwood & Henderson 2000). Traps were set up about one hour before sunset and collected about one hour after sunrise. Although the carbon dioxide sources used differed between Wellington and Auckland, the designs of the traps themselves (including the very small light bulb) were practically identical.

Insect specimens (most being dry, but some in 70 % ethanol) were identified to family, genera, and species, or were given species numbers, using a combination of conventional taxonomy techniques and the taxonomic minimalism approach (Beattie & Oliver 1994). With many of the Cecidomyiidae females, for example, we could not separate the material beyond the family level. A range of taxonomic guides was employed as cited in Macfarlane and Andrew (2000), *viz* Marshall (1896), Hutton (1901), Edwards (1923, 1927), Miller (1923), Tonnoir & Edwards (1927), Collin (1928), Malloch (1930a,b), Satchell (1950, 1954), Freeman (1959), Harrison (1959), Wyatt (1963), Dugdale (1969), Vockeroth (1981), Huckett (1987), Matile (1989), Bickel (1996) and Mohrig & Jaschhof (1999). Specimens of Cecidomyiidae were slide-mounted in Hoyers' medium so that male genitalia could be examined. Names of taxa and their ranks were standardised following Evenhuis (1989) or more recent literature where appropriate, but many identifications were conservative because much of the material on which they were based was damaged, and some had lost body parts, or colours had faded. Most genera were definable, as were some species, and if the latter could not be named with confidence, but it was apparent that they were different from other individuals in that genus, we then applied the taxonomic minimalism described by Beattie and Oliver (1994). Being non-specialists, we decided that it would be more prudent to limit our identifications to the generic level and give each species a discrete number, except where identification to species could be done unequivocally. Despite this, we have analysed the data on a family basis because the presence of many singletons among the catches made analysis based on genera or species difficult, and validity questionable. Where there were sufficient numbers of insects, comparisons were made of the distribution of some species in some families at different heights using a chi-square analysis. In addition, total numbers of insects at two heights in the three most speciose families (Cecidomyiidae, Chironomidae and Tipulidae) were also compared.

Results

Overall 405 specimens were collected, representing 13 different dipteran families, as listed in Table 1. The Culicidae that were also collected have already been discussed by Derraik *et al.* (2003, 2005). Individuals from all families comprised at least 55 genera or numbered species (Table 1), but the majority were numerically rare, with 34 (62 %) being represented by only one (23 instances) or two (11 instances) specimens (Table 1). The Anisopodidae, Anthomyiidae, Coelopidae, Ditomyiidae, Empididae and Tachinidae, were each represented by just a single specimen (Table 1). In contrast, the Cecidomyiidae, Tipulidae and Chironomidae were the most abundant families with 232, 106 and 26 specimens, respectively (Table 1). There were no significant differences in the relative frequencies of these families at either ground or 10m levels (all $P > 0.05$). While the Cecidomyiidae comprised *ca* 6 species, the Tipulidae (*sensu* Edwards 1923) was the most speciose family with at least 24 different species in 7 genera (Table 1). It was possible to separate the Cecidomyiidae into distinct taxa on the basis of the male terminalia, but the absence of recent literature on this group prevented further identification.

Table 1 (*continued overleaf*). List of Diptera and respective number of specimens collected at two heights from CO_2-baited light traps at Otari-Wilton's Bush (n = 18 trapping nights) and Wellington Zoo (n = 18), and from dry ice-baited light traps at Cascade-Kauri Park (n = 4). A '?' denotes uncertainty about the generic designation.

		Ground			10 m		
Family	**Genus and species**	**Otari**	**Zoo**	**Cascade**	**Otari**	**Zoo**	**Cascade**
Anisopodidae	*Sylvicola notatus* Hutton	-	-	-	1	-	-
Anthomyiidae	*Anthomyia punctipennis* Wiedemann	-	-	-	1	-	-
Cecidomyiidae	*Proterodiplosis* sp.	9	9	1	3	2	-
	Species 1*	2	3	-	5	1	1
	Species 2	18	10	1	-	-	1
	Species 3	-	-	-	-	-	1
	Species 4	-	-	1	-	-	1
	Unidentifed spp.**	64	13	20	28	10	28
Chironomidae	Subfamily Orthocladiinae	-	-	-	-	-	4
	Orthocladius sp.	2	-	-	-	-	-
	Podonomus sp.	-	-	-	1	-	-
	?*Polypedilum* sp.	-	-	1	-	1	1
	Polypedilum sp.	-	1	-	-	-	-
	?*Smittia* sp.	-	-	13	-	-	-
	Zavrelimyia harrisi Freeman	-	-	-	-	-	6
Coelopidae	*Chaetocoelopa littoralis* Hutton	-	1	-	-	-	-
Ditomyiidae	*Nervijuncta* sp.	-	-	-	-	1	-
Empididae	Subfamily Empidinae	-	-	-	-	-	1
Keroplatidae	*Chiasmoneura (Prochiasmoneura) fenestrata* Edwards	1	-	2	-	1	-
	Macrocera scoparia Marshall	-	-	-	1	-	-
	Macrocera unipunctata Tonnoir	-	-	-	-	1	-
Mycetophilidae	*Exechia hiemalis* Marshall	-	-	-	1	-	-
	Unidentified sp.	-	-	-	-	-	1
Psychodidae	*Pericoma* sp.	-	1	-	-	-	-
	Psychoda sp.1	-	-	-	1	-	-
	Psychoda sp. 2	-	-	3	-	-	1
	Psychoda sp. 3	-	-	3	-	-	-

(Table 1 continued)

Sciaridae	*Sciara marcilla* Hutton[a]	-	2	-	-	-	-
	Sciara sp.	-	-	3	-	-	1
Tachinidae	*Plagiomyia longipes* Malloch	-	-	-	1	-	-
Tipulidae	*Amphineurus* sp. 1	1	-	-	6	-	-
	Amphineurus sp. 2	-	1	-	-	-	-
	Gynoplistia sp.	1	-	-	-	-	-
	Leptotarsus sp. 1.	-	-	1	-	-	-
	Leptotarsus sp. 2	-	-	-	-	2	-
	Leptotarsus sp. 3	-	-	-	-	2	-
	Leptotarsus sp. 4	6	-	-	-	-	1
	Leptotarsus sp. 5	-	2	-	-	-	-
	Leptotarsus sp. 6	5	1	-	-	3	-
	Leptotarsus sp.7	2	-	-	-	-	-
	Leptotarsus sp. 8	-	-	2	-	-	-
	Limnophilella sp.	15	-	-	-	-	-
	Limonia sp. 1	-	2	-	-	-	-
	Limonia sp. 2	2	-	-	2	-	-
	Limonia sp. 3	1	-	-	-	-	-
	Limonia sp. 4	-	-	-	-	1	-
	Limonia sp. 5	-	6	-	-	-	-
	Limonia sp. 6	4	-	1	3	2	-
	Limonia sp. 7	6	-	-	-	2	-
	Molophilus sp. 1	2	-	-	-	-	-
	Molophilus sp. 2	-	-	-	1	-	-
	Molophilus sp. 3	-	-	15	-	-	1
	Molophilus sp. 4	-	-	2	-	-	-
	Molophilus sp. 5	-	1	-	-	-	-
	Unidentified sp.	-	-	-	-	1	-

* These species designations are for males only

** These represent females, unidentified males and specimens where the sex could not be determined

[a]Possibly *Bradysia amoena* (Mohrig & Jaschhof 1999)

In relation to the height distribution, seven of the families (54 %) were restricted to either ground (one family) or canopy traps (six families), with the remaining six families being recorded at both heights (Table 1). In terms of numbers of specimens, 194 were collected on the ground in Wellington, and 85 at 10m. For Auckland the relative catches were 69 specimens on the ground and 57 at 10m. The Cecidomyiidae were trapped at both localities, but were most numerous at the Wellington sites (77 at ground level, 38 at 10m; not significant, $P > 0.05$), with five recognisable species and an unknown number of genera, except for *Proterodiplosis* sp., at both localities. In the Cecidomyiidae, there were significantly more individuals at ground level than at 10 m for species 2 ($P < 0.01$) and for the unidentified species ($P < 0.05$), but not for *Proterodiplosis* sp.

The Tipulidae were more numerous at ground level (58 specimens) than at 10m (19 specimens) at the Wellington sites, but not significantly so ($P > 0.05$). In all, six genera were recognised and represented among the Tipulidae in Wellington, but only three genera in Auckland, with a total of 21 specimens at ground level and 2 at 10m. The only tipulids collected in Auckland were *Leptotarsus* sp., *Limonia* sp., and *Molophilus* sp. These genera, together with *Amphineurus* sp., *Gynoplistia* sp., and *Limnophilella* sp., also occurred in Wellington. The genera *Limonia, Leptotarsus and Molophilus* were the most common with 32, 27 and 22 specimens each, respectively, over both localities. *Molophilus* sp. 3 had significantly more ($P < 0.05$) individuals at ground level than at 10 m.

The Chironomidae were represented by a total of 30 specimens and approximately seven species across both localities, and were predominantly represented by *Smittia* sp. and *Zavrelimyia harrisi* with 13 and six specimens respectively, the former on the ground only and the latter at 10m only, and with both exclusively at the Auckland site. There were significantly more ($P < 0.01$) ?*Smittia* sp. at ground level than at 10 m. Five of the families were collected only in Wellington, although they were represented by only one species each (Table 1). The Empididae was represented by only one species, in Auckland, whereas all other families were trapped at both sites in varying proportions of numbers and species.

There was a combined total of 18 trap nights at Otari-Wilton's Bush and Wellington Zoo, but only four at Cascade-Kauri Park. Despite this difference in collecting opportunities between the sites, the catch sizes were not correspondingly higher. There were eight families represented at the West Auckland forest, in comparison to nine at Otari and eight at the Zoo. There were also 126, 194 and 85 specimens, respectively, recorded at those sites.

Discussion

This study provided a preliminary indication of vertical stratification of dipteran families in trees within the two habitats investigated, with some taxa either found only at ground level or only in the canopy (Table 1). The Tipulidae, being the most numerous, provided the strongest indication of stratification with 13 out of 24 recognisable taxa at ground level only, and four at 10m only, with the remainder at either level. The Cecidomyiidae were fairly evenly dispersed across both strata, but too many were unidentifiable beyond the family level for any conclusions to be reached on the numbers of taxa assignable to either level. The Chironomidae, though not numerous, also showed some evidence of stratification, with three species at ground level and another three at 10m. Such variation among species was expected, as adult activity is directly related to the ecology of the individual species. For instance, larvae of chironomids were common in the leaf axils of the native epiphyte *Collospermum hastatum* in the Wellington and Auckland regions (Derraik & Heath 2005), and the presence of adults in canopy traps would not be surprising.

Didham (1997) found that patterns of family representation among Diptera varied markedly between habitat types and to a lesser degree between tree species, and while Mycetophilidae dominated in that study, Cecidomyiidae and Tipulidae were abundant in a way similar to that seen in the present study. Didham (1997) concentrated on the tree crown, thus excluding stratification as a factor. Moeed & Meads (1984) and McWilliam & Death (1998) did not identify arthropods beyond ordinal level, and only Moeed & Meads (1984) investigated stratification.

Basset *et al*. (2003b) identified four determinants of arthropod vertical distribution: abiotic factors, forest physiognomy and tree architecture, resource availability, and arthropod behaviour *per se*. Many arthropod species are likely to forage at preferred levels in the forest canopy (Basset *et al.* 2003a), and some of our findings may represent such preferences. However, many species in the present study were rare in traps and a single canopy specimen could, for example, have been lifted by up-draughts into the forest canopy where they were then trapped. Furthermore, the representation of a large number of species by singletons and doubletons meant that any inferences regarding their ecology and activity must be made with care. For instance, it is not known to what extent the tree species might have influenced the species composition of Diptera catches. Other factors that can be invoked as confounding are the effects, possibly inhibitory, of CO_2 on Diptera other than Culicidae, and the extent to which light emanating from the traps could be attractive outside the immediate zone of interest.

In regards to the taxonomic impediments, it must be emphasised that many of the identifications were indicative, partly because the New Zealand fauna is incompletely known, and there is, as well, a lack of up-to-date revisions for many groups (Macfarlane & Andrew 2000). We cannot ignore, either, the constraints imposed by damage to specimens that more care in handling trapped material may have alleviated. These concerns aside, the data presented here serve to illustrate that there is substantial scope for studies of stratification among Diptera that go beyond ordinal and family diagnosis in trapped material.

Acknowledgements

We would like to thank the people and organizations that provided logistical assistance and/or free access to land under their care: Mauritz Basson (Wellington Zoo); Eleanor Burton, Jane Wright and John Dawson (Otari-Wilton's Bush); Dave Galloway, Richard Gribble, Scott De Silva and Barry Green (Auckland Regional Council).

Dave Slaney (University of Otago), Bob Clarke (Plymouth Marine Lab, U.K.), and Phil Sirvid (Museum of New Zealand Te Papa Tongarewa) have also helped us with valuable input and assistance. Lilian Morrison undertook the statistical analyses. Thanks also to Gerry Closs and Cathy Rufaut (University of Otago) for feedback on a previous version of this manuscript. The University of Otago provided funding support.

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