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Taxonomic composition of Coleoptera, Hemiptera (Heteroptera and Coleorrhyncha) and Mutillidae (Hymenoptera) at five different altitudes in Lamington National Park (Queensland, Australia)

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ABSTRACT

This study describes the taxonomic composition of Coleoptera and selected groups of Hemiptera (Heteroptera and Coleorrhyncha) and Hymenoptera (Mutillidae) in the understorey of a subtropical rainforest along an altitudinal gradient in Lamington National Park, Queensland, Australia. The altitudinal gradient was subdivided into five zones (300, 500, 700, 900 and 1100 m above sea level (a.s.l.)) within each of which, four replicated sampling sites were established. A total of 16 783 individuals from 1219 species of Coleoptera, 715 from 92 species of Hemiptera and 105 from 17 species of Mutillidae were collected from beating low vegetation. Total species richness and abundance were generally high throughout the gradient, with more than 3000 individuals from over 400 species at each of the five altitudinal zones, but significantly fewer species and individuals were present at higher elevations (900 and 1100 m a.s.l.). Different taxonomic groups showed various patterns of altitudinal zonation, with many groups restricted to the higher elevations, particularly at 1100 m. Of the species unique to one altitudinal zone, half were restricted to 1100 m. The results of the present study provide important base-line data upon which predictions can be made in early warning monitoring systems with regard to climatic change. □ *IBISCA, Hemiptera, Hymenoptera.*

The insect fauna of Australian rainforests is highly diverse with a large proportion of endemic taxa (Naumann 2000; Austin *et al.* 2004). There is a number of studies on the community structures of insects in these forests (e.g. Basset 1991; Kitching & Arthur 1993; Grove 2002; Stork & Grimbacher 2006, Wilson *et al.* 2007a). However, these studies are often restricted to certain taxonomic groups the fauna of particular tree species, habitats or strata (Kitching *et al.* 2001). Large data sets of insect assemblages from different tropical forests

are key components to understand ecosystem patterns and processes (Huston & Gielbert 1996; Basset 2001). Differences or change in such assemblages may have implications for ecosystem functioning and conservation issues (e.g. Didham 1997; Watt *et al.* 1997; Basset *et al.* 2003; Stork *et al.* 2007; Chen *et al.* 2009).

Assemblage structure and diversity of insect communities change substantially along altitudinal gradients (Hågvar 1976; Janzen *et al.* 1976; Stork & Brendell 1990; Stevens 1992; Olson

1994; Andrew *et al.* 2003; Brehm & Fiedler 2003; Wilson *et al.* 2007a; Colwell *et al.* 2008). In general, species diversity decreases with altitude (Stevens 1992), however, a peak of diversity is often seen at mid elevations (Janzen *et al.* 1976; Olson 1994, Wilson *et al.* 2007b; Colwell *et al.* 2008). In addition, diversity does not change consistently across taxonomic groups (Stork & Brendell 1990). Low species richness at higher elevations may reflect the lower rates of invasion and higher rates of extinction of populations that colonise them, as well as differences in abiotic factors (MacArthur 1972; Stevens 1992).

The target taxa of this study include diverse and ecologically important components of the arthropod fauna. The beetles are the most species rich and ecologically diverse order of insects (Lawrence *et al.* 2000) with an estimated 100 000 species in Australia (Yeates *et al.* 2003). However, knowledge of beetles is very poor in this continent with, approximately, only 28 300 species currently described (Lawrence & Britton 1994). The Heteroptera include about 2100 described Australian species, which is about half of the estimated Australian fauna (Cassis & Gross 1995, 2002). The velvet ants (Mutillidae) are wasps that are parasitic on other wasps, bees or ants, and they include several hundred largely unstudied and undescribed Australian species (Austin *et al.* 2004).

The aims of the present study was to describe the taxonomic composition of selected insect groups in the lower strata of a subtropical rainforest, and to build up knowledge on how insect communities change along altitudinal gradients. In order to predict the effects of future climatic changes, it is essential to accumulate such baseline knowledge upon which predictions can be made. One of the predicted scenarios of climate change is a faunal shift to higher elevations due to elevated temperatures and reduced precipitation (Stork *et al.* 2007), which may result in lowland biotic attrition and mountaintop extinctions (Wilson *et al.* 2007b; Colwell *et al.* 2008; Chen *et al.* 2009). As tropical mountaintop biotas of the

tropics, to a large extent, consist of endemic taxa, (e.g. Bell *et al.* 2002) such scenarios of climate change may cause severe species extinctions. In this case, it is particularly important to identify taxonomic components susceptible to such changes in order to develop early warning monitoring systems (Moritz *et al.* 2001).

MATERIAL AND METHODS

Study area. This study was carried out along an altitudinal transect in Lamington National Park, Queensland, Australia. Rainforests within this park can be classified into several structural types including warm subtropical, cool subtropical, warm temperate and cool temperate rainforests (Williams *et al.* 1984; Laidlaw *et al.* 2011). Rainfall averages 1830 mm with most falling during the summer months and at higher elevations (see also Strong *et al.* 2011). Insect samples were obtained from four plots at each of five different elevations; 300, 500, 700, 900, and 1100 m above sea level (a.s.l.). 'Lower elevations' and 'higher elevations' were defined as 300 to 700 m a.s.l., and 900 to 1100 m a.s.l., respectively. Locations and elevations of the individual plots are given by Kitching *et al.* (2011).

Collecting method. Insects were sampled by beating vegetation, using a 1.5 m long beating stick and a 1 x 1 m nylon sheet for collecting the falling material. Vegetation included all structures, foliage and the trunks of large trees to thin branches, both living and dead. Each sample was obtained by beating all reachable vegetation on both sides of a 20 m long transect starting just outside the 20 x 20 m standard IBISCA plots (see Kitching *et al.* 2011) and walking in a straight line away from the plot. A forest area of approximately 3 x 20 m (60 m²), and a forest volume of 60 m² x 3 m height (180 m³) was covered by each sample. A total of 10 parallel samples (10 transects) were taken at each plot, all performed in different directions from the same starting point to prevent

Taxonomic composition of Coleoptera, Hemiptera and Mutillidae

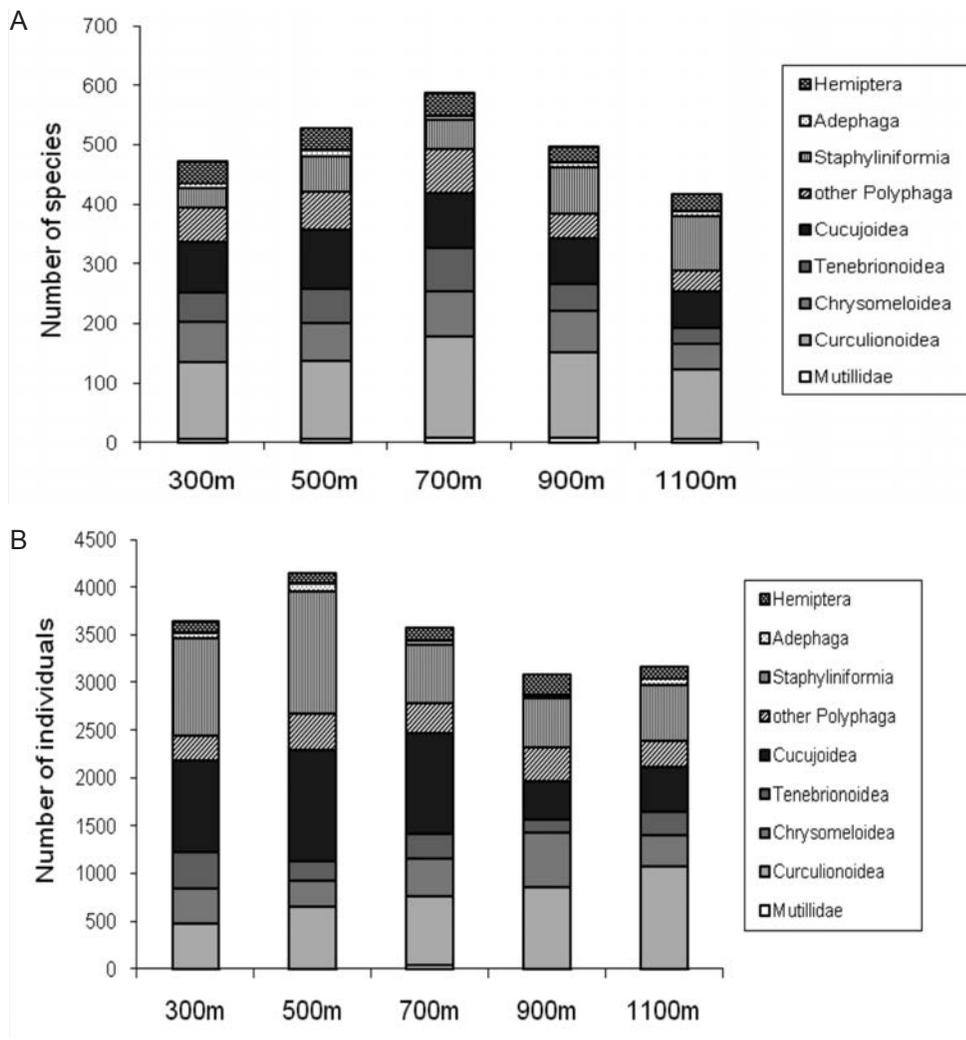


FIG. 1. Total species richness; A, and abundances; B, of different taxonomic groups at the five altitudinal zones. The composite group 'other Polyphaga' includes the Scarabaeiformia, Elateriformia, Bostrichiformia and Cleroidea within the Cucujiformia.

re-beating of the same area. Catches from the 10 parallel samples in each plot were pooled before analyses. The sampling procedure was replicated at three different periods of the year, each representing a different season: spring (6 to 24 October 2006), autumn (8 to 28 March 2007) and summer (14 to 30 January 2008).

Accordingly, a total of 600 samples was obtained (10 samples x 20 plots x 3 seasons).

Material. Each sample of beaten material was collected in a zip-lock bag and all samples were sorted into different target groups the same day. The target taxonomic groups, which consist

of a wide range of feeding guilds, included beetles (Coleoptera), true bugs (Heteroptera including Coleorrhyncha) and velvet ants (Mutillidae, Hymenoptera). All specimens of these groups were dry mounted, labelled, sorted into morphospecies and databased. The collection is stored in the first author's collection at the Norwegian Institute for Nature Research (NINA).

Statistical analyses. The data were first collated into nine taxonomic groups (Hemiptera, Adephaga, Staphyliformia, 'other Polyphaga', Cucujoidea, Tenebrionoidea, Chrysomeloidea, Curculionoidea, Mutillidae). Individual groups were analysed separately for species richness and abundance. The groups were treated as independent of each other, so testing the effect of altitude on their responses has been performed on each group separately. The variation between plots of the same altitude and the seasonal variation were not incorporated in these analyses, but may introduce a systematic bias in the estimated variance within the altitudes. In these analyses we considered altitude to be a categorical variable with five levels, so the test was a standard one-way ANOVA. We also performed post-hoc two-sample equal variance *t*-tests between pairs of adjacent altitudinal zones and low (300, 500 and 700 m) versus high (900 and 1100 m) elevational groups. All statistical analyses were performed with the free statistical software R (R Development Core Team 2008).

RESULTS

The material gave a total of 16783 Coleoptera individuals sorted to 1219 species of 70 families. The Hemiptera material consisted of 715 specimens sorted to 92 species of 13 families of the suborder Heteroptera and one family of Coleorrhyncha (Peloridiidae). Hymenoptera material consisted of 105 velvet ants (Mutillidae) belonging to 17 species. The number of species and abundance of each family collected at each elevation are presented in Appendix 1.

The altitudinal distribution of total species richness showed a peak at 700 m (Fig. 1a), a pattern that seems to be driven by many taxonomic groups including Cucujoidea, Tenebrionoidea, Chrysomeloidea and Mutillidae (Fig. 2). There was significantly lower species richness at higher elevations (Fig. 1, see also Tables 1, 2). This pattern was reflected in the species richness of most taxonomic groups including the Cucujoidea, Tenebrionoidea and other Polyphaga, with the exception of Staphyliformia whose species richness increased at higher elevations (Fig. 2, Table 2).

The number of individuals was largest at 500 m with significantly less individuals at higher elevations (900 and 1100 m) (Fig. 1, see also Tables 1, 2). These patterns were driven by differences in several taxonomic groups including Staphyliformia, Cucujoidea and the Tenebrionoidea whose abundance decreased at higher elevations (Fig. 3). The abundance of Curculionoidea increased gradually all along the elevation gradient, and species richness was significantly greater at the higher compared to the lower altitudinal group (Table 2).

Particular families showed very pronounced patterns of altitudinal zonation. The large number of weevils at higher elevations (Fig 3) were mainly caused by the wood-boring subfamily Cryptorhynchinae (see Appendix 1). The beetle families Byrrhidae and Phloeostichidae, and the bug families Peloridiidae, Enicocephalidae and Schizopteridae were almost exclusively found at 1100 m, while no families were restricted to the lower elevations. High abundance and species richness of Staphyliformia and Lygaeidae were also found at higher altitudes (Appendix 1). The Adephaga (Carabidae in this case) were also significantly more abundant and species rich at 1100 m compared to 900 m (Table 2).

A total of 185 species (14%) were exclusively found at 1100 m, and when we also include species restricted to 900 m (105 spp) and both 900 m and 1100 m (61 spp), a total

Taxonomic composition of Coleoptera, Hemiptera and Mutillidae

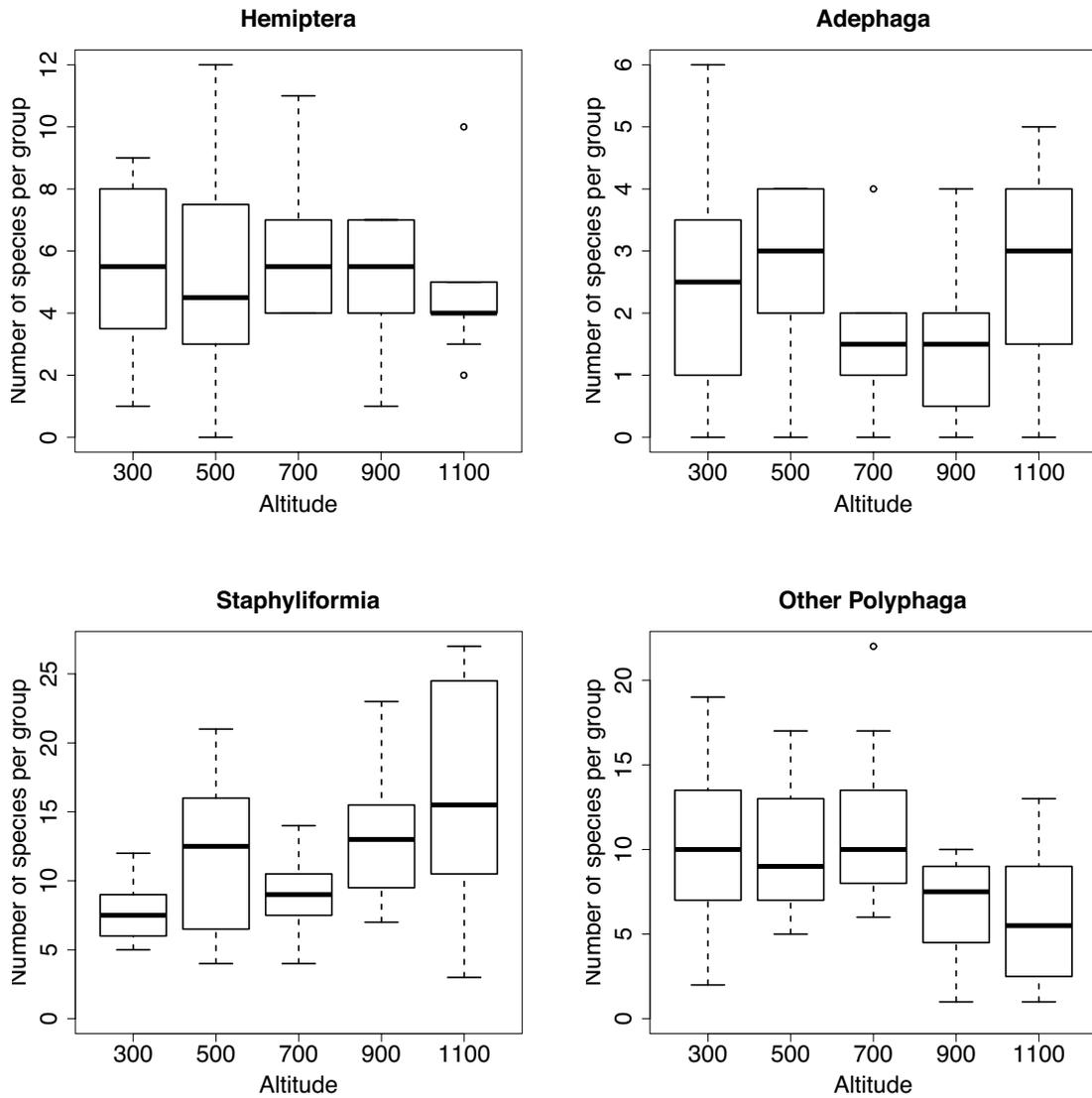
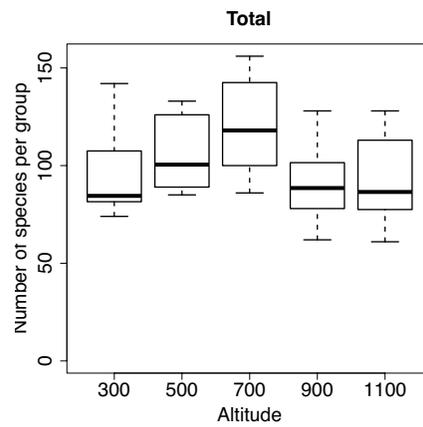
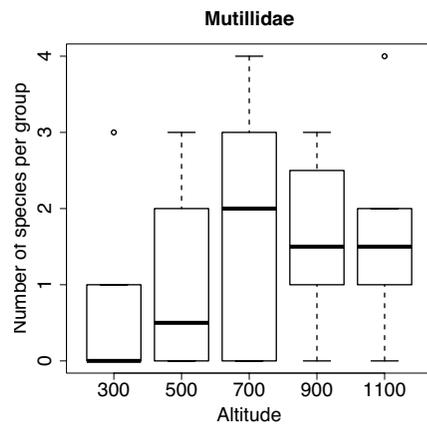
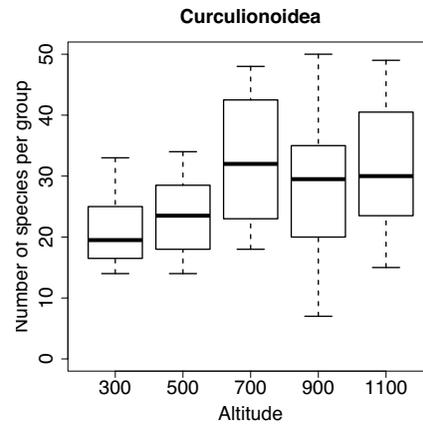
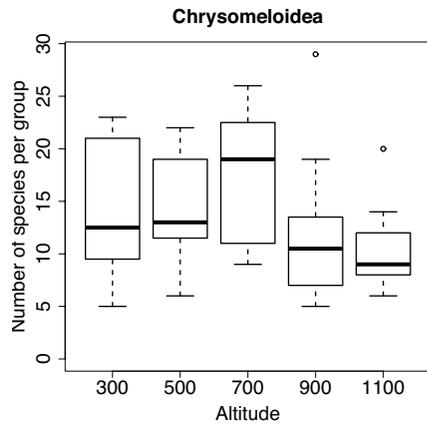
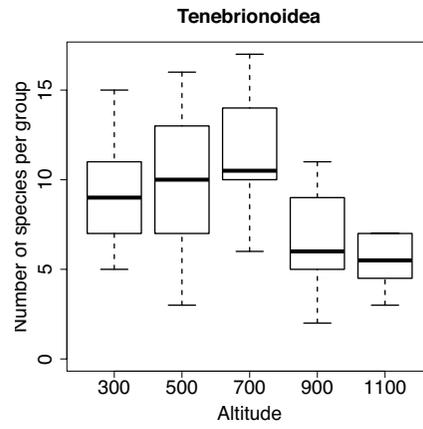
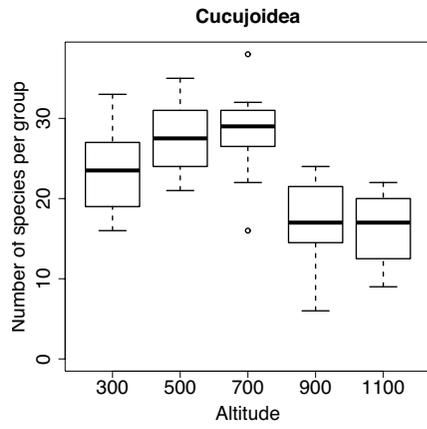


FIG. 2. (This page and opposite) Box-plots for species richness of the nine taxonomic groups and all groups combined ('total') at five different altitudinal zones. The composite group 'other Polyphaga' includes the Scarabaeiformia, Elateriformia, Bostrichiformia and Cleroidea within the Cucujiformia.



Taxonomic composition of Coleoptera, Hemiptera and Mutillidae

TABLE 1. *P*-values from one-way ANOVA tests for differences in the number of individuals and species richness of the nine taxonomic groups and all groups combined ('total') among the five altitudinal zones. The composite group 'other Polyphaga' includes the Scarabaeiformia, Elateriformia, Bostrichiformia and Cleroidea within the Cucujiformia.

Group	individuals	species
Hemiptera	0.2451	0.7579
Adephaga	0.0912	0.0392*
Staphyliformia	0.0000 ***	0.0009 ***
Other Polyphaga	0.6258	0.0057 **
Cucujoidea	0.0000 ***	0.0000 ***
Tenebrionoidea	0.0001 ***	0.0000 ***
Chrysomeloidea	0.0228 *	0.0320 *
Curculionoidea	0.0058 **	0.0142 *
Mutillidae	0.05407	0.0682
Total	0.0488*	0.0121 *

TABLE 2. Significant *P*-values ($p < 0.05$) representing differences in species richness (spp.) and abundance (ind.) between pairs of different altitudinal zones, or groups of altitudinal zones for nine taxonomic groups and all groups combined. Altitudinal zones of 300, 500 and 700 m were grouped as lower elevation (low el.), and 900 and 1100 m grouped as higher elevation (high el.). The composite group 'other Polyphaga' includes the Scarabaeiformia, Elateriformia, Bostrichiformia and Cleroidea within the Cucujiformia.

	300 m vs. 500 m		500 m vs. 700 m		700 m vs. 900 m		900 m vs. 1100 m		low el. vs. high el.	
	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.
Hemiptera	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Adephaga	n.s.	n.s.	n.s.	0.0108	n.s.	n.s.	0.0385	0.0233	n.s.	n.s.
Staphyliformia	n.s.	0.0298	0.0001	n.s.	n.s.	n.s.	n.s.	n.s.	0.0004	0.0003
other Polyphaga	n.s.	n.s.	n.s.	n.s.	n.s.	0.0087	n.s.	n.s.	n.s.	0.0002
Cucujoidea	n.s.	0.0482	n.s.	n.s.	<0.0001	0.0001	n.s.	n.s.	<0.0001	<0.0001
Tenebrionoidea	0.0012	n.s.	n.s.	n.s.	0.0124	0.0007	0.0434	n.s.	0.0189	<0.0001
Chrysomeloidea	n.s.	n.s.	0.0459	n.s.	n.s.	0.0374	0.0453	n.s.	n.s.	0.0041
Curculionoidea	n.s.	n.s.	n.s.	0.0185	n.s.	n.s.	n.s.	n.s.	0.0018	n.s.
Mutillidae	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
All groups	n.s.	n.s.	n.s.	n.s.	n.s.	0.0062	n.s.	n.s.	0.0085	0.0255

of 351 species (26.4%) were restricted to higher elevations. However, as rare species may be found at one particular elevation by chance, we repeated the calculations for species with more than 5 individuals in the total samples. The pattern remained the same with as many as 86 (16.5%) out of 522 species restricted to higher elevations (900 and 1100 m). Of the 72 species (with more than 5 individuals) unique to one elevation, half (50 %) were restricted to 1100 m (Fig. 4).

DISCUSSION

The present study found decreasing abundance and species richness of insects at higher elevations which agrees with most studies of species diversity along altitudinal gradients (Stork & Brendell 1990; Stevens 1992). However, the span of elevations in the present study was probably not large enough to see the prominent diversity declines such as those normally seen at even higher elevations, e.g. between 1500 and 3500 m a.s.l. (Brehm & Fiedler 2003; Wilson *et al.* 2007b; Chen *et al.* 2009). Decrease in diversity with altitude may be explained by parameters such as climatic factors and metapopulation structures (Hågvar 1976; Janzen *et al.* 1976; Stork & Brendell 1990; Stevens 1992; Olson 1994; Andrew *et al.* 2003; Brehm & Fiedler 2003). In addition, the vegetation structure at the 1100 m plots differs from the others by having a significantly smaller number of tree species and a much more prominent epiphyte flora. However, the total effects of these contrasting factors on species diversity are unknown, and investigation of individual parameters is beyond the scope of the present paper.

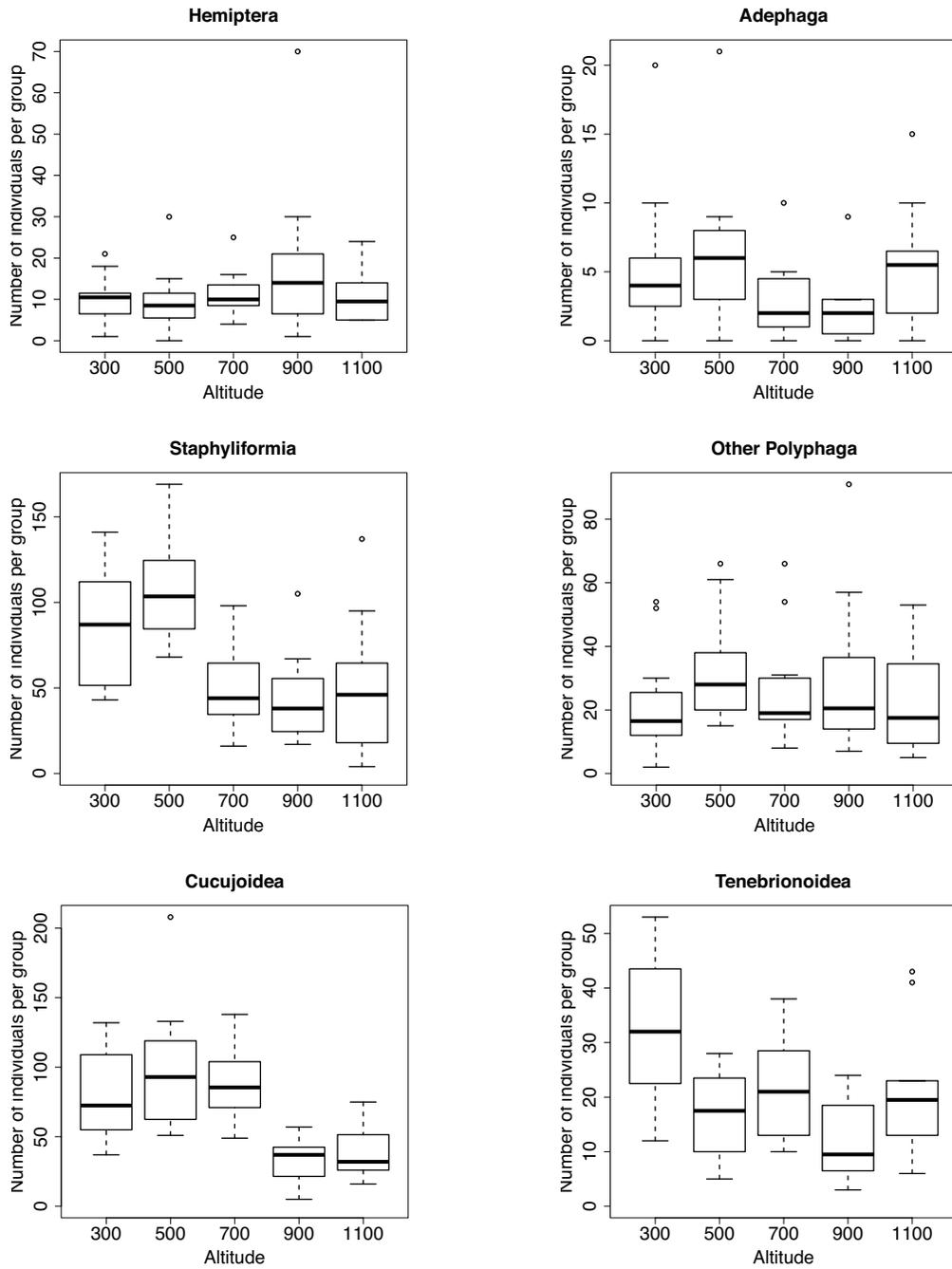
Community structure of insects may be measured at larger taxonomic scales. For instance, if the distributions of specific resources change along altitudinal gradients, relative abundances of particular feeding guilds may be used to capture differences in community structure of

insects. However, larger taxonomic scales may mask changes in species composition nested within the same taxonomic group or feeding guild (Grimbacher & Stork 2007). In order to detect such changes, it is necessary to scale down the taxonomic resolution of the target groups as much as possible, ideally to the species level. For instance, overall abundance of Staphyliniformia decreased with increased altitude. Only species-level identification revealed the intriguing pattern that some extremely common species predominate at lower altitudes, while the higher elevations are characterised by a unique and species rich fauna. On the other hand, if species assemblages respond similarly to environmental factors, responses may be readily detectable for nested taxonomic groups or feeding guilds. Hence, the identification of proper target taxa or guilds for early warning monitoring systems is a key stone in order to detect changes, such as climate warming.

The present study is based on samples from only one forest stratum (understorey) and particular tree species where processes may not be representative of other strata or tree species. Tree species may be affected differentially by climatic changes and elevated CO₂ levels due to their unique characteristics such as different root structures, hydraulic properties or photosynthetic rates (Stork *et al.* 2007). The effects of climate change may be more pronounced in canopy than the understorey, for example, through changes in leaf traits. However, the structures of feeding guilds of beetles in the canopy of tropical rainforests in northern Australia did not differ from that at ground level (Grimbacher & Stork 2007).

A large proportion of the species in this study were restricted to higher elevations. Due to the large proportion of rare species, however, the exact proportion of high-altitude specialists remains unknown. In the case of this study, the true percentage of species restricted to higher elevations should probably lie somewhere be-

Taxonomic composition of Coleoptera, Hemiptera and Mutillidae



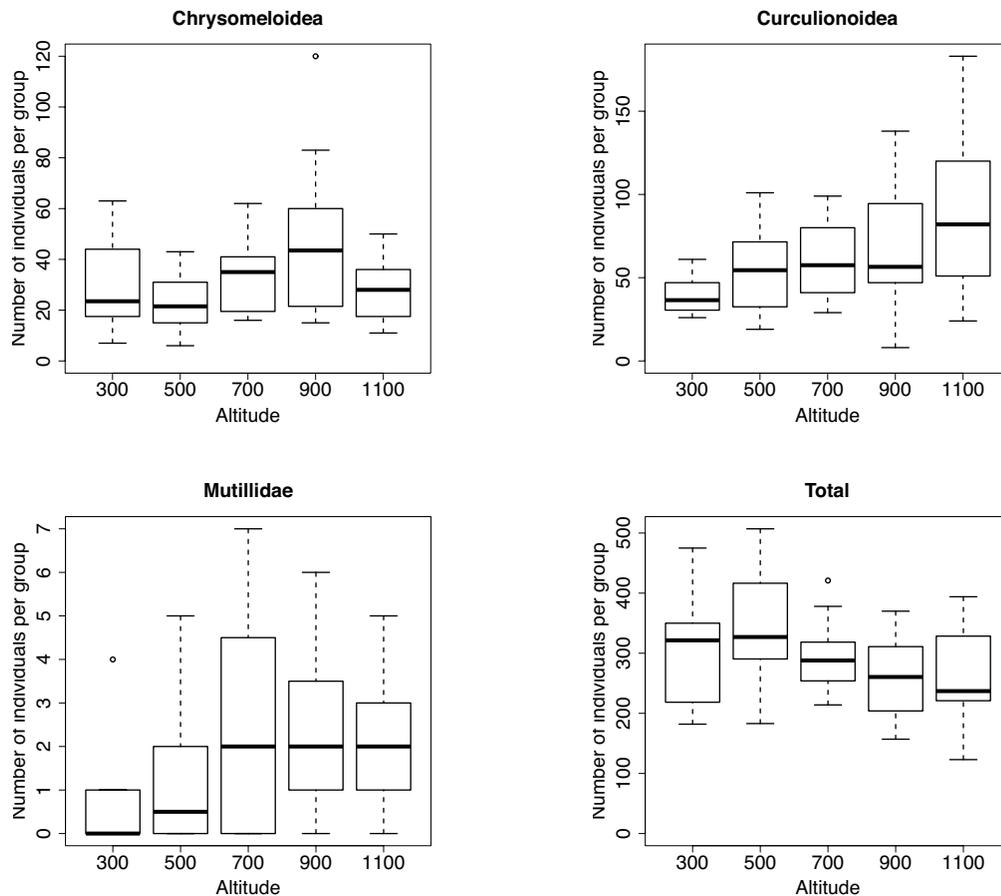


FIG. 3. (This page and opposite) Box-plots of abundances of the nine taxonomic groups and all groups combined ('total') at five different altitudinal zones. The composite group 'other Polyphaga' includes the Scarabaeiformia, Elateriformia, Bostrichiformia and Cleroidea within the Cucujiformia.

tween 16.5 % and 26.4 %. A substantial increase in sampling intensity may be necessary to describe the elevational preferences of all taxa, but singletons found in our study also provide valuable information as many almost certainly prefer the elevation from where they were recorded, based on knowledge of the general feeding habit of the groups to which they belong. The species restricted to higher elevations are generally dominated by moss-feeders and taxa

associated with the moist environment in the *Nothofagus*-forest.

The results of the present study may serve as important base-line data upon which predictions can be made in early warning monitoring systems with regard to climatic change. If levels of moisture and precipitation decrease in these forests as predicted from climatic models (Foster 2001), species restricted to certain ranges of altitudes may shift their

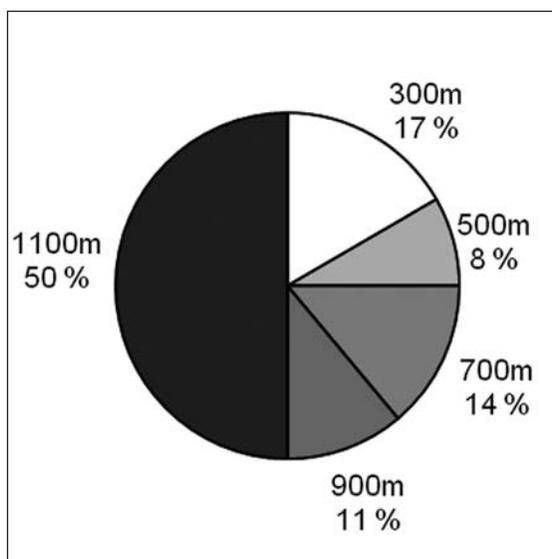


FIG. 4. The proportion of altitude specialists at each of the five altitudinal zones. The data is based on 72 species recorded only from one altitudinal zone, and represented by 5 or more specimens in the total samples.

distribution upwards. These effects may cause loss of high altitude specialists, which has implications for composition and function of the forest ecosystem in the future. In addition, the large proportion and high number of species restricted to high altitudes may have conservation implications as their distributions are already restricted to mountain tops.

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LITERATURE CITED

- Andrew, N.R., Rodgerson, L. & Dunlop, M. 2003. Variation in invertebrate-bryophyte community structure at different spatial scales along altitudinal gradients. *Journal of Biogeography* **30**: 731-746.
- Austin, A.D., Yeates D.K., Cassis G., Fletcher M.J., La Salle J., Lawrence J.F., McQuillan P.B., Mound L.A., Bickel D.J., Gullan P.J., Hales D.F. & Taylor G.S. 2004. Insects "Down Under" - Diversity, endemism and evolution of the Australian insect fauna: examples from select orders. *Australian Journal of Entomology* **43**: 216-234.
- Basset, Y. 1991. The taxonomic composition of the arthropod fauna associated with an Australian rainforest tree. *Australian Journal of Zoology* **39**: 171-190.
2001. Invertebrates in the canopy of tropical rain forests. How much do we really know? *Plant Ecology* **153**: 87-107.
- Basset, Y., Novotny V., Miller S.E. & Kitching R.L. 2003. Canopy entomology, an expanding field of natural science. Pp. 4-6. In, Basset, Y., Kitching, R.L., Miller, S. & Novotny, V. (eds) *Arthropods of tropical forests. Spatio-temporal dynamics and resource use in the canopy*. (Cambridge University Press: Cambridge).
- Bell, K.L., Yeates, D.K., Moritz, C. & Monteith, G.B. 2004. Molecular phylogeny and biogeography of the dung beetle genus *Tennoplectron* Westwood

- (Scarabaeidae: Scarabaeinae) from Australia's wet tropics. *Molecular Phylogenetics and Evolution* **31**(2): 741-753.
- Brehm, G. & Fiedler, K. 2003. Faunal composition of geometrid moths changes with altitude in an Andean montane rainforest. *Journal of Biogeography*, **30**: 431-440.
- Cassis, G. & Gross, G.F. 1995. Hemiptera: Heteroptera (Coleorrhyncha to Cimicomorpha). *Zoological Catalogue of Australia*. **27.3A**.
2002. Hemiptera: Heteroptera (Pentatomomorpha). *Zoological Catalogue of Australia*. **27.3B**. Pp 752.
- Chen, I.-C., Shiu, H.-J., Benedick, S., Holloway, J. D., Chey, V. K., Barlow, H. S., Hill, J. K. & Thomas C. D. 2009. Elevation increases in moth assemblages over 42 years on a tropical mountain. *Proceedings of the National Academy of Sciences* **106**: 1479-1483.
- Colwell, R.K., Brehm, G., Cardelús, C.L., Gilman, A.C. & Longino, L.T. 2008. Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *Science* **322**: 258-261.
- Didham, R.K. 1997. An overview of invertebrate responses to forest fragmentation. Pp. 303-320. In, Watt, A.D., Stork, N.E. & Hunter, M.D. (eds) *Forests and insects*. (Chapman & Hall: London).
- Foster, P. 2001. The potential negative impact of global climate change on tropical montane cloud forests. *Earth-Science Review* **55**: 73-106.
- Grimbacher, P.S. & Stork, N.E. 2007. Vertical stratification of feeding guilds and body size in beetle assemblages from an Australian tropical rainforest. *Austral Ecology* **32**: 77-85.
- Grove, S.J. 2002. The influence of forest management history on the integrity of the saproxylic beetle fauna in an Australian lowland tropical rainforest. *Biological Conservation* **104**: 149-171.
- Huston, M. & Gielbert, L.E. 1996. Consumer diversity and secondary production. Pp. 33-47. In, Orians, G.H., Dirzo, R. & Cushman, J.H. (eds) *Biodiversity and Ecosystem Processes in Tropical Forests*. (Springer: Berlin).
- Hågvar S. 1976. Altitudinal zonation of the invertebrate fauna on branches of birch (*Betula pubescens* Ehrh.). *Norwegian Journal of Entomology* **23**: 61-74.
- Janzen, D.H., Ataroff, M., Farinas, M., Reyes, S., Rincon, N., Soler, A., Soriano, P. & Vera, M. 1976. Changes in the arthropod community along an elevational transect in the Venezuelan Andes. *Biotropica* **8**: 193-203.
- Kitching, R.L. & Arthur, M. 1993. The biodiversity of arthropods from Australian rainforest canopies: summary of projects and impact of drought. *Selbyana* **14**: 29-35.
- Kitching, R.L., Li, D. & Stork, N.E. 2001. Assessing biodiversity 'sampling packages': how similar are arthropod assemblages in different tropical rainforests? *Biodiversity and Conservation* **10**: 793-813.
- Kitching, R.L., Putland, D., Ashton, L.A., Laidlaw, M.J., Boulter, S.L., Christensen, H. & Lambkin, C.L. 2011. Detecting biodiversity changes along climatic gradients: the IBISCA-Queensland. Project. *Memoirs of the Queensland Museum-Nature* **55**(2): 235-250.
- Lawrence, J.F. & Britton, E.B. 1994. *Australian Beetles*. (Melbourne University Press: Carlton).
- Lawrence, J.F., Hastings, A.M., Dallwitz M.J., Paine T.A. & Zurcher E.J. 2000. *Beetles of the World*. (CSIRO: Collingwood).
- MacArthur, R.H. 1972. *Geographical ecology: patterns in the distribution of species*. (Harper & Row: New York).
- Moritz, C., Richardson, K.S, Ferrier, S., Monteith, G.B., Stanisci, J., Williams, S.E. & Whiffin, T. 2001. Biogeographical concordance and efficiency of taxon indicators for establishing conservation priority in a tropical rainforest biota. *Proceedings of the Royal Society London B* **268**: 1875-1881.
- Naumann, I.D. 2000. *The insects of Australia: a textbook for students and research workers (2nd edition)*. (Melbourne University Press: Melbourne).
- Olson, D.M. 1994. The distribution of leaf litter invertebrates along a Neotropical altitudinal gradient. *Journal of Tropical Ecology* **10**: 129-150.
- R Development Core Team. 2008. R: A language and environment for statistical computing. (Royal Foundation for Statistical Computing: Vienna).
- Stevens, G.C. 1992. The elevational gradient in altitudinal range: an extension of Rapoport's latitudinal rule to altitude. *The American Naturalist* **140**: 893-911.
- Stork, N.E., Balston, J., Farquhar, G.D., Franks, P.J., Holtum, J.A.M. & Liddell, M.J. 2007. Commentary: Tropical rainforest canopies and climate change. *Austral Ecology* **31**: 105-112.
- Stork N.E. & Brendell M.J.D. 1990. Variation in the insect fauna of Sulawesi trees with season, altitude and forest type. Pp. 173-190. In, Knight, W.J. & Holloway, D.J. (eds) *Insects and the Rain Forest of South East Asia (Wallacea)*. (Royal Entomological Society of London: London).

Taxonomic composition of Coleoptera, Hemiptera and Mutillidae

- Stork N.E. & Grimbacher P.S. 2006. Beetle assemblages from an Australian tropical rainforest show that the canopy and the ground strata contribute equally to biodiversity. *Proceedings of the Royal Society of London B* **273**: 1969-1975.
- Watt, A.D., Stork N.E., Eggleton, P., Srivastava, D., Bolton, B., Larsen, T.B., Brendell, M.J.D. & Bignell D.E. 1997. Impact of forest loss and regeneration on insect abundance and diversity. Pp. 273-286. In, Watt, A.D., Stork, N.E. & Hunter, M.D. (eds) *Forests and insects*. (Chapman & Hall: London).
- Williams, J.B., Harden, G.J. & Mc Donald, W.J.F. 1984. *Trees & Shrubs in Rainforests of New South Wales & Southern Queensland: Botany* (Department of the University of New England: Arimdale).
- Wilson, R.D., Trueman, J.W.H., Williams, S.E. & Yeates, D.K. 2007a. Altitudinally restricted communities of schizophoran flies in Queensland's wet tropics: Vulnerability to climate change. *Biodiversity and Conservation* **16**: 3163-3177.
- Wilson, R.J., Gutiérrez, D., Gutiérrez, J. & Monserrat, V.J. 2007b. An elevational shift in butterfly species richness and composition accompanying recent climate change. *Global Change Biology* **13**(9): 1873-1887.
- Yeates D.K., Harvey M.S. & Austin A.D. 2003. New estimates for terrestrial arthropod species-richness in Australia. *Records of the South Australian Museum Monograph Series* **7**: 231-241.

APPENDIX 1.

Summary of numbers of individuals (ind.) and species (spp.) collected from five different elevations in Lamington National Park (Qld, Australia). Taxonomic resolution is at the family level for most groups and subfamilies for large families. Some groups of Hemiptera are presented at the level of superfamily.

Group	Sum		300 m		500		700 m		900 m		1100 m	
	ind.	spp.										
HEMIPTERA												
Peloriidiidae	1	1	0	0	0	0	0	0	0	0	1	1
Enicocephalidae	7	2	0	0	0	0	0	0	0	0	7	2
Schizopteridae	13	2	0	0	1	1	1	1	1	1	10	1
Dipsocoroidea	4	2	0	0	2	2	2	1	0	0	0	0
Reduviidae	24	8	9	6	8	4	6	3	1	1	0	0
Anthocoridae	73	7	8	4	12	5	37	4	15	3	1	1
Tingidae	176	10	31	6	43	6	26	5	72	2	4	2
Miridae	52	12	6	5	8	4	29	8	8	4	1	1
Lygaeidae	265	24	25	2	21	6	8	5	110	9	101	18
Coreidae	9	2	5	1	2	1	1	1	1	1	0	0
Pyrocoroidea	17	4	7	3	3	3	7	2	0	0	0	0
Berytidae	4	1	0	0	0	0	4	1	0	0	0	0
Aradidae	50	6	21	4	16	4	10	3	3	3	0	0
Pentatomoidea	20	11	8	7	1	1	4	4	4	3	3	2
Total	715	92	120	38	117	37	135	38	215	27	128	28
COLEOPTERA												
Carabidae	264	22	62	8	77	10	34	7	27	8	64	9
Hydrophilidae	110	3	0	0	0	0	0	0	93	2	17	2

APPENDIX 1. continued ...

Group	Sum		300 m		500		700 m		900 m		1100 m	
	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.
Histeridae	5	3	0	0	1	1	2	2	0	0	2	2
Hydraenidae	1	1	1	1	0	0	0	0	0	0	0	0
Ptiliidae	3	3	0	0	1	1	0	0	1	1	1	1
Leiodidae	41	6	0	0	3	2	1	1	29	3	8	2
Scydmaenidae	192	33	10	3	45	12	39	11	43	11	55	15
Staphylinidae	3593	101	1004	24	1227	36	574	30	331	50	457	48
Scaphidinae	35	15	4	4	6	4	6	3	6	5	13	5
Pselaphinae	61	21	0	0	4	4	1	1	17	6	39	15
Scarabaeoidea	19	8	7	4	7	5	5	4	0	0	0	0
Scirtidae	62	11	0	0	7	3	12	6	3	2	40	5
Clambidae	15	3	2	2	0	0	1	1	9	2	3	1
Ptilodactylidae	7	3	1	1	5	3	0	0	1	1	0	0
Buprestidae	6	5	0	0	3	2	1	1	0	0	2	2
Byrrhidae	74	3	0	0	0	0	0	0	1	1	73	2
Limnicidae	20	1	6	1	8	1	5	1	1	1	0	0
Psephenidae	1	1	0	0	0	0	1	1	0	0	0	0
Eucnemidae	8	5	5	2	0	0	1	1	1	1	1	1
Throscidae	15	2	5	1	2	1	7	2	1	1	0	0
Elateridae	717	38	135	17	208	19	153	19	209	13	12	6
Lycidae	28	10	8	5	6	4	10	7	2	1	2	2
Cantharidae	222	18	13	5	24	8	13	5	65	7	107	6
Dermestidae	1	1	0	0	0	0	0	0	0	0	1	1
Anobiidae	45	12	5	3	9	6	8	4	3	2	20	2
Cleridae	58	13	32	8	4	3	16	9	3	2	3	1
Trogossidae	5	3	2	1	1	1	2	2	0	0	0	0
Dasytidae	226	15	30	6	89	6	56	6	44	4	7	5
Malachidae	46	6	9	2	7	2	19	5	11	3	0	0
Nitidulidae	217	17	108	6	54	7	25	6	7	4	23	6
Cybocephalinae	25	5	3	3	3	3	7	3	12	3	0	0
Monotomidae	2	1	1	1	1	1	0	0	0	0	0	0
Phloeostichidae	27	4	0	0	0	0	1	1	1	1	25	4
Silvanidae	121	4	19	3	58	3	42	2	2	2	0	0
Cucujidae	1	1	0	0	0	0	1	1	0	0	0	0
Laemophloeidae	49	4	6	2	15	3	9	3	6	2	13	2
Phalacridae	133	14	51	9	34	8	29	5	17	6	2	2
Cryptophagidae	609	9	90	4	153	6	184	6	69	5	113	6
Erotylidae	49	2	3	1	25	1	10	2	10	1	1	1
Biphylidae	28	3	4	1	16	3	6	1	1	1	1	1
Cerylonidae	9	3	1	1	2	1	2	1	1	1	3	2
Bothriideridae	6	4	3	3	0	0	3	3	0	0	0	0
Endomychidae	94	8	24	5	29	4	18	3	20	2	3	2

Taxonomic composition of Coleoptera, Hemiptera and Mutillidae

APPENDIX 1. continued ...

Group	Sum		300 m		500		700 m		900 m		1100 m	
	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.
Coccinellidae	713	49	187	15	97	22	238	24	92	18	99	17
Corylophidae	1425	34	324	18	572	23	367	22	99	20	63	12
Latridiidae	508	22	132	13	102	12	106	11	53	10	115	7
Mycetophagidae	16	5	3	2	5	3	5	4	1	1	2	1
Ciidae	11	5	2	2	0	0	1	1	5	3	3	1
Melandryidae	58	14	14	4	16	7	9	3	5	3	14	7
Mordellidae	137	7	63	4	16	3	33	2	25	2	0	0
Rhipiphoridae	3	3	2	2	1	1	0	0	0	0	0	0
Zopheridae	72	10	11	3	5	2	14	6	5	4	37	4
Tenebrionidae	266	19	10	5	26	12	38	12	20	8	172	4
Lagrinae	1	1	0	0	1	1	0	0	0	0	0	0
Alleculinae	138	14	17	5	21	8	59	8	35	8	6	3
Prostomidae	1	1	0	0	0	0	0	0	1	1	0	0
Oedemeridae	3	3	2	2	0	0	1	1	0	0	0	0
Pythidae	7	1	0	0	5	1	2	1	0	0	0	0
Pyrochroidae	45	7	5	1	3	3	10	5	26	3	1	1
Salpingidae	20	4	0	0	4	2	8	3	4	1	4	2
Anthicidae	262	8	202	4	45	3	10	5	2	2	3	2
Aderidae	151	27	42	12	39	11	56	16	12	8	2	2
Scraptidae	36	6	14	3	9	2	12	3	1	1	0	0
Cerambycidae	331	55	115	36	46	15	122	26	37	20	11	7
Chrysomelidae												
Megalopodinae	5	3	0	0	1	1	1	1	1	1	2	1
Clytrinae	9	4	0	0	0	0	8	3	0	0	1	1
Chrysomelinae	249	33	38	9	64	15	69	20	48	17	30	8
Eumolpinae	47	12	10	3	8	5	6	3	18	5	5	2
Galerucinae	516	25	195	15	133	15	147	15	35	11	6	3
Alticinae	792	31	5	4	25	11	52	7	434	14	276	21
Cassidinae	9	2	2	1	1	1	4	2	1	1	1	1
Anthribidae	245	39	35	17	63	22	51	19	73	19	23	6
Attelabidae	53	9	16	3	10	3	11	4	12	3	4	2
Nemonychidae	9	2	1	1	6	2	2	1	0	0	0	0
Belidae	6	3	5	2	0	0	1	1	0	0	0	0
Brentidae	15	7	1	1	2	2	8	4	3	2	1	1
Apionidae	34	11	6	3	1	1	4	3	8	5	15	3
Curculionidae												
Otiorynchinae	375	16	60	5	34	2	28	7	132	8	121	7
Curculioninae s.l.	1160	91	148	36	304	34	229	45	199	24	280	27
Hylobiinae	24	4	9	3	4	1	8	3	3	2	0	0
Magdalinae	31	6	2	2	8	4	21	3	0	0	0	0

APPENDIX 1. continued ...

Group	Sum		300 m		500		700 m		900 m		1100 m	
	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.	ind.	spp.
Cossoninae	54	13	8	5	2	2	5	2	15	7	24	5
Cryptorhynchinae	1588	156	143	44	169	53	335	74	365	71	576	64
Platypodinae	1	1	1	1	0	0	0	0	0	0	0	0
Scolytinae	107	11	32	6	35	5	19	5	14	3	7	2
Total	16783	1219	3516	429	4017	484	3404	541	2831	461	3015	383
HYMENOPTERA												
Mutillidae	105	17	7	5	14	6	31	7	28	8	25	5
Total of all groups	17603	1328	3643	472	4148	527	3570	586	3074	496	3168	416