

# Diversity and distribution of forest canopy Coleoptera on eastern Viti Levu, Fiji Islands

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In Fiji, few systematic studies have been conducted that describe insect distributions, especially with respect to ecological gradients (e.g., habitat type, climate, altitude, and seasonality) that are known to influence their diversity and distribution. In this study, canopy coleopteran assemblages within undisturbed forest in eastern Viti Levu, Fiji, were intensively surveyed over a range of geographical locations and altitudes, namely lowland Nakobalevu (200–400 m), upland Waisoi (400–600 m) and cloud montane forest Monasavu (600–1000 m). Dominant beetle families sampled from the canopy included Curculionidae, Chrysomelidae and Staphylinidae. Multidimensional scaling revealed a division in the canopy beetle assemblages between lowland forest (<400 m), upland forest (400–600 m) and cloud montane forests (600–1 000 m). We tentatively conclude that diversity was highest at mid-to-high altitudes represented at Monasavu. Direct Gradient Analysis (RDA) indicated that 49% of data variability was explained by two axes that represented altitude and seasonality respectively.

Key words: altitude, Coleoptera, diversity, assemblage, Fiji.

## INTRODUCTION

Fiji has the richest biota, largest number of endemic species and, apart from Hawaii, the greatest degree of higher taxonomic endemism of any island group within the Polynesia/Melanesia biodiversity hotspot (Prendergast *et al.*, 1993; Lumaret & Lobo 1996). However, little is known of the invertebrate fauna of Fiji, particularly with respect to their distribution and ecology. It is estimated that the Pacific island region is home to about 915,000 species of terrestrial invertebrates, representing approximately 15% of the world total, with more than half the insect species unknown to science (Allison & Englund, 2005). New Guinea has the highest species richness within the Pacific region and there is a decline eastwards towards Fiji and beyond (Allison & Englund, 2005). High rates of endemism are also characteristic of this region, attributed to the extreme geographic isolation of many island groups. A general review of the Fijian arthropod biogeography within the southwest Pacific has been discussed by Gressitt (1961), Keast (1996), Miller (1996), and Mueller-Dombois & Fosberg (1998), demonstrating dominant affinities with the Papuan/Western Pacific region, as indicated through studies on macrolepidoptera (Robinson, 1975), cicadas (Boer & Duffels, 1996), dolichopidid flies (Bickel 1996) and some beetle families (Gressitt, 1961). Despite this, relatively little is known of the invertebrate fauna of Fiji, particularly with respect to their distribution and ecology.

Currently for Fiji and many other Pacific islands, habitat loss through deforestation remains the most serious threat to its endemic fauna and flora (Watling & Chape, 1992),

although Fiji is considered to have some of the best remaining forest areas in the central Pacific with over 40% of natural forest cover remaining. Most extant forest is restricted to the higher and wetter portions of the islands and is subject to extensive fragmentation. These upland forested areas harbour the greatest diversity of native arthropod species and are considered to be particularly vulnerable to perturbations which promote the likelihood of extinctions (Evenhius & Bickel, 2005).

It is known that the distribution of Coleoptera is dependent to a large extent on vegetation and climate — which in turn are dependent upon altitude and landscape forms. To our knowledge, there have been no comparative studies on the diversity and ecology of Fijian Coleoptera at different geographical locations or altitudes. We therefore used a standardized canopy fogging technique (at locations representing key forest habitats on the main island of Viti Levu) to investigate how Coleoptera diversity and distribution patterns were mediated by geographical location, altitude and season.

## METHODS

### Study location

The Fiji islands are located 3 000 km east of Australia in the Pacific Ocean at 16–20°S latitude and 178°E–178°W longitude. Fiji consists of over 300 named islands, which occupy an ocean area of some 650 000 km<sup>2</sup> and a total land area of 18 345 square kilometres (Parham, 1972; Evenhius & Bickel, 2005). There are: two large islands, Viti Levu (10 388 km<sup>2</sup>) and Vanua Levu (5 535 km<sup>2</sup>); two mid-sized islands, Taveuni (434 km<sup>2</sup>) and Kadavu (408 km<sup>2</sup>); and numerous

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Fig. 1. Map of Viti Levu, Fiji showing sampling locations.

smaller islands, 97 of which are inhabited (Parham, 1972; Evenhius & Bickel, 2005).

According to Fiji's meteorological office, mean annual monthly rainfall is highest around February–March (averaging 380 mm) and lowest around June–July (averaging 150 mm). Mean maximum temperatures occur during December–January (averaging 32°C), whilst mean minimum temperatures occur during July (averaging 18°C). Fiji experiences distinct “wet” (November to April) and “dry” (May to October) seasons. The main island, Viti Levu, on which the survey was conducted, has a pronounced wet (east) and dry (west) zone due to the prevailing winds and the effect of a central mountain range. The current survey was conducted only on the rainforest-dominated wet zone of the island, which has an average annual rainfall of 3 000 mm on the coast and 6 000 mm on the mountainous sites. The relative humidity is usually over 85% in the wet zone. Three study sites were selected on the wet eastern zone: Nakobalevu (Province Naitasiri), Waisoi (Province Namosi) and Monasavu (Province Naitasiri). The

sites covered an altitudinal range extending from 200 m to 1000 m above sea level, had good intact rainforest systems and good accessibility (Figure 1).

#### Sampling technique and experimental design

A standardized canopy fogging technique was employed to sample Coleoptera assemblages. Sampling was conducted twice — once in the wet season and once in the dry season during 2005/06. Sampling locations for each season were proximal, but not identical, to ensure that prior sampling effort did not influence the outcome of the study. Sampling took approximately 12 days per occasion. Sampling was conducted in the early morning hours in windless conditions rather than in the evenings, as previous studies by Stork and Hammond (1997) showed that there were more “tourist” species in the evening samples compared to morning samples.

At each geographical location, intact forest sites were selected that were accessible, had similar aspect and gradient, and had closed

Table 1. Description of sampling localities.

Location	Altitude metres above sea level	1st survey — dry season	2nd survey — wet season	GPS coordinates		Topography
Nakobalevu	200 m	30 June 2005	12 January 2006	18°02'53"S	178°26'26"E	Ridge
	400 m	01 July 2005	13 January 2006	18°03'34"S	178°24'51"E	Ridge
Waisoi	400 m	06 July 2005	18 January 2006	17°59'51"S	178°08'43"E	Slope to ridge
	600 m	07 July 2005	19 January 2006	17°59'29"S	178°08'31"E	Ridge
Monasavu	600 m	13 July 2005	01 February 2006	17°44'05"S	178°04'46"E	Flat Ridge
	800 m	14 July 2005	02 February 2006	17°45'00"S	178°02'07"E	Slope to ridge
	1000 m	15 July 2005	03 February 2006	17°48'10"S	178°01'27"E	Ridge



canopy cover (Table 1). At each location sampling sites were selected at all possible altitudes within the range 200–1000 m, with a 200 m interval. Due to topographical constraints, altitudes sampled were: 200 and 400 m (Nakobalevu), 400 and 600 m (Waisoi) and 600, 800 and 1000 m (Monasavu) respectively. A GPS and an altimeter were used to accurately locate the sampling sites and record altitude. Temperature (°C) and relative humidity (%) were also recorded using a cable-free weather station (model: WMR112A). Seasonality (wet/dry), canopy cover (%) and identification of trees, shrubs and epiphytes to family (to gain a general sense of botanical diversity) was also done on each sampling occasion.

At each sample site, four 10 m x 10 m quadrats (approximately 30 m apart) were selected that represented a mix of tree species and the forest type at the location. Within each of the four quadrats, ten 0.5 m<sup>2</sup> collecting funnels (Kitching *et al.*, 1993) were suspended from ropes positioned at head height.

On each sampling event, an insecticide was delivered for a continuous five minutes using a fogging technique (Kitching *et al.*, 2000). A synthetic pyrethroid chemical, “Reslin” was used for this study (Stork & Hammond, 1997). Reslin contains 50g/L bioresmethrin synergized with 400g/L piperonyl butoxide which degrades quickly in the environment when exposed to sunlight (hence, no harmful residues remain and environmental impact is minimal). The fogging technique employed used a Solo-Port 423 backpack mist blower. Upon spraying, an insecticidal mist was generated that treated the

canopy above the collecting funnels. The area was left for an initial 30-minute interval before checking each funnel for arthropods. A two-hour drop-time (inclusive of the initial 30 minutes) was allowed, following the methodology of Stork and Hammond (1997). Specimens from the ten collecting hoops within each quadrat were combined to constitute one sample (therefore  $n=4$  for each sampling location). Samples of the order Coleoptera were preserved in 80% ethanol and returned to the lab for identification to family following CSIRO’s CD-ROM “Beetles of the World” and the “Beetles of Australia” by Lawrence and Britton (1994).

### Analysis

Simpson’s index was used as a diversity measure (Biodiversity Pro software, Version 2) and is regarded as a robust measure which is strongly dependent on both species richness and abundance. Direct Gradient Analysis (RDA) was carried out (Canoco, Version 4.5) to investigate and visualize community structure using log transformed counts. Monte Carlo simulation was performed for the RDA analysis to test the significance of environmental variables included in the model. Multidimensional Scaling (Community Analysis Package, version 4.0) based on Sorensen’s similarity index was used in order to describe major ecological gradients for the sample sites. Finally, Analysis of Similarities (ANOSIM) was carried out to determine whether there were differences evident in the assemblages when grouped by geographical location, altitude, or season (Community Analysis Package, version 4.0).

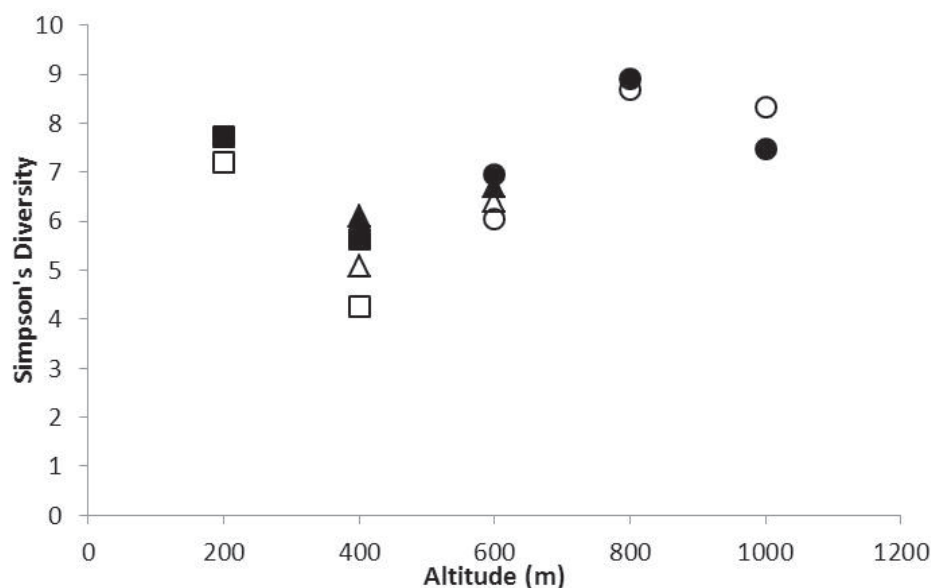


Fig 2. Simpson’s diversity indices for coleopteran families sampled by canopy fogging sampled over an altitudinal range of 200–1000 m at: Nakobalevu (n), Waisoi (p) and Monasavu (l). Filled and unfilled symbols represent the dry and wet seasons respectively.

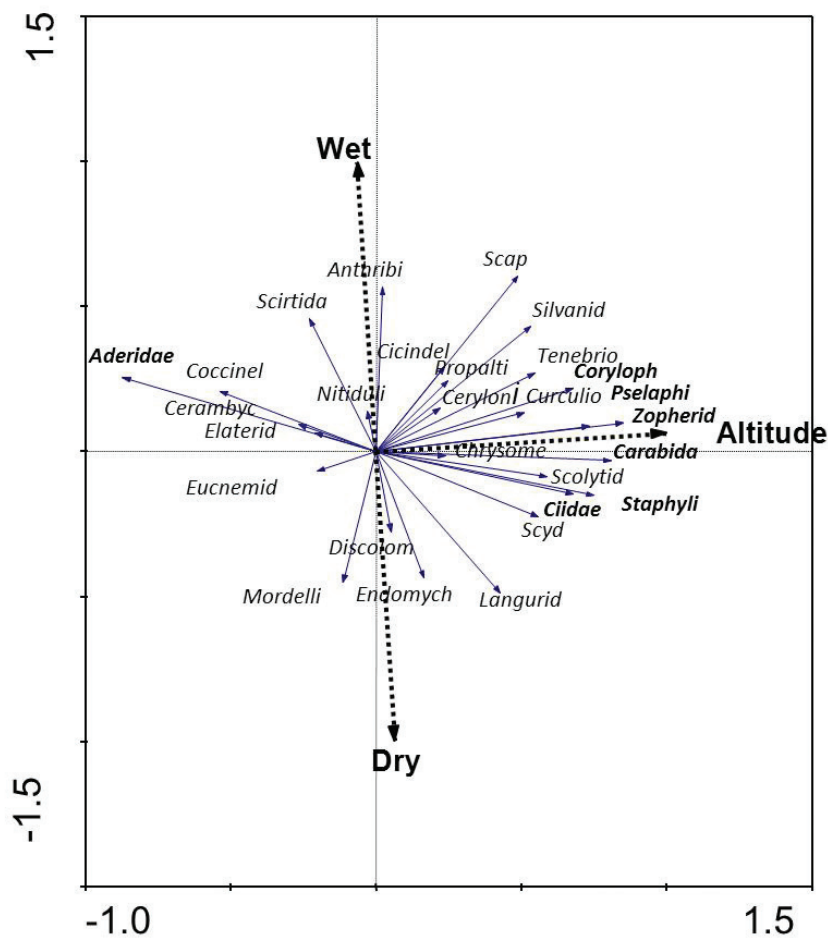


Fig. 3. Direct Gradient Analysis including all coleopteran families and the two most important environmental variables, altitude and season. Families in bold were significantly influenced by Axis 1 (altitude).

**RESULTS**

**General description and diversity**

A total of 3326 individual beetles and 28 families were sampled by canopy fogging during the dry season, June–July 2005 and the wet season, January–February 2006 combined (Table 2). Of these, 1643 beetles from 26 families were sampled during the dry season and 1683 beetles from 27 families during the wet season.

Three families, Curculionidae, Staphylinidae and Chrysomelidae were dominant in most samples. Three families occurred with moderate abundance at mid-to-high altitude areas (400–1000 m): Tenebrionidae (400–1000m), Carabidae (600–1000m) and Pselaphidae (400–1000m). Three other families (Anthribidae, Ciidae and Mordellidae) were moderately abundant throughout all sample sites, whilst the remaining families (Corylophidae, Coccinellidae, Scolytidae, Cerambycidae, Cerylonidae, Languridae, Nitidulidae, Scirtidae, Scydmaenidae, and Zopheridae) occurred with low abundance. A single family, Aderidae was present only at low altitude and with low

abundance. Diversity indices revealed a peak in family diversity at an altitude of 800 m during both the wet and dry seasons (Figure 2), where diversity was generally higher than sites at lower (400–600 m) altitudes. However, one low altitude site (Nakobalevu 200 m) also had relatively high diversity. A slight decline in diversity was observed at the higher altitude of 1000 m.

**Direct Gradient Analysis**

Direct gradient analysis was performed to ascertain whether environmental parameters explained the observed distribution of coleopteran families. Abundance data was log transformed and Automatic Selection (including all environmental variables — latitude, longitude, season, temperature rainfall and altitude) with Monte Carlo testing was performed. The analysis indicated that altitude (Axis 1) was the most important explanatory variable, explaining 39.3% of the variability, followed by season (Axis 2), which explained 10.1% of the variability (Figure 3). As altitude was the most important environmental variable measured, a further analysis using a threshold

level of 39 (since 39.3% of variation in the data was explained by the Axis 1) was conducted to identify coleopteran families that were significantly influenced by altitude (Figure 3). The analysis showed that seven families (Zopheridae, Staphylinidae, Corylophidae, Pselaphidae, Carabidae, Ciidae and Aderidae) showed a strong association with altitude. A Monte Carlo test performed on the first canonical axis showed it to be highly significant ( $F=5.96$ ,  $P=0.002$ ). These families, with the exception of Aderidae (which had an expected negative response as it was only present at low altitudes) were therefore indicators of increasing altitude. Inspection of Figure 3 also illustrated that Mordellidae, Discolomidae and Endomychidae had an affinity with the dry season, and Anthribidae and Scirtidae with the wet season, respectively.

location. ANOSIM demonstrated that geographical location ( $R=0.71$ ,  $P=0.001$ ) and altitude ( $R=0.45$ ,  $P=0.002$ ) significantly influenced species assemblage. Thus, there was evidence that coleopteran assemblages were dependent on both altitude and geographic location.

## DISCUSSION

This study provides baseline data for the distribution of Coleoptera within Fiji forest habitats. These data should be treated with some caution, firstly because the family-level taxonomic resolution did not allow us to investigate the ecologies of the species collected (family-level identification represents a surrogate of, rather than actual, species diversity — it was not known whether samples were dominated by

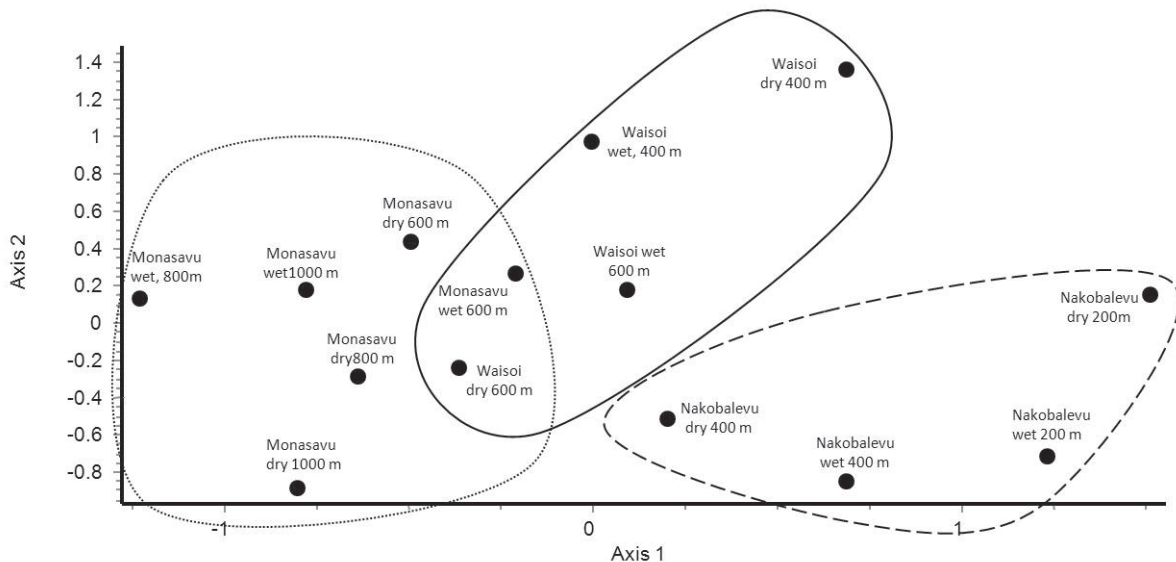


Fig. 4 Multidimensional scaling plot showing similarities in coleopteran composition between sites. Boundary lines represent clusters of samples taken from the same geographical location.

### Multidimensional Scaling

Multidimensional scaling was used to provide a simple visual representation of similarities between sites. Sites of similar geographic location clustered together, demonstrating similarities in their assemblages (Figure 4). The low altitude sites within Nakobalevu (200, 400m) clustered to one end of the plot, the sites within Waisoi (400, 600 m) generally clustered towards the centre of the plot and sites within the high altitude Monasavu area (600, 800, 1000 m) clustered towards the opposite end of the plot. Hence, the Waisoi cluster was intermediate between Nakobalevu and Monasavu. Additionally, the plot revealed altitudinal transition, where sites of similar altitude were located relatively close to each other, disregarding geographic

abundant species), and secondly because it was not possible to represent all altitudes at each location which makes direct altitudinal comparisons difficult. Nevertheless, the study revealed clear differences in coleopteran diversity between sample sites. We conclude that assemblages are influenced by environmental factors mediated by the combined effects of both geographical location and altitude (Figures 3 and 4 and ANOSIM analysis), and to a lesser extent season (Figure 3).

Studies have demonstrated that mid-elevations often exhibit relatively high diversity (Janzen 1973; Janzen *et al.*, 1976; Tenborgh, 1977; Gagné, 1979; Wolda, 1987; Holloway *et al.*, 1990; Rozenzweig, 1995; Rahbek, 1995). We tentatively conclude that the coleopteran

diversity observed in this study follows a similar pattern (Figure 2), and note that this effect has also been observed in Fijian forests in a detailed and systematic study of ants (E. Sarnat, *pers. comm.*). The mid elevation (800m) site at Monasavu had the highest diversity, although further study would be necessary to confirm this as the 200 m sampling interval may have failed to detect the true peak (Gunthart 1984). We observed a mixing of upland and cloud montane forest habitats at this site and a high number of tree families, which would provide greater habitat diversity and encourage high diversity of plant-host specific Coleoptera. It is commonly accepted that diversity increases at habitat boundaries due to mixing of species from neighbouring habitats (Didham 1997; Axmacher *et al.*, 2004). Elevated diversity at intermediate elevations may also be due to high primary production (Janzen 1973; Janzen *et al.*, 1976; McCoy 1990) with a consequent increase in beetle abundance (Janzen *et al.*, 1976; Olson 1994).

In the tropics, seasonality is not considered to be a major factor affecting the abundance of insect taxa because of more stable climatic conditions (Young, 1982), although arthropods have been shown to synchronize their fluctuating abundances with the phenology of their host trees (Wolda 1978, Lowman 1982, Basset 1991, Aide 1993). We observed some evidence of seasonality (Figure 2), with dry season diversity exceeding that of the wet season for all sites except at the highest altitude. High altitude forests in the wet tropics are generally continuously cold and wet even during regionally "dry" conditions (Samson *et al.*, 1997). Additionally, Axis 2 of the Direct Gradient Analysis explained 10.1% of observed variability and represented season (Figures 3). However, as our study compared only a single wet and dry season our conclusion must be considered preliminary. A shift in diversity may be due to lower abundance of phytophagous insects during the dry season (we observed increased abundance of phytophagous beetles including Chrysomelidae, Curculionidae and Mordellidae during the wet season). This may be attributed to reduced food resources (Wagner, 1999), whilst a relative increase in abundance of phytophagous insects during the wet season may be due to leaf-flush periods (Basset 1991; Aide 1993), preferences for young leaves (Price *et al.*, 1980; Coley & Aide, 1991) or the presence of new foliage (Young 1980).

From previous studies it is known that the distribution of Coleoptera is influenced by altitudinal range (Monteith and Davies, 1984; Hammond, 1990; Holloway *et al.*, 1990; Stork and Brendell, 1990; Olson 1994; Olson *et al.*, 2010). Additionally, it is known that for the conservation of representative habitats with distinct faunal assemblages, it is necessary to

maintain intact tracts of tropical forests that extend across an altitudinal range (Stiles, 1985, 1988; Janzen, 1986; Loiselle and Blake, 1991; Levey and Stiles, 1992; Powell and Bjork, 1993). The current study indicates that both location and altitude probably influence beetle diversity yet virtually nothing is known in detail with regards to this phenomenon in Fiji. To develop coherent conservation strategies further work at a higher taxonomic resolution would support informed decision-making for conservation planning.

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