

Biodiversity of soil oribatid mites (Acari: Oribatida) in a tropical highland plateaux, Bi Doup–Nui Ba National Park, Southern Vietnam

MARIA A. MINOR^{1,*}, SERGEY G. ERMILOV², ALEXANDER E. ANICHKIN^{3,4}

¹*Institute of Agriculture & Environment, Massey University, Private Bag 11222, Palmerston North, New Zealand*

²*Tyumen State University, Tyumen, Russia*

³*Joint Russian-Vietnamese Tropical Research and Technological Centre, Hanoi-Ho Chi Minh, Vietnam*

⁴*A.N. Severtsov Institute of Problems of Ecology and Evolution, Russian Academy of Sciences, Moscow, Russia*

Abstract: Biodiversity patterns (alpha-, beta- and gamma-diversity, abundance, community structure) of oribatid mites were investigated in six sites in a tropical montane forest in the Central Highlands region of Southern Vietnam. The diversity patterns in oribatid communities were investigated in relation to substrate (leaf litter vs. soil) and forest type (conifer-dominated vs. broadleaf-dominated). The density and species richness of oribatid mites in the soil were greater in the conifer-dominated sites. The community structure was also different between conifer-dominated and deciduous tree-dominated sites. Species from families Galumnidae, Otocephidae, Haplozetidae and Scheloribatidae were dominant in each plot. In conclusion, density and species richness of Oribatida were influenced by both forest type and substrate, and community composition was strongly influenced by the substrate.

Key words: Abundance, community structure, forest type, microarthropods, species richness, substrate effects.

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Introduction

Tropical forests support a unique and highly complex biodiversity in the soil; the interactions between plant roots, litter, and soil biota contribute to the tight nutrient cycling and health of these ecosystems (Barantal *et al.* 2012; Pires 2015; Swift *et al.* 1998). Oribatid mites (Acari: Oribatida) are an important part of soil

decomposer community (Behan-Pelletier 1999). Unlike many other members of soil microfauna, oribatid mites are often K-strategists, with low fecundities, slow development, and long life cycles (Behan-Pelletier 1999). These traits make Oribatida especially suitable as indicators of long-term disturbances (see reviews by Gergócs & Hufnagel 2009 and Gulvik 2007). Worldwide, oribatid mites have been used as indicators for

*Corresponding Author; e-mail: m.a.minor@massey.ac.nz

assessment of soil biological degradation (Bedano *et al.* 2011), rainforest restoration success (Proctor *et al.* 2011), impacts of land use intensification in tropical rainforest margins (Migge-Kleian *et al.* 2007), logging practices (Hasegawa *et al.* 2014), invasion of exotic tree species (Gutierrez-Lopez *et al.* 2014; Kohyt & Skubala 2013), human tramping in recreational forest parks (Fredes *et al.* 2009), forest fires (Camann *et al.* 2008), and forest vitality (Hogervorst *et al.* 1993).

In this paper we present data on alpha, beta, and gamma biodiversity of oribatid mites in the soil of several types of tropical montane forest in Bi Doup–Nui Ba National Park (BNBNP), Southern Vietnam. At present, quantitative data on soil biodiversity in Vietnam are limited. A number of Oribatida species have been recorded and/ or described (e.g. Golosova 1983; Ermilov & Anichkin 2011; Ermilov & Anichkin 2014; Ermilov *et al.* 2012; Krivolutskiy *et al.* 1997; Niedbala & Ermilov 2013), but ecological information is scarce (Nguyen & Vu 2012; Vu & Nguyen 2000; Vu & Nguyen 2004; Vu 2011). Biodiversity and community structure of oribatid mites have been found to be closely related to the changes of the environmental conditions in other National Parks of Vietnam, and have been suggested as bioindicators of sustainable management of forest ecosystems (Nguyen & Vu 2012; Vu & Nguyen 2000).

Tropical montane forests are one of the most endangered ecosystems, with only fragments remaining in densely populated areas of the world (Harrison & Pearce 2000). Like many protected reserves in South-East Asia, the BNBNP is under considerable pressure caused by the population expansion in the region. The human population and agricultural production in the buffer zone surrounding BNBNP are growing, causing increasing pressure on land and natural resources both inside and adjacent to the Park. Land encroachment by farmers in the buffer zone is one of the main threats compromising the integrity and biodiversity of the BNBNP. Another great threat is the uncontrolled development within the BNBNP, including commercial development along the major road which bisects the Park, as well as commercial ecotourism development (Bond 2008). Clear buffer zone and ecotourism management regulations are only being established (Sobey 2008; The Prime Minister of Vietnam 2014).

The only existing publication on soil Acari in BNBNP is that by Ermilov & Anichkin (2014) who presented a check-list of oribatid mite species

collected in six sites of the BNBNP and described 14 new species. The data on abundance and diversity presented here will complement that check-list, and provide an important baseline for soil biodiversity assessment in the BNBNP. This data will allow future comparisons to be made with soil biodiversity in the Park, providing an option for ecological monitoring of land degradation. Additionally, the results add to the knowledge of soil biodiversity in tropical montane forests.

Material and methods

Study sites

The study sites were located within the Bi Doup–Nui Ba National Park (BNBNP), Lam Dong Province, in the south of Central Highlands region of Vietnam (Fig. 1). BNBNP (12°00'N to 12°52'N, 108°17'E to 108°42'E) is located on the Da Lat Plateau, part of the southern reaches of the Truong Son (Annamite) Range. Located about 40 km from Da Lat City, BNBNP covers ca. 56,000 ha (excluding the buffer zone); the park has a complex mountain relief, with many hills and valleys; it is almost fully forested, including old-growth forest (BNBNP 2015).

The Park is one of five centres of plant diversity in Vietnam, with 1933 species of plants present; there are 91 species of local endemics such as *Pinus dalatensis* Ferré and 62 rare species, including *Ducampopinus krempfii* (Lecomte) A. Chev. (BNBNP 2015). Vegetation is largely subtropical montane evergreen forest dominated by Fagaceae, Elaeocarpaceae, Theaceae, Lauraceae, Ericaceae, Illiciaceae, Magnoliaceae, and some Podocarpaceae gymnosperms, with areas of coniferous forests dominated by *Pinus kesiya* (Royle ex Gordon) and mixed broadleaf-coniferous forests with *P. dalatensis* and *D. krempfii* (Sobey 2008).

The climate is temperate, varying according to the height of the terrain, with a cool dry season and a warmer monsoon season. Average annual rainfall is ca. 1800 mm, with less than 50 mm month⁻¹ from December to March; the onset of monsoon rains is in May–June, and the rainfall increases to more than 200 mm month⁻¹ in July–October (average 2000–2012). The mean annual temperature is around 20 °C; mean annual high is 25 °C, the mean annual low is 16.6 °C. Montane forests are frequently covered with fog.

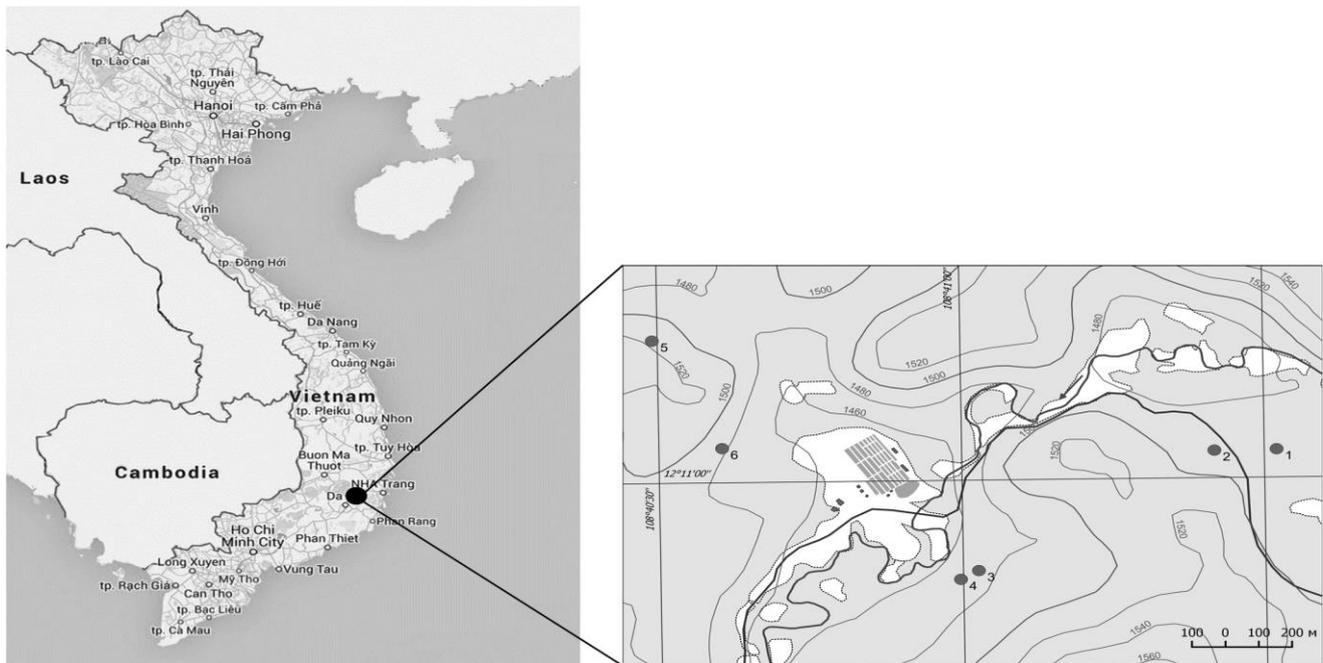


Fig. 1. Study sites in the Bi Doup–Nui Ba National Park, Lam Dong, Southern Vietnam.

Data were collected by S. G. Ermilov and A. E. Anichkin in December 2013 at six localities, located in the middle part of mountain range at altitudes ranging from 1450 to 1530 m asl (Fig. 1). A full detailed geographical and floristic descriptions of collecting sites was given in Ermilov & Anichkin (2014), only a brief description is included here (Table 1).

Sampling

Ten soil cores (7.8 cm dia., 10 cm deep) were collected at each site, litter (leaves, branches and

loose detritus) was brushed off prior to collection of cores. Intact cores in metal cylinders were transported to the laboratory, where soil mites were extracted for 10 days into 75% ethanol using Berlese funnels heated with 40W lamps. Additionally, 16 litter samples were collected using a 50 × 50 cm stainless steel frame. The litter samples were pooled, and passed through a sifter with the mesh size 2 × 2 cm. The resulting fine fraction was placed into a Winkler extractor and extracted at room temperature for 20 days into 75% ethanol. Oribatida mites were identified to a

Table 1. Study sites in the Bi Doup–Nui Ba National Park, Lam Dong, Southern Vietnam, 6-7th December, 2013.

Site	Coordinates	Elevation (a.s.l.) and relief	Forest type and description*
1	12°11'03.38"N, 108°41'31.23"E	1495 m, flat relief	Mixed forest dominated by <i>Pinus dalatensis</i> and <i>Dacrydium ellatum</i> , with well-developed understory and ground cover
2	12°11'03.29"N, 108°41'25.06"E	1492 m, gentle slope, W aspect	Mixed forest dominated by deciduous trees; ground cover sparse
3	12°10'49.16"N, 108°41'01.52"E	1473 m, flat relief	Mixed forest dominated by <i>Ducampopinus krempfii</i> ; ground cover fragmentary
4	12°10'48.13"N, 108°40'59.74"E	1469 m, flat relief	Deciduous forest; ground cover fragmentary
5	12°11'17.09"N, 108°40'29.49"E	1517 m, top of a small mountain	Open coniferous forest dominated by <i>Pinus kesiya</i> ; ground cover well developed
6	12°11'04.11"N, 108°40'36.27"E	1485 m, slope of a mountain	Deciduous forest; ground cover fragmentary

*Note: see Ermilov & Anichkin (2014) for detailed description of the sites

species level (Ermilov & Anichkin 2014), except for Ptyctima, which were not identified. Juvenile oribatid mites, which can be difficult to assign to a species, were included in the abundance counts, but excluded from community composition analysis and diversity estimates.

Diversity estimates

Abundance values in soil and litter were standardized to individuals m^{-2} . Alpha diversity was estimated as the local species diversity at a site, using observed species richness, the Shannon's diversity index, and two diversity estimates (Jackknife1 and Chao2) calculated in Estimate S9.10 for Windows (Colwell 2013) to predict expected species richness at a site.

Beta diversity represents the variation in species composition among sites; it was quantified as the slope of the similarity decay in the species composition in relation to geographical distance between sites (Nekola & White 1999).

Gamma diversity was estimated as a regional diversity from pooling data for all six sites, and computing diversity statistics for the region (Whittaker 1972).

Statistical analysis

We compared the mean abundance and species richness of Oribatida across sites and in two main

forest types, represented by three sites each—those dominated by coniferous trees (sites 1,3,5), and those dominated by deciduous trees (sites 2,4,6) (SAS 9.3, PROC MIXED).

The multi-response permutation procedures method (MRPP) in PC-Ord for Windows (MjM Software, version 5) was applied to species abundance matrix with the Bray-Curtis distance as a similarity measure to tests the null hypothesis of no difference in community composition of Oribatida between forest types (separately for soil and for litter data); groups with low abundance (less than 5 individuals across all sites) were excluded (McCune & Grace 2002). Presence-absence data (blocked by site) were used in MRPP to compare assemblages in soil and litter substrates. Habitat associations between species of Oribatida and types of substrate and forest were analysed using the Indicator Species Analysis (Dufrêne & Legendre 1997) in PC-Ord. Significance level $\alpha = 0.05$ was used for all statistical tests.

Results

Abundance and alpha-diversity

In the Winkler-extracted litter the density of oribatid mites was very low and their species richness was similar across sites (Table 2). In the soil cores both the mean density of Oribatida and

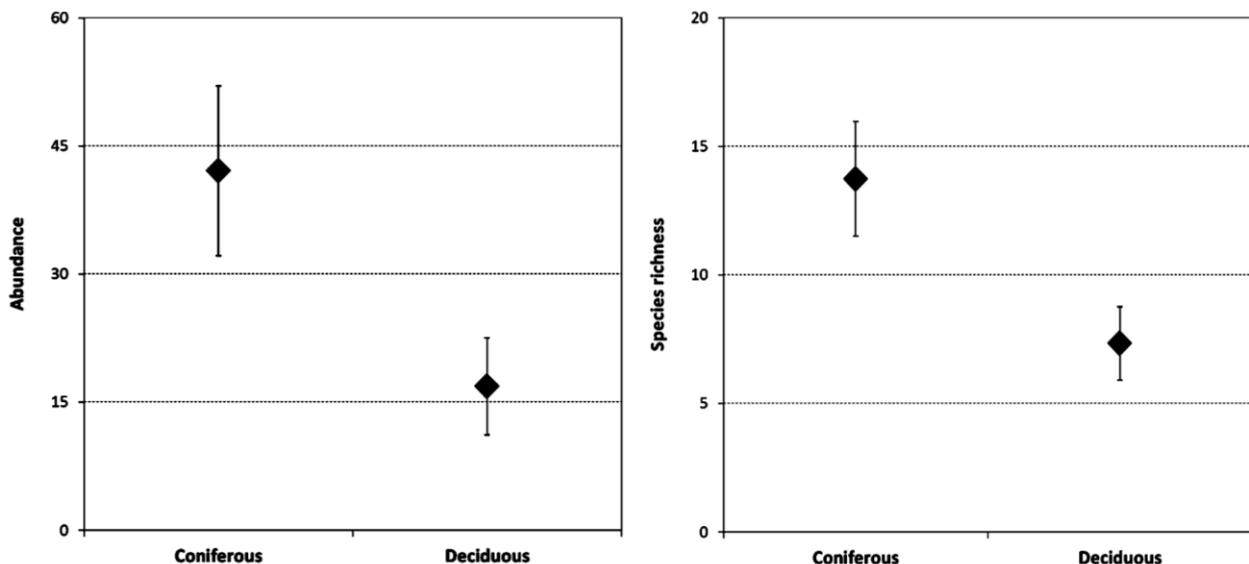


Fig. 2. Mean abundance (individuals/core) and species richness (species/core) of Oribatida in the soil of conifers–dominated and deciduous tree-dominated forests in the Bi Doup–Nui Ba National Park, Lam Dong, Vietnam (Dec. 2013). Error bars are 95% confidence intervals, $n = 30$.

Table 2. Site-level (alpha) and park-level (gamma) diversity of oribatid mites in the Bi Doup–Nui Ba National Park, Lam Dong, Vietnam (Dec. 2013): density (ind. m⁻²), observed species richness (S_{obs}), Shannon’s diversity index (H'), estimated species richness (Jack-1, Chao 2, mean \pm st. dev.). Forest type: “C”–dominated by conifers, “D”–dominated by deciduous trees.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Total all sites
Forest type	C	D	C	D	C	D	
	Litter ¹						
Density	85.5	67.25	173.0	114.0	96.0	155.0	-
S_{obs}	35.0	30.0	33.0	34.0	41.0	34.0	80.0
Unique spp	2.0	1.0	1.0	5.0	9.0	6.0	19.0
H'	-	-	-	-	-	-	3.41
Jack1 \pm SD	-	-	-	-	-	-	101.7 \pm 7.0
Chao2 \pm SD	-	-	-	-	-	-	92.9 \pm 6.9
	Soil ²						
Density	178.2 \pm 643.3	2804.3 \pm 424.0	9124.47 \pm 485.4	2636.89 \pm 201.0	10128.99 \pm 496.7	5127.28 \pm 219.6	-
S_{obs}	43.0	27.0	49.0	36.0	49.0	40.0	88.0
Unique spp	5.0	1.0	4.0	5.0	7.0	2.0	27.0
H'	2.88	2.52	3.03	3.08	3.19	2.83	3.49
Jack1 \pm SD	61.0 \pm 6.7	39.6 \pm 4.3	70.6 \pm 7.4	54.0 \pm 4.8	63.4 \pm 4.1	56.2 \pm 6.1	108.0 \pm 4.5
Chao2 \pm SD	68.7 \pm 15.9	36.8 \pm 6.9	81.4 \pm 18.4	72.0 \pm 23.5	61.8 \pm 8.5	64.3 \pm 15.9	102.4 \pm 7.9
	Total for soil and litter ¹						
S_{obs}	58.0	43.0	61.0	54.0	65.0	52.0	107.0
Unique spp	1.0	0.0	2.0	5.0	5.0	2.0	-

¹pooled data; variance, H' , and diversity estimates are not available

² $n = 10$

their alpha-diversity parameters varied significantly among sites (abundance: $F_{5,54} = 5.18$, $P < 0.001$; richness $F_{5,54} = 9.90$, $P < 0.001$; Table 2), and both the mean species richness and the mean density of Oribatida were significantly higher in the three sites dominated by coniferous trees (Fig. 2). This tendency was also observed for the total species richness for each site (soil and litter combined) (Table 2). The conifer-dominated site 5 had the highest abundance and the richest species composition of Oribatida.

Community composition and beta-diversity

Oribatida communities of soil cores and of Winkler-extracted litter samples markedly differed in composition (MRPP for substrate, blocked by site: $A = 0.086$, $P = 0.008$). The Indicator Analysis identified groups of species significantly associated with either the litter or the soil (Table 3).

NMS ordination (not shown) suggested that Oribatida communities of deciduous-dominated sites 2 and 4 were closer to each other than to the

conifer-dominated sites 1 and 3, with which they were paired geographically. Overall, Oribatida communities in the soil cores from conifer-dominated forests were significantly different from those in deciduous-dominated sites (MRPP for forest type: $A = 0.086$, $P = 0.025$); however, none of the species were significantly associated with a particular forest type. Litter community did not differ much among the two forest types (MRPP: $A = -0.012$, $P = 0.555$), possibly because the abundances in the litter were too low to show differences in community structure.

Beta diversity was relatively constant, and not related to the geographical distance between sites (Fig. 3).

Gamma-diversity

Collectively from all sites, 107 species belonging to 40 families were distinguished (Table 2; see Ermilov & Anichkin 2014 for a species list). Of these, 33 species were each represented by less than 5 individuals. Dominant and sub-dominant

Table 3. Species of oribatid mites associated with either soil or litter, and their average body sizes (Dec. 2013). Indicator Value and *P*-value are derived from the Indicator Species Analysis (Dufrêne & Legendre 1997).

Species	Body size (µm)	Indicator Value (%)	<i>P</i> -value
Soil			
<i>Papillacarus aciculatus</i> (Berlese, 1905)	600	98.6	0.008
<i>Nanharmannia thaiensis</i> (Aoki 1965)	490–528	89.5	0.013
<i>Protoribates</i>			
<i>paracapucinus</i> (Mahunka 1988)	337–371	74.9	0.033
<i>Opiella nova</i> (Oudemans 1902)	220–320	69.7	0.031
Litter			
<i>Dolicheremaeus cf. damaeoides</i> (Berlese 1913)	560	97.7	0.002
<i>Zetorchestes saltator</i> (Oudemans 1915)	330–455	97.6	0.002
<i>Austroceratoppia japonica</i> (Aoki 1984)	470–480 310–400	89.7 88.2	0.009 0.002
<i>Yoshiobodes</i> sp.			
<i>Dampfiella angusta</i> (Hammer 1979)	640	83.3	0.017
<i>Galumna praeoccupata</i> (Subías 2004)	326–365	82.4	0.033

families were Oppiidae, Scheloribatidae, Tetracondylidae, Zetorchestidae, Galumnidae, Haplozetidae. In the soil, approximately 21% of all Oribatida were *Opiella nova*. Although the species accumulation curves (not shown) displayed decreased rates of species accrual with increased number of sites, the curves did not attain an asymptote neither in the soil, nor in the litter. Observed species richness underestimated diversity by 15–20%, as suggested by Jack knife and Chao 2 diversity estimates (Table 2).

Discussion

The densities of Oribatida in the BNNBP (2600–10000 ind. m⁻²) are within the range reported for forest soils in Vietnam (Vu 2011), elsewhere in the South East Asia (Hasegawa *et al.* 2006), and in the Neotropics (Kaspari & Yanoviak 2009). The data support the long-standing observation that the densities of Oribatida in tropical forest ecosystems are much lower than in the forests of temperate zone (Maraun *et al.* 2007); for comparison, the density of oribatid mites in temperate forests often exceeds 100 000 ind. m⁻² (Maraun & Scheu 2000; Migge *et al.* 1998). The mechanisms responsible for the low density of Oribatida and some other soil decomposers in tropical forests are not well understood, but may be related to either limiting P availability (Kaspari & Yanoviak 2009), or the litter trait syndrome

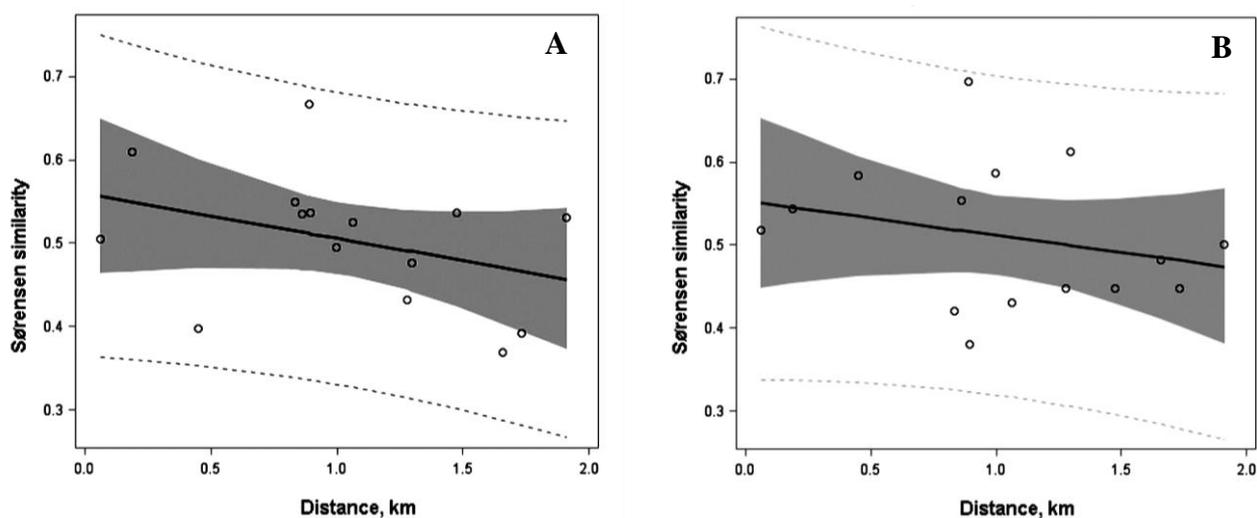


Fig. 3. Beta diversity of Oribatida in the litter (A) and soil (B) in relation to the geographical distance between sites; the Bi Doup–Nui Ba National Park, Lam Dong, Vietnam (Dec. 2013). Open circles—data points, solid line—OLS regression, shaded region—95% confidence limits, dotted lines—95% prediction limits. OLS: adjusted $r^2 = 0.060$; $P = 0.192$ for litter (A); $r^2 = -0.005$, $P = 0.351$ for the soil (B).

(Hättenschwiler *et al.* 2011), a syndrome of poor litter quality across tree species in nutrient-poor tropical rainforests, which results in very slow litter decomposition despite favourable climatic conditions (Coq *et al.* 2010; Hättenschwiler *et al.* 2011). The litter trait syndrome, which controls the abundance and activity of decomposers, may have evolved to divert limiting P to plants via their mycorrhizal associations (Hättenschwiler *et al.* 2011).

The observed site-to-site variations in abundance and diversity are not unusual for microarthropods. Factors such as the quality and quantity of organic matter (Hasegawa *et al.* 2006; Maraun & Scheu 2000), landscape position (Illig *et al.* 2010), tree species composition (Hasegawa *et al.* 2013; Sylvain & Buddle 2010), microhabitat heterogeneity (Hansen & Coleman 1998), soil moisture (Lindberg *et al.* 2002; Noti *et al.* 2003) and soil nutrient content (Kaspary & Yanoviak 2009; Minor 2011) have been linked to abundance, diversity and dominance patterns of Oribatida. However, these linkages are not consistent, and it is equally common to find no correlation between abundance and diversity of Oribatida and soil properties or vegetation patterns (Migge *et al.* 1998; Minor 2011; Zaitsev *et al.* 2014). Establishing global patterns is difficult, especially in poorly studied tropical systems, and we can only speculate that observed site differences were caused by landscape-, biogeochemistry-, or site-related variables which were not identified directly.

The clear differences in density, diversity and community composition of Oribatida between conifer-dominated and deciduous-tree dominated sites in our study reflect the different properties of soil and litter formed under these two forest types. In conifers-dominated forests the upper humus horizons were thick, with a layer of partially decomposed pine needles and small branches on the surface, and a thick spongy layer of raw humus underneath; these soils are high in organic matter and porous. Broadleaf-dominated forests were characterized by an ephemeral layer of leaf litter and by dense underlying soil horizons with high clay content and weak structure; these soils supported lower abundance and diversity of oribatid mites, which are soil pore-dwellers. Organic matter content and porosity of soils are important determinants of soil productivity, structure, and biological activity (Magdoff & Weil 2004), and the negative effects of soil compaction on oribatid mites are well known (Battigelli *et al.*

2004; Borcard & Matthey 1995; Lindo & Visner 2003).

In addition, the differences in Oribatida communities between forest types in the BNNBP may reflect the corresponding differences in the amount and quality of food resources such as litter quality and/or prevalence of ectomycorrhiza on tree roots. Analysing the ^{15}N signatures of Oribatida in the litter of a neotropical montane forest, Illig *et al.* (2005) found that the majority of Oribatida were secondary decomposers (fungi- and bacteria-feeders); only few were primary decomposers (litter-feeders). Although feeding preferences of fungal-feeding tropical Oribatida are poorly known, it is likely that similarly to the temperate species they are “choosy generalists”, utilizing a range of ectomycorrhizal and saprotrophic fungi, but feeding selectively when preferred food is available (Schneider *et al.* 2004; Schneider & Maraun 2005). While a recent study showed no direct correlation between abundance of soil fungi (expressed through ergosterol content) and feeding structure of Oribatida communities (Zaitsev *et al.* 2014), the links between abundance and community composition of Oribatida and the abundance and species identity of ectomycorrhizal fungi have been established (Remen *et al.* 2010; Setälä 2000). Although we have no data on fungal communities in the BNNBP, conifers such as *Pinus kesiya* are ECM trees with a rich complex of mycorrhizal fungi (Bâ *et al.* 2014; Rao *et al.* 1997), whereas broadleaves dominant in deciduous sites vary to have either arbuscular mycorrhiza, ECM, or no mycorrhiza (Haug *et al.* 1994; Wang & Qiu 2006), which may translate into differences in Oribatida communities.

The data also emphasise the importance of combining several sampling methods for biodiversity census. Although the litter and soil data are not directly comparable due to different sampling methods, the difference in species census and community composition between soil and litter is remarkable, and indicates that the two substrates provide different living environments. It is believed that surface-dwelling Oribatida tend to be large, as more adverse (drier) conditions favour species with lower surface-to-volume ratio and thicker cuticle (Krivolutsky 1995; Zaitsev & Wolters 2006). However, Lindberg *et al.* (2002) found that larger Oribatida were particularly drought-sensitive, presumably because they were unable to reach refugia deeper in the soil during drought events. We did not observe much difference in average body size between dominant

litter-dwelling and soil-dwelling species (Table 3), which suggests that moisture level was perhaps not the main factor in shaping community composition.

Valdecasas & Camacho (2003) emphasized that a biodiversity analysis for conservation purposes is only as good as the available biodiversity data. Species-level identification is especially important, because simply recording changes in species richness is misleading and the knowledge of species' life histories, distribution, feeding type, tolerance levels, etc., is crucial when monitoring changes in biodiversity (Lawton *et al.* 1998). The use of Oribatida as indicators of soil conditions and ecosystem disturbance in the tropics is often precluded by the poor knowledge of fauna and the lack of baseline ecological data (Behan-Pelletier *et al.* 1993; Noti *et al.* 2003). The data we supply in this publication will provide a baseline for future research on soil biodiversity in the BNNP, enable comparisons with the literature from other tropical regions, add to the recognised conservation value of the sites, and help to evaluate and compare future management practices in the National Park.

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