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Influence of leaf litter composition on ant assemblages in a lowland tropical rainforest in Thailand

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ABSTRACT. In tropical rainforests, variability in the distribution of soil and litter arthropods is usually explained at regional scales by altitude, soil nutrients, and disturbance regimes. However, the influence of these factors on insect assemblages at the micro-habitat scale has rarely been studied. We investigated whether the species identity of decomposing leaves in tropical forest affected the composition of ant assemblages around them. Ants were extracted from litter below three common tree species, *Parashorea stellata* (Dipterocarpaceae), *Intsia palembanica* (Fabaceae) and *Shorea gratissima* (Dipterocarpaceae) in a 24 ha lowland rainforest plot in southern Thailand. A total of 2,257 individual ants, representing 71 species in 38 genera of 6 subfamilies were collected in the dry and wet seasons during 2010. Ant species richness was never significantly different among litter samples under the crown cover of three tree species. Ant species richness was higher in the wet season than the dry season. Our results demonstrate that ant assemblages are seasonally heterogeneous. Leaf mass and litter mass did not relate to the presence of ant diversity. Soil humidity was the only important factor influencing ant diversity in this study. Future studies should consider the importance of soil moisture related to litter ant diversity.

Keywords: ant assemblages, indicator species, leaf litter, microhabitat, southern Thailand, spatial ecology, tropical rainforest

INTRODUCTION

The ubiquitous distribution of arthropods, their species richness, abundance, and short generations make them well suited for biodiversity monitoring (Mattoni *et al.* 2000). The arthropod component of soil and litter fauna appears important in the processes of decomposition and nutrient cycling (Wolters 2001). However, soil/litter fauna remain poorly studied, particularly in old-growth tropical forests (Atkin & Proctor 1988; Burgess *et al.* 1999; André *et al.* 2002; Goehring *et al.* 2002; Wiwatwitaya & Takeda 2005).

In tropical rainforests, variance in distribution of soil/litter arthropods can be explained at the regional scale by altitude, soil nutrients and disturbance (Atkin & Proctor 1988; Burghouts *et al.* 1992; Olson 1994; Thomas & Proctor 1997). At the local scale, the situation may be confounded by many factors, and high variance in abundance of tropical soil/litter arthropods may be expected, even at the scale of a few metres (Kaspari 1996). Soil and litter moisture content, topography, standing crop litter, litter fall, and canopy cover from diverse tree species represent important variables potentially influencing the distribution of soil/litter arthropods (Levings 1983; Levings & Windsor 1984; Frith & Frith 1990; Burghouts *et al.* 1992; Burgess *et al.* 1999; Noti *et al.* 2003). Also, seasonal variance of soil/litter arthropods may be influenced by changes in rainfall, severity of dry season, and timing and periodicity of litterfall (Willis 1976; Levings & Windsor 1982, 1985; Frith & Frith 1990). One reason for this lack of consensus may be that many studies on tropical soil/litter arthropods were analyzed at large scales or regional scale levels (*e.g.* altitude, forest types, soil nutrients and disturbance regimes) (Levings & Windsor 1984; Pearson & Derr 1986; Atkin & Proctor 1988; Frith & Frith 1990; Burghouts *et al.* 1992; Thomas & Proctor 1997; Burgess *et al.* 1999). At large scales, many comparisons of ant diversity (*e.g.* undisturbed forest v.s. disturbed forest) involve all tree species in a plot with diversity compared among plots without considering local confounding factors (tree variaties). In contrast, litter from various tree species produce different kinds of structural and chemical components that may influence ant assemblages. We hypothesize that litter fall and canopy cover of different tree species may influence the species richness and species composition of ant assemblages under particular trees. To test this hypothesis, we conducted a study in a forest of known composition: The 24 ha Khao Chong (KC) forest dynamics plot managed by the Center for Tropical Forest Science (CTFS plot) in Trang, peninsular Thailand. Every tree >1 cm DBH (diameter breast height) in this plot is mapped, identified to species, and has its DBH measured every five years. Vegetation data from CTFS allowed us to design a protocol minimizing the confounding factors of disturbance, topography, and spatial distribution. We extracted ants with a standard protocol often used in the tropics (Agosti *et al.* 2000) and identified ants to species. The sampling protocol was designed to address the following questions:

(1) Does leaf litter derived from different tree species influence the ant assemblages living in the litter?
(2) Are leaf litter ant assemblages influenced by proximity to tree trunks?
(3) Does seasonality affect spatial patterns of ant assemblages in the leaf litter?

METERIAL AND METHODS

Study site

Ant assemblages were sampled in March and October 2010 at the Khao Chong CTFS forest dynamics plot in the Khao Chong Botanic Garden, Trang province, southern Thailand (7º 32’ N, 99º 47’ E). The 24 ha plot contains 593 tree species. The plot is located on a slope in lowland seasonal evergreen forest. The main ecological gradient affecting tree distribution is probably related to topography, which ranges between 108-280 m asl over a span of 600 m. Climate data was recorded at the Khao Chong Botanical Garden, which receives annual rainfall of *ca*. 2,800 mm, with average air humidity of $84.2 \pm 10.6\%$ (mean ± SD) and an average temperature of $28.2 \pm 1.5°$ C.

Ant collection

Ants were extracted from leaf litter using the ALL (Ants of the Leaf Litter) protocol, which involves sifting and concentrating the finest leaf litter and arthropods before separating the ants with

Table 1. Information on individuals of the focal tree species under which litter was sampled at 24-ha CTFS plot in the Khao Chong Botanic Garden, Trang province, southern Thailand.

Tree species	Tree tag	Coordinates	Altitude (masl)	DBH (cm)	Height (m)	Crown size (m×m)
P. stellata	1100931	7°32′468″N, 99°47′811″E	147	165.0	45.2	2.0×12.0
	2301015	7°32′404″N, 99°47′776″E	196	166.0	40.0	9.0×9.5
	3501026	7°32′341″N, 99°47′802″E	218	124.0	38.6	13.0×11.0
	3601481	7°32′315″N, 99°47′844″E	211	121.0	40.8	10.0×9.0
	2901412	7°32′382″N, 99°47′847″E	178	130.0	45.8	7.0×6.5
S. gratissima	50507	7°32′487″N, 99°47′773″E	136	40.8	31.0	3.0×3.0
	30603	7°32′508″N, 99°47′784″E	140	61.5	38.0	5.5×7.0
	50596	7°32′497″N, 99°47′790″E	148	55.2	39.6	4.0×6.0
	60694	7°32′499″N, 99°47′791″E	155	65.5	48.8	3.5×3.0
	50661	7°32′506″N, 99°47′800″E	157	64.0	38.6	4.0×3.5
I. palembanica	70360	7°32′491″N, 99°47′758″E	129	66.0	30.8	10.0×4.5
	1000474	7°32′472″N, 99°47′749″E	148	45.0	23.8	7.5×6.5
	1087	7°32′479″N, 99°47′803″E	145	50.0	30.8	10.0×7.0
	1201738	7°32′466″N, 99°47′876″E	147	123.0	33.6	14.5×19.0
	1000665	7°32′481″N, 99°47′778″E	147	109.0	36.0	7.5×10.0

Winkler extractors (Besuchet *et al.*1987; Agosti *et al.* 2000). Three of the most locally abundant tree species were chosen using data from the plot: *Parashorea stellata* Kurz (Dipterocarpaceae), *Shorea gratissima* Dyer (Dipterocarpaceae) and *Intsia palembanica* (Miq.) Baker (Fabaceae). Information on location and size of the focal tree specimens is given in Table 1.

With the help of vegetation data for the Khao Chong plot, we selected five trees per species that were (a) reasonably well spread spatially within the plot between 129-218 m asl, (b) of a similar DBH (and hence of similar age/crown size and likely to yield similar local amount of leaf litter), and (c) at least 40 m away from any congener. The tree diameter range chosen was selected to be representative of most adult trees at Khao Chong.

We sampled all leaf litter in four 0.5 m^2 quadrats under each focal tree ($N = 5$ per species; totalling 60 Winkler samples for the three focal tree species) following the method of Agosti *et al.* (2000) and positioned (1) touching the tree trunk and (2) below the main projected area of the tree crown 2.5 m from the trunk. Four quadrats per tree were sampled once in the wet season and once in the dry season, for a total of 120 Winkler samples. Following sifting, arthropods were extracted from litter samples for 72 hours using Winkler extractors. All ants were isolated from the collected material, representative ants were mounted, identified to morphospecies, and databased.

Micro-environmental variables

We estimated soil humidity content by comparing wet and dry weights, volume of sifted litter (leaf mass) under each of the three focal tree species, leaf species heterogeneity (number of leaf species contained in 0.5 m^2) was estimated within the quadrat measured from each tree.

Ant identification

The ant fauna of Khao Chong is reasonably well characterized (Jaitrong & Ting-Nga, 2005). Ants were identified to subfamily and genus according to Bolton (1994) and to species by comparison

Table 2. Indicator species analysis results of the litter ant sampling below one of the three common tree species (*P. stellata, S. gratissima* and *I.palembanica*).

Habitat	Dry season			Wet season		
	Ant species	IndVal (%)	*P*-value	Ant species	IndVal (%)	*P*-value
P. stellata	*Hypoponera* sp.3	58.7	0.001	*Nylanderia* sp.1	60.7	0.005
	Ectomomyrmex sp.2	39.3	0.01	*Odontomachus rixosus*	39.8	0.03
	Discothyrea sp.1	32.3	0.01	*Hypoponera* sp.3	31.1	0.002
				Pseudolasius sp.1	30.0	0.05
				Strumigenys sp.3	26.7	0.04
S. gratissima	*Lophomyrmex* sp.1	35.7	0.02	*Lophomyrmex* sp.1	67.8	0.001
				Strumigenys sp.2	49.1	0.006
				Mayriella sp.1	40.6	0.01
				Tetramorium sp.1	40.0	0.02
				Carebara sp. 3	38.6	0.01
				Strumigenys sp. 5	37.9	0.01
				Hypoponera sp. 1	36.9	0.02
				Pristomyrmex pungens	34.3	0.01
I. palembanica	*Strumigenys* sp.3	60.0	0.04	*Strumigenys* sp.6	52.6	0.003
	Hypoponera sp.2	37.2	0.01	*Hypoponera* sp.2	31.1	0.04

with specimens in the Forest Insect Collection at Department of National Parks, Wildlife and Plant Conservation (DNP), Bangkok, Thailand. Taxonomic updates were taken from http://www.antweb.org and http://www.antbase.de). Unidentified specimens were coded based on ant reference collections in the Forest Insect Collection at DNP. The number of individuals of each species was counted for calculating ant abundance.

Data analyses

Ant diversity and micro-environmental variables

1. Data on micro-environmental variables; quantities of leaf mass, litter mass, leaf species heterogeneity (number of leaf species in 0.5 m^2) sampling quadrats and soil moisture collected under each of focal tree species (*I. palembanica*, *P. stellata* and *S. gratissima*) were compared using ANOVA and post-hoc Tukey tests. Two-way ANOVA was then used to contrast microenvironment variables under each of focal tree species (*I. palembanica*, *P. stellata* and *S. gratissima*) between seasons.

2. Species richness (number of species) of ants sampled under each of the three focal tree species (*I. palembanica*, *P. stellata* and *S. gratissima*) was compared using ANOVA and post-hoc Tukey tests. Two-way ANOVA was then used to contrast abundance and species richness of ants sampled under each of focal tree species (*I. palembanica*, *P. stellata* and *S. gratissima*) between seasons.

3. Species richness of ants sampled near the trunk of common trees was compared with ants sampled under the projected crown 2.5 m from the trunk using paired sample *t*-tests.

Indicator species and ant composition

To identify ant species characteristics of the litter under common tree species, we performed Indicator Species Analysis (ISA) using the technique of Dufrêne and Legendre (1997) with a significance level of $\alpha = 0.05$. Similarity among ant

Table 3. Sørensen similarity matrix of the ant composition in leaf litter under one of three common tree species: *P. stellata*, *S. gratissima* and *I. palembanica*. Numbers in the upper right half of the table are the number of species shared between each tree species. The lower lefts are the indices of similarity which are shaded light grey.

Tree species	*P. stellata*	*S. gratissima*	*I. palembanica*
Dry season			
P. stellata		10	10
S. gratissima	0.48		9
I. palembanica	0.50	0.46	
Wet season			
P. stellata		16	20
S. gratissima	0.47		13
I. palembanica	0.62	0.44	

assemblages under the three common focal tree species was assessed with the Sørensen similarity index (QS), using the formula QS = 2c/ (a+b), where a is the number of species in sample a; b is the number of species in sample b and c is the number of species found in both samples (Sørensen 1948). The relationships between ant species diversity and micro-environmental variables (leaf mass, litter mass, leaf species heterogeneity (number of leaf species) and soil humidity) were assessed using regressions. All statistical analyses were performed with Systat Version 8 (Systat Software 1998).

RESULTS

Ant species richness

A total of 2,257 individual ants were collected, which represented 71 species in 38 genera of 6 subfamilies (Ectatomminae, Dolichoderinae, Formicinae, Myrmicinae, Proceratiinae and Ponerinae, see Appendix A1). We recorded 489 individuals of 39 species collected in the dry season and 1,768 individuals of 56 species in the wet season. The most species-rich genera were *Pheidole* (9 spp.), *Strumigenys* (6 spp.), *Carebara* (6 spp.) and *Hypoponera* (4 spp.). The five most abundant species were *Nylanderia* sp. 1, *Lophomyrmex* sp.1, *Bothroponera* sp.1, *Hypoponera* sp.3 and *Odontomachus rixosus*, respectively (Appendix A1).

Ant species richness does not differ under different tree species

Species richness under the three focal tree species did not differ significantly in either season (dry season: ANOVA, $F_{2,12} = 0.49$, $P = 0.63$, wet season: ANOVA, $F_{2,12} = 0.65$, $P = 0.54$), but richness was higher in the wet season than in the dry season (ANOVA, $F_{1,24} = 23.63$, $P < 0.01$; Fig. 1).

Proximity to tree trunks does not affect ant diversity

Proximity to tree trunks did not affect ant diversity in the plot because data analysis showed no differences in species number of ants between the area close to tree trunks and the area 2.5 m from tree trunks in both seasons (dry season: *t*-test, $t_{14} = -1.89$, $P = 0.07$, wet season: *t*-test, $t_{14} = 0.44$, $P = 0.66$; Fig. 2).

Indicator species of different habitats were sometimes season-specific

Table 2 demonstrates that there were fewer indicator species in the dry season than the wet season, and that some ant species were only indicative of particular habitats in one season or the other.

About half of ant species are shared between specific trees

Ant species composition was separately calculated for dry and wet seasons as shown in Table 3. On average, half the ant species found under a particular tree species were sampled in both the wet and dry seasons.

Seasonal differences in the environmental variables

Total dry leaf-mass per unit area was higher in the dry season than the wet season (ANOVA, $F_{1,24}$ = 30.72, P = 0.001), but there were no differences in leaf mass between tree species in each seasons (dry season: ANOVA, $F_{2,12}$ = 0.57, P = 0.58, wet season: ANOVA, $F_{2,12}$ = 0.25, P < 0.77; Fig. 3a; Appendix A2). Litter mass under different tree species varied with season (ANOVA, $F_{1,24}$ = 10.78, P < 0.01). Ground under *P. stellata* had a greater volume of litter than under *S. gratissima* and *I. palembanica* in the dry season (dry season: ANOVA, $F_{2,12}$ = 8.36, P < 0.05, wet season), while *I. palembanica* had more litter than the other two species in the wet season (ANOVA, $F_{2,12}$ = 6.57, P < 0.01; Fig. 3b).

The species diversity of leaves in litter samples collected under three focal species was not significantly different between seasons (ANOVA, $F_{1,24}$ = 0.72, P = 0.40), and did not differ between tree species in each season (dry season: ANOVA, $F_{2,12}$ = 1.70, P = 0.22, wet season: ANOVA, $F_{2,12}$ = 0.17, P = 0.84; Fig. 3c).

Soil humidity was higher in the wet than the dry season (ANOVA, $F_{1,24}$ = 55.86, P < 0.001, but did not differ between tree species in each season (dry season: ANOVA, $F_{2,12}$ = 0.02, P = 0.98, wet season: ANOVA, $F_{2,12}$ = 0.64, P = 0.54; Fig. 3d).

Regression analyses showed that soil humidity was related to the presence of ants: soil moisture accounted for 29% of the variation in abundance (r^2 = 0.29; $F_{1,28}$ = 11.70, P = 0.02) and 24% of variation in species richness (r^2 = 0.24; $F_{1,28}$ = 8.78, P < 0.05). Leaf mass was related to the ant assemblages, and accounted for 25% of the variation in abundance (r^2 = 0.25; $F_{1,28}$ = 9.30, P = 0.05) and 37% of variation in species richness (r^2 = 0.37; $F_{1,28}$ = 16.57, P < 0.001). Regression analysis of the number of leaf species was also related to ant assemblages (abundance:r^2 = 0.21; $F_{1,28}$ = 7.55, P = 0.01, species richness: r^2 = 0.18; $F_{1,28}$ = 6.25, P = 0.01). However, litter mass regression did not show clear relation to the presence of abundance and richness of ants; (abundance:r^2 = 0.07; $F_{1,28}$ = 1.84, P = 0.186, species richness: r^2 = 0.06; $F_{1,28}$ = 2.23, P = 0.146).

DISCUSSION

Ant species assemblages were temporally variable.

The species number of ground dwelling ants below canopies of the common trees *P. stellata*, *S. gratissima* and *I. palembanica* was not significantly different from each other within seasons. However, species richness was significantly greater in the wet season (56 spp.) than the dry season (39 spp.; Appendix A1), as has previously been recorded in Thailand (Wichaikam *et al.* 2010; Sakchoowong *et al*. 2008). In our study, leaf fall and litter under the canopies of three focal tree species produce similar patterns of micro-environment variables. In fact, none of the measured micro-environmental variables were significantly different between tree species within a season. Hence, few differences may be expected in ant species richness between the litter samples of focal tree species. Donoso *et al*. (2010) tested whether tree species differed in resource quality and quantity of leaf litter and whether more heterogeneous litter supports more arthropod species (oribatids, gamasids and ants), and found that the response specialization of these arthropods to particular tree species was low, and more heterogeneous litter between trees did not necessarily support higher diversity.

Table 2 shows that there were fewer ant indicator species in the dry season than the wet season, and species were only indicative of particular habitats in one season or the other. However, McGeoch *et al*. (2002) indicated that the percentage of the indicator value (IndVal, %) itself is also important. They reported that a species is usually considered to be characteristic of a particular habitat when its IndVal is more than 70%. According to our data, none of the ant species collected is highly indicative of a particular leaf litter microhabitat.

Ant species composition under the canopies of each focal tree species was similar. Table 3 showed that litter ant species composition found under a particular common tree species were shared about 44 to 62% (Sørensen index; 0.44- 0.62) in both the wet and dry seasons. Our result is similar to the report of Yanoviak and Kaspari (2000) that litter ants in the lowland, seasonally wet forest of Barro Colorado Island,

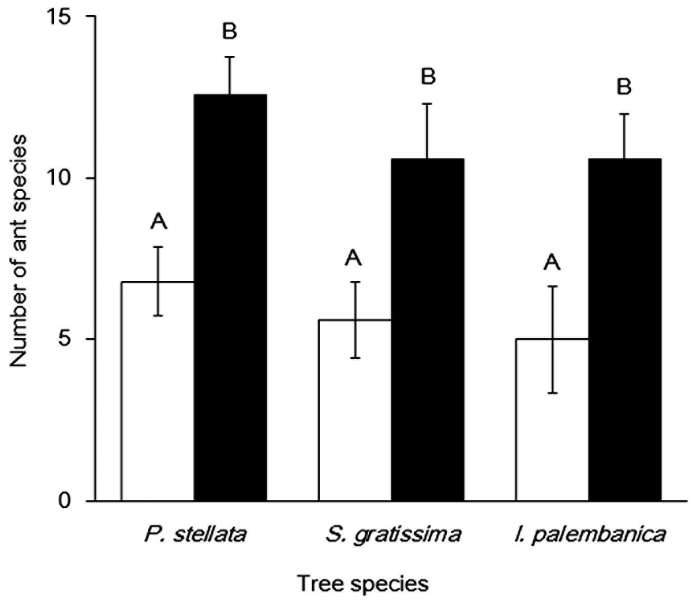

Fig. 1. Mean number (± SE) of ant species collected from litter samples below focal tree species ($N = 5$ per species) during the dry (open bars) and wet (closed bars) seasons. Different letters indicate significant differences between tree species (Tukey's tests, $P < 0.05$).

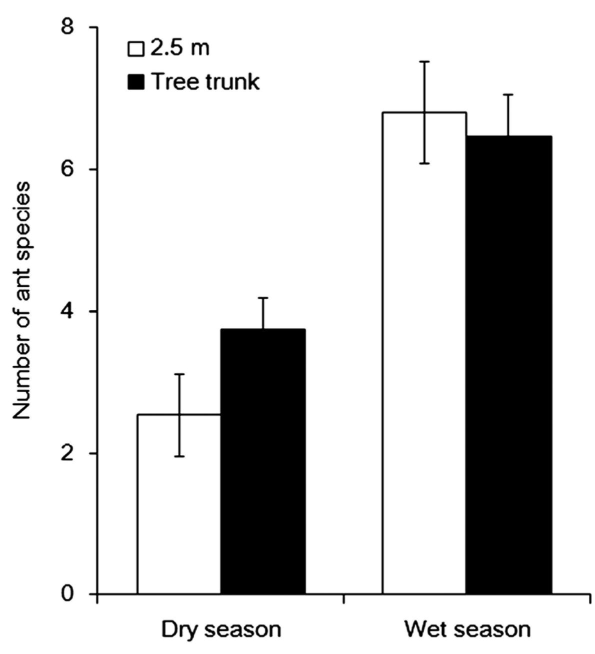

Fig. 2. Mean number (± SE) of ant species per sample collected close to tree trunks (open bars) and 2.5 m away from the tree trunks (closed bars) ($N = 15$).

Panama shared species composition among tree species about 65% (Morisita-Horn index; 0.65), while ants in the canopy between the same-pair trees in their report were three times less similar than the litter ant assemblages (Morisita-Horn index; 0.21).

How does leaf-litter composition influence ant assemblages in this lowland forest?

Figure 3 showed that leaf mass was higher in the dry season than in the wet season and litter mass varied with season but there were fewer ant species in the dry season than the wet season. These findings suggest that in this lowland forest, ant species diversity increase in the wet season did not depend on leaf mass and litter mass. Donoso *et al.* (2010) reported a similar study that ant species richness on Barrio Colorado Island did not correlate with litter depth (quantity of litter) under the tree species studied. One other variable, leaf species heterogeneity (number of leaf species) was not different between tree species (Fig. 3). Therefore, three factors in this study showed no clear relation to the increment of ant diversity. Undoubtedly, soil humidity is only a significant factor in relation to the presence of ant diversity in this study as the case that ant species richness was higher in wet season than dry season. Soil/litter humidity is a seasonal effect but why is soil/litter humidity important to the presence of arthropods? Several tropical studies also reported the important role of soil/litter humidity on soil arthropod diversity (Lieberman & Dock, 1982; Frith & Frith, 1990; Medianero *et al*. 2007).

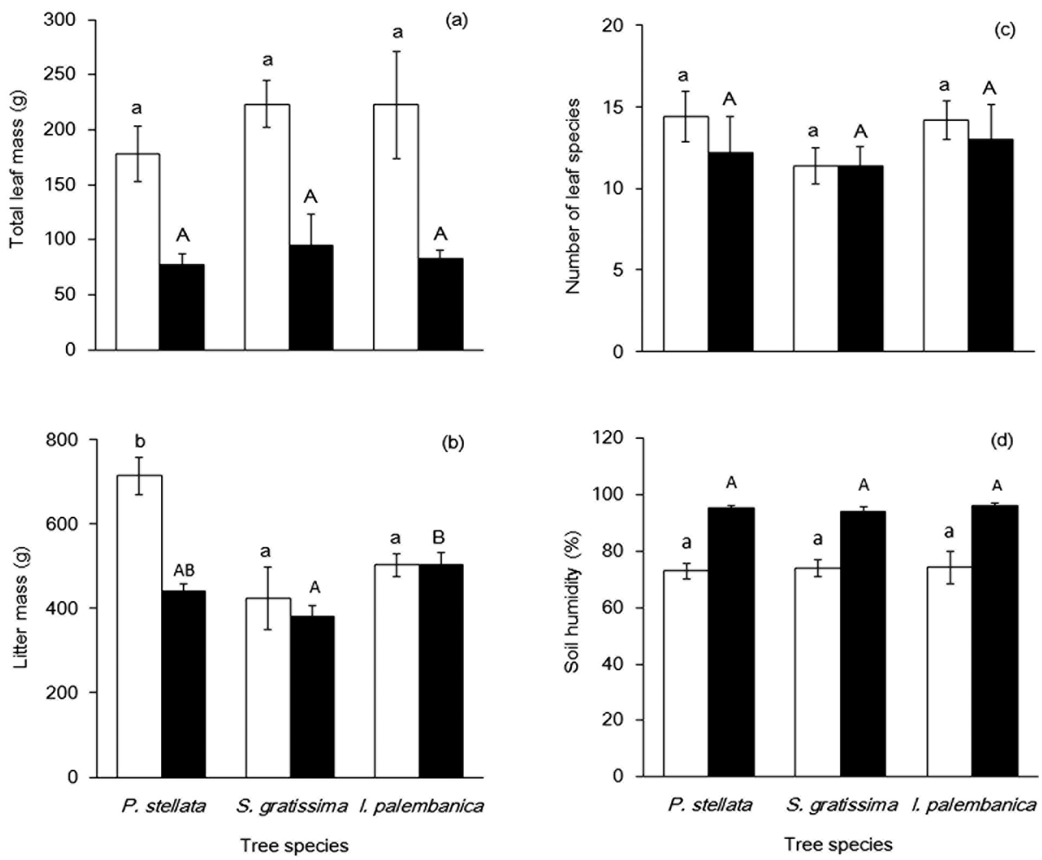

Fig. 3. Mean number (± SE) of micro-environmental variables; (a) Total leaf mass, (b) Litter mass, (c) Number of leaf species and (d) Soil humidity collected under crown of trees (N = 5 per species) during the dry (open bars) and wet (closed bars) seasons. Different letters indicate significant differences (Tukey's test, $P < 0.05$) among tree species.

Many studies of tropical insects demonstrate that humidity is crucial to the high diversity and abundance of insects in the wet season (van der Hammen & Ward, 2005; Hilt *et al*., 2007; Checa *et al*. 2014). However, further questions might arise. For instance, how does soil moisture act to increase ant diversity and why does ant diversity decrease during the dry season? Does moisture influence the availability of ant nesting sites or the abundance of small prey items eaten by predacious litter ants?

The relationship between insect diversity and biotic and abiotic factors is difficult to understand due to the complexity of biotic and abiotic conditions, particularly in tropical world. This is a challenge for future studies.

CONCLUSION

Leaf litter moisture seems to have significant effects on the diversity of litter-dwelling ants. Ant species richness was always higher in the wet season compared with the dry season. The dry season had more leaf litter but fewer ant species compared with the wet season. Ant diversity was not different between tree species in the same forest and ant species composition between tree species was approximately 50% shared.

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Appendix A1

List of ant species and number of individuals collected under the focal tree species in the 24 ha CTFS plot during the dry/wet seasons in 2010.

Habitat-under tree crown abbreviations; PS =*P. stellata*, SG = *S. gratissima* and IP = *I. palembanica*

Scientific name	Species Abbr.	Habitat-under tree crown		
		PS	SG	IP
Dolichoderinae				
Dolichoderus thoracicus (Smith, 1860)	Ant6	2 / 0	-	1 / 0
Technomyrmex kraepelini Forel, 1905	Ant66	0 / 24	0 / 8	0 / 21
Technomyrmex sp.1	Ant65	20 / 0	29 / 0	-
Ectatomminae				
Gnamptogenys sp.1	Ant8	-	28 / 6	0 / 1
Formicinae				
Acropyga acutiventris Roger, 1862	Ant82	-	-	0 / 22
Myrmoteras sp.1	Ant17	1 / 0	-	-
Nylanderia sp.1	Ant35	17 / 235	8 / 77	1 / 55
Nylanderia sp.2	Ant36	0 / 71	0 / 1	0 / 1
Paratrechina longicornis (Latreille, 1802)	Ant33	-	-	0 / 1
Prenolepis sp.1	Ant54	1 / 0	-	-
Pseudolasius sp.1	Ant58	10 / 3	-	-
Myrmicinae				
Carebara sp.1	Ant21	6 / 31	1 / 2	-
Carebara sp.2	Ant22	0 / 4	0 / 2	0 / 5
Carebara sp.3	Ant19	-	0 / 6	-
Carebara sp.4	Ant20	-	0 / 24	-
Carebara sp.5	Ant89	-	0 / 10	-
Carebara sp.6	Ant95	0 / 33	-	-
Crematogaster sp.1	Ant4	-	1 / 0	-
Crematogaster sp.2	Ant85	-	0 / 2	-
Crematogaster sp.1	Ant4	-	1 / 2	-
Eurhopalothrix sp.1	Ant7	-	-	1 / 0
Lasiomyrma sp.1	Ant75	0 / 2	-	-
Lophomyrmex sp.1	Ant13	7 / 0	27 / 229	3 / 1
Mayriella sp.1	Ant87	-	0 / 4	-
Monomorium sechellense Emery, 1894	Ant15	1 / 58	1 / 4	14 / 11
Myrmecina sp.1	Ant16	-	-	6 / 0

Pheidole sp.1	Ant37	4 / 1	-	2 / 10
Pheidole sp.2	Ant38	-	5 / 0	-
Pheidole sp.3	Ant39	-	1 / 0	-
Pheidole sp.4	Ant40	-	0 / 10	0 / 3
Pheidole sp.5	Ant41	-	-	0 / 8
Pheidole sp.6	Ant42	0 / 1	-	-
Pheidole sp.7	Ant44	0 / 4	0 / 6	0 / 3
Pheidole sp.8	Ant79	0 / 9	-	-
Pheidole sp.9	Ant47	0 / 9	-	-
Pheidologeton diversus (Jerdon, 1851)	Ant50	-	0 / 1	1 / 0
Pheidologeton sp.1	Ant51	1 / 0	-	-
Pristomyrmex pungens Mayr, 1866	Ant55	1 / 0	0 / 12	-
Pristomyrmex sp.2	Ant56	0 / 1	-	-
Proatta butteli Forel, 1912	Ant57	0 / 12	24 / 38	1 / 14
Solenopsis sp.1	Ant60	6 / 0	12 / 1	18 / 0
Strumigenys sp.1	Ant61	0 / 1	2 / 1	7 / 0
Strumigenys sp.2	Ant62	-	0 / 18	23 / 0
Strumigenys sp.3	Ant63	0 / 23	8 / 4	0 / 6
Strumigenys sp.4	Ant64	0 / 1	-	0 / 3
Strumigenys sp.5	Ant80	-	0 / 18	-
Strumigenys sp.6	Ant90	0 / 12	-	0 / 85
Strumigenys sp.7	Ant59	0 / 11	-	-
Strumigenys sp.8	Ant91	0 / 2	0 / 1	-
Tetramorium lanuginosum Mayr, 1870	Ant68	0 / 1	-	0 / 2
Tetramorium sp.1	Ant69	1 / 0	0 / 6	-
Tetramorium sp.2	Ant92	-	0 / 2	-
Vollenhovia sp.1	Ant74	-	1 / 1	-
Ponerinae				
Anochetus graeffei Mayr, 1870	Ant1	-	1 / 0	1 / 0
Hypoponera sp.1	Ant9	2 / 3	1 / 47	1 / 0
Hypoponera sp.2	Ant10	0 / 1	-	27 / 7
Hypoponera sp.3	Ant11	60 / 45	1 / 6	-
Hypoponera sp.4	Ant31	60 / 6	1 / 0	0 / 16
Leptogenys diminuta (Smith, 1857)	Ant86	0 / 2	-	-
Odontomachus rixosus Smith, 1857	Ant18	6 / 45	1 / 9	4 / 28
Brachyponera sp.1	Ant23	6 / 25	11 / 1	34 / 3
Brachyponera sp.2	Ant26	0 / 1	-	-

Brachyponera sp.3	Ant27	0 / 2	-	0 / 11
Ectomomyrmex sp.1	Ant24	1 / 0	-	1 / 0
Ectomomyrmex sp.2	Ant25	18 / 0	-	-
Bothroponera sp.1	Ant76	0 / 85	-	0 / 102
Pachycondyla sp.1	Ant78	0 / 2	-	-
Ponera sp.1	Ant52	0 / 3	0 / 1	1 / 5
Ponera sp.2	Ant53	-	1 / 0	-
Proceratiinae				
Discothyrea sp.1	Ant5	7 / 4	-	0 / 3
Probolomyrmex sp.1	Ant84	-	-	0 / 9
Total		952	722	583

Appendix A2

Total leaf mass (g) collected and identified in samples obtained from the litter below the focal tree species, detailed for the dry and wet seasons of 2010. Habitat-under tree crown abbreviations; PS =*P. stellata*, SG = *S. gratissima* and IP = *I. palembanica*. An asterisk (*) indicates the focal tree species.

Family / Scientific name	Habitat under tree crown					
	Dry season			Wet season		
	PS	SG	IP	PS	SG	IP
Achariaceae						
Hydnocarpus castanea Hook.f. & Thomson	3.79		11.25	4.61		
Ryparosa javanica (Blume) Kurz ex. Koord & Valetion	4.21		4.06	1.64		26.57
Anacardiaceae						
Bouea oppositifolia (Roxb.) Meisn.	5.03			1.71		
Mangifera sp. 1		10.75			2.19	
Parishia insignis Hook.f.	2.76	0.58			0.60	
Annonaceae						
Miliusa cf. longipes King		0.47			0.89	
Pseuduvaria rugosa (Blume) Merr.	10.06	0.72	13.34	6.46		
Xylopia malayana Hook.f. & Thomson				3.07		
Apocynaceae						
Alstonia scholaris (L.) R.Br.	4.92	46.52	124.60		25.14	11.46
Burseraceae						
Canarium denticulatum Blume				0.93	1.79	11.87
Cannabaceae						
Gironniera nervosa Planch					0.76	10.89
Chrysobalanaceae						

Maranthes corymbosa Blume				1.76		
Clusiaceae						
Calophyllum polyanthum Wall. ex Choisy	7.95	31.95		21.42		
Garcinia cf. hombroniana Pierre	14.42			16.41		5.63
Dilleniaceae						
Tetracera loureiri (Fin.& Gagnep.) Pierre ex Craib					0.31	
Dipterocarpaceae						
Dipterocarpus costatus Gaertn.f.	10.56				1.93	
Dipterocarpus grandiflorus Blanco	3.36	10.54	9.82	4.88	1.53	8.51
Parashorea stellata Kurz *	448.60		139.40	79.27		11.32
Shorea gratissima Dyer *	21.99	679.50	13.06	0.74	56.37	
Ebenaceae						
Diospyros toposia Buch.-Ham	0.64					
Euphorbiaceae						
Aporosa yunnanensis (Pax & K.Hoffm.) F.P.Metcalf	11.40		1.43	1.27		
Balakata baccata (Roxb.) Esser	0.73	5.08				
Ptychopyxis sp. 1	0.96					33.40
Fabaceae						
Cynometra malaccensis Meeuwen	25.76	2.78	1.29	15.39		
Intsia palembanica (Miq.) Baker *	3.85	0.23	281.50	1.12	0.31	32.25
Millettia atropurpurea (Wall.) Schot					3.40	6.64
Sindora coriacea (Baker) Prain.	4.02		2.48			1.04
Lauraceae						
Nothaphoebe umbelliflora (Blume) Blume	2.45					
Lecythidaceae						
Barringtonia macrostachya (Jack) Kurz.	6.16	1.76	4.96	4.36	1.11	
Leguminosae-Caesalpinioideae						
Bauhinia pottsii G. Don *var. subsessilis* (Craib) de Wit.	22.29		14.51	22.87		9.47
Malvaceae						
Heritiera elata Ridl.	0.75					
Microcos laurifolia (Hook.f. ex Mast.) Burret				0.72		1.48
Meliaceae						
Aglaia spectabilis (Miq.) Jain & Bennet	10.72					
Chisocheton macrophyllus King		1.18				
Chisocheton penduliflorus Planch. ex Hiern	0.90		1.29			
Dysoxylum alliaceum (Blume) Blume	10.19					

Dysoxylum densiflorum (Blume) Miq.	10.83		0.79	6.58		
Moraceae						
Streblus ilicifolius (Vidal) Corner	6.03	0.87	1.52			0.86
Myrtaceae						
Cleistocalyx nervosum var. paniala (Makiang)	6.71			12.82		1.52
Syzygium attenuatum (Miq.) Merr. & Perry						0.84
Syzygium polyanthum R.Br. ex Gaertn	0.81	37.66	1.51		11.92	1.98
Syzygium sp. 1	4.06				0.66	1.15
Syzygium sp. 22		1.11				
Rhizophoraceae						
Carallia cf. suffruticosa Ridl.				0.90		
Rubiaceae						
Rothmannia schoemannii (Teijsm. & Binn.) Tirveng				2.62		1.50
Salicaceae						
Osmelia maingayi King	0.28	6.11	0.92			
Sapindaceae						
Nephelium lappaceum cf. var. pallens (Hiern) Leenh			1.47			1.05
Xerospermum noronhianum (Blume) Blume	0.90			0.67	2.00	0.78
Sapotaceae						
Palaquium cf. gutta (Hook.) Burck	15.68	62.14	78.06			10.94
Unknown families						
Unknown	207.50	216.80	406.40	170.40	362.00	221.30
Total weight (g)	891.20	1117.00	1112.00	384.10	472.90	412.40
Average weight/sample (g)	178.24	223.35	222.42	76.82	94.58	82.49

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