BIODIVERSITAS ISSN: 1412-033X
Volume 24, Number 11, November 2023 E-ISSN: 2085-4722
Pages: 5937-5946 DOI: 10.13057/biodiv/d241112

Ground-dwelling ant diversity in forests and agricultural land use at Sakaerat Biosphere Reserve, Thailand

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Manuscript received: 15 June 2023. Revision accepted: 14 November 2023.

Abstract. *Khongthawie S, Hasin S, Ponpinij S, Pinkaew N. 2023. Ground-dwelling ant diversity in forests and agricultural land use at Sakaerat Biosphere Reserve, Thailand. Biodiversitas 24: 5937-5946.* Ants play essential roles in terrestrial ecosystems, for example, soil engineers, seed dispersers, biological control agents, and indicators to monitor environmental stress and disturbance. This research aimed to study the diversity and community composition of ground-dwelling ants at Sakaerat Biosphere Reserve and its surrounding areas. Pitfall traps collected ground-dwelling ants from three habitat types: agricultural areas, dry dipterocarp forests, and dry evergreen forests; the environmental factor in this work was soil temperature. The results revealed that 109 ant species in 40 genera belonging to 8 subfamilies. Notably, the dry dipterocarp forest exhibited the highest ant diversity with 71 species, followed by the dry evergreen forest and agricultural area with 62 and 54 species, respectively. Overall, the present study reveals that soil temperature and vegetation significantly influenced ant species composition; ant species being more likely to be found in forests than in agricultural areas, and species classified as uncommon groups based on occurrence were the largest group in every study site. Besides, the information on ant species obtained from this work had the potential to be used as bioindicator species for ecosystem management and human impacts on forests.

Keywords: Agriculture, ants, diversity, forest, Sakaerat Biosphere Reserve

INTRODUCTION

Ants are an ecologically important insect group widespread through terrestrial ecosystems worldwide (Kass et al. 2022). They play vital roles in terrestrial ecosystems as soil engineers (Wu et al. 2015(, seed dispersers (Ortiz et al. 2021), biological control agents (Offenberg 2015), and biological indicators to assess the impacts of human activities on land utilization (Gerlach et al. 2013). Notably, the different diversity and composition patterns of ants result from several circumstances, including the mechanisms combined with spatial variation of diverse landscapes such as microclimatic variation (e.g., temperature, moisture content, specific shelter) (Gordon et al. 2013; Reymond et al. 2013; Fernandez et al. 2014; García-Martínez et al. 2015; Almeida et al. 2023), species interactions (Dejean et al. 2015; Baidya and Bagchi 2021), vegetation characteristics (Thongphak and Kulsa 2014; Ahuatzin et al. 2019), soil type (Glasier et al. 2019), geographical factors (Cerdá et al. 2012; Guilherme et al. 2022), climate or season variables, (Andersen et al. 2015; Del Toro et al. 2015; de Queiroz et al. 2022) and elevation variables (Bharti et al. 2013; Subedi et al. 2021). Indeed, the factors and mechanisms in spatial scale at landscape heterogeneity and land-use play as ant dispersal and richness limitation (Cuautle et al. 2016; Assis et al. 2018; Rabello et al. 2021; Zhang et al. 2022). These topics are often reported as the result of species distribution and diversity patterns. Notably, the influence of the growing season, food source, and reproduction cycle correspond with the change in ant diversity and population (Philpott et al. 2010).

Habitats with closed canopies are important sources of increasing ant assemblages. According to Lawes et al. (2017), the aged restoration forest positively influenced ant diversity due to the dense closed canopy, indicating a positive restoration trend for fauna and plants. Ants are somewhat sensitive to habitat change, where many studies illustrated that the landscape transformation of forest to agriculture negatively affected ant diversity and functional groups (Urrutia-Escobar and Armbrecht 2013; García-Martínez et al. 2015; Rubiana et al. 2015; de Queiroz et al. 2020). Besides, an intensive agricultural practice resulted in the loss of ant biodiversity (Masoni et al. 2017). However, protecting forests surrounding agricultural areas will conserve reservoirs of biodiversity (García-Martínez et al. 2015). Recently, researchers have introduced the utilization of ant populations in terrestrial ecosystems as biological indicators to assess the impact of human activities on land utilization (Gerlach et al. 2013; de Castro Solar et al. 2016; Dalle Laste et al. 2019; de Queiroz et al. 2020). Therefore, assessing ants' biodiversity and community composition in forests and surrounding agricultural areas is beneficial for land use management (Urrutia-Escobar and Armbrecht 2013).

Sakaerat Biosphere Reserve (SBR) was established in 1967 and certificated by the United Nations Educational Scientific and Cultural Organization (UNESCO) under the Man and Biosphere (UNESCO 2019). The biosphere reserve is a valuable habitat for biodiversity, established for biodiversity conservation in forest and non-forest ecosystems. SBR mainly comprises dry evergreen, mixed deciduous, dry dipterocarp, and reforested areas. The surrounding areas are covered by agricultural areas, forests, and economic plantations, where forest ecotones present as transitional belts between forest areas and surrounding areas with the protected interior of forest biodiversity. Forest ecotones are areas of steep transition between ecosystems, and they support unique ecological dynamics with become significant elements of heterogeneous landscapes (Kark 2013).

Herein, we examined the ground-dwelling ant diversity inhabiting forest and non-forest areas, including the agricultural area, dry dipterocarp forest, and dry evergreen forest at the SBR. Regarding the previous findings, there are two hypotheses in this study: i) ant diversity and community composition are more likely to be detected in forests than in agricultural areas, and ii) soil temperature in agricultural areas is higher than in forest areas. Indeed, these variables (e.g., temperature and vegetation type) greatly influence ant species composition.

MATERIALS AND METHODS

Study area

The Sakaerat Biosphere Reserve (SBR) is located in Nakhon Ratchasima province (14°26′ to 14° 32′ N, 101° 50′ to 101° 57′ E; 280-762 m above sea level), Thailand. The area of this research station is about 78.08 km^2. The main vegetation covered by the SBR consists of dry dipterocarp forest and dry evergreen forest, and the remaining areas are bamboo, plantation forest, and grassland. The north and south of the SBR are surrounded by agricultural fields (Figure 1) (UNESCO 2019). The average annual temperature at Sakaerat is 26.8°C. The lowest and highest temperature occurs in December and April at about 17.8°C and 34.1°C, respectively. The lowest relative humidity is about 76.9% in February, and the highest is about 86.7% in September. The average annual rainfall is 1,134.7 mm. Average monthly rainfall is relatively low from December to February (about 4.9-16.0 mm).

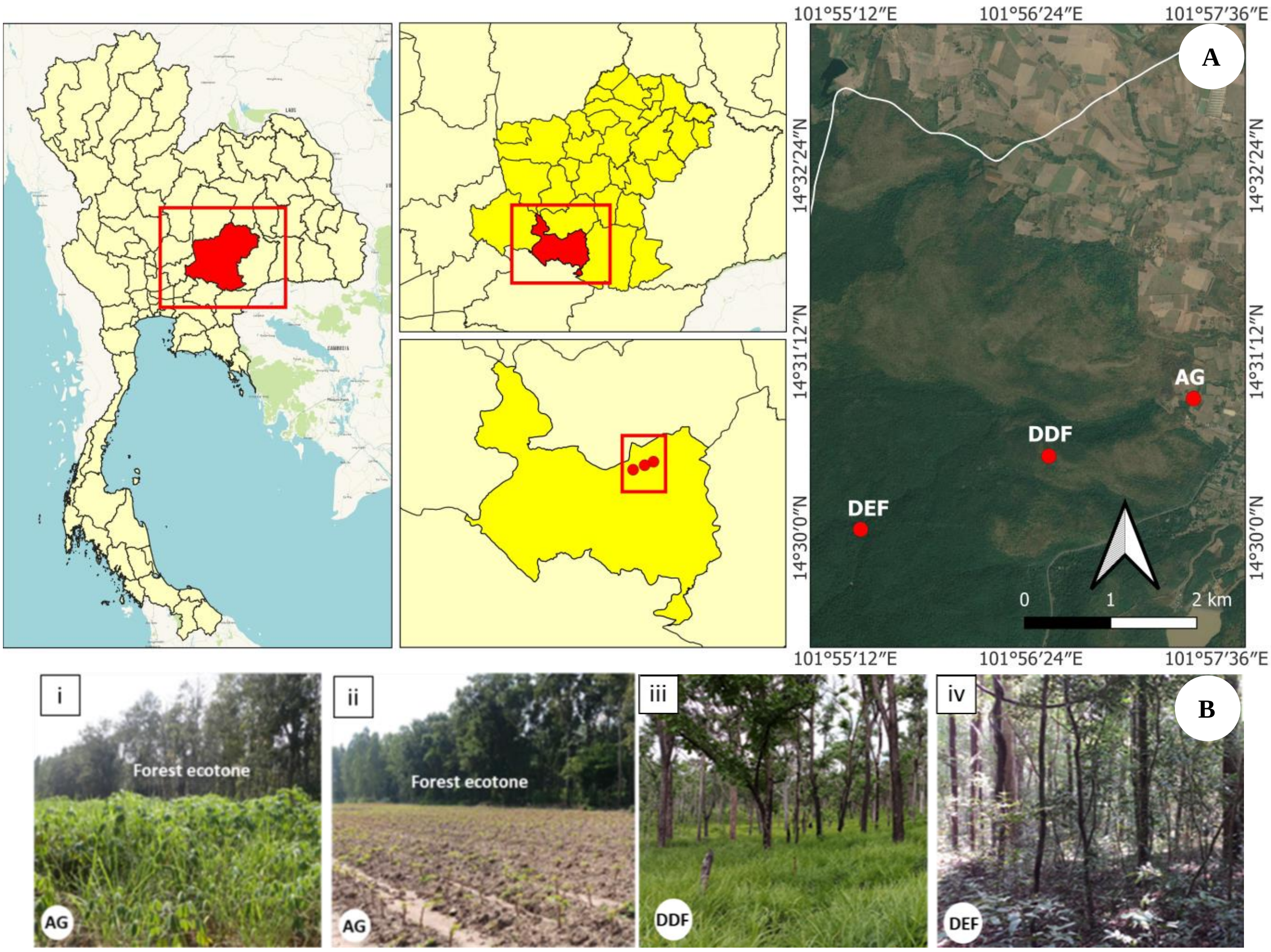

Figure 1. A. Map of the study sites and sampling plots from three different vegetation types at SBR, B. The photo of: i. The Agricultural area (AG) of the cassava crop before harvesting, ii. The cassava crop after plantation, iii. Dry Dipterocarp Forest (DDF), and iv. Dry Evergreen Forest (DEF)

This study examined 3 different vegetation types at SBR and surrounding areas (Figure 1), including Agricultural area (AG), Dry Dipterocarp Forest (DDF), and Dry Evergreen Forest (DEF). AG was adjacent to DDF in the north part of SBR. For this study, agricultural plots were located 100-500 m from the ecotone of two vegetation types. The distance between the study sites was approximately 2 km. This area was a cornfield and cassava field usually used for year-round cultivation. The DDF, dominant tree species were *Shorea obtusa*, *Shorea siamensis*, *Dipterocarpus intricatus*, *Pentacme suavis*, *Shorea floribunda*, and *Pterocarpus macrocarpus*. Tree seedlings and grasses covered the Forest floor; the DEF was in the core zone of SBR. Dominant plant species, including *Hopea ferrea*, *Hopea odorata*, *Shorea sericeiflora*, *Afzelia xylocrapa*, and *Hydnocarpus ilicifolius*, and the canopy trees were approximately 30 to 40 m (SERS 2015).

Collection of ants and environmental variable

Ground-dwelling ants were collected using pitfall traps. Three 40×40 m^2 sampling plots were conducted at each study area. The distance between sampling plots in each study area was at least 100 m apart. Each sampling plot was divided into 10×10 m^2 (16 subplots/sampling plot). Then, the pitfall trap was placed at the center of each subplot. A cylindrical plastic cup with diameter and depth of 9 and 7 cm, respectively, filled with the mixture solution of 70% ethyl alcohol and surfactant. It was buried to ground level at the center of each subplot, covered with a plastic roof, and left for 72 hours every two months in 2018. Ground-dwelling ants were identified and classified based on Hölldobler and Wilson (1990) and Bolton et al. (2006). Soil temperature was measured using Shinwa Sokutei Digital Thermometer (73081) at a 5 cm depth of plot level, and the thermometer was allowed to stabilize for 1 minute before reading. The measurement was taken at five points next to the pitfall trap in subplots at the center and four corners.

Data analysis

Biodiversity and community composition of ground-dwelling ants were described, comprising species richness, Shannon diversity, Simpson diversity, species evenness, and frequency of occurrence. Species richness and diversity were described based on Hill numbers (Jost 2006; Chao et al. 2014). Hill numbers (q): species richness (q=0), Shannon diversity (q=1, the exponential of Shannon entropy), and Simpson diversity (q=2, the inverse of Simpson concentration), the observed sample of incidence data of ants in each plot was computed by iNEXT package (Hsieh et al. 2022) in R software 4.3.1 (R Core Team 2023) with the associated 95% confidence intervals by a bootstrap method based on 999 replications and plot Sample-size-based rarefaction and extrapolation sampling curves.

The evenness was calculated using the PAST program for Windows version 3.0. The normality distribution and homogeneity of the data were confirmed before analysis using the Shapiro-Wilk test. Non-distributed variables were transformed to improve normality before statistical analysis. One-way ANOVA was conducted to compare all indices to test differences in vegetation types (AG, DDF, DEF). Pairwise comparisons (least significant difference post hoc tests; LSD) were performed when the differences were considered significant at $p<0.001$ using IBM SPSS Statistics 23.

The frequency of occurrence of each ground-dwelling ant species in each study area was analyzed using the presence or absence of ants (percentage of the number of occupied sampling plots/total number of sampling plots of each study area).

Ants were divided into 3 groups using the frequency of occurrence values (Hasin and Booncher 2020; Hasin and Tasen 2020), where a value in the range of 1-35% was considered as an uncommon ant group, a value in the range 36-70% was considered as a common ant group and a value in the range 71-100% was considered as the dominant ant group.

Permutational Multivariate Analysis of Variance (PERMANOVA; Clarke 1993) was used to test the difference in ant species composition (frequency of occurrence) between habitat types. This method used the "adonis2" function in the vegan package in R (Oksanen et al. 2022) with 999 randomizations and the Bray-Curtis index as the dissimilarity measurement.

Non-metric Multidimensional Scaling (NMDS; Kruskal 1964) was performed to examine the trends of community composition (frequency of occurrence) using the function "metaMDS" with Bray-Curtis dissimilarity index calculation. Temperature values (continuous variable) were displayed as contour lines using the "ordisurf" function with vegetation and species composition data. The NMDS analysis was implemented with R software (R Core Team 2023) using the vegan package (Oksanen et al. 2022).

RESULTS AND DISCUSSION

Ant diversity and composition

In this study, 149,606 ants were collected by 864 pitfall traps in three land types: AG, DDF, and DEF. The results revealed 109 ant species, comprising 40 genera belonging to 8 subfamilies. Ground-dwelling ants' species richness and diversity were based on Hill numbers of three habitat types demonstrated as sample-size-based rarefaction and extrapolation curves. The results showed that DDF exhibited more ant species for species richness, although the confidence intervals overlapped in the extrapolation range. Consequently, Shannon diversity and Simpson diversity were the highest values in DDF, significantly different from DEF and AG. At the same time, DEF was slightly higher than AG with the overlapped confidence intervals of rarefaction and extrapolation (Figure 2). Therefore, for the three orders of Hill numbers, the diversity of ants in vegetation was DDF>DEF>AG. In addition, the evenness was greater in the DDF (0.71±0.03) and the AG (0.67±0.03) compared to that of the DEF (0.57±0.02: $p<0.001$: Figure 3).

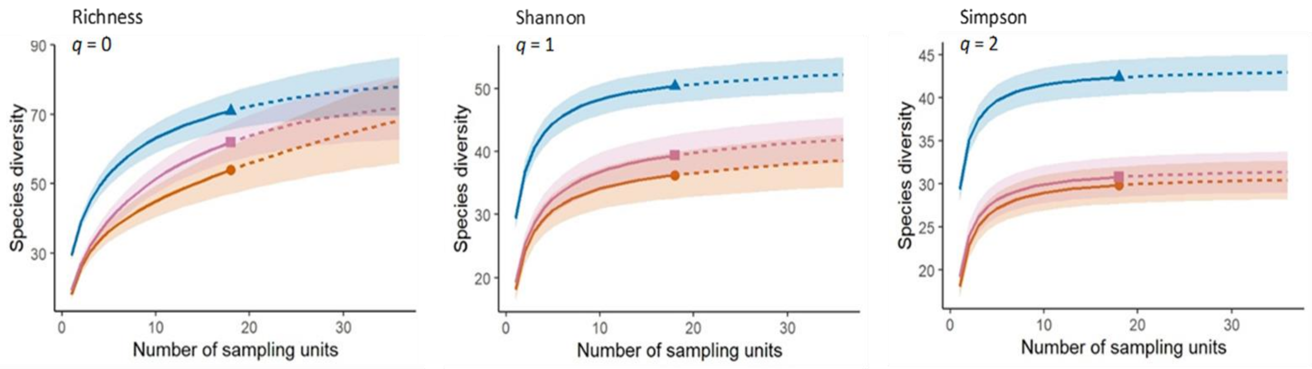

Figure 2. Sample-size-based rarefaction (solid line) and extrapolation (dashed line) curves for ant species diversity based on Hill numbers (q) of three habitats with 95% confidence intervals; A. Species richness (q=0), B. Shannon diversity (q=1), and C. Simpson diversity (q=2). Orange circles, lines, and buffers: Agricultural area (AG); Pink squares, lines, and buffers: Dry Evergreen Forest (DEF); Blue triangles, lines, and buffers: Dry Dipterocarp Forest (DDF)

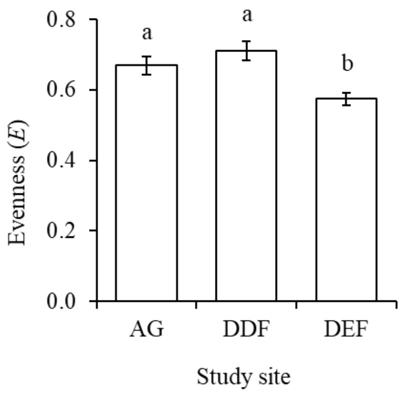

Figure 3. Comparison among average (±SE) values of evenness in each study site. Significantly differences were presented by the difference in lowercase letters at each bar (p<0.001)

Ant community was separated into 3 groups using the value of the frequency of occurrence, which diverged among study sites (Figure 4). Notably, the largest number of uncommon ant groups was observed in the AG, with 33 species (61% of all species collected in AG). In comparison, the common ant group with 13 species (24%) and the dominant ant group with 8 species (15%) were revealed in AG, as can be seen in Figure 4A. Three ant species, *Anoplolepis gracilipes* F. (Smith, 1857); (*Pheidole butteli* Forel, 1913); and *Iridomyrmex anceps* (Roger, 1863), were the most common. In the DDF, uncommon ant species were also dominant. The uncommon ant group with 42 species (59% of all species) was revealed, followed by the dominant ant group and common ant group with 20 species (28%) and 9 species (13%), respectively (Figure 4.B). Five ant species, including *A. gracilipes*, *Nylanderia* sp.1, *Odontoponera denticulata* (Smith, 1858), *Diacamma rugosum* Le Guillou, 1842, and *Camponotus rufoglaucus* (Jerdon, 1851), were the most common. Similarly, the uncommon ant group also dominated in DEF with 43 species (70% of all species collected). Also, Figure 4C displayed the dominant ant group and common ant group found in DEF, with 12 species (19%) and 7 species (11%), respectively. Three ant species, including *O. denticulata*, *Monomorium* sp.1, and *Pheidole plagiaria* (Smith, 1860), were the most common.

Relationship between environmental factors and ant community

The PERMANOVA results showed the strong influence of vegetation type (R^2 = 0.472, F = 28.394, p<0.001) and temperature (R^2 = 0.113, F = 13.556, p<0.001) of experimental plots on ground-dwelling ant species composition (Table 1). Then, NMDS ordination into two dimensions represented the clear groups of each vegetation type in temperature gradient (stress = 0.116). The NMDS surface fitting plots considerably correlated species composition and temperature (R^2 = 0.245, F = 0.34, p<0.001) (Table S2). AG plots were grouped in the high-temperature gradient, followed by DDF and DEF; the DEF plots were located in the lower-temperature gradient (Figure 5.A). Moreover, *I. anceps*, *Solenopsis geminata* (Fabricius, 1804), *Meranoplus bicolor* (Guérin-Méneville, 1844), and *Paratrechina longicornis* (Latreille, 1802) were likely to be found with a high frequency of occurrence in the high-temperature AG area (Figure 5.B, Table S1). The ground-dwelling ants related to low temperature were almost the species in genera *Leptogenys* and *Aenictus*, particularly *Leptogenys kitteli* (Mayr, 1870), which was found to have a high frequency of occurrence in DEF (Figure 5.B, Table S1). DDF plots grouped on intermediate temperature gradient, with high species richness of genera *Camponotus* and *Crematogaster* observed. Then, *C. rufoglaucus* reached a high frequency of occurrence in this area (Figure 5.B, Table S1).

Table 1. Permutational Multivariate Analysis of Variance (PERMANOVA) described the relationship between ant composition and environmental variables, including soil temperature and vegetation

Predictor	***df***	**Sum of squares**	R^2	F	p
Temperature	1	1.472	0.113	13.556	<0.001***
Vegetation	2	6.166	0.472	28.394	<0.001***
Residual	50	5.429	0.415		
Total	53	13.067	1.000		

Note: ***Significant $p<0.001$ (p values determined by permutation)

Table S1. Frequency of occurrence of ground-dwelling ants of each study site (N=18). Acronym: Agricultural area (AG), Dry Dipterocarp Forest (DDF), and Dry Evergreen Forest (DEF)

Subfamily/species	**Abbr.**	**Frequency of occurrence (%)**			
		AG	**DDF**	**DEF**	**Total (N=54)**
Amblyoponinae					
Stigmatomma reclinatum (Mayr, 1879)	AM	5.6	-	-	1.9
Dolichoderinae					
Dolichoderus thoracicus (Smith, 1860)	Pd	-	-	5.6	1.9
Iridomyrmex anceps (Roger, 1863)	DLi	100	-	-	33.3
Philidris cordata fusca (Forel, 1901)	DLp	-	-	16.7	5.6
Tapinoma melanocephalum (Fabricius, 1793)	DLt1	50.0	66.7	38.9	51.9
Technomyrmex kraepelini (Forel, 1905)	DLtk	5.6	27.8	44.4	25.9
Technomyrmex modiglianii (Emery, 1900)	DLts	5.6	61.1	5.6	24.1
Dorylinae					
Aenictus binghamii (Forel, 1900)	AE1	5.6	22.2	11.1	13.0
Aenictus dentatus (Forel, 1911)	AE2	5.6	27.8	11.1	14.8
Aenictus javanus (Emery, 1896)	AE3	-	-	11.1	3.7
Aenictus laeviceps (Smith, 1857)	AE4	-	-	11.1	3.7
Aenictus peguensis (Emery, 1895)	AE5	-	5.6	5.6	3.7
Aenictus sp.1	AE6	-	5.6	-	1.9
Aenictus sp.2	AE7	-	-	5.6	1.9
Aenictus sp.3	AE8	5.6	-	-	1.9
Cerapachys sulcinodis (Emery, 1889)	DRc1	-	-	27.8	9.3
Cerapachys sp.	DRc2	33.3	-	-	11.1
Dorylus laevigatus (Smith, 1857)	DRd	5.6	-	-	1.9
Ectatomminae					
Stictoponera binghamii (Forel, 1900)	Egb	-	-	11.1	3.7
Formicinae					
Anoplolepis gracilipes F. (Smith, 1857)	Fag	100	100	83.3	94.4
Camponotus rufoglaucus (Jerdon, 1851)	Fcr	11.1	100	-	37.0
Camponotus sericeus (Fabricius, 1798)	Fc1	5.6	16.7	22.2	14.8
Camponotus sp.1	Fc2	-	50.0	-	16.7
Camponotus sp.2	Fc3	-	-	5.6	1.9
Nylanderia sp.1	Fn	83.3	100	33.3	72.2
Nylanderia sp.2	Fpa	5.6	5.6	16.7	9.3
Nylanderia sp.3	DLt2	-	22.2	-	7.4
Paratrechina longicornis (Latreille, 1802)	Fpl	94.4	16.7	-	37.0
Plagiolepis sp.1	Fp1	-	22.2	-	7.4
Plagiolepis sp.2	Fp2	22.2	50.0	-	24.1
Polyrhachis halidayi (Emery, 1889)	Fpo	5.6	16.7	-	7.4
Pseudolasius silvestrii (Wheeler, 1927)	Fps	-	-	16.7	5.6
Myrmicinae					
Cardiocondyla emeryi (Forel, 1881)	Mce	38.9	27.8	-	22.2
Cardiocondyla nuda (Mayr, 1866)	Mcn	77.8	11.1	-	29.6
Cardiocondyla wroughtonii (Forel, 1890)	Mcw	11.1	5.6	-	5.6
Carebara affinis (Jerdon, 1851)	Mca	-	38.9	44.4	27.8
Carebara diversa (Jerdon, 1851)	Mcd	55.6	94.4	27.8	59.3
Carebara sp.1	Mc1	5.6	-	-	1.9
Carebara sp.2	Mc2	-	-	5.6	1.9
Carebara sp.3	Mc3	-	5.6	-	1.9
Crematogaster aurita (Karavaiev, 1935)	Mcr1	50.0	66.7	-	38.9
Crematogaster rogenhoferi (Mayr, 1879)	Mcr	-	38.9	-	13.0
Crematogaster sp.1	Mcr2	-	27.8	-	9.3
Crematogaster sp.2	Mcr3	-	16.7	16.7	11.1
Crematogaster sp.3	Mcr4	-	83.3	11.1	31.5
Crematogaster sp.4	Mcr5	-	16.7	-	5.6

Crematogaster sp.5	Mcr6	-	-	11.1	3.7
Crematogaster sp.6	Mcr7	-	-	11.1	3.7
Crematogaster sp.7	Mcr8	-	5.6	-	1.9
Meranoplus bicolor (Guérin-Méneville, 1844)	Mmb	72.2	27.8	-	33.3
Meranoplus sp.	Mm1	-	11.1	-	3.7
Monomorium pharaonis (Linnaeus, 1758)	Mmp	27.8	61.1	72.2	53.7
Monomorium sp.1	Mmo1	50.0	94.4	100	81.5
Monomorium sp.2	Mmo2	22.2	-	-	7.4
Monomorium talpa (Bolton, 1987)	Mmt	16.7	11.1	11.1	13.0
Mayriella transfuga (Baroni Urbani, 1977)	Mmy	-	16.7	-	5.6
Oligomyrmex sp.1	Mo1	-	5.6	88.9	31.5
Oligomyrmex sp.2	Mo2	-	-	11.1	3.7
Oligomyrmex sp.3	Mo3	11.1	-	5.6	5.6
Pheidole butteli (Forel, 1913)	Mp5	100	94.4	27.8	74.1
Pheidole fervens (Smith, 1858)	Mp3	-	88.9	5.6	31.5
Pheidole longipes (Latreille, 1802)	Mpl	-	5.6	55.6	20.4
Pheidole plagiaria (Smith, 1860)	Mp1	66.7	88.9	100	85.2
Pheidole rabo (Forel, 1913)	Mp7	11.1	11.1	83.3	35.2
Pheidole yeensis (Forel, 1902)	Mp2	-	72.2	5.6	25.9
Pheidole sp.1	Mp4	-	-	33.3	11.1
Pheidole sp.2	Mp6	27.8	77.8	-	35.2
Pheidole sp.3	Mp8	16.7	94.4	66.7	59.3
Pheidole sp.4	Mp9	16.7	72.2	16.7	35.2
Pheidole sp.5	Mp10	-	-	88.9	29.6
Pheidole sp.6	Mp11	-	-	5.6	1.9
Pheidole sp.7	Mp12	5.6	-	-	1.9
Pheidole sp.8	Mp13	5.6	-	-	1.9
Recurvidris recurvispinosa (Forel, 1890)	Mr	-	27.8	-	9.3
Strumigenys sp.	Ms	-	11.1	-	3.7
Solenopsis geminata (Fabricius, 1804)	Msg	61.1	-	-	20.4
Tetramorium aptum (Bolton, 1977)	Mt1	44.4	94.4	16.7	51.9
Tetramorium cuneinode (Bolton, 1977)	Mt5	27.8	33.3	-	20.4
Tetramorium lanuginosum (Mayr, 1870)	Mtl	-	22.2	83.3	35.2
Tetramorium nacta (Bolton, 1976)	Mt6	-	-	5.6	1.9
Tetramorium simillimum (Smith, 1851)	Mts	66.7	-	-	22.2
Tetramorium smithi (Mayr, 1879)	Mts1	66.7	33.3	-	33.3
Tetramorium walshi (Forel, 1890)	Mtw	77.8	94.4	-	57.4
Tetramorium sp.1	Mt2	-	38.9	-	13.0
Tetramorium sp.2	Mt3	-	27.8	94.4	40.7
Tetramorium sp.3	Mt4	-	5.6	38.9	14.8
Trichomyrmex destructor (Jerdon, 1851)	Mmd	55.6	88.9	5.6	50.0
Vollenhovia emeryi (Wheeler, 1906)	Mv	-	5.6	-	1.9
Ponerinae					
Anochetus graeffei (Mayr, 1870)	AE9	-	-	16.7	5.6
Brachyponera luteipes (Mayr, 1862)	Pplu	5.6	33.3	-	13.0
Diacamma rugosum (Le Guillou, 1842)	Pdr	44.4	100	83.3	75.9
Diacamma vagans (Smith, 1860)	Pdv	-	72.2	-	24.1
Ectomomyrmex astutus (Smith, 1858)	Ppa	-	11.1	5.6	5.6
Ectomomyrmex annamitus (André, 1892)	Pp1	-	-	5.6	1.9
Ectomomyrmex leeuwenhoeki (Forel, 1886)	Ppl	-	5.6	-	1.9
Hypoponera sp.1	Ph1	27.8	88.9	50.0	55.6
Hypoponera sp.2	Ph2	16.7	-	-	5.6
Leptogenys birmana (Forel, 1900)	Plb	-	-	5.6	1.9
Leptogenys diminuta (Smith, 1857)	Pld	5.6	5.6	-	3.7
Leptogenys kitteli (Mayr, 1870)	Plk	5.6	-	77.8	27.8
Leptogenys myops (Emery, 1887)	Pl1	5.6	-	5.6	3.7
Leptogenys sp.	Pl2	5.6	11.1	-	5.6
Leptogenys atra (Arimoto and Yamane, 2018)	Pl3	-	-	16.7	5.6
Leptogenys cyanicatena (Arimoto and Yamane, 2018)	Pl4	-	5.6	5.6	3.7
Myopias maligna punctigera (Emery, 1900)	Pm	-	-	5.6	1.9
Odontomachus rixosus (Smith, 1857)	Por	-	-	11.1	3.7
Odontoponera denticulata (Smith, 1858)	Pod	55.6	100	100	85.2
Platythyrea parallela (Smith, 1859)	Ppt	-	22.2	-	7.4
Pseudomyrmecinae					
Tetraponera attenuata (Smith, 1877)	Mta	-	11.1	-	3.7
Total of subfamily		6	6	6	8
Total of species		54	71	62	109

Table S2. The NMDS surface fitting results which were based on species composition and continuous variable (temperature) in SBR

Results of NMDS surface fitting				
Family: Gaussian				
Link function: Identity				
Parametric coefficients:				
	Estimate	*Std. Error*	*t value*	*Pr(>|t|)*
(Intercept)	26.796	0.467	57.41	<2e-16***
Approximate significance of smooth terms:				
	edf	*Ref.df*	*F*	*p-value*
te(x1,x2)	3.138	53	0.34	0.000591***
R-sq.(adj) = 0.245				
Deviance explained = 28.9%				
-REML = 145.3, Scale est. = 11.766, n = 54				

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

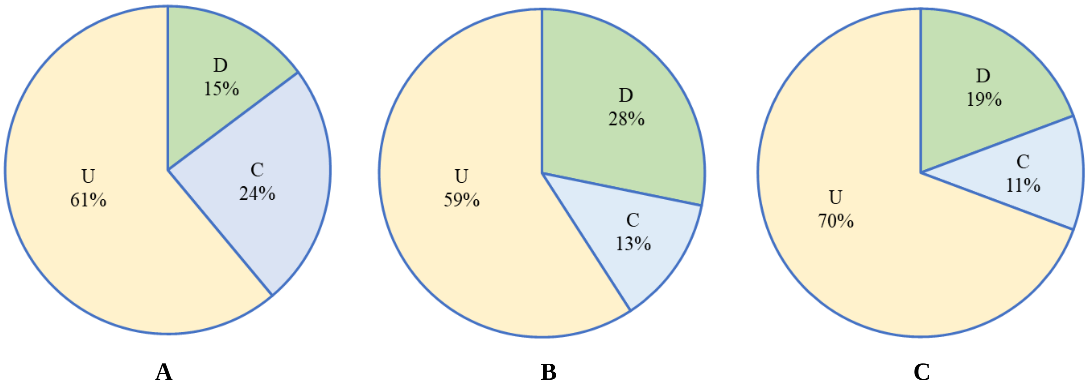

Figure 4. Proportion values of ant species groups in the: A. AG, B. DDF, and C. DEF. U: uncommon ant group, C: common ant group, D: dominant ant group

Discussion

The DDF exhibited the highest ant diversity, with 71 species, followed by the DEF and AG, with 62 and 54 species, respectively. Interestingly, DDF and DEF highlighted unique species not detected in AG. These results were likely associated with the natural phenomenon that ant diversity and communities are influenced by habitat type, vegetation management, and effects of culture establishment (de Castro Solar et al. 2016; Narváez-Vásquez et al. 2021; Wilker et al. 2023).

In comparing the proportion of indicator species groups among study sites, it was found that the dominant-group in AG had the lowest proportion. In contrast, the proportions of the DDF and DEF dominant groups were higher than AG. This observation may be associated with various consequences in AG, including tillage and agricultural practices (Pacheco et al. 2013; Rocher et al. 2022). The forest ecosystem in SBR is more stable than that of the AG, resulting from vegetation cover and less disturbance by human activities. Besides, considering the dominant groups in the forests can indicate the abundance of food supplies. For example, ant species of the genera *Leptogenys* were more diverse in DEF than in other study sites and had a high frequency of occurrence (*Leptogenys kitteli*). The genus *Leptogenys* were mostly prey specialists such as terrestrial isopods, termites, and large millipedes (Li et al. 2013; Schmidt and Shattuck 2014; Peeters and De Greef 2015; Hoenle 2021). Therefore, they were classified as specialist predators of ant functional groups (Andersen 1995; Bharti et al. 2013).

The DDF had the most diversity of the dominant groups. *Camponotus rufoglaucus* was one of the dominant species and represented the areas covered by trees. In this study, *C. rufoglaucus* was dominant in DDF and randomly found in agricultural sites adjacent to DDF. Many species of the *Camponotus* were classified as Subordinate Camponotini of ant functional groups (Bharti et al. 2013; Luo et al. 2023), resulting in a positive response to tree planting. The abundance and richness of *Camponotus* were higher under tree canopies than in open areas. Therefore, this genus represented woodlands and greater croplands. An association with trees of *Camponotus* corresponds with honeydew, a key dietary requirement for these ants (Parkhurst et al. 2021).

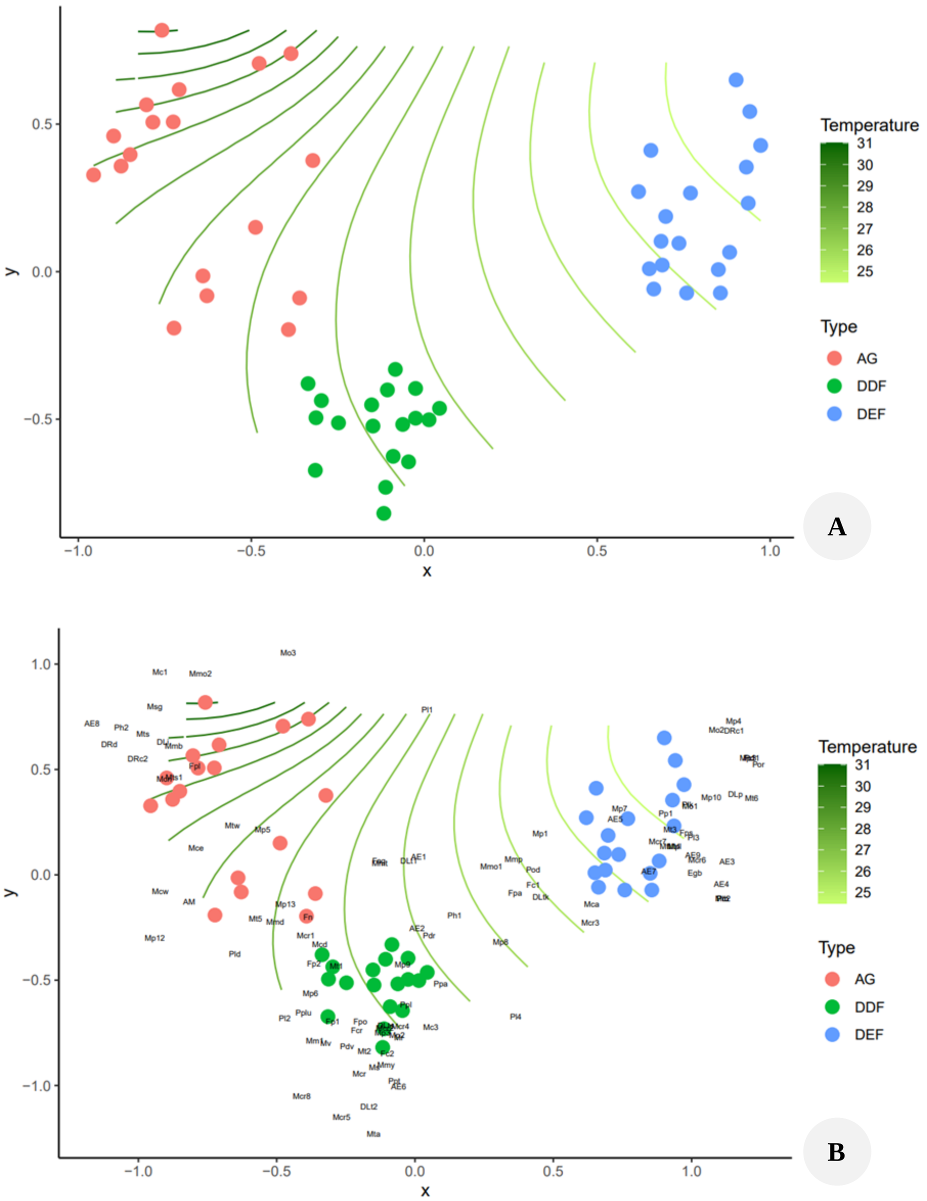

Figure 5. Non-metric Multidimensional Scaling (NMDS) plots of ground-dwelling ant composition in various habitat types in SBR (stress = 0.116). Temperature was fitted as two-dimensional smooth surfaces with: A. Vegetation type and B. Vegetation type and species. The fill circles demonstrated vegetation type; red circles, green circles, and blue circles indicated the plots of Agricultural area (AG), Dry Dipterocarp Forest (DDF), and Dry Evergreen Forest (DEF), respectively. Species list and codes were provided in Supplementary Table S1

Interestingly, two ant species, *Iridomyrmex anceps*, and *Solenopsis geminata*, predominated, with at least 61% of the frequency of occurrence. Their relatively high abundance in agricultural sites combined with they are a member of omnivorous regimes (Agosti et al. 2000). *Iridomyrmex anceps* was classified as Dominant Dolicoderinae, and *S. geminata* was classified as a hot climate specialist (Andersen 1995; Bharti et al. 2013); both groups were preeminent in a hot and open environment. This observation is likely attributed to their ecological dominance in agricultural areas (Agosti et al. 2000; Arnan et al. 2011; Cerdá et al. 2012; Reymond et al. 2013) as occurs in the other most common ant species (*Anoplolepis gracilipes* and *Pheidole butteli*) of AG, which the results of NMDS, and frequency of occurrence in this area classify them. This also highlights their potential function as effective indicator species within the agricultural ecosystem.

A high proportion of uncommon ant groups was obtained, with at least 59% in every study site. This was likely associated with the activity of this group, frequently reducing the abundance and foraging success. In these cases, it might be affected by competition in food, habitat, and climate conditions (Agosti et al. 2000). Noticeably, a similar phenomenon was also detected in the dominant species. These groups have less occurrence proportion in every study site. Their competitive forces may appear to be the major mechanism organizing the foraging activity of each other species (Retana and Cerdá 2000).

Another dominant group of this study, *Meranoplus bicolor*, had a high frequency of occurrence in AG, and, indeed, it can be found in DDF while it is absent in the DEF. The species was positively related to high soil temperature, as shown in the NMDS results. These results revealed that *M. bicolor* is the most common species in open areas, disturbed environments, and open forest canopies. This genus was classified as a hot climate specialist in ant functional groups (Andersen 1995; Bharti et al. 2013). The important role of this species is associated with seed distribution in the ecosystem. Notably, regarding the previous studies by other research groups, this ant works as a seed predator or disperser, depending on the plant (Majer 1982; Andersen and Lonsdale 1990). Moreover, *M. bicolor* is the unique ant species for open areas or open canopy with criteria of physical and biological factors, including high temperature and vegetation, which occurred in DDF and AG.

In conclusion, the SBR and adjacent agricultural areas have clear seasonal fluctuations and land management practices. Ant diversity and community structure might be significantly affected by macro and micro-scale factors, including microclimate, microhabitat effects, and interspecific competition among species and within species. Therefore, studying various aspects of macro and micro-scale factors could contribute even more in the future. Finally, a challenge to further study may be using ants obtained from this study as an indicator of association with the disturbed environments or beneficial for land use management.

ACKNOWLEDGEMENTS

We gratefully acknowledge the Thai Royal Government (Development and Promotion of Science and Technology Talents Project; DPST) for financial support. We thank the Department of Entomology, Kasetsart University, Thailand for supporting the facility and equipment for the research. We would like to sincerely thank all Sakaerat Environmental Research Station staff for kindly supporting the necessary help of the research at Sakaerat.

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