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Ant Species Diversity and Community Composition in Three Different Habitats: Mixed Deciduous Forest, Teak Plantation and Fruit Orchard

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ABSTRACT.– The species diversity of ants in three different land use types: a mixed deciduous forest, and a derived commercial teak plantation and a durian orchard, were studied to determine and compare the ant species diversity in these areas. Five sampling methods: handling capture over constant time, sugar-protein bait trap, pitfall trap, leaf litter sifting and soil sifting, were conducted each month from September 2007 to September 2008, inclusive. The species richness of ants in the area was 62 identified species and 67 morpho-species, belonging to 49 genera in nine subfamilies. The Shannon-Wiener's species diversity index indicated that the diversity was the highest in the mixed deciduous forest (2.387), followed by the durian orchard (1.997) and lastly the teak plantation (1.463). The β-diversity, using Sorensen's similarity coefficient to determine the similarity in community composition, was highest between the forest and the teak plantation at 65.5%, and then between the teak plantation and the durian orchard at 45.5%, and between the forest and the durian orchard at 39.7%, indicating that both ant species diversity and community composition were distinctly varied in these three sites which may relate to their different land use types. Therefore, the information from this preliminary study suggests that, subject to confirmation and further clarification, ant species diversity may be used to assist the conservation and management planning of agro-forestry ecosystems.

KEY WORDS: ant, community composition, species diversity, land use type

INTRODUCTION

Although the proportion of biomass represented by ground-dwelling ants in comparison with other soil microfauna (e.g. termites and earthworms) in the tropics can vary from relatively low (0.02 – 5%), to high (80%) (Hölldobler and Wilson, 1990), in terms of population density even when at a low relative biomass ants make a far larger contribution ranging typically from 7 – 53% (Lavelle and Pashanasi, 1989). Indeed, both arboreal and ground-dwelling ants play diverse and important ecological roles. They may function in an ecosystem as predators, prey, detritivores, mutualists, herbivores, or in combinations, and their functions are usually related to the species and genera they belong to (Alonso, 2000; Schultz and McGlynn, 2000). In addition, they create mycorrhizal reservoirs, effect nutrient immobilization, water movement, nutrient cycling, soil movement and other physical and chemical changes to the soil profile (e.g. reviewed in Folgarait, 1998; Lobry de Bruyn, 1999, Philpott and Armbrecht, 2006).

Ants are collectively classified in a single family, the Formicidae, in the order

Hymenoptera (Hölldobler and Wilson, 1990). Worldwide there are 23 subfamilies of ants comprised of 287 genera and approximately 12,000 described species, with a likely much larger number of species, yet to be described (Bolton et al., 2006). Despite the fact that tropical forests are amongst the poorest surveyed areas, they still have the highest recorded species diversity with, for example, some ~2200 species recorded in Asia (Hölldobler and Wilson, 1990). Within Thailand, there are nine recorded subfamilies; Aenictinae, Cerapachyinae, Dolichoderinae, Dorylinae, Formicinae, Leptanillinae, Myrmicinae, Ponerinae and Pseudomyrmecinae (Wiwatwitaya and Jaitrong, 2001).

Ants have numerous advantages that make them suitable for biodiversity and environmental monitoring studies. Ants are eusocial organisms, characterized by cooperative brood care, overlapping generations of workers within the colony, and a highly developed caste system (Wilson, 1971, cited in Agosti et al. 2000), which contribute towards the ants' numerical and biomass dominance, high diversity and their presence in almost every habitat throughout the world. Moreover, ants as indicators of ecological niches, especially soil systems, have other advantages, such as a fairly good existent taxonomic knowledge for ease of identification, their relative ease of collection, stationary nesting habits that allow them to be resampled overtime and their relative sensitivity to environmental changes (Alonso and Agosti, 2000; Andersen et al., 2002). Thus, overall, as well as broadly common species, most habitats are likely to have specialized species, which occur in sufficient species diversity and abundance as to be able to serve as suitable terrestrial indicator species of habitat quality and changes. However, this assumption has not been tested and the suitable indicator species identified, for most habitats including the changing forest land usage of the tropics, such as in Southeast Asia and especially Thailand.

Thong Pha Phum district, in the Kanchanaburi province, western Thailand, is located at the junction of three ecoregions; the Tenasserim-South Thailand semi-evergreen rain forest, the Kayah-Karen montane rain forest and the Chao Phraya lowland moist deciduous forest (Beamish, 2007). Therefore, with such a relatively high diversity of habitats and organisms including flora, then likewise the biodiversity of ants including habitat-specific or specialist species, is expected to be high. Consistent with this notion is that Bourmas (2005) reported that 202 ant species, belonging to 56 genera in nine subfamilies, were found from four forest types; namely a dry evergreen, lower mixed-deciduous, dry upper mixed-deciduous and disturbed mixed-deciduous forests, in the Golden Jubilee forest reserve in Thailand. Besides the forest reserve and national park, Thong Pha Phum district also has several other land use types which include the commercial plantings of teak, *Tectona grandis* (Lamiales: Verbeniceae), and rubber, *Hevea brasiliensis* Mull. Arg. (Malpighiales: Euphorbiaceae) trees, and agricultural areas, such as the cultivation of fruit orchards, rice and field crops. However, there is currently no information about the biodiversity of ants in these habitats which have been modified from the natural forest, yet such changes in the land-use patterns have resulted in areas that significantly differ in vegetative cover, management and some environmental factors and so would be expected to have changed the ant community composition and abundances.

With the increasing loss of habitats and biodiversity around the world, there is an urgent need for biodiversity assessments to be carried out during the conservation planning process (Alonso, 2000), as well as factors influencing biodiversity variation, such as habitats and/or land use types. The aim of this preliminary study is to determine and compare ant species diversity and composition in three different types of land use within the same broad area; specifically a natural mixed deciduous forest, and the two thereof derived states, a teak plantation and an intensively agrochemical used agricultural area represented by a durian fruit orchard, to investigate the potential feasibility of using ants as indicator species in land usage changes of forest systems. Within this context, the rational of this preliminary study is that the basic knowledge of ant species diversity and composition in different land usage habitats will assist in evaluating and planning for biodiversity conservation management.

MATERIALS AND METHODS

Study sites.– The study sites were located within the Huai Khayeng sub-district, Thong Pha Phum district, Kanchanaburi province, in western Thailand bordering Myanmar. Three areas were selected based on differences in land usage types: (i) a natural habitat represented by a mixed deciduous forest, (ii) a largely monoculture based forestry plantation, represented here by a teak plantation, and (iii) an agrochemically intensive farm, represented here by an evergreen durian orchard (Fig. 1). The mixed deciduous forest was located in the Golden Jubilee reserved forest, which covers a total area of 5,637.12 hectares and consists of dry evergreen, mixed deciduous and dry dipterocarp forests (Bourmas, 2005). The canopy of mixed deciduous forest was approximately 80 and 20 % in the wet and dry seasons, respectively. A 20 - 25 years old teak (*T. grandis*) plantation is located in the Huai Khayeng Reserve Forest Restoration Project, where the teak trees were planted at 6 × 6 m intervals, and rattan palm (*Calameae* sp.) trees were planted between the teak rows in an eight hectare area in 2006. The canopy of teak plantation was approximately 60 and 10 % in the wet and dry seasons, respectively. Local cattle browsing and grazing on small bamboo and seedlings were occasionally found in this area. The durian orchard covers an area of 20.8 hectares with the durian trees planted orderly in a 5 × 5 m interval and managed therefore, and the canopy cover was approximately 50% without leaf shedding throughout the year. Agrochemicals, including pyrethroid and organophosphate pesticides (Cypermethrin and Chlorpyrifos, respectively), the herbicide Glyphosate that can also affect some arthropods, and mixed fertilizers for nitrogen, phosphorus and potassium, were applied all year round. Thus, ant species and composition can be differentially affected through either direct poisoning or indirectly affected through loss of prey species. The wet and dry season of this study were determined by the monthly total rain fall that was obtained from the meteorological station at Thong Pha Phum district, Kanchanaburi province. The months which had a total rain fall higher than 100 mm were included as the rainy season (Whitmore, 1975), making the rainy season in this study periods from April to October and the dry season from November to March.

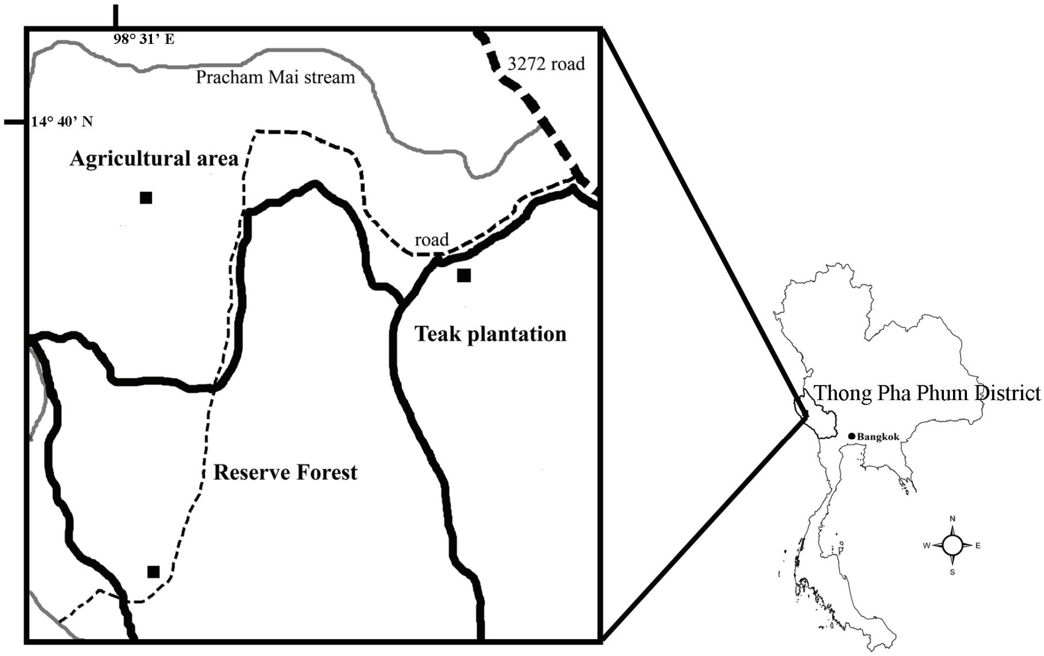

FIGURE 1. The study site map in Huai Khayeng sub-district, Thong Pha Phum district, Kanchanaburi province of Thailand, depicting the three studied sites sampled in 2007 - 2008: Reserve forest (a mixed deciduous forest), Teak plantation, and Agricultural area (an agrochemically intensive durian orchard).

Sampling methods.– In each of the three habitat types, a permanent plot of 15 × 50 m was selected as a sampling area. The surveys at each site were conducted every month from September 2007 to September 2008, inclusive. Five easy, common and cheap sampling methods that are relatively non-time consuming to use, outlined below, were used to harvest ants in order to study the species diversity and abundance of ants in each habitat taking into account the potential shortfalls and biases each method alone would involve (e.g. Majer and Delabie, 1994; Folgarait et al., 1997; Majer, 1997; Folgarait 1998). This rational is based upon future applicability, as in farmers or park wardens need indicators (in this case ant species diversity and composition) of soil or environment quality/ sustainability that are not too technically demanding, cheap and quick to attain, but reliable and widely applicable. For each method, sampling was conducted once a month every month during the 13 successive month time period.

Handling capture with constant time.– Each permanent plot (15 × 50 m) was divided into three strip quadrates (5 × 50 m), and one person collected the ants for 30 minutes at each quadrat. The ants in each habitat were collected in three alternating time periods, in the morning, late morning and afternoon. The ants were extensively searched for on the bare ground, in the leaf litter, under stones, in decaying logs and under and on shrubs and tree bases up to 1.5 m height above ground.

Sugar-protein baiting trap (applied from Bestelmeyer et al., 2000).– Each permanent plot was divided into 30 smaller quadrates

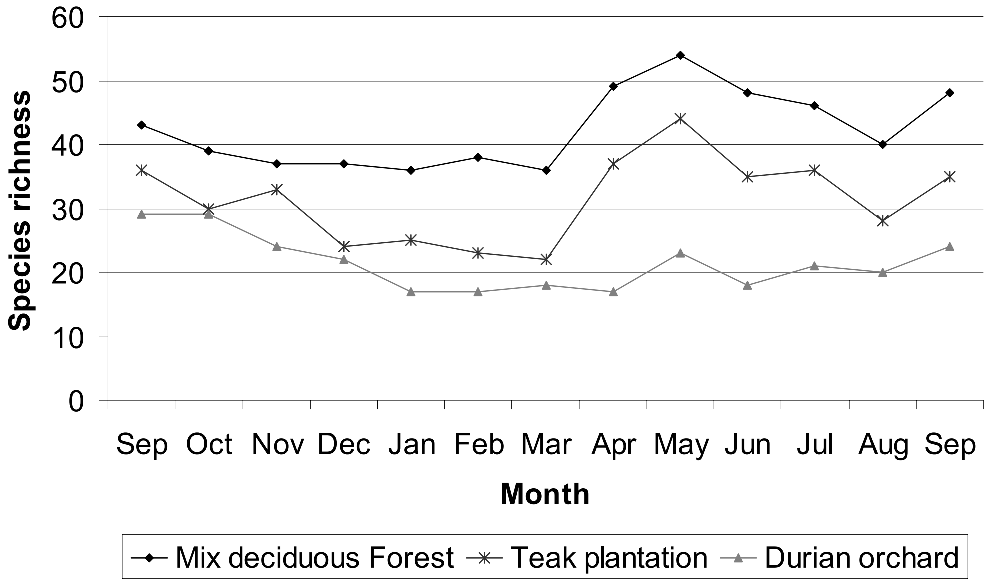

FIGURE 2. The species richness of ants among sampling months from the three habitats outlined in the legend to Figure 1.

(5 × 5 m). Canned tuna fish was mixed with 80% (w/v) sugar solution at a 1:1 (w/v) ratio and used as bait. Three grams of bait were placed directly on the center of a piece of cotton cloth (9 × 9 cm). The baited cloth was placed on each quadrat, and the ants on the cloth were harvested after 45 minutes.

Pitfall trap (applied from Bestelmeyer et al., 2000).– Each permanent plot was divided into 30 quadrates, similar to the baiting method detailed above, except that a hole was dug at the center of each quadrat. A plastic container (8 cm diameter × 12 cm height) was placed in each hole with the lip of the trap level with the soil surface. Petroleum gel was applied around the inner lip of trap and a 2% (v/v) (alkylbenzene sulfonate Sunlight®, Unilever Thai Holding Comp.) detergent solution was poured into the trap to a depth of about two cm. Samples were collected after 24 hours and taken to the laboratory for sorting. Note each trap was not placed directly on any ant nest.

Leaf litter sifting.– Each permanent plot was divided into 30 (5 × 5 m) quadrates, as above, from which ten were randomly selected. The leaf litter was collected from within a 1 × 1 m quadrat positioned in the center of each selected 5 x 5 m quadrat. After collection, the leaf litter samples were sieved with a 0.8 × 0.8 cm mesh and the ants were collected using forceps.

Soil sifting.– The soil was sampled in the same sampling quadrat as the leaf litter sample (above) in each site. In the center of the leaf litter sampling quadrat, the soil was collected in an area of 25 x 25 m to five cm depth from the soil surface. The soil samples were sieved with 0.8 × 0.8 cm mesh and the ants were collected using forceps.

Soil texture.– The soil texture was determined from three replicate soil samples selected randomly from each study site. The soil texture was determined by the Bouyoucos Hydrometer method (Department of Soil Science, Faculty of Agriculture, Kasetsart University, 2006). The percentage of soil particles was calculated.

Ant collection and identification.– For all sampling methods, upon collection the ants were preserved in 95% (v/v) ethyl alcohol and subsequentially taken back to the laboratory for classification to (morpho-) species level and counting the numbers of each (morpho-) species. Identification of ants to family, genus and species (nearly all cases), or morpho-species where this was not possible, was based on the keys by Bolton (1994), Hölldobler and Wilson (1990), and Wiwatwitthaya and Jaitrong (2001).

The specimens were also compared with the reference collections at the Ant Museum, Faculty of Forestry, Kasetsart University, and the Museum of Zoology, Faculty of Science, Chulalongkorn University. Unidentified specimens were coded based on their reference collections, the sp. of AMK is the code of Ant Museum, Kasetsart University and the sp. of CUMZ is the code of Chulalongkorn University Museum of Zoology.

Data analysis.– The Shannon-Wiener's diversity index (Krebs, 1999), was used to calculate the diversity of ants collected from four of the collection methods, i.e. the sugar-protein baiting trap, pitfall trap, leaf litter sifting and soil sifting. Hand (visual encounter) based collection, with its inherent bias, was excluded from this the Shannon-Wiener's diversity index since it cannot be used to reliably support the relative abundance of each species. The formula of the Shannon-Wiener's diversity index used is presented below:

$$H' = \sum_{i=1}^{s} (pi)(\ln pi)$$

Where, H' = Species diversity index
s = Number of species
p_i = Proportion of the total sample belonging to i^{th} species

The Sorensen's similarity coefficient (Krebs, 1999) was used to measure the beta-diversity or the similarity between two study sites as follows:

$$S = \frac{2a}{2a + b + c}$$

Where, S = Sorensen's similarity coefficient
a = Number of species in site A and site B
b = Number of species in site B but not in site A
c = Number of species in site A but not in site B

The evenness index (Krebs, 1999) was calculated to determine the equal abundance of ants in each study site as follows:

$$\text{Evenness} = \frac{H'}{H'_{\text{MAX}}}$$

Where, H' = Observed index of species diversity
H'_{MAX} = Maximum possible index of diversity

TABLE 1. The collecting methods, study sites, percentage occurrence, and some biology of each species in the legend to Figure 1. (H = handling capture with constant time, B = sugar-protein baiting trap, P = pitfall trap, S =, soil sifting, L = leaf litter sifting, F = mix deciduous forest, T = teak plantation, O = durian orchard, * = % occurrence less than 40%, ** = % occurrence between 40-69%, *** = % occurrence more than 70%, D = dry season, W = wet season.)

Subfamily/species	Collecting					Study sites			% Occurrence	Some biology (Brown, 2000)
	H	B	P	S	L	F	T	O		
Aenictinae										
Aenictus camposi	✓					–,W	–,–	–,–	*	Army ants
Aenictus ceylonicus	✓		✓			–,W	–,W	–,–	*	
Aenictus dentatus	✓					–,W	–,W	–,–	*	
Aenictus laeviceps	✓					–,–	–,W	–,–	*	
Aenictus nishimurai	✓					–,W	–,–	–,W	*	
Aenictus sp.5 of AMK	✓					–,W	–,W	–,–	*	
Cerapachyinae										
Cerapachys sp.3 of AMK	✓					–,–	D, –	–,–	*	Army ants, predators of other ants
Cerapachys sp.5 of AMK	✓					–,–	–,W	–,–	*	
Cerapachys sp.14 of AMK	✓			✓		D,W	–,–	–,–	*	
Dolichoderinae										
Philidris sp.1 of AMK	✓	✓	✓	✓	✓	D,W	D,W	–,–	**	Foragers
Tapinoma indicum	✓					–,–	–,–	–,W	*	Generalized foragers
Tapinoma melanocephalum	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	
Technomyrmex albipes	✓	✓	✓	✓	✓	D,W	–,W	–,–	*	Generalized foragers
Technomyrmex kraepelini (group)	✓			✓	✓	D,W	–,W	–,–	*	
Dorylinae										
Dorylus orientalis	✓		✓	✓	✓	D,W	D,W	D,W	*	Army ants
Formicinae										
Acropyga acutiventris	✓			✓		D,W	–,–	–,–	*	Tend coccids
Anoplolepis gracilipes	✓	✓	✓	✓	✓	D,W	D,W	–,–	**	Foragers
Camponotus (Myrmamblys) sp.1 of AMK	✓			✓		–,–	D,W	–,–	*	Generalized foragers
Camponotus ruflogaucus	✓	✓	✓	✓	✓	–,–	D,W	D,W	**	
Camponotus sp.7 of AMK-group	✓	✓	✓	✓	✓	D,W	D,W	D,W	**	
Oecophylla smaragdina	✓	✓	✓	✓	✓	D,W	D,W	–,–	**	Predators, tend homopterans
Paratrechina opaca	✓					D, –	–,–	–,–	*	Generalized foragers
Paratrechina sp.1 of AMK	✓	✓	✓	✓	✓	D,W	–,–	–,–	*	
Paratrechina sp.4 of AMK	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	
Paratrechina sp.8 of AMK	✓	✓				–,W	D,W	D,W	*	
Paratrechina sp.9 of AMK	✓	✓	✓	✓	✓	D,W	–,–	D,W	**	
Paratrechina sp.10 of AMK	✓	✓	✓			D,W	D,W	D,W	*	
Plagiolepis sp.1 of AMK	✓	✓	✓		✓	–,–	D,W	D,W	*	Generalized foragers
Plagiolepis sp.2 of AMK	✓	✓	✓	✓	✓	–,W	D,W	–,–	*	
Polyrhachis (Campomyrma) halidayi	✓			✓	✓	–,W	–,–	–,W	*	Generalized foragers
Polyrhachis (Cyrtomyrma) laevissima	✓					–,W	D,W	–,–	*	

TABLE 1. Continues.

Subfamily/species	Collecting					Study sites			% Occurrence	Some biology (Brown, 2000)
	H	B	P	S	L	F	T	O		
Polyrhachis (Myrma) illaudata	✓					D,W	–,–	–,–	*	
Polyrhachis (Myrma) proxima	✓	✓	✓	✓	✓	D,W	D,W	–,–	**	
Polyrhachis (Myrmhopla) armata	✓					D,W	–,W	–,–	*	
Polyrhachis (Myrmhopla) furcata	✓					–,W	–,–	–,–	*	
Polyrhachis (Myrmhopla) hippomanes-group	✓					–,W	–,W	–,–	*	
Polyrhachis (Myrmhopla) tibialis	✓		✓			D, –	–,W	–,–	*	
Polyrhachis (Myrmhopla) sp.5 of AMK	✓					D, –	–,–	–,–	*	
Pseudolasius sp.1 of AMK	✓	✓	✓	✓	✓	D,W	–,–	–,–	*	Cryptic foragers
Leptanillinae										
Leptanilla sp.1 of AMK	✓			✓	✓	–,W	–,–	–,W	*	Cryptic mass predators
Leptanilla sp.2 of AMK	✓					–,W	–,–	–,–	*	
Myrmicinae										
Calyptomyrmex sp.1 of AMK	✓			✓		–,W	–,W	–,–	*	–
Cardiocondyla emeryi	✓					–,–	–,–	–,W	*	–
Cardiocondyla nuda	✓	✓			✓		–,W	D,W	*	
Cardiocondyla wroughtonii	✓	✓	✓	✓	✓	D,W	D,W	D, –	**	
Carebara sp.1 of AMK	✓			✓		–,W	–,W	D,W	*	–
Cataulacus sp. (queen)	✓					–,W	–,–	–,–	*	–
Crematogaster (Orthocrema) sp.1 of AMK	✓					–,W	–,–	–,–	*	Generalized foragers
Crematogaster (Orthocrema) sp.2 of AMK	✓					–,W	–,–	–,–	*	
Crematogaster sp.2 of AMK			✓			–,–	D, –	–,–	*	
Crematogaster sp.5 of AMK	✓					–,W	–,W	–,–	*	
Crematogaster sp.9 of AMK	✓	✓			✓	D,W	–,W	–,–	*	
Lophomyrmex lucidus				✓		–,–	–,W	–,–	*	Generalized foragers
Meranoplus bicolor	✓	✓	✓	✓		–,–	–,W	D,W	*	Seed harvesters and general foragers
Monomorium floricola	✓	✓	✓			D,W	–,W	–,–	*	Generalized foragers, harvesters
Monomorium latinode	✓	✓		✓	✓	D,W	–,W	D,W	*	
Monomorium pharaonis	✓	✓	✓		✓	D,W	–,–	–,–	*	
Monomorium sechellense	✓		✓		✓	–,W	–,W	–,–	*	
Monomorium sp.1 of AMK	✓	✓	✓	✓	✓	D,W	D,W	–,–	**	
Myrmecina sp.4 of AMK	✓			✓	✓	–,W	–,W	D,W	*	Predators of mites
Myrmicaria brunnea	✓	✓				–,–	–,W	–,–	*	–
Myrmicaria sp.1 of CUMZ	✓	✓		✓		–,–	–,W	–,–	*	

TABLE 1. Continues.

Subfamily/species	Collecting					Study sites			% Occurrence	Some biology (Brown, 2000)
	H	B	P	S	L	F	T	O		
Oligomyrmex sp.1 of AMK	✓		✓	✓	✓	D,W	–,–	–,–	*	Cryptic foragers, termite thief ants
Oligomyrmex sp.11 of AMK	✓					–,W	–,–	–,–	*	
Oligomyrmex sp.1 of CUMZ	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	
Pheidole sp. 1 (eq 101)[a]	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	Many seed harvesters, many omnivorours
Pheidole sp. 2 (eq 141)[a]	✓	✓	✓		✓	D,W	D,W	–,–	**	
Pheidole noda (group)	✓	✓	✓	✓	✓	D,W	D,W	–,–	**	
Pheidole planifrons	✓	✓	✓		✓	D,W	D,W	–,–	**	
Pheidole rabo	✓	✓	✓			–,–	–,–	D,W	*	
Pheidole rinae taipoana	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	
Pheidole sp.14 of AMK	✓	✓	✓	✓	✓	–,–	D,W	–,–	*	
Pheidole sp.2 of CUMZ	✓	✓	✓	✓		–,W		D,W	*	
Pheidole sp.3 of CUMZ	✓	✓	✓	✓	✓	D,W	–,W		**	
Pheidologeton affinis	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	Generalized, and mass foragers
Pheidologeton diversus	✓	✓	✓	✓	✓	D,W	D,W	–,–	*	
Pheidologeton pygmaeus	✓	✓	✓	✓	✓	D,W	–,–	–,–	*	
Recurvidris sp.3 of AMK	✓	✓	✓	✓		D,W	D,W	–,–	*	Generalized foragers
Rhopalomastix sp.2 of AMK	✓					–,–	–,W	–,–	*	
Solenopsis geminata	✓	✓	✓	✓	✓	–,–	–,–	D,W	*	Generalized foragers
Strumigenys sp.6 of AMK					✓	–,W	–,–	–,–	*	Predators, especially of collembolans
Strumigenys sp.7 of AMK				✓		–,–	–,–	D, –	*	
Strumigenys sp.4 of AMK	✓		✓	✓	✓	–,–	D,W	D,W	**	
Tetramorium bicarinatum	✓		✓			–,–	D,W	–,–	*	Generalized foragers
Tetramorium kheperra	✓	✓	✓	✓	✓	–,W	D,W	D,W	**	
Tetramorium pacificum	✓	✓	✓	✓	✓	D,W	–,W	–,–	*	
Tetramorium parvum					✓	–,W	–,–	–,–	*	
Tetramorium simillimum	✓	✓	✓	✓	✓	–,–	–,W	D,W	*	
Tetramorium smithi	✓					–,–	–,–	–,W	*	
Tetramorium sp.6 of AMK	✓	✓	✓	✓	✓	D,W	D,W	D,W	**	
Tetramorium sp.10 of AMK	✓	✓	✓	✓	✓	D,W	–,–	–,–	*	
Vollenhovia sp.2 of AMK	✓					–,W	–,–	–,–	*	
Vollenhovia sp.7 of AMK	✓					–,W	–,W	–,–	*	
Ponerinae										
Amblyopone reclinata	✓				✓	–,W	–,W	–,–	*	Predators
Amblyopone sp.4 of AMK	✓					D, –	–,–	–,–	*	
Amblyopone sp.5 of AMK	✓					–,W	–,W	–,–	*	
Anochetus graeffei	✓		✓	✓	✓	D,W	–,–	D,W	**	Predators
Anochetus sp.1 of AMK	✓				✓	D,W	D,W	D, –	*	
Centromyrmex feae	✓			✓		D,W	–,–	–,–	*	Cryptic predators of termites
Diacamma vagans	✓	✓	✓	✓	✓	D,W	D,W	–,–	**	Predators
Gnamptogenys bicolor	✓	✓	✓	✓	✓	–,–	D,W	D,W	*	Predators and scavengers

TABLE 1. Continues.

Subfamily/species	Collecting					Study sites			% Occurrence	Some biology (Brown, 2000)
	H	B	P	S	L	F	T	O		
Harpegnathos venator			✓			–,W	–,–	–,–	*	Predators
Hypoponera sp.3 of AMK	✓					–,–	–,–	–,W	*	Generalized foragers
Hypoponera sp.5 of AMK	✓		✓	✓		D,W	–,W	D,W	**	
Hypoponera sp.7 of AMK	✓			✓	✓	D,W	–,W	–,–	*	
Leptogenys birmana	✓				✓	–,W	–,–	–,–	*	Predators of isopods and mass foraging predators
Leptogenys diminuta	✓					D,W	–,–	–,–	*	
Leptogenys sp.1 of AMK	✓		✓			D,W	–,–	–,–	*	
Leptogenys sp.12 of AMK	✓		✓		✓	–,W	D,W	–,–	*	
Leptogenys sp.14 of AMK	✓		✓			–,W	–,–	–,W	*	
Leptogenys sp.23 of AMK	✓		✓			D,W	D,W	–,–	*	
Leptogenys sp.5 of AMK	✓					–,W	–,–	–,–	*	
Leptogenys sp.20 of AMK	✓			✓	✓	–,W	–,W	–,–	*	
Odontomachus rixosus	✓	✓	✓	✓	✓	D,W	–,–	–,–	*	Predators
Odontoponera denticulata	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	Predators
Pachycondyla amblyops			✓			–,–	–,–	–,W	*	Predators
Pachycondyla astuta-group	✓		✓			D,W	–,–	–,–	*	
Pachycondyla leeuwenhoeki	✓		✓		✓	D,W	–,–	–,–	*	
Pachycondyla luteipes	✓	✓	✓	✓	✓	D,W	D,W	D,W	***	
Pachycondyla rufipes	✓		✓		✓	D,W	D,W	–,W	**	
Pachycondyla sp.5 of AMK	✓		✓	✓	✓	D,W	–,–	–,W	*	
Pachycondyla sp.7 of AMK	✓		✓	✓	✓	–,–	–,–	D,W	*	
Platythyrea parallela	✓					–,W	–,–	–,–	*	Predators, many on termites
Ponera sp.7 of AMK				✓		–,–	–,–	D, –	*	Predators of small arthropods
Probolomyrmex sp.4 of AMK	✓					–,W	–,–	–,–	*	Predators
Pseudomyrmecinae										
Tetraponera rufonigra		✓				–,–	D, –	–,–	*	–
Tetraponera allaborans	✓					D,W	–,–	–,–	*	
Tetraponera attenuata	✓		✓			D,W	–,W	–,–	*	
Tetraponera difficilis	✓					D, –	–,W	–,–	*	

[a]: eq-codes, codes of Katsuyuki Equchi for *Pheidole* spp.

RESULTS

Species diversity.– Across the three sites 129 ant species and morphologically recognizable taxa from 49 genera were recorded which represents a reasonably good species richness. In summary, these ants belong to the nine subfamilies; Aenictinae, Cerapachyinae, Dolichoderinae, Dorylinae, Formicinae, Leptanillinae, Myrmicinae, Ponerinae and Pseudomyrmecinae. Some species, such as *Pachycondyla luteipes*, *Pheidologeton affinis* and *Odontoponera denticulata*, were found in all three land use types, whilst other species, such as *Acropyga acutiventris*, *Polyrhachis (Myrma) illaudata*, *Odontomachus rixosus* and *Centromyrmex feae*, were found only in the forest. Whereas, some species, such as

TABLE 2. The species richness, the Shannon-Wiener's species diversity index, and the evenness index of ants from the three habitats outlined in the legend to Figure 1.

Study site	Mix deciduous forest	Teak plantation	Durian orchard
Species richness	100	77	46
Species diversity index	2.387	1.463	1.997
Evenness index	0.562	0.365	0.545

Camponotus (Myrmamblys) sp.1 of AMK, *Myrmicaria brunnea*, and *Cerapachys* sp.5 of AMK, were found only in the teak plantation and some species were found only in the orchard, such as *Pheidole rabo*, *Solenopsis geminata* and *Hypoponera* sp.3 of AMK (Table 1).

With respect to the comparative ant communities between the three sites, the highest number of species was recorded in the mixed deciduous forest followed by the teak plantation and the lowest in the durian orchard. The Shannon-Wiener's species diversity index indicated that the year round diversity was the highest in the mixed deciduous forest, followed by the durian orchard and lastly the teak plantation. Moreover, the highest value of the evenness index of ants was in the mixed deciduous forest, followed closely by the durian orchard, whereas that for the teak plantation was markedly lower (Table 2). This indicates that a relatively equal abundance of each ant species was present in the mixed deciduous forest and the durian orchard whereas the teak plantation had an unequal abundance of some ant species.

The species richness of ants between each sampling month in the forest and the teak plantation showed a similar trend, whereas a more constant richness was found in the durian orchard. The highest ant species richness was found in the reserve forest in all of the 13 sampled months, followed by the teak plantation and then the durian orchard, respectively. There was a difference in the number of ants species number between wet and dry seasons, where in the wet season (from April to October) ant species numbers were high in all three study sites and then lower in the dry season (from November to March). In the forest and the teak plantation, the highest ant diversity was in May 2008 whereas the lowest in the forest was in January and March 2008, and in the teak plantation was in March 2008. The orchard was different in that the highest ant species diversity numbers was in September and October 2007 and the lowest in the period of January to April 2008 (Fig. 2).

Species similarity.– The species similarity between the forest and the teak plantation, as evaluated by Sorensen's similarity coefficient, was the highest whilst that between the teak plantation and the durian orchard and between the forest and the durian orchard were intermediate and the lowest, respectively (Table 3).

The soil texture.– The three types of percentage of soil texture were similar trend in the forest and the durian orchard whereas the teak plantation was distinctively different having less sand, and more silt and clay as a percentage composition (Table 4).

TABLE 3. The Sorensen's similarity coefficient of ants from the three habitats outlined in the legend to Figure 1. Remark: F= mixed deciduous forest, T= teak plantation, and D= durian orchard

Sites	F	T	D
F	1	-	-
T	0.655	1	-
D	0.397	0.455	1

TABLE 4. The percentages of soil texture from the three habitats outlined in the legend to Figure 1.

Study sites	Soil texture (% ± SD)		
	Sand	Silt	Clay
Mixed deciduous forest	72.91±3.05	8.09±2.23	18.99±2.69
Teak plantation	47.53±1.53	19.33±0.58	34.14±1.00
Durian orchard	76.98±2.18	6.45±1.27	16.57±1.36

DISCUSSION

Both the species richness and the diversity indices of ants were highest in the mixed deciduous forest, whereas the ranked order (Forest > Teak > Durian and Forest > Durian > Teak for species richness and diversity, respectively) showed a slight difference between the teak plantation and the durian orchard. The relatively high ant species diversity in the mixed deciduous forest may be caused by the correspondingly high diversity in the plant community and as such would potentially reflect the differences in the canopy cover and leaf shedding. In this scenario, the leaf litter, soil moisture content, and leaf litter biomass in each study site would likely be affected by differences in each plant community, as reported by Bourmas (2005) and Hasin (2008). Additionally, in the dry season, the various plants in the mixed deciduous forest and the teak trees in the plantation shed their leaves, which did not occur to the same extent with the evergreen durian trees. However, in March 2008, there was a fire in the teak plantation which removed the leaf litter and consequentially the mixed deciduous forest had a higher leaf litter than the other sites, and was covered by the litter all year round. The leaf litter provides both food and nest sites to many ant species, so it might be expected that an addition of both resources will produce a stronger response from litter-nesting ants (Armbrecht et al., 2006). So, there were more leaf litter species in the forest than the teak plantation, such as *Paratrechina* sp.1 of AMK, *Paratrechina* sp.9 of AMK, and *Odontomachus rixosus*. The distinct soil texture in the teak plantation may be another reason since the higher in clay proportion makes this area very hard in the dry season and more saturated in the wet season, making it un suitable for ground nesting species. The interpretation of the data across these three different habitats with respect to land usage, like with respect to soil types is somewhat restricted by the fact that the data is derived from only one site per habitat, and thus an inability to state inter-habitat variation is greater than intra-habitat or inter-site variations independent of land usage. Regardless, the higher species richness of ants in the natural deciduous forest than in the teak plantation was similar to the reported trend for ant diversity at Sabah, Malaysia, which was higher in the primary and secondary forests than in the oil palm plantation (Yahya, 2000). Moreover, there were various microhabitats in the forest sites such as leaf litter, decaying logs and under stones or bark. In the forest site, many predatory ants were found including litter specialist predators, such as *Leptogenys* and *Oligomyrmex*, and litter generalist predators, such as *Hypoponera* and *Anochetus*.

Although the durian orchard had the lowest species richness, it had a higher evenness index than in the teak plantation, and was at almost the same level as the natural forest (ranking for evenness is Forest~Durian > Teak), which is reflected in the higher species diversity index than in the teak plantation. Another possible reason is that most of the ants found in the durian orchard were genera that usually form large colonies containing large numbers of workers and can easily be found all year round, such as *Pheidologeton*, *Pheidole* and

Solenopsis, reducing the risk of stochastic noise due to random missing of multiple but infrequent species at each site. In the durian orchard, the leaf litters were gathered around the tree, except after the harvesting period when the leaf litters were abandoned (June to August), so the moisture was maintained by the grass cover. The orchard was irrigated all year round, and especially in the dry season. These activities yield a higher moisture content in the orchard than in the teak plantation, leading to a relative abundance of soil arthropods, such as springtails, symphylans and diplurans, being found all year round, and thus in the presence of those predatory ant species that prey on them. Moreover, in the durian orchard, agrochemicals, such as pesticides and fertilizers, were applied all year round, so there were no arboreal ant species in this area except for *Polyrhachis* (*Campomyrma*) *halidayi*, which was found as only as one individual (reproductive caste) with no evidence of persistence (nest site or workers), whereas this species was persistent in the reserve forest.

The highest ant species richness was in the reserve forest in all 13 of the sampled months followed by the teak plantation and the orchard, respectively, supporting that the forest is a more suitable habitat than the teak plantation and the durian orchard, all year round. In the dry season, there were lower soil and litter moisture contents and a high temperature, conditions which are unsuitable for ants and their prey leading to a lower ant biodiversity and population levels and so a lower species number being recorded. In the wet season, there is more soil and litter moisture contents which are hence more suitable for many soil faunas that serve as ant prey. Thus, with an increase in the population size and potential biodiversity, a higher of predatory ants were found in this period. Legionary ants, also known as army ants (indicated in Table 1) were occasionally collected, and their action as mobile generalist predators in the litter layer can influence the composition of the fauna. However, although they were rarely found, care in estimating their actual abundance and significance is required due to their nomadic life-style with quiet large ranges and movement rates relative to the small sampling area and time periods (Delabie et al., 2000).

The similarity indices indicated that the species composition of ants between the natural forest and the teak plantation was higher than that between the forest and durian orchard. Compared with the primary land use as a natural forest, this result suggests that these two modified land usages reduce the ant diversity and that, despite the fire in the teak plantation during the sampling year, the durian orchard land can support a lower ant biodiversity than the teak plantation. This may be due to the fact that the tree canopy of the durian orchard was treated all year round by agrochemicals, including pyrethroid and organophosphate pesticides and the herbicide *Glyphosate* that can also affect some arthropods and other food sources such as weed nectar and seeds; and mixed fertilizers for nitrogen, phosphorus and potassium. These agrochemicals can differentially affect the ant species composition, through either direct poisoning or indirectly through loss of prey species, and so explain the different ant species composition in the durian orchard compared to that in the teak and natural mixed deciduous forests. Therefore, the canopy ants, even ant species commonly found in disturbed areas, such as *Oecophylla smaragdina* or other canopy ants such as *Crematogaster*, *Tetraponera*, and some *Polyrhachis* species were absent in the durian plantation. Moreover, some predatory ants that might be of benefit in the control of certain insect pests in this area, such as *Odontoponera denticulata*, were regulated by the agrochemical practices of the farmer.

From this study, the difference in three sites, which may reflect the different land usages of these sites but that awaits more detailed studies to confirm, potentially influenced the ant community species diversity and composition, as somewhat intuitively expected but not to date ascertained for these habitats. Some species were found in all three land use types, whilst other species were more specialized being found only in specific microhabitats in the forest. If an understanding of microhabitats used by specific ant species can be developed, along with the key trophic interactions, then the potential of using ants as terrestrial indicator species for detecting environmental changes can potentially be reliably and easily (low cost and time) performed compared to some other indicator species.

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