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Agricultural land use alters species composition but not species richness of ant communities

Ratna Rubiana[1*], Akhmad Rizali[2], Lisa H. Denmead[3], Winda Alamsari[1], Purnama Hidayat[1], Pudjianto[1], Dadan Hindayana[1], Yann Clough[3], Teja Tscharntke[3] and Damayanti Buchori[1]

[1] Department of Plant Protection, Faculty of Agriculture, Bogor Agricultural University. Jl. Kamper, Kampus IPB Dramaga, Bogor, 16680 Indonesia
[2] Department of Plant Pests and Diseases, Faculty of Agriculture, University of Brawijaya. Jl. Veteran, Malang, 65145 Indonesia
[3] Agroecology, Georg-August-University, Grisebachstr. 6, 37077, Göttingen, Germany

*Corresponding author's email: ratna.rubiana@gmail.com

ABSTRACT. Land-use change causes undesirable effects such as biodiversity decline, altered community structure and reduced ecosystem services. Changes in species composition and disrupted trophic interactions between pests and their natural enemies may also result causing decreased ecosystem services. We studied the effects of forest habitat transformation on the community structure of ants, which include major biological control agents. We focused on four types of land use around Harapan Forest (Harapan) and Bukit Duabelas National Park (BDNP), Jambi, Sumatra, Indonesia: forest, jungle rubber, rubber plantations and oil palm plantations. Four replicate patches of each land-use type were sampled, with plot sizes of 50 x 50 m at each of the 32 sites. Ants were collected by hand in combination with tuna and sugar baiting on three strata *i.e*. leaf litter, soil and tree. We found 104 ant species in total. Surprisingly, ant species richness per plot was not significantly different among land-use types, both in Harapan and BDNP. However, few ant species were shared among different land-use types. Forest and jungle rubber communities are relatively similar to each other (but still different), and distinct from communities in oil palm and rubber plantations. We conclude that conversion of remnant forested habitats to plantations would result in a net loss of ant species, even though ant species richness in plantations and forested habitats are similar.

Keywords: land-use change, hand-collecting, oil palm, rubber, Sumatra island

INTRODUCTION

Habitat transformation is an unfortunate consequence of human population increase. Natural habitats ever-growing are being altered by anthropogenic activities (Morris 2010). Habitat transformation degrades natural habitats and interferes with the resources necessary for the survival of many organisms (Pringle 2007). When their habitat is destroyed, plants and animals that had occupied the habitat are often displaced or destroyed, thus reducing biodiversity and enhancing the likelihood of extinction (Swift *et al.* 2004). Therefore, habitat transformation is one of the major causes of biodiversity decline along with climate change, nitrogen deposition and increased atmospheric CO_2 concentration (Sala *et al.* 2000).

Biodiversity is important in regulating and sustaining the direct and indirect contributions of ecosystems to human (ecosystem services) (Alberti 2005). The reduction of species richness often causes decreases in ecosystem services (Naeem *et al.* 1999). In agricultural production systems, insects provide ecosystem services such as pest control, pollination, and soil fertility (Power 2010). Decreasing the number of species in economically important functional groups may lead to increased pest density, reduced pollinator and natural enemies services (Tscharntke *et al.* 2012). Ants (Hymenoptera: Formicidae) provide important ecosystem services including biological pest control, seed dispersal, and soil modification (Hill & Hoy 2003; Gammans *et al.* 2005; Lach *et al.* 2010; Philpott *et al.* 2010). However, ants are sensitive to changes in their environment including changes in dominant vegetation structure, food availability, and nesting resources (Andersen 2000). The changes of vegetation structure resulting from forest transformation usually experience changes in ant community structure (Nakamura *et al.* 2007). Habitat transformation may severely impact the abundance, community structure, and interaction behavior of ants toward each other and other organisms (*e.g*. avoidance of predators and parasitism) (Kaspari *et al.* 2003). Due to the benefits of ants for ecosystem services (Wielgoss *et al.* 2013), as well as their sensitivity to change, they are an ideal focus group to investigate the impacts of habitat transformation.

Here, we compare ant communities in remnant forested habitats of Jambi province, Sumatra, with those found in several common agricultural land-use types: rubber agroforests with diverse vegetation (jungle rubber), monoculture rubber and oil palm plantations. The objectives of this research were to (1) compare the diversity of ants in the different types of land use, (2) compare the species composition and community structure across the different habitat types, and (3) investigate changes in ant dominance patterns resulting from transformation of their habitat.

MATERIALS AND METHODS

Study sites

Fieldwork was conducted in the tropical lowland rainforest in Jambi Province in southwest Sumatra, Indonesia (Fig. 1). Two sites were chosen for this research: Bukit Duabelas National Park (BDNP) and Harapan Forest (Harapan). The habitat transformation systems investigated consisted of lowland rainforest, jungle rubber (extensively managed rubber plantations, which have been logged at least once, but usually more often), and intensive rubber and oil palm plantations. In each of the two areas, four sites (plot size 50 x 50 m) in each type of land use were established, for a total of 32 study plots. Each plot had five sub-plots (5 x 5 m) defined for sample collection. Subplot location was determined randomly, and was reassigned for every plot.

Sample collection and identification

We used both direct sampling and baiting of ants. Direct sampling allowed estimation of the number of ant species per unit area. Direct sampling in each stratum (leaf litter, soil, and tree) lasted 5 - 10 min. Leaf litter was separated into coarse and fine litter and ants were taken from the fine litter in the tray. For the soil strata, ants were collected directly from the ground with forceps. Sampling on trees was combined with baiting, using tuna and sugar bait to attract the ants (Bestelmeyer *et al.* 2000). Sugar water and canned tuna were put in a plastic plate with a diameter of 20 cm with 4 bait containers with a diameter of 2 cm. Sugar water was absorbed into a foam that was placed in the container. Baits were installed for 1 hour. Ant sampling was completed between 09.00 and 11.00 am from 22 February to 31 March 2013 and only carried out during sunny weather.

All specimens were stored in 70% ethanol and were identified to morphospecies using a stereo microscope and an identification guide for Bornean Ants (Hashimoto 2003).

Data Analysis

To understand whether ant species richness differed between habitat types, we used an analysis

Table 1. Ant species richness in four land-use types in Bukit Duabelas National Park (BDNP) and Harapan Forest. The difference of ant species richness between land-use types on each site was tested using ANOVA.

Land-use	Subfamily	Genus	Species	Average	Statistic
BDNP					
Primary forest	5	27	42	17.5	$F_{3,10} = 1.26$ $P = 0.340$
Jungle rubber	5	22	31	14.0	
Rubber plantation	5	29	45	21.5	
Oil palm plantation	5	27	40	21.3	
Sub total	6	50	86	39.5	
Harapan Forest					
Primary forest	5	26	42	19.3	$F_{3,15} = 0.37$ $P = 0.779$
Jungle rubber	5	29	48	19.5	
Rubber plantation	5	25	45	20.5	
Oil palm plantation	5	25	43	17.8	
Sub total	5	38	81	44.5	
Total	6	52	104		

Table 2. Dissimilarity of ant species (Bray-Curtis index) between different land-use types in Bukit Duabelas and Harapan sites. The first letter indicates landscape (B: Bukit Duabelas, H: Harapan) and the second letter indicates the land-use type (F: forest, J: jungle, O: Oil palm, R: rubber)

Land-use	BF	BJ	BO	BR	HF	HJ	HO	HR
BF	0							
BJ	0.45	0						
BO	0.61	0.61	0					
BR	0.54	0.53	0.48	0				
HF	0.36	0.36	0.51	0.49	0			
HJ	0.52	0.53	0.53	0.47	0.45	0		
HO	0.53	0.49	0.37	0.39	0.58	0.50	0	
HR	0.56	0.47	0.43	0.27	0.42	0.44	0.30	0

of variance (ANOVA). Ant community structure was compared between different land-use types within each study area based on Bray-Curtis dissimilarity index and further analyzed using non-metric multidimensional scaling (NMDS). Significance tests for differences in community composition between land-use types were performed using the analysis of similarity test (ANOSIM; Clarke 1993). All analyses were performed using R statistic (R Core Team 2014).

RESULTS

A total of 104 ant species were collected, representing six subfamilies and 52 genera (Table 1). Species richness in the BDNP site (86 species) was slightly higher than in Harapan site (81 species). There were no significant differences in ant species richness between land-use types, neither in BDNP (ANOVA, $F_{3, 10} = 1.26$, P = 0.340) nor in Harapan (ANOVA, $F_{3, 15} = 0.37$, P = 0.779).

Nevertheless, species accumulation curves show differences in ant species diversity between the different sites and land-use types (Fig. 2).

Sites within each land-use type had a higher similarity of ant species composition than sites from different land-use types (Table 2). NMDS ordination analysis showed that there were significant differences in ant community structure between land-use types in both, BDNP (ANOSIM, R = 0.737, P = 0.001) and Harapan (ANOSIM, R = 0.652, P = 0.001) sites (Fig. 3).

In both, BDNP and Harapan sites, nine ant species were recorded in all habitat types, *i.e*. forest, jungle rubber, rubber plantations and palm oil plantations (Fig. 4). Several ant species dominated the study plots (Fig. 5) that are mostly categorized by Brühl & Eltz (2010) as non-forest species and do not normally occur in forest habitats, i.e. *Anoplolepis gracilipes* (Smith, 1857), *Dolichoderus* sp. 01 and 02, *Odontoponera denticulate* (Smith, 1858), *Monomorium* sp. 02, *Technomyrmex* sp. 02, *Oecophylla smaragdina* (Fabricius, 1775), *Nylanderia* sp. 02, and *Crematogaster* sp. 01.

DISCUSSION

Transformation of near-primary forests to agroforests and plantations is often accompanied by drastic changes in biodiversity. Against our expectation, species richness did not differ significantly between the forest, jungle rubber, rubber and oil palm sites. However, species composition differed strongly between land-use types. Ant communities in rubber and oil palm plantations, both in the BDNP and Harapan sites, could be clearly distinguished from forest and jungle rubber communities. Forest and jungle rubber sites were more similar, even partly overlapping in one of the two areas studied.

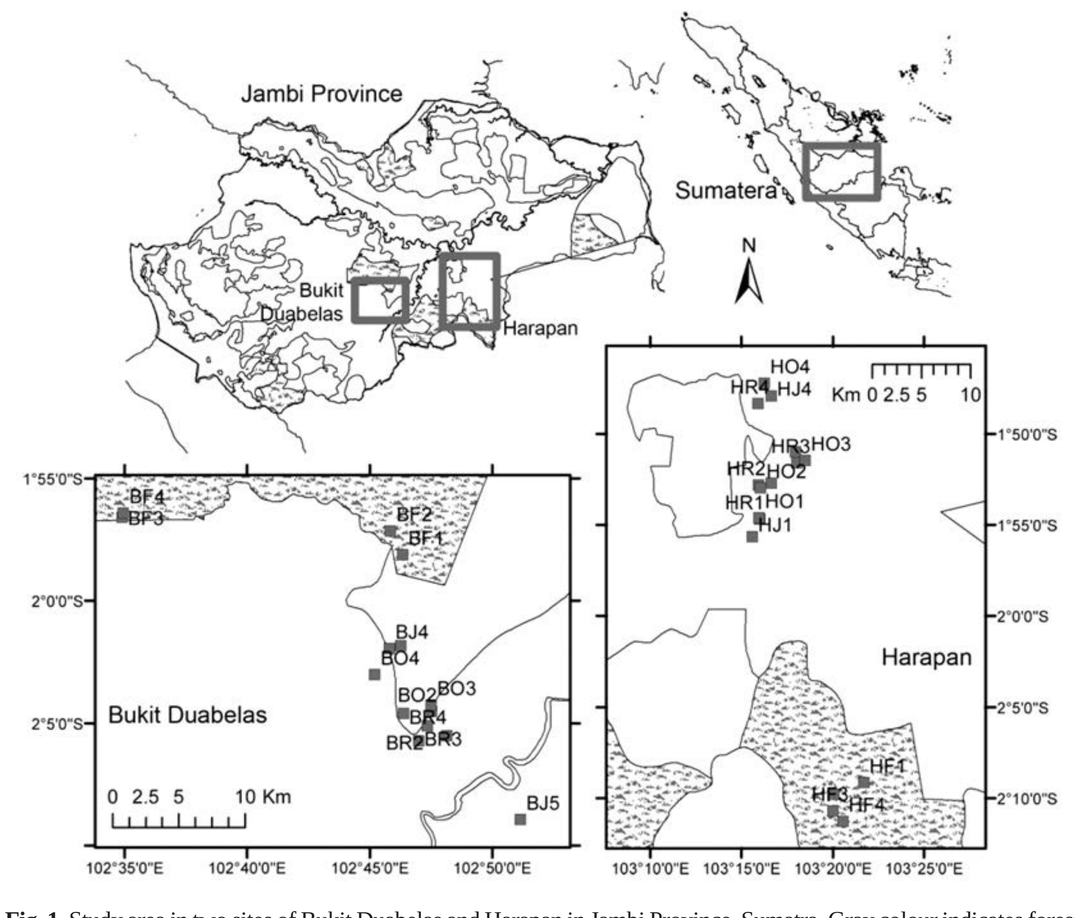

Fig. 1. Study area in two sites of Bukit Duabelas and Harapan in Jambi Province, Sumatra. Gray colour indicates forest.

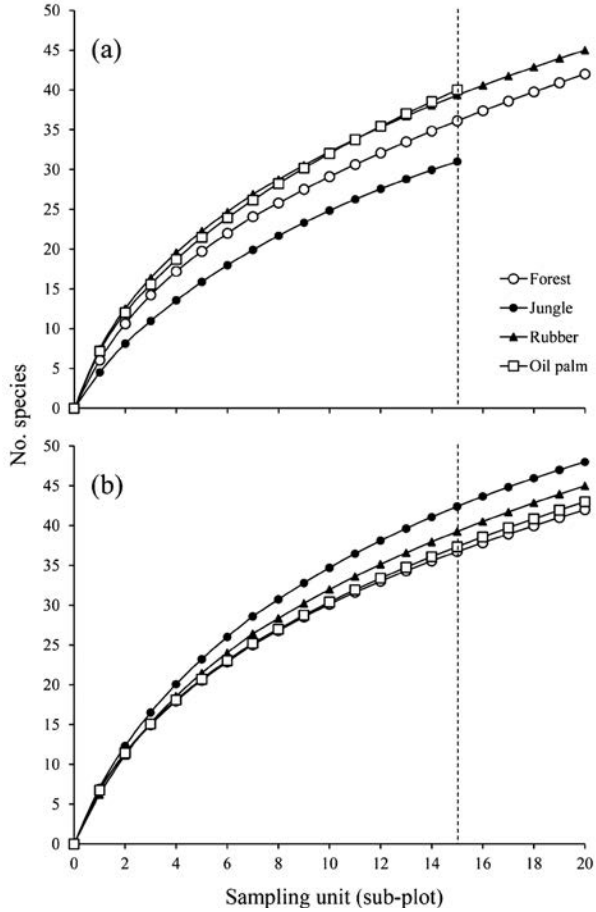

Fig. 2. Species accumulation curves of ant species found four land use types within the two study sites, (a) Bukit Duabelas National Park and (b) Harapan Forest. The dashed line indicates ant species richness from 15 sub-plots.

The absence of significant differences in ant species richness between forests and agricultural land-uses could be due to the fact that the remaining dry lowland forests in the region are not primary but secondary forests. Similarly, most forests that were transformed into palm oil plantations were not primary but secondary forest (as the forest plots in our project area are), which had previously been used for logging, or as agroforests (Koh & Wilcove 2008), so that the ant species pool may already be eroded at the regional level by past land-use changes. However, as we discuss below, our results suggest that a fairly large number of common and generalist ant species, tolerant of, or specialized to, open land and monoculture plantations, inhabit the man-made habitats.

In contrast to species richness, ant community structure greatly differed between all land use types, with differences most evident between forests and agroforests on one hand, and the monoculture plantations on the other. The direct effects of the present habitat, such as differences in available resources (food, shelter, potential nesting sites), environmental conditions (temperature, light), the open land phase of establishment of monocultures, and indirect effects mediated by a shift towards dominant, invasive species are likely to explain these patterns. Ant communities in BDNP oil palm plantations showed high similarities among plots compared to other habitats including oil palm in Harapan, which may be due to the homogeneous understory vegetation in oil palm plantations in the BDNP site.

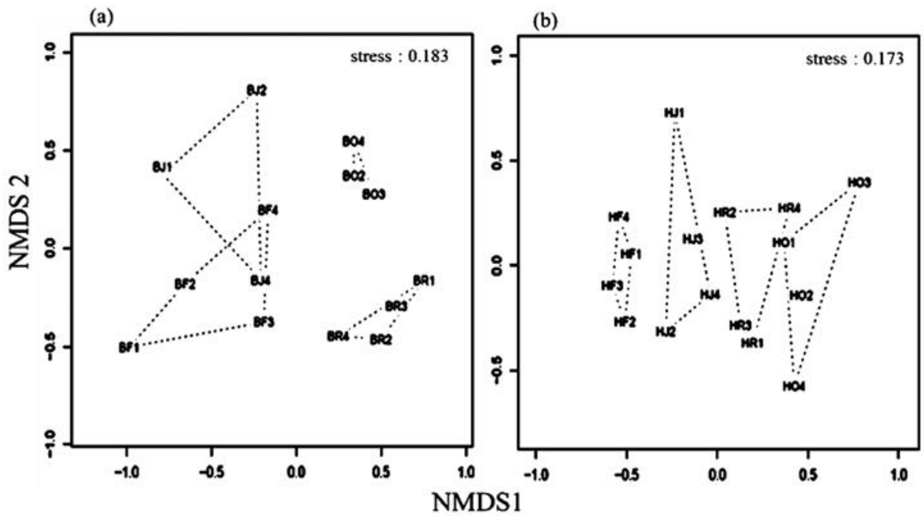

Fig. 3. Variation in ant community structure between study sites in the two study areas (a) BDNP and (b) Harapan, in non-metric multidimensional scaling (NMDS) ordination (based on abundance data and a Bray-Curtis distance metric). Forest sites are denoted by an F as the second letter, Jungle Rubber sites with J, Rubber sites with R and Oil Palm sites by an O. Stress values are given for a 2 dimensional NMDS.

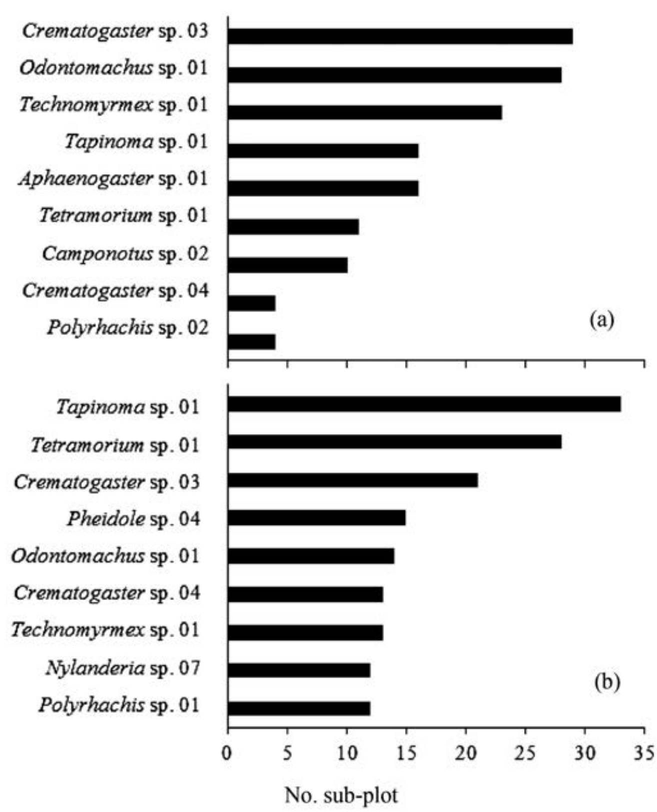

Fig. 4. Common ant species recorded from all land use types in (a) Bukit Duabelas and (b) Harapan area.

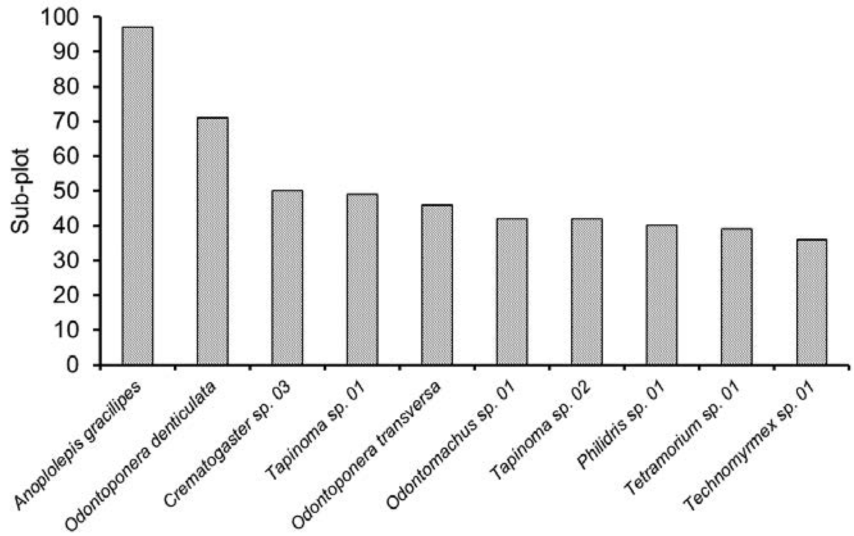

Fig. 5. The most abundant ant species based on number of subplots collected from Bukit Duabelas and Harapan sites.

The species of ants found in all four land-use types can be characterized as generalists, and are probably species that originate from primary forest and tolerate the transformation to plantations (Perfecto & Vandermeer 2006). Species in the genera *Crematogaster* and *Pheidole* were present in all four land-use types and are often generalist species. The subfamily Myrmicinae, in which the majority of ants species collected are included, harbours many common ant species that are widespread in warmer habitats, and includes more than 900 described species worldwide (Eguchi *et al.* 2006). There is often competition between these generalist species and species of the Dolichoderinae subfamily (Andersen 2000), represented here for example by ants of the genera *Tapinoma* and *Technomyrmex*, that are also present in the four land-use types studied here. Ant species that were dominant in oil palm and rubber plantation are generally tramp species, *i.e*. species that benefit from habitat degradation and human association (McGlynn 1999). These include species of the genus *Pheidole* and *Tetramorium* that are found in this study, which can be invasive (Schultz & McGlynn 2000).

One of the species that is present in three types of agricultural land use (jungle rubber, oil palm and rubber plantations) but not the forest is *A. gracilipes*. This species is well-known as invasive species and thrives in disturbed areas, but not forest. Brühl *et al.* (2003) also found that *A. gracilipes* is the most common species on 70% of all baits placed in oil palm plantations in Sabah, Malaysia. *A. gracilipes* is one of the most invasive species in the Indonesian cocoa plantations and is associated with land-use systems with low tree canopy cover and a small number of forest ant species (Bos *et al.* 2008).

Overall, the most dominant ant species are invasive non-forest ants such as *A. gracilipes* and *Odontoponera denticulata.* In oil palm and rubber plantations, *O. denticulata* replaced a species of the same genus found in forest and jungle rubber, *Odontoponera transversa*, These two related species can be used as bio-indicators, because they seem to have different adaptability and different habit preferences, as already suggested by a previous study, in which *O. denticulata* were only found in urban areas, while *O. transversa* were found only in relatively intact forests (Rizali *et al.* 2008).

Forest ant species in the genera *Cataulacus*, *Tetraponera* and *Polyrhachis* were not commonly found in any of the plots, not even regularly in the forest. This could be because it is more difficult to sample the complete ant fauna in a forest because of its high microhabitat heterogeneity. *Tapinoma* sp. 01 is abundant and very active in Harapan site. When *Tapinoma* sp. 01 is abundant, other ant species were unlikely to be present, even physically large ant species such as *Camponotus gigas* and *Polyrhachis* spp.. In habitats where dolichoderine species were not found, we found many individuals of small species such as *Monomorium* and large species such as *Oecophylla* and *Tetraponera*, suggesting that dolichoderines outcompete species from other subfamilies.

To conclude, the conversion of forested habitat results in severe changes in ant communities. While our study suggests this needs not be accompanied by a decrease in species richness, the identity of the species, the abundance of tramp and invasive ants, and the dominance patterns are different in agricultural habitats. The functional consequences are not clear, but in terms of large-scale biodiversity, our results suggests that any further losses of forest habitat, including conversion to jungle rubber, would result in a decrease in regional biological diversity, as those species dependent on forested habitats cannot persist in monoculture plantations.

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Appendix 1

Ant species sampled in different land-use regimes from Harapan Forest and Bukit Duabelas National Park (+ means present). [a]F = Forest, J = Jungle Rubber, R = Rubber plantation, O = Oil palm plantation.

No	Subfamily	Harapan Forest				Bukit Duabelas National Park			
		Land-use[a]				Land-use[a]			
	Species	F	J	R	O	F	J	R	O
	Dolichoderinae (Forel, 1878)								
1	*Dolichoderus* sp. 01	+	+	+					
2	*Dolichoderus* sp. 02	+		+	+				
3	*Iridomyrmex* sp. 01	+							
4	*Loweriella* sp. 01	+	+					+	
5	*Philidris* sp. 01	+	+	+		+	+	+	
6	*Philidris* sp. 03		+						
7	*Philidris* sp. 06	+							
8	*Tapinoma* sp. 01	+	+	+	+	+	+	+	+
9	*Tapinoma* sp. 02		+	+	+	+		+	+
10	*Tapinoma* sp. 03		+	+	+				
11	*Tapinoma* sp. 04		+	+					
12	*Tapinoma* sp. 05	+							
13	*Technomyrmex* sp. 01	+	+	+	+	+	+	+	+
14	*Technomyrmex* sp. 02						+	+	
15	*Technomyrmex* sp. 03		+	+					
	Dorylinae (Leach, 1815)								
16	*Dorylus* sp. 01								+
17	*Dorylus* sp.02								+
	Formicinae (Latreille, 1809)								
18	*Acropyga* sp. 01	+	+	+				+	
19	*Anoplolepis gracilipes* (Smith, 1857)		+	+	+		+	+	+
20	*Camponotus gigas* (Latreille, 1802)	+	+	+		+	+		
21	*Camponotus* sp. 02					+	+	+	+
22	*Camponotus* sp. 03	+	+	+		+	+	+	
23	*Camponotus* sp. 05	+				+		+	
24	*Camponotus* sp. 07					+		+	
25	*Camponotus* sp. 08								+
26	*Echinopla* sp. 01					+	+		
27	*Echinopla* sp. 02		+						
28	*Nylanderia* sp. 01	+		+					
29	*Nylanderia* sp. 02								

No	Subfamily	Harapan Forest				Bukit Duabelas National Park			
		Land-use[a]				Land-use[a]			
	Species	F	J	R	O	F	J	R	O
30	*Nylanderia* sp. 03	+		+	+				
31	*Nylanderia* sp. 04	+							
32	*Nylanderia* sp. 05			+				+	
33	*Nylanderia* sp. 07	+	+	+	+				
34	*Nylanderia* sp. 08		+						
35	*Oecophylla smaragdina* (Fabricius, 1775)			+	+				
36	*Paratrechina longicornis* (Latreille, 1802)		+						
37	*Plagiolepis* sp. 01	+	+	+	+			+	
38	*Polyrhachis* sp. 01					+		+	+
39	*Polyrhachis* sp. 02	+		+	+	+	+	+	+
40	*Polyrhachis* sp. 04	+		+	+		+		+
41	*Polyrhachis* sp. 05	+	+			+			
42	*Polyrhachis* sp. 06								+
	Myrmicinae								
43	*Acanthomyrmex* sp. 01	+	+						
44	*Acanthomyrmex* sp. 02	+							
45	*Acanthomyrmex* sp. 03					+			
46	*Aphaenogaster* sp. 01	+	+		+	+	+	+	+
47	*Calyptomyrmex* sp. 01								+
48	*Cardiocondyla* sp. 01		+	+	+		+	+	
49	*Cardiocondyla* sp. 02			+	+				
50	*Cataulacus* sp. 01	+	+				+		
51	*Crematogaster* sp. 01					+			
52	*Crematogaster* sp. 02	+		+	+		+	+	+
53	*Crematogaster* sp. 03	+	+	+	+	+	+	+	+
54	*Crematogaster* sp. 04	+	+	+	+	+	+	+	+
55	*Crematogaster* sp. 05		+						
56	*Crematogaster* sp. 14		+						
57	*Lophomyrmex* sp. 01			+	+			+	
58	*Lophomyrmex* sp. 02	+		+	+				
59	*Lordomyrma* sp. 01			+					
60	*Lordomyrma* sp. 02			+					
61	*Lordomyrma* sp. 03			+					+
62	*Meranoplus* sp. 01	+				+			
63	*Monomorium floricola* (Jerdon, 1851)		+	+	+				
64	*Monomorium* sp. 02			+	+			+	+

No	Subfamily	Harapan Forest				Bukit Duabelas National Park			
		Land-use[a]				Land-use[a]			
	Species	F	J	R	O	F	J	R	O
65	*Monomorium* sp. 03				+				+
66	*Myrmicaria* sp. 01			+					
67	*Pheidole* sp. 01		+	+	+			+	+
68	*Pheidole* sp. 02	+		+			+		
69	*Pheidole* sp. 03							+	
70	*Pheidole* sp. 04	+	+	+	+				
71	*Pheidole* sp. 05							+	
72	*Pheidole* sp. 06						+		
73	*Pheidole* sp. 07		+						
74	*Pheidole* sp. 08				+		+		
75	*Pheidole* sp. 09					+			
76	*Pheidole* sp.10					+			
77	*Pheidole* sp. 11	+	+		+	+	+		+
78	*Proatta butteli* (Forel, 1912)				+				+
79	*Recurvidris* sp. 01		+		+				
80	*Recurvidris* sp. 02			+					
81	*Solenopsis* sp. 01					+			
82	*Solenopsis* sp. 02							+	
83	*Strumigenys* sp. 01					+			
84	*Tetheamyrma* sp. 01	+				+	+	+	+
85	*Tetramorium* sp. 01	+	+	+	+	+			
86	*Tetramorium* sp. 02		+		+	+			+
87	*Tetramorium* sp. 03				+				
	Ponerinae								
88	*Anochetus* sp. 01								+
89	*Cryptopone* sp. 01					+			+
90	*Diacamma rugosum* (Le Guillou, 1842)					+	+		
91	*Emerypone* sp. 01					+			
92	*Hypoponera* sp. 01		+	+	+				
93	*Leptogenys* sp. 01	+		+		+	+		+
94	*Mesoponera* sp. 01	+	+	+				+	+
95	*Myopias* sp. 01								+
96	*Odontomachus* sp. 01	+	+	+	+	+	+	+	+
97	*Odontoponera denticulata* (Smith, 1858)			+	+			+	+
98	*Odontoponera transversa* (Smith, 1857)					+	+		
99	*Platythyrea* sp. 01						+		

No	Subfamily	Harapan Forest				Bukit Duabelas National Park			
		Land-use[a]				Land-use[a]			
	Species	F	J	R	O	F	J	R	O
100	*Platythyrea* sp. 02						+		
101	*Ponera* sp. 01			+	+			+	+
102	*Ponera* sp. 02				+				
	Pseudomyrmecinae								
103	*Tetraponera* sp. 01	+	+	+		+	+	+	
104	*Tetraponera* sp. 03			+	+				