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Species composition of herbivorous insects and ants on trees in the plantations of durian *Durio zibethinus* and citrus fruits *Citrus amblycarpa* in Tarakan Island of Borneo

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Abstract In the tropics, the specific insect communities are observed in the fruit plantations as one form of agroforestry systems. The information on the communities of herbivorous insects as pests and ants as pest-control agents could be useful in facilitating effective management of plantations. Durian *Durio zibethinus* and citrus fruits *Citrus amblycarpa* are traditionally grown as agricultural products in the North Kalimantan region of Borneo, though the information on herbivorous insects and ants remains scant. In this study, we assessed the species composition and densities of herbivorous insects and ants inhabiting on trees in the plantations of durian and citrus fruits in Tarakan Island of North Kalimantan. From 2016 to 2017, 55649 individuals of herbivores comprised of 61 species and 64360 ant workers comprised of 25 species were collected by tree-beating sampling on 59 durian and 63 citrus trees in three plantation sites (A-C). In citrus fruit trees, aphid *Toxoptera citridida* was dominant in the herbivore communities. While, in durian trees, more than 80% of herbivores was occupied by various herbivore groups, leaf beetle, moth, mealybug, psyllid and leafhopper. In ants, more than 60% of ants collected in each site was occupied by three species *Tapinoma melanocephalum, Technomyrmex albipes,* and *Oecophylla smaragdina*. NMDS analyses showed the patterns of classification in herbivorous insect and ant communities were similar: the groups in site C could be classified, independent on the groups in site A and B. Probably, it may be caused by the environmental factors in site C. Otherwise, the characteristics of herbivores community are possibly affected by any interactions with ants, resulting in the association among the structures of herbivore and ant communities. Our data could provide useful information for the pest control activities in the plantations of durian and citrus fruits in North Kalimantan.

Keywords. herbivorous insects; ant; community; durian; citrus; plantation

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1 Introduction

Agroforestry systems (AF) are mixed cultivation systems that comprise crop plants and animals in some form of spatial arrangement or temporal sequence [1-3]. They offer a variety of ecosystem services beyond food production, including recycling of nutrients, regulation of microclimates, facilitating hydrological processes, and enabling more diverse farm activities [4-6]. Plantation agriculture is one of form of agroforestry. In the tropics, numerous crops, such as cacao, oil palm, and some woody species have been planted and the production activities are managed by human activities. In the lowlands of Southeast Asia, many tropical fruits including banana, mango, and pineapple, are also cultivated through plantation farming. Such fruit production activities are some of the major agricultural services in Indonesia and Malaysia.

Agroforestry systems support a wide variety of organisms and high biodiversity [6-9]. Tropical fruit plantations are habitats for herbivorous insects that exploit the plant resources, including flowers, fruits, seeds, and leaves. Specific communities of herbivorous insects are frequently observed in the plantations. However, many herbivores are regarded as fruit pests, with considerable negative impacts on production activities. Therefore, information of herbivorous insect communities could be critical for plantation management. In plantations of some tropical fruits in Southeast Asia, the characteristics of herbivorous insect communities, such as species composition, densities, and distribution have been monitored by researchers from public institutions. In addition, the plantations are adversely affected by the presence of ants, which are one group of social insects [8, 10-11]. Ant biomass is highest among all animals in the tropics. They influence ecosystem as predators, prey, scavengers and symbionts in both degraded and natural habitats [12]. Particularly, the predatory role of ants is important in plantations, where they have a negative effect on for herbivorous insect populations [13-14]. However, some ant species exhibit mutualistic interactions with some aphids and mealybugs by attending them on trees of some fruit species. Consequently, such interactions could have negative effects on fruit tree species in any cases. Ants interacts with herbivorous insects in diverse ways. Therefore, the characteristics of herbivorous insect communities in plantations could similarly be influenced by ant communities in various ways.

Information on insect herbivore communities and ants, acting as pests and as pest control agents, respectively, could be useful in facilitating effective management of plantations. Durian, *Durio zibethinus*, and citrus fruits, *Citrus amblycarpa*, are traditionally grown in agroforestry plantations in the North Kalimantan region of Borneo [15]. However, the information on herbivorous insects and ants inhabiting the plantations in the region remains scant, though it is suggested that the largest part of the arthropod biomass is rich [16-18]. In the present study, we assessed species composition and densities of herbivorous insects and ants in the field with the aim of obtaining data on arboreal insect and ant communities in durian and citrus fruit plantations.

2 Methods

Field studies were conducted in the Tarakan Island in Borneo, Indonesia (Fig. 1). Three plantation sites were selected on the island: site A at Mamburungan (3°18'15"N, 117°37'12"E), site B at East Mamburungan (3°17'14"N, 117°38'1"E), and site C at Kampung Enam village (3°18'41"N, 117°38'1"E). All three plantations were opened 7-8 years ago. Durian *D. zibethinus* and citrus fruits, *C. amblycarpa* were planted in that time. Citrus fruits as non native species were introduced. Horticultural crops, including, banana, mango, maize, cabbage, and other crops were also planted in the sites.

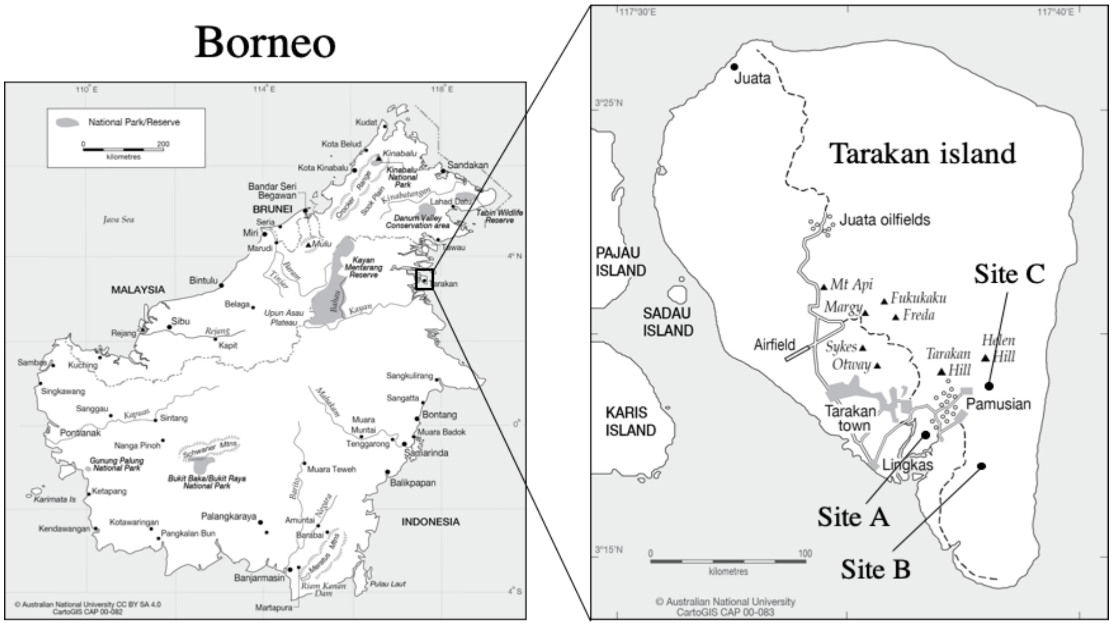

Figure 1 Map of Tarakan island and the location of three study sites (copyright of the source of the maps: CatroGIS Services, College of Asia and the Pacific, The Australian National University).

The plantations in site A and C were established in open land including grassland and plowed field. The densities of crop trees were low and the height of crop trees was relatively low. The plantations in site B were adjacent to secondary forests and shrubs at hilly area. Many trees other than durian and citrus were present within and around the plantation. The height of crop trees was relatively high. Although the farmers did not extensively apply pesticides in the study areas, weed and pest management activities were sometimes carried out using herbicides and various types of insecticides. However, such the management activities had minimal impacts on ants, since the pest and weed management activities were not frequent.

In the plantations, we set up a study area covering 2.0 ha (200 m × 100 m), where many durian and citrus fruits were under intense cultivation. In site A and C, we selected 66 (*D. zibethinus*: 44 and *C. amblycarpa*: 22) and 30 (*D. zibethinus*: 15 and *C. amblycarpa*: 15) trees as trees to be sampled, respectively. In site B, only 26 citrus trees were selected. Collection of arboreal insects and ants was carried out from March to September in 2016 and 2017. Ten branches (length: 50–80 cm, diameter: 5–10 cm) in a tree were selected and insects and ants that were present on them were collected by using tree beating method. In the case of insect species such as aphids, mealybugs, and fruit flies, the number of insects on 20 branches was counted. The number of ants walking on an additional 20 branches was also counted. In site A and B, the collection and counting activities were carried out 1-7 times, while they were carried out 1-2 times in site C. All collected samples were stored in 99% ethanol and sorted in the laboratory. Subsequently, the species of insects and ants were identified, using identification manuals and online resources.

Frequency of species and the densities in insects and ants were compared among three sites by calculating the average of collected number (/branch/tree/sampling time). To compare the species composition and community structures, non-metric dimensional scaling (NMDS) analyses were carried out. The differences in the community structures were quantified based on presence or absence of species. The similarity matrix was then reduced to a two-dimensional ordination. Packages vegan and MASS in R (R Core Development Team) were used for NDMS analyses.

3 Results

From 2016 to 2017, we collected 55649 herbivorous insect individuals, comprised of 61 species from 60 genera, 32 families, and five orders, in three sites. They were mainly collected from the surfaces of leaves, flowers, and fruits. To evaluate the composition of the herbivore species, we classified the collected insects under the following 11 functional groups based on scientific classification and foraging behavior:

(1) Leaf beetle: beetles specializing on feeding on leaves, flowers, pollen, nectar, and other plant parts, belonging to the families Chrysomelidae, Meloidae, Cerambycidae, Mordellidae, and other families in order Coleoptera
(2) Weevil: beetles belonging to the superfamily Curculionidae in the order Coleoptera
(3) Fruit fly: tephritid fruit flies in the family Tephritidae in the order Diptera
(4) Leaf-miner fly: flies feeding on leaves belonging to the family Agromyzidae in the order Diptera
(5) Aphid: small-sucking hoppers of the family Aphididae in the order Hemiptera
(6) Mealybug: scale insects in the families Pseudococcidae and Coccidae in the order Hemiptera
(7) Leafhopper: small-sucking hoppers in the family Cicadellidae in the order Hemiptera
(8) Psyllid: small-sucking insects in the superfamily Psylloidea superfamily in the order Hemiptera
(9) Other bugs: other sucking bugs, sap-sucking bugs, and stink bugs in the family Lygaeidae, Corediae, Pentatomidae, and other families in the order Hemiptera
(10) Moth and Butterfly: larvae and adults of lepidopterans in the order Lepidoptera
(11) Thrip: thrips in the family Thripidae in the order Thysanoptera

Table 1 Species and collection number of herbivorous insects on durian trees in the two sites.

Functional Group	Order	Family	Species	Collection number	
				A	C
Leaf beetle	Coleoptera	Cantharidae	*Mimopolemius* sp. 1	19	1
		Cerambycidae	Unknown sp. 1	1	1
		Chrysomelidae	*Aulacophora similis*	253	10
			Unknown sp. 3	11	1
			Unknown sp. 4	15	0
			Unknown sp. 5	99	2
			Unknown sp. 6	14	1
			Unknown sp. 7	1	1
			Lema pectoralis	13	2
			Menolepta bifasciata	0	1
			Mimastra pallida	5	0
			Phratora vitellinae	134	3
			Rhabdoscelus leprosus	10	2

		Meloidae	*Epicauta* sp.1	32	0
		Mordellidae	*Tolidopalpus nitidicoma*	1	0
			Tolidopalpus sp. 1	3	0
		Nitidulidae	*Carpophilus mutilatus*	2	0
		Tenebrionidae	*Atoichus pemanoa*	1	0
Weevil	Coleoptera	Curculionidae	*Alcidodes* sp. 1	0	1
			Hypomeces squamosus	79	0
			Omobaris calentus	4	0
			Sternochetus trigidus	5	1
			Xylosandrus mongerus	1	3
Fruit fly	Diptera	Thepritidae	*Bractocera dorsalis*	5	8
			Unknown sp. 8	12	1
Leaf-miner fly	Diptera	Agromyzidae	*Chromatomyia* sp. 1	12	0
			Liriomyza sp. 1	277	0
			Ophiomyia sp. 1	55	0
			Unknown sp. 9	25	4
Aphid	Hemiptera	Aphididae	*Toxoptera citridida* (*Aphis tavaresi)*	83	4
Mealybug	Hemiptera	Coccidae	*Coccus viridis*	75	0
		Pseudococcidae	*Planococcus citri*	1089	28
Leafhopper	Hemiptera	Cicadellidae	*Idioscopus clypealis*	663	372
			Unknown sp. 10	21	9
			Unknown sp. 11	14	3
			Unknown sp. 12	14	1
		Ricaniidae	Unknown sp. 13	0	5
Psyllid	Hemiptera	Carsidaridae	*Allocaridara malayensis*	250	581
Other bugs	Hemiptera	Aleyrodidae	*Leptocorisa acuta*	11	4
		Coreidae	*Physomerus grossipes*	13	0
		Lygaeidae	Unknown sp.14	2	2
		Pentatomidae	*Cappaea taprobanensis*	38	3
			Nezara viridula	15	0
		Pyhrocorridae	*Dysdercus* sp. 1	0	1
		Reduviidae	*Sycanus* sp. 1	1	0
		Tingidae	Unknown sp. 15	6	0
Moth and Butterfly	Lepidoptera	Gracillariidae	Unknown sp. 16	21	0
			Unknown sp. 17	73	10
		Licaenidae	Unknown sp. 18	0	5
		Lymantriidae	Unknown sp. 19	1	0
		Noctuidae	Unknown sp. 20	27	0

		Psychidae	*Mahasena* sp. 1	27	2
		Pyralidae	*Citripestis sagittiferella*	255	19
			Unknown sp. 22	9	1
			Unknown sp. 23	32	0
Thrip	Thysanoptera	Phlaeothripidae	*Haplothrips* sp. 1	3	3
		Thripidae	*Megalurothrips usitatus*	56	0
			Thrips parvispinus	0.001	0

Table 2 Species and collection number of herbivorous insects on citrus trees in the three sites.

Functional group	**Order**	**Family**	**Species**	**Collection number**		
				A	**B**	**C**
Leaf beetle	Coleoptera	Cantharidae	*Mimopolemius* sp. 1	6	0	0
		Cerambycidae	*Neospondylis* sp. 1	1	1	0
			Unknown sp. 1	0	3	0
			Unknown sp. 2	0	1	0
		Chrysomelidae	*Aulacophora similis*	26	50	2
			Unknown sp. 3	1	1	0
			Unknown sp. 4	5	4	0
			Unknown sp. 5	10	19	2
			Unknown sp. 6	4	2	0
			Unknown sp. 7	25	5	0
			Lema pectoralis	2	2	0
			Menolepta bifasciata	1	0	0
			Mimastra pallida	1	5	0
			Phratora vitellinae	12	17	2
			Rhabdoscelus leprosus	5	5	1
		Languriidae	*Languria mozardi*	0	3	0
		Meloidae	*Epicauta* sp. 1	15	21	1
		Mordellidae	*Tolidopalpus nitidicoma*	2	0	0
			Tolidopalpus sp. 1	1	0	0
		Nitidulidae	*Carpophilus mutilatus*	31	20	0
		Tenebrionidae	*Atoichus Pemanoa*	0	1	0
Weevil	Coleoptera	Curculionidae	*Alcidodes* sp.1	0	1	0
			Hypomeces squamosus	48	197	0
			Omobaris calentus	1	1	0
			Sternochetus trigidus	5	3	0
			Xylosandrus mongerus	2	1	0

Fruit fly	Diptera	Thepritidae	*Bractocera dorsalis*	14	80	5
			Unknown sp. 8	2	7	0
Leaf-miner fly	Diptera	Agromyzidae	*Chromatomyia* sp. 1	26	5	0
			Liriomyza sp. 1	57	73	2
			Ophiomyia sp. 1	15	7	0
			Unknown sp. 9	4	6	8
Aphid	Hemiptera	Aphididae	*Toxoptera citridida* (*Aphis tavaresi*)	7614	33696	3523
Mealybug	Hemiptera	Coccidae	*Coccus viridis*	3	0	0
		Pseudococcidae	*Planococcus citri*	2920	1168	163
Leafhopper	Hemiptera	Cicadellidae	*Idioscopus clypealis*	11	27	12
			Unknown sp. 10	7	83	1
			Unknown sp. 11	0	3	0
		Ricaniidae	Unknown sp. 13	0	1	1
Psyllid	Hemiptera	Carsidaridae	*Allocaridara malayensis*	2	14	103
Other bugs	Hemiptera	Aleyrodidae	*Leptocorisa acuta*	0	1	0
		Lygaeidae	Unknown sp. 14	5	12	0
		Pentatomidae	*Cappaea taprobanensis*	54	16	5
			Nezara viridula	1	9	2
		Pyhrocorridae	*Dysdercus* sp. 1	13	2	0
		Reduviidae	*Sycanus* sp. 1	4	0	0
		Tingidae	Unknown sp. 15	2	0	0
Moth and Butterfly	Lepidoptera	Gracillariidae	Unknown sp. 16	1	1	0
			Unknown sp. 17	1	2	1
		Licaenidae	Unknown sp. 18	0	1	1
		Lymantriidae	Unknown sp. 19	1	12	2
		Noctuidae	Unknown sp. 20	1	2	0
		Pieridae	Unknown sp. 21	0	2	0
		Psychidae	*Mahasena* sp. 1	15	9	5
		Pyralidae	*Citripestis sagittiferella*	14	22	24
			Unknown sp. 22	0	3	0
			Unknown sp. 23	10	0	0
Thrip	Thysanoptera	Phlaeothripidae	*Haplothrips* sp. 1	11	10	0
		Thripidae	*Megalurothrips usitatus*	33	27	1
			Thrips parvispinus	6	1	0

Figure 2 illustrates the species composition in durian and citrus fruit trees in the three sites. The compositions were considerably varied among the three sites and among fruit tree species (site: χ^2=1961.4, P<0.01, fruits: χ^2=4592.5, P<0.01, G-test). In citrus fruit trees, the aphid *Toxoptera* *citridida* a synonym of *Aphis tavaresi*, was dominant among the insect herbivore communities (site A: 68.9%, site B: 94.5%, site C: 91.1%). In durian trees, more than 80% of the insect herbivores fell under numerous functional groups, including leaf beetles, moths and butterflies, mealybugs, psyllids, and leaf hoppers. The compositions of groups were different between site A and C. In all sites, the following nine species were dominant: leaf hopper *Idioscopus clypeus*, mealy bug *Planococcus citri*, green weevil *Hypomeces squamosus*, leaf miner fly *Liriomyza* sp. 1, aphid *T. citridida*, durian psyllid *Allocarsidara malayensis*, leaf beetle *Aulacophora similis*, stink bug *Cappaea taprobanensis*, and citrus fruit borer *Citripestis sagittiferella*.

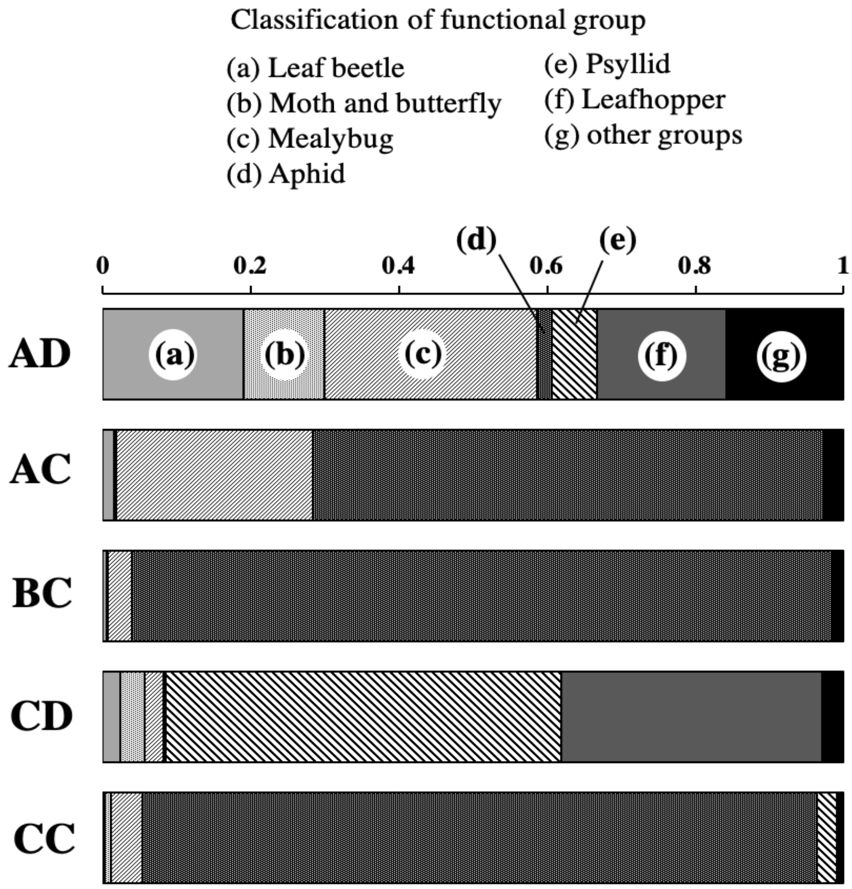

Figure 2 Frequency of functional groups of herbivorous insects in two fruit species at three sites. AD and AC: durian and citrus fruit trees in site A, BC: citrus fruit trees in site B, CD and CC: durian and citrus fruit trees in site C.

In the three sites, 64360 ant workers were collected. They were comprised of 22 species from 16 genera and five subfamilies (Table 3). Three species, including *Tapinoma melanocephalum, Technomyrmex albipes,* and *Oecophylla smaragdina* accounted for more than 60% of all the worker ants in each site (Fig. 3). They dominated the trees by nesting in branches and trees and building weaver nests on trees. In addition, species composition was significantly varied among three sites (χ^2=22413.2, P<0.01, G-test). In site A and B, *T. melanocephalum* and *O. smaragdina* were dominant, while *T. albipes* and *O. smaragdina* were dominant in site C. However, ant species composition was not substantially different between durian and citrus fruits trees.

Table 3 Species and collection number of arboreal ants on durian and citrus trees in the three sites.

Subfamily	Species	Collection number				
		Durian		Citrus		
		A	C	A	B	C
Ponerinae	*Ponera* sp.1	4	0	0	1	0
Dolichoderinae	*Dolichoderus* sp. 1	0	2	2	2	6
	Iridomyrmex anceps	3101	15	670	371	49
	Philidris sp.1	541	1	245	71	0
	Tapinoma melanocephalum	19703	3	7106	4020	42
	Tapinoma sp. 1	96	30	192	45	0
	Technomyrmex albipes	3945	2363	1509	383	697
Formicinae	*Anoplolepis gracilipes*	1031	0	1294	697	11
	Oecophylla smaragdina	5923	578	2208	294	455
	Camponotus sp. 1	49	1	8	7	0
	Polyhachis sp. 1	22	5	7	47	3
Pseudomyrmicinae	*Tetraponera* sp. 1	281	8	44	66	0
	Tetraponera sp. 2	30	0	19	1	0
Myrmiciane	*Crematogaster sewardi*	1314	4	807	592	14
	Crematogster sp. 1	753	28	53	65	20
	Crematogster sp. 2	139	0	6	14	0
	Trichomyrmex destructor	2099	16	613	341	4
	Monomorium sp. 1	350	0	52	0	0
	Monomorium sp. 2	48	0	92	37	0
	Tetramorium sp. 1	67	8	499	119	30
	Tetramorium sp. 2	22	0	10	26	0
	Pheidole sp. 1	16	0	0	4	0

Figure 4 illustrates the classification of herbivorous insects and ant groups in fruit tree species and sites. The patterns of classification were similar between (Fig. 4a) and ants (Fig. 4c): the groups in site C were classified by NMDS 1 as independent of the groups in site A and B. In herbivorous insects, 27 among 61 species had significant correlation with NMDS axes. The classifications of groups in site C were characterized by *Idioscopus clypealis* and Ricaniidae sp. (unknown sp. 13) as leafhopper and *C.sagittiferella* and Gracillariidae sp. (unknown sp.16) as moth and butterfly (Fig. 4b, Table 1 and 2). In ants, 21 among 25 species had significant correlation with NMDS axes and the classifications of site C were characterized by *T. albipes* as the dominant species in the site (Fig.

4d). In addition, NMDS1 in the classification of herbivorous insects was significantly correlated with NMDS axes in the classification of ants (r^2=0.47, P<0.0001), indicating that the species composition of the herbivorous insects was associated with that of ants.

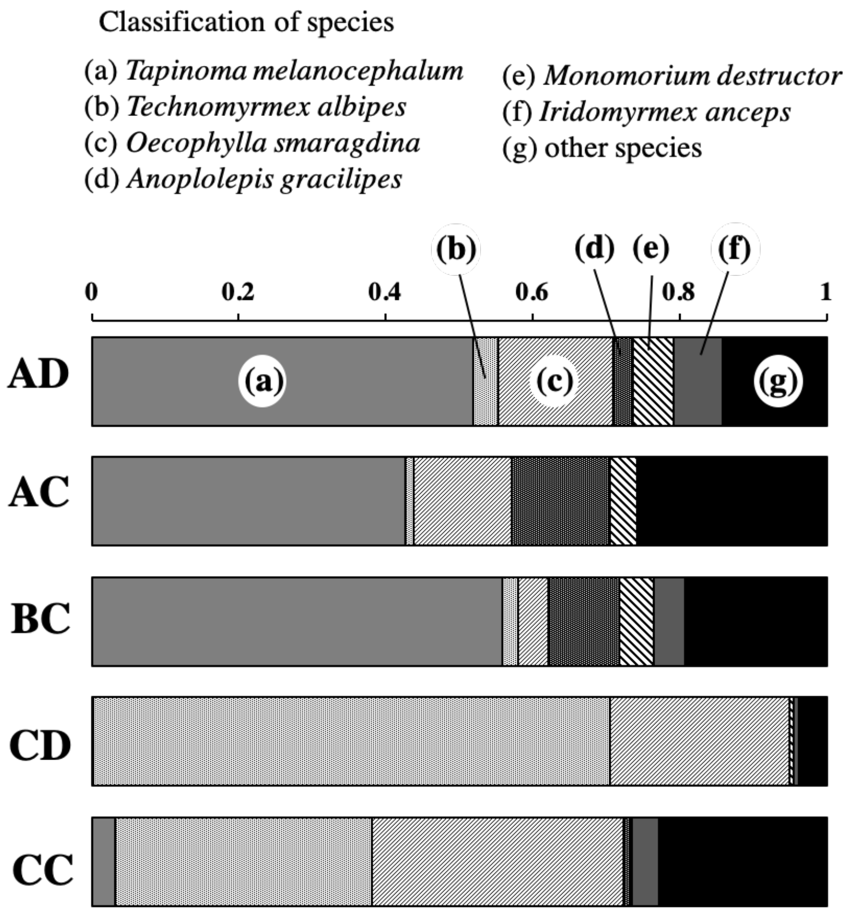

Figure 3 Frequency of ant species in two fruits at three sites. AD and AC: durian and citrus fruit trees in site A, BC: citrus fruit trees in site B, CD and CC: durian and citrus fruit trees in site C.

4 Discussion

The species compositions of herbivorous insects in the plantations were different among fruit tree species and sites. In citrus fruit, *C. amblycarpa*, the aphid *T. citridida* was dominant in all sites. It is one of representative pests of citrus and vectors of the pathogenic plant virus [19]. Moreover, the aphid is an invasive species that is widely distributed in the world, with considerable adverse effects on the farming of citrus fruits. The results indicate pest control activities against the aphid would be required to manage to the citrus fruit plantations in North Kalimantan. In durian, *D. zibethinus*, the herbivorous insect communities were composed of more species and functional groups. In site A, the community was composed of many herbivore groups, while psyllid *A. malayanensis* and leafhopper *I. clypeus* were dominant in site C. Durian has more potential resources for various herbivorous insect groups, while citrus is mainly exploited by a specific insect group. In future, more extensive control strategies and techniques for various pests should be carried out for the effective management of durian plantations.

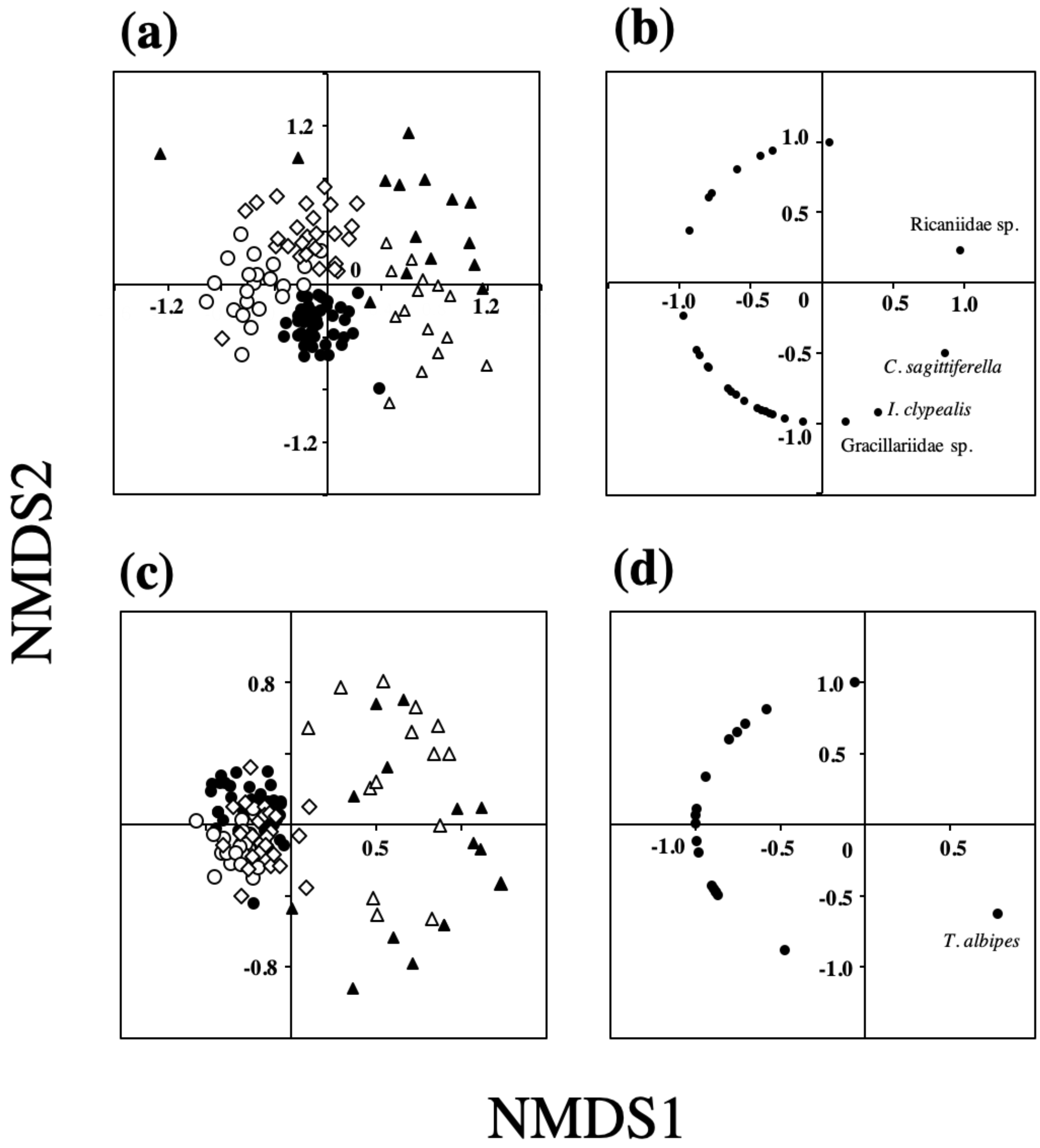

Figure 4 Classification of species composition in herbivorous insect and ant communities by NMDS. (a) and (c) show the biplots of NMDS in herbivorous insects and ants. The symbols circle, rhombus and triangle, mean site A, B, and C respectively. Black and white symbols mean durian and citrus trees. (b) and (d) show the ordinations of each species which had significant correlation with NMDS. In (b) and (d), the species name characterized the groups was shown.

The classification patterns derived from NMDS analyses tended to be similar for herbivorous insect and ant communities. In particular, the species composition in site C was independent of those of the two other sites, which was potentially because of two factors. The characteristics of herbivorous insect and ant communities may be determined by various environmental factors in site C, including natural and geographical conditions. In general, the community structures could be greatly influenced by environmental factors [20]. For example, the plantations in site C were established in open land with relatively low tree densities. Such forest conditions may represent unique environmental conditions, which limit the species inhabiting in the plantations, resulting in specific communities exploiting such environments. Additionally, the characteristics of herbivore communities could be influenced by interactions with ants. In site C, *T. albipes* was dominant and influenced the classification of ant communities. Blüthgen et al. [21] reported that *T. albipes* had trophobiotic interactions with 22 leafhopper species of the family Cicadellidae in a tropical rainforest of Borneo. Some psyllid species in the family psyllidae were also attended by some ants [22-23]. Therefore, the attendance by *T. albipes* possibly increased the densities of leafhopper *I. clypealis* and psyllid *A. malayensis*. Moreover, the densities of *T. melanocephalum*, which were the dominant species in the two other sites, were lower in site C. The ant is an invasive species and a major predator of other insects and arthropods [24-25]. Low densities of *T. melanocephalum* may result in high densities of any herbivorous insects, *C. sagittiferella* and Gracillariidae sp. (unknown sp. 16), characterized the classification of herbivore communities in site C. Such interactions may result in the association among the species composition of herbivore and ant communities. To test the hypotheses, response of *T. albipes* and *T. melanocephalum* to herbivorous insects and their interactions should be investigated in the field.

In our study, the number of sampling and trees was smaller in site C than site A and B. The data may be biased among the sites by such the difference of sampling efforts; the collection data in site C is underestimated. As a possibility, herbivorous insect communities on durian trees in site C may be composed of more various species. Additionally, in ant communities in site C, *O. smaragdina* and *I. anceps* are more dominant. For the exact comparison of the communities among the plantation sites, more sampling efforts are needful. However, the data of our study presents basic data on herbivorous insect communities in durian and citrus fruit plantations in North Kalimantan. In collected insect species, it had been reported that *H. squamosus, A. malayensis*, and *P. citri* were the major durian pests while *T. citridida, C. taprobanensis, C. sagittiferella, P. citri,* and *H. squamosus* were the major citrus fruit pests [19, 26-27]. Effective pest control methods and techniques could facilitate the proper management of the plantations. Furthermore, many arboreal ants have important predator roles against herbivorous insects and arthropods in the plantations [28-32]. In plantation managemant starategies, arboreal ants have been used to control herbivorus insects in the plantations [33-36]. Our study could provide useful informmation for the pest control activities using ants in durian and citrus fruit plantations in North Kalimantan.

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