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Effect of the distance between natural forest and Acacia forest on termite diversity in Acacia plantation forests

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Abstract The species diversity of termites was investigated in three different types of forest: isolated acacia plantations, acacia plantations wholly surrounded by natural forests and acacia plantations partly adjacent to natural forests. The 100 m belt transect protocol was used to assess the species richness and abundance of termites. The results showed that the presence of adjacent natural forests contributes to an increase of biodiversity in acacia plantations. It was also found that the presence of acacia plantations caused a decrease of biodiversity in adjacent natural forests. The proportion of common species among the three types of forest arrangement was also compared.

Keywords Termites, Species diversity, Acacia plantation forest, Natural forest

Introduction

Termites are widely distributed in tropical and subtropical regions and play a crucial role in forest ecosystems as a decomposition agent. Termite diversity varies according to differences of the environments they inhabit, such as differences of vegetation, latitudinal differences, disturbance level, and so on (Eggleton et al. 1995; Davies 1997; Eggleton et al. 1999; Jones 2000; Gathorne-Hardy et al. 2001; Eggleton et al. 2002; Inoue et al. 2006; Donovan et al. 2007; Dosso et al. 2010; Neoh et al. 2015a etc.). Termite diversity generally tends to be higher in natural rain forests than in disturbed areas (Eggleton et al. 1995; Jones 2000). In this study, we consider the termite diversity and abundance in isolated acacia plantations as well as acacia plantations wholly surrounded by natural forests or those partly adjacent to natural forests. It is thought that termite communities in the acacia plantations recover from disturbed states by migration of some species from neighboring natural forests. The objective here is to evaluate the effect of the presence of neighboring or adjacent natural forests on the recovery of disturbed acacia plantations. Our interest lies also in the number of termite species common to both acacia plantations and neighboring natural forests.

Materials and methods

Study sites

We investigated the difference of species diversity of termites among three types of forest arrangement: isolated acacia plantation forests (Fig. 1A), acacia plantation forests partly adjacent to natural forests (Fig. 1B) and acacia plantation forests wholly surrounded by natural forests (Fig. 1C) in Sabah and Sarawak, Malaysia.

In the case of the isolated acacia plantation forests, the study was conducted in *Acacia* hybrid (*Acacia auriculiformis-mangium*) plantation forests of KM Hybrid Plantation SDN. BHD. in Keningau, Sabah, Malaysia in 2006–2008. We selected 7 sites of the *Acacia* hybrid forest; they were 4 young forests of 2, 3, 4 and 6 years after plantation and 3 acacia abandoned forests of 20 years (disturbed and undisturbed) and 30 years. We made the survey also in a clear land. For comparison, a sampling was conducted in a natural forest (a lowland dipterocarp forest) in Bornean Timber, Sarawak, Malaysia. In the case of the acacia forests partly adjacent to natural forests, the surveys were conducted in *Acacia mangium* plantation forests as well as the adjacent natural forests of Sarawak Forest Department Experimental Forest, Sampadi, Sarawak, Malaysia in 2012. We surveyed the termite diversity of three sites, at 5 m, 30 m and 100 m away from the forest boundaries on both sides (Fig. 2B). In the case of the acacia forests wholly surrounded by natural forests, the surveys were conducted in *Acacia mangium* plantation forests as well as the surrounding natural forests of Sarawak Planted Forest Sdn Bhd, Bintulu, Sarawak, Malaysia in 2013. We surveyed the termite diversity of three sites, at 10 m, 100 m and 300 m away from the forest boundaries on the acacia forest side, and at 10 m and 100 m on the natural forest side (Fig. 2C).

Fig. 1 Design of forest arrangement.

Fig. 2 Design of sampling sites.

Fig. 3 Sampling design of 100m transect method.

Sampling method

The 100 m belt transect protocol was used to assess the species richness and abundance of termites. This protocol is a standardized sampling protocol for evaluating faunal and functional diversity, as described by Jones and Eggleton (2000). Sampling was carried out along a 100 m belt transect of 2 m width (Fig. 3). A transect was divided into forty sections each 5 m long and 1m wide, and sampled sequentially. To standardize the sampling effort, one person collecting termites from dead wood, mounds, soil and arboreal nests searched each section for 30 minutes. One transect (100 × 2 m) was run at each site. The number of species and the number of encounters for each species were summarized. The number of encounters was taken as the index of relative abundance of termites.

Identification and functional group classification

The collected termites were sorted and identified to the species level. Termites were then classified into three feeding groups with regard to their decomposing abilities as follows: wood-feeders, termites feeding on cellulose materials; fungus-feeders, termites feeding on wood and litter that grow fungi and decomposing cellulose and lignin; and soil-feeders, termites distributed in the soil and humus and feeding on some products of plant degradation or microbial populations in the soil. Their ability to decompose cellulose and lignin is low.

Results and Discussion

Comparison of species and functional diversity

A total of 10 species were collected from the isolated acacia plantations (Table 1). The rhinotermitid species *Heterotermes*, *Coptotermes* and *Schedorhinotermes* were dominant in the acacia plantations. There were none in the clear land. On the other hand, 28 species were collected from the natural forest, which was a far greater abundance of species than that from the acacia plantations. In the case of the isolated acacia forests, it was found that the species richness of the

Table 1 List of termite species found in the isolated acacia forests and the natural forests. FG; Functional group, W = wood feeder, F = fungus feeder, S = soil feeder. The species with gray bars indicate the species found in common in acacia forests and natural forests.

Genus	Species	FG	Natural	Secondary	6 years	3 years	Clear Land
1 <i>Heterotermes</i>	<i>tenuior</i>	W	X	X	X	X	
2 <i>Coptotermes</i>	<i>curvignathus</i>	W	X		X		
3 <i>Coptotermes</i>	<i>kalshoveni</i>	W	X				
4 <i>Coptotermes</i>	<i>sepangensis</i>	W			X		
5 <i>Schedorhinotermes</i>	<i>javanicus</i>	W	X	X	X	X	
6 <i>Schedorhinotermes</i>	<i>tarakanensis</i>	W	X				
7 <i>Parrhinotermes</i>	<i>microdentiformis</i>	W	X				
8 <i>Odontotermes</i>	<i>denticulatus</i>	F	X				
9 <i>Macrotermes</i>	<i>gilvus</i>	W		X	X	X	
10 <i>Macrotermes</i>	<i>malaccensis</i>	F	X		X		
11 <i>Nasutitermes</i>	<i>havilandi</i>	W		X			
12 <i>Nasutitermes</i>	<i>longinasus</i>	W	X				
13 <i>Nasutitermes</i>	<i>regularis</i>	W	X				
14 <i>Nasutitermes</i>	sp.1	W	X				
15 <i>Havilanditermes</i>	<i>atripennis</i>	W	X				
16 <i>Bulbitermes</i>	<i>borneensis</i>	W		X			
17 <i>Bulbitermes</i>	<i>flavicans</i>	W	X				
18 <i>Oriensublittermes</i>	sp.1	S	X				
19 <i>Amitermes</i>	<i>dentatus</i>	S	X				
20 <i>Globitermes</i>	<i>globosus</i>	W	X				
21 <i>Microcerotermes</i>	<i>sabahensis</i>	W	X				
22 <i>Microcerotermes</i>	<i>serrula</i>	W	X	X			
23 <i>Dicuspiditermes</i>	<i>santschii</i>	S	X				
24 <i>Homallotermes</i>	<i>foraminifer</i>	W	X				
25 <i>Pericapritermes</i>	<i>foraminifer</i>	S	X				
26 <i>Pericapritermes</i>	<i>nitobei</i>	S	X				
27 <i>Pericapritermes</i>	<i>semarangi</i>	S	X				
28 <i>Pericapritermes</i>	sp.1	S	X				
29 <i>Procapritermes</i>	<i>neosetiger</i>	S	X	X			
30 <i>Procapritermes</i>	sp.1	S	X				
31 <i>Termes</i>	<i>propinquus</i>	S	X				
32 <i>Termitinae</i>	sp.	S	X				
Number of species			28	7	6	3	0

natural forest was markedly higher than that of acacia plantations, and there was little difference in the species richness among acacia plantations irrespective of their years after plantation. This indicates that the species diversity of termites in a natural forest is damaged by serious disturbances imposed upon the forest such as thorough forest clearance, and that even after the subsequent plantation the communities would not significantly recover for a long time.

Table 2 List of termite species found in the acacia plantations partly adjacent to natural forests and natural forests. FG; Functional group, W = wood feeder, F = fungus feeder, S = soil feeder. The species with gray bars indicate the species found in common in both acacia plantations and natural forests.

Genus	species		N100	N5	A5	A30	A100
1 <i>Heterotermes</i>	<i>tenuior</i>	W	X	X	X	X	
2 <i>Coptotermes</i>	<i>borneensis</i>	W			X	X	
3 <i>Coptotermes</i>	<i>sebangensis</i>	W			X	X	X
4 <i>Termitogeton</i>	<i>planus</i>	W	X	X			
5 <i>Schedorhinotermes</i>	<i>medioobscurus</i>	W				X	X
6 <i>Schedorhinotermes</i>	<i>sarawakensis</i>	W	X				
7 <i>Schedorhinotermes</i>	<i>tarakanensis</i>	W	X	X	X	X	X
8 <i>Parrhinotermes</i>	<i>microdentiformis</i>	W	X				
9 <i>Parrhinotermes</i>	<i>pygmaeus</i>	W	X	X	X	X	X
10 <i>Odontotermes</i>	<i>denticulatus</i>	F			X	X	X
11 <i>Odontotermes</i>	<i>sarawakensis</i>	F				X	
12 <i>Nasutitermes</i>	<i>fuscipennis</i>	W	X			X	
13 <i>Nasutitermes</i>	<i>matangensis</i>	W	X	X	X	X	X
14 <i>Havilanditermes</i>	<i>atripennis</i>	W				X	
15 <i>Bulbitermes</i>	<i>borneensis</i>	W		X			
16 <i>Bulbitermes</i>	<i>sarawakensis</i>	W	X	X			
17 <i>Hospitalitermes</i>	<i>hospitalis</i>	W	X	X	X		
18 <i>Longipeditermes</i>	<i>longipes</i>	W	X			X	
19 <i>Hirtitermes</i>	<i>hirtiventris</i>	W		X			
20 <i>Oriensublittermes</i>	<i>inanis</i>	S		X			
21 <i>Leucopitermes</i>	sp.1	S		X			
22 <i>Malaysiitermes</i>	sp.1	S	X	X			
23 <i>Nasutitermitinae</i>	sp.1	S	X				
24 <i>Microcerotermes</i>	<i>sabahensis</i>	W			X		
25 <i>Globitermes</i>	<i>globosus</i>	W	X		X	X	
26 <i>Prohamitermes</i>	<i>mirabilis</i>	W	X	X	X		X
27 <i>Labritermes</i>	sp.1	S	X	X			
28 <i>Euhamitermes</i>	sp.1	S	X	X	X		
29 <i>Homallotermes</i>	<i>eleanorae</i>	W	X				X
30 <i>Dicuspidermes</i>	<i>nemerosus</i>	S	X				
31 <i>Dicuspidermes</i>	<i>santschii</i>	S	X	X			
32 <i>Pericapritermes</i>	<i>semarangi</i>	S	X				
33 <i>Pericapritermes</i>	sp.1	S	X	X			
34 <i>Pericapritermes</i>	sp.2	S					X
35 <i>Procapritermes</i>	<i>neosetiger</i>	S	X				
36 <i>Procapritermes</i>	<i>setiger</i>	S	X				
37 <i>Procapritermes</i>	<i>silvaticus</i>	S	X	X			
38 <i>Procapritermes</i>	sp.1	S		X			
39 <i>Procapritermes</i>	sp.2	S		X			
40 <i>Procapritermes</i>	sp.3	S	X				
41 <i>Termes</i>	<i>propinquus</i>	S	X				
Number of species			27	20	12	13	9

* N100, natural forest 100 m from the forest boundary; N5, natural forest 5 m from the forest boundary; A5, acacia plantation 5 m from the forest boundary; A30, acacia plantation 30 m from the forest boundary; A100, acacia plantation 100 m from the forest boundary.

Table 3 List of termite species found in the acacia plantations wholly surrounded by natural forests and in natural forests. FG; Functional group, W = wood feeder, F = fungus feeder, S = soil feeder. The species with gray bars indicate the species found in common in both acacia plantations and natural forests.

Genus	species		N100	N10	A10	A100	A300
1 <i>Glyptotermes</i>	sp.1	W					X
2 <i>Cryptotermes</i>	sp.1	W				X	
3 <i>Heterotermes</i>	<i>tenuior</i>	W	X	X	X	X	X
4 <i>Coptotermes</i>	<i>borneensis</i>	W			X	X	X
5 <i>Coptotermes</i>	<i>curvignathus</i>	W		X	X	X	X
6 <i>Coptotermes</i>	<i>sepangensis</i>	W			X	X	X
7 <i>Parrhinotermes</i>	<i>aequalis</i>	W	X			X	X
8 <i>Schedorhinotermes</i>	<i>medioobscurus</i>	W	X	X	X	X	X
9 <i>Schedorhinotermes</i>	<i>sarawakensis</i>	W	X	X			
10 <i>Odontotermes</i>	<i>sarawakensis</i>	F	X				
11 <i>Odontotermes</i>	sp.1	F	X				
12 <i>Nasutitermes</i>	<i>matangensis</i>	W					X
13 <i>Nasutitermes</i>	<i>regularis</i>	W	X	X	X	X	
14 <i>Havilanditermes</i>	<i>atripennis</i>	W	X	X	X	X	X
15 <i>Hirtitermes</i>	<i>hirtiventris</i>	W		X	X	X	
16 <i>Bulbitermes</i>	<i>constrictus</i>	W				X	
17 <i>Bulbitermes</i>	<i>flavicans</i>	W	X				X
18 <i>Bulbitermes</i>	<i>sarawakensis</i>	W	X			X	X
19 <i>Hospitalitermes</i>	<i>hospitalis</i>	W	X				
20 <i>Hospitalitermes</i>	<i>lividiceps</i>	W				X	
21 <i>Malaysiotermes</i>	sp.1	S	X				
22 <i>Globitermes</i>	<i>globosus</i>	W	X	X			X
23 <i>Prohamitermes</i>	<i>mirabilis</i>	W	X		X	X	X
24 <i>Microcerotermes</i>	<i>serrula</i>	W	X			X	
25 <i>Homalotermes</i>	<i>eleonorae</i>	W	X	X	X	X	X
26 <i>Dicuspiditermes</i>	<i>nemerosus</i>	S	X	X		X	X
27 <i>Dicuspiditermes</i>	<i>santschii</i>	S	X	X			
28 <i>Pericapritermes</i>	<i>semarangi</i>	S					X
29 <i>Procapritermes</i>	<i>neosetiger</i>	S		X	X	X	
30 <i>Procapritermes</i>	<i>sandakanensis</i>	S	X				
31 <i>Procapritermes</i>	<i>silvaticus</i>	S	X				
32 <i>Termes</i>	<i>borneensis</i>	S		X		X	
Number of species			20	13	11	19	16

* N100, natural forest 100 m from the forest boundary; N10, natural forest 10 m from the forest boundary; A10, acacia plantation 10 m from the forest boundary; A100, acacia plantation 100 m from the forest boundary; A300, acacia plantation 300 m from the forest boundary.

A total of 19 species were collected from the acacia plantations partly adjacent to natural forests, whereas 33 species were found from the natural forests (Table 2). In the case of the acacia plantations partly adjacent to natural forests, the number of species in natural forests was markedly higher than that in acacia plantations, and the difference was caused by the larger number of soil-feeders in the natural forests. There was little difference of the number of species among acacia plantations irrespective of the distance from the adjacent natural forests. However, the number of species in the acacia plantations partly adjacent to natural forests was markedly higher than those in the isolated acacia plantations.

A total of 24 species were collected from the acacia forests wholly surrounded by natural forests, while 24 species were found from the natural forests (Table 3). In the case of the acacia plantations wholly surrounded by natural forests, there was little difference of the number of

species and functional group composition between the natural forest and acacia plantations and also among acacia plantations irrespective of the distance from the adjacent natural forests. The number of species in the acacia plantations wholly surrounded by natural forests was also significantly higher than those in the isolated acacia plantations.

These results indicate that the species richness of acacia plantations increases as the adjacent area of natural forests increases, and the difference in species diversity between natural forests and acacia plantations decreases as the adjacent area of natural forests increases. The species richness of termites is affected by not only the surrounding environment but also by the forest condition, such as wood debris and moisture caused by the forest modification. In the isolated forest there was no wood debris and the environment was very dry, whereas the acacia plantations adjacent to or surrounded by natural forests had much wood debris and were relatively moist. The higher diversity in the acacia plantations adjacent to or surrounded by natural forests was due to the moist condition and wood debris, which provided nesting places and food for termites. The samplings of these three types of forest arrangement in the same area were needed to reveal the accurate relationship between termite diversity and the forest arrangement.

Comparison of proportion of common species

The restoration of termite diversity in an area would depend on the capability of termite migration from outside of the area and the capability of settlement in the area.

It is thought that the degree of migration depends on the distance from the non-disturbed forests. Therefore, the proportion of species common to both natural forests and acacia plantations in acacia plantations means the proportion of migration from natural forests to acacia plantations, while that in natural forests means the proportion of the species that can easily migrate to acacia plantations. It is also thought that the capability of settlement of each species depends on the feeding group. Most of the soil-feeding termites and the nasutitermitin wood-feeding termites are thought to prefer the non-disturbed natural forests. However, the other wood-feeding species and fungus-feeding species, including many wood pests, are capable of inhabiting both non-disturbed and disturbed areas. Thus, it can be said that these are opportunistic species.

In the case of isolated acacia plantations, 22 species were found only in natural forests and 6 species were common species. In the case of the acacia plantations partly adjacent to natural forests, 22 species were found only in natural forests and 11 species were common species. In the case of the acacia plantations wholly surrounded by natural forests, 8 species were found only in natural forests and half of the total species were common species. Natural forest species consisted of many soil-feeders and nasutitermitin wood-feeders. Common species consisted of the rhinotermitid species, mainly pest species, and wood-feeding termitids. These results indicate that the proportion of common species in isolated acacia forests is relatively lower than that in acacia plantations adjacent to natural forests, and the proportion of common species in natural forests increases as the adjacent areas of acacia forests increases. The number of species that are capable of migration to acacia plantations increases as the adjacent area of acacia forests increases.

Neoh et al. (2015b) reported that natural forest environments support forest-dependent termites, and the resilient and opportunistic termites were adaptable to disturbed forests. We think that the resilient and opportunistic termites may consist of common species to natural and adjacent acacia plantation forests.

Summary

The present results showed that the presence of natural forests contributed to an increase of biodiversity in acacia plantation forests. On the other hand, the presence of acacia plantation forests caused a decrease of biodiversity in natural forests. Thus, the presence of natural forests around plantation forests is important to maintain the environment of natural forests and to recover the termite diversity in plantation forests. We should pay attention to the balance of forest areas and arrangement of natural forests and plantation forests.

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