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Community structure of termites in a hill dipterocarp forest of Belum–Temengor Forest Complex, Malaysia: emergence of pest species

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Abstract. Termites are the major decomposers of organic matter in tropical rainforests. The distribution of termite species in a hill dipterocarp forest and effect of forest clearance for ecotourism development on termite diversity were investigated at the Belum–Temengor Forest Complex (BTFC) of Perak, Malaysia. Standardised belt-transect protocol was used in this study, with some additional casual sampling of pest species. A total of 40 species of termites, comprising 19 genera from five subfamilies (Coptotermitinae, Rhinotermitinae, Macrotermitinae, Termitinae, and Nasutitermitinae) were identified. Nasutitermitinae was found to be the major subfamily of termites in BTFC. The natural forest areas within the BTFC recorded 32 species of termites, while the disturbed forest areas were only represented by 21 species of termites. Dissimilarity of species diversity between these two areas, calculated based on Whittaker's beta diversity, was valued at β_W: 0.51. The wood feeders group (27 species) makes up about 67.5% of the overall termite fauna found. High number of representatives from this feeding group increases the risk of infestation on wooden man-made structures. Most of the wooden structures within the disturbed areas were found to be infested and damaged by termites. At least 12 species (30%) from the total termite found in BTFC were designated as pest species. Subfamily Macrotermitinae were represented by seven pest species making it the most important with *Odontotermes sarawakensis* and *Ancistrotermes pakistanicus* being the most common.

Key words. Termite, community structure, pest species, Belum–Temengor Forest Complex

INTRODUCTION

Termites (Order: Blattodea) are the major decomposers of organic matter in the tropics and subtropics regions (Wood & Sands, 1978; Bignell & Eggleton, 2000). Although small in size and usually unnoticed in an environment, a colony of termite species may consist of millions of individuals (e.g., *Globitermes sulphureus*, *Coptotermes gestroi*; Ngee & Lee, 2002; Abdul Hafiz & Abu Hassan, 2008). Through their feeding, tunnelling, and mound-building activities, termites contribute significantly to formation, texture, quality, and nutrient enrichment of soil (Wood, 1988; Lee et al., 2003; Yamada et al., 2005, 2006).

Tho (1992) listed an estimated number of 175 species of termites from 42 genera and three families (Kalotermitidae, Rhinotermitidae, and Termitidae) all across Peninsular Malaysia. A more recent review on termite taxonomy in the Sundaland region by Gathorne-Hardy (2004) listed about 132 species of termites in the Peninsula. Termites can be divided into two groups based on their feeding ecology; the higher termites (e.g., Termitidae) and the lower termites (e.g., Kalotermitidae and Rhinotermitidae; Ohkuma et al., 2001). They can also be further classified into several functional feeding groups: soil-feeders, soil/wood interface-feeders, wood-feeders, litter-foragers, epiphyte feeder, grass-feeders, and some other minor feeding group (Collins, 1984; Donovan et al., 2001).

Peninsular Malaysia houses a vast area of lowland and upland dipterocarp forests. Numerous forest reserves, national parks as well as state parks have been gazetted across the Peninsula to conserve and protect these natural rainforests. One of the largest protected areas in Peninsular Malaysia is the Belum–Temengor Forest Complex (BTFC), located in the northern state of Perak. The Malaysian government, through the National Ecotourism Plan in 1996, has identified the BTFC as a prospective site for ecotourism development in Malaysia (MOCAT, 1996). Several locations within the forest area have to be cleared to give way for the development process. Therefore the effects of development and forest clearance on the natural ecosystem need to be monitored and kept minimal.

Being responsive to habitat disturbance and environmental changes, the termite composition and assemblages in an area may be used as a model to evaluate the disturbance effects on an ecosystem (Davies, 2002) and as potential indicator to investigate climatic change in a given area (Gathorne-Hardy et al., 2002b). In general, termite species richness declines along disturbance gradients and the trophic structure of termite assemblages changes with the environmental

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changes (Eggleton et al., 1996, 1999; Jones & Eggleton, 2000; Davies, 2002). However, while some species responds negatively to disturbances, more tolerant species thrive in new environments (Eggleton et al., 2002; Jones et al., 2003). The present study was conducted to investigate the community structure and assemblages of termites in the BTFC in relation to the effects of small-scale forest clearance for ecotourism activities on the assemblages and diversity of termites in the area. This study also aims to identify local termite species that are emerging as economically important pests of structures built in the forest area.

MATERIAL AND METHODS

Study site. This study was conducted in the Belum–Temengor Forest Complex (BTFC; 5°30'N, 101°20'E) of Gerik in the northern state of Perak (Fig. 1) which covers approximately 300,000 ha of tropical rain forest with elevations ranging from 130–1500 m above sea level (asl). Mostly covered by upland dipterocarp forests, this vast area that serves as a water catchment area for the Temengor Lake, a man-made lake formed upon the completion of the Temengor Dam in 1977. This lake submerges approximately 15,200 ha of the BTFC landscape. The remaining forest area is divided into the upper and lower sections. The Upper Belum forest area, currently known as the Royal Belum State Park (RBSP), stretches across about 117,500 ha of primary forest that was gazetted on 17 April 2007. The lower area is known as the Temenggor Lake Catchments area (TLCA), mostly covered by secondary forests where economic activities such as logging and hunting are permissible with permits (Wong, 2003; Azreen et al., 2011). In general, the BTFC can be described to have a typical tropical monsoon climate with relatively high temperatures (± 24.2°C–29.9°C) and humidity range from 70–98%. It receives high rainfall in month of April and October annually reaching 3,000 mm per year at times while experiencing low rainfall in February and July. This forest complex is rich in various types of flora including Mersawa (*Dipterocarpus costulatus* V. Sl.), Jelutong (*Dyera costulata*, syn. *D. laxiflora*), Keruing mempelas (*Dipterocarpus crinitus* Dyer), Meranti bukit (*Shorea platyclados*) and Merbau (*Intsia palembanica*) trees as well as patches of bamboos and ferns.

Termite sample collections were done in eight sites within the BTFC located at elevations ranging from 270–400 m asl (Fig. 1). Four sites of undisturbed natural forest area; two at each of the forest sections, RBSP (Sungai [=River] Kejar = SK, Sungai Mes = SM) and TLCA (Sungai Gadong = SG, Sungai Telang = ST) located near tributary rivers of Temengor lake (10–30 m away from river bank), as such may partly be subjected to riparian forest ecosystem. Although there are ongoing logging activities in some part of the TLCA, the study sites chosen within the TLCA were considered as old logged forest (>30 years) where signs of logging were barely found and canopy covers between sites were similar to those in RBSP. Studies in the Sunda region indicate high similarity in termite species composition and assemblages between the primary forest and secondary forest (Gathorne-Hardy et al., 2002a, 2006). Therefore differences between these forest areas were overlooked and the sites were only segregated into natural forest (NF) sites (undisturbed forest sites) and disturbed forest (DF) areas to study the differences between these two conditions.

The disturbed forest area refers to an area within any of these two forest sections that had been cleared and developed for ecotourism activities. The size of these areas varies but all are approximately less than 1 ha. The forest floor in these areas was cleared and only a small number of trees were left to provide shade in the area. Mostly wooden structures and facilities were built to accommodate the ecotourism activities. Two of the disturbed forest sites located on island within the TLCA (Pulau [=Island] Bendong = PB, Pulau Pertanian = PP) and two located within the RBSP (Sungai Kejar Base Camp = SKJBC, Sungai Kenarong Base Camp = SKNBC). Transects in the disturbed forest ran through these base camps and facilities.

Collection of samples. The study sites were surveyed by utilising a standardised sampling protocol using belt transects adopted from Jones & Eggleton (2000). The 100-m belt transect consisted of 20 plots of 5 × 2 m² that were

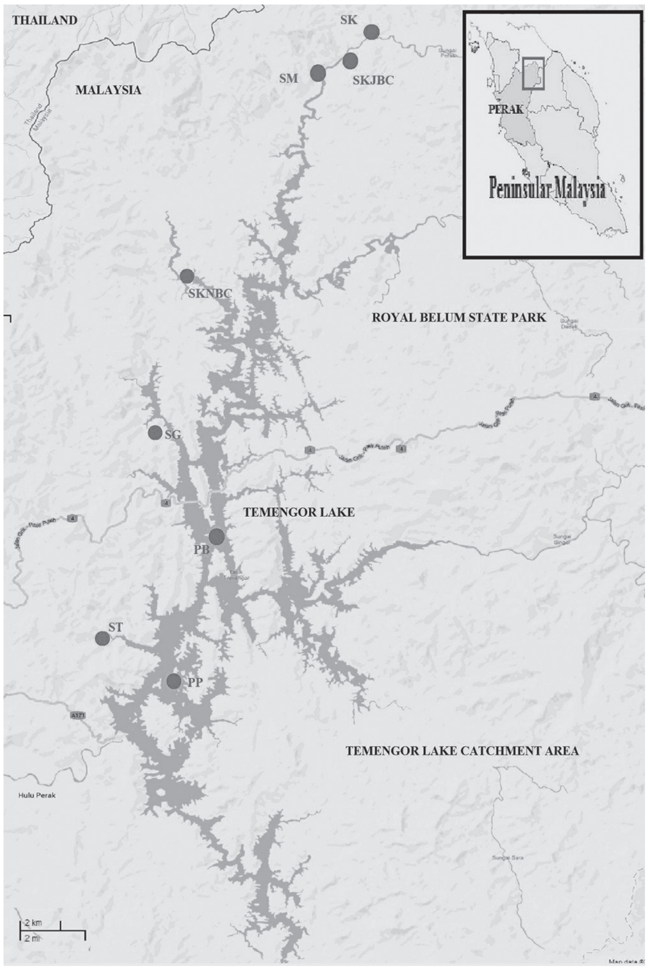

Fig. 1. Map of Belum–Temengor Forest Complex and location of study sites. Sites: SK = Sungai [=River] Kejar; SM = Sungai Mes; ST = Sungai Telang; SG = Sungai Gadong; SKJBC = Sungai Kejar Base Camp; SKNBC = Sungai Kenarong Base Camp; PB = Pulau [=Island] Bendong; PP = Pulau Pertanian.

sampled sequentially. Each plot was sampled for 30 min by two workers and collection of samples were made in the following microsites: forest litter, dead wood, tree trunks and buttress roots, mounds, soil surface to 5 cm depth (10–15 points) and runways to 2 m height in the vegetation. Casual sampling method was deployed in the disturbed forest area to inspect the building and structures for signs of termite infestation. Species that were observed infesting the structures were recorded as pest species. Samples were preserved in universal bottles containing alcohol (ethanol 80%). The presence of a species in one section of a transect was recorded as an encounter. This will give measures of relative abundance of termites with maximum score of 20 (20 sections per transect).

Assigning feeding group. Termites found were assigned into one of five feeding groups based on classification given in Collins (1984) and Eggleton et al. (1997). The feeding groups are as follows: wood feeders (termites feeding on living or dead wood); wood-litter feeders (foraging termites feeding on leaf litter or woody litter); soil feeders (termites feeding on humus and mineral soil); soil-wood interface feeders (termites feeding on highly decayed, friable and soil-like wood); and epiphyte feeders (termites feeding on lichens, epiphytes and other free living non-vascular plants). An additional group classified as fungus growers was added as a functional feeding group. Mound-building termites of Macrotermitinae that grow fungus in their nests are known as fungus growers. These termites are also wood feeders or wood-litter feeders.

Identification of termites. The identification of termites to the species level was done using taxonomic keys provided by Ahmad (1965), Thapa (1981), Tho (1992), Gathorne-Hardy (2001, 2004), Syaukani & Thompson (2011), and other relevant publications.

Calculating the beta diversity index. Beta diversity measures the dissimilarity in species composition of two or more localities. The value gives a quantitative measure to diversity changes resulting from shifting environmental conditions. The beta diversity (β_W) equation given by Whittaker (1960) is as follows:

$$\beta_W = S/\alpha - 1$$

Where $S = a + b + c$ is the total number of species recorded in both communities and $\alpha = (2a + b + c)/2$ is the average number of species within the communities. Given a is the number of species shared between two habitats, b and c are the number of species found only in habitats 1 and 2 respectively. Therefore the equation can now be written as:

$$\beta_W = (b + c) / (2a + b + c)$$

The beta diversity value is ranged from 0 (complete similarity) to 1 (no overlapping species composition).

RESULTS

A total of 40 termite species from 19 genera were recorded from the BTFC (Table 1). These species represent five subfamilies (Coptotermitinae, Rhinotermitinae, Macrotermitinae, Termitinae, and Nasutitermitinae) of Rhinotermitidae and Termitidae. The dry-wood group of termite from family Kalotermitidae was not encountered during this study. Nasutitermitinae was found to be the major subfamily of termites in BTFC with a total of 16 representative species, followed by Macrotermitinae (11 species), and Termitinae (9 species). The lower termite family (Rhinotermitidae) was poorly represented by only four species (*Coptotermes curvignathus*, *Schedorhinotermes medioobscurus*, *Schedorhinotermes malaccensis*, and *Parrhinotermes buttel-reepeni*). Total number of species encountered in the natural forest sites (NF; 32 species) was higher compared to the disturbed forest sites (DF; 21 species).The composition of termites (Fig. 2) and their feeding groups (Fig. 3) across all eight transects showed variation from each other although transects in natural forest were generally higher in number of species.

The calculated beta diversity index (Whittaker, 1960) between the termite communities in the natural forest and disturbed areas of BTFC at β_W: 0.51 indicated that these two habitats shared approximately 51% similarity in species composition. Some species were common in both areas while some others were exclusive to the given area. From the 40 species of termites found in this study, there were 13 species, mainly of the Macrotermitinae subfamily, found in both habitats.

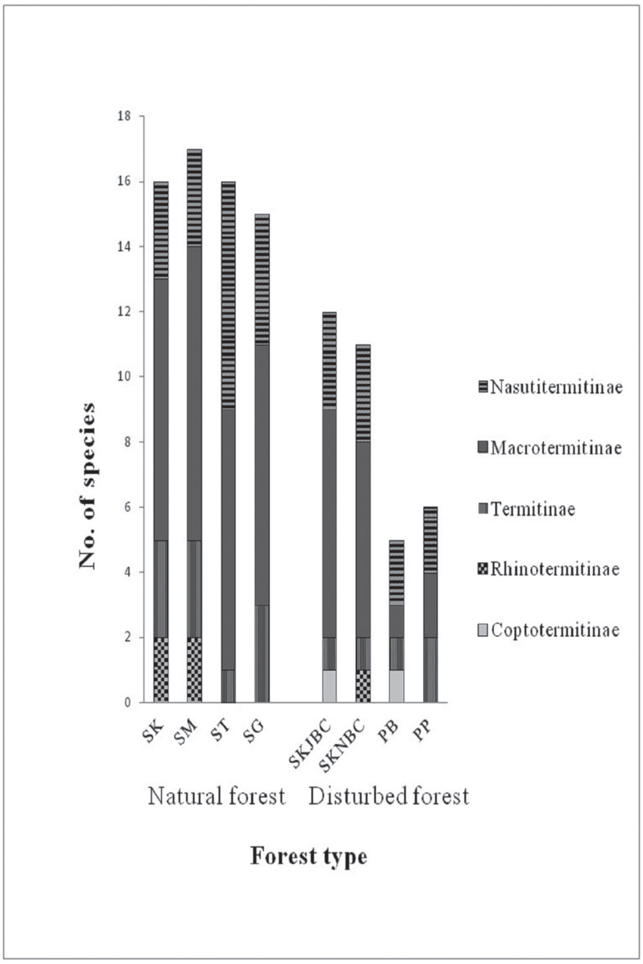

Fig. 2. The composition of termite assemblages in the natural forest and disturbed forest areas of the Belum–Temengor Forest Complex.

Table 1. Checklist of 40 termite species collected from eight sites (4 = natural forest, 4 = disturbed area) within the Belum–Temengor Forest Complex. Feeding group: W= wood feeders; WL = wood-litters feeders; S/SW = soil/soil-wood interface feeders; E = epiphyte feeders; (F) = fungus grower. Sites: NF = natural forest; DF = disturbed forest. Sites: SK = Sungai [=River] Kejar; SM = Sungai Mes; ST = Sungai Telang; SG = Sungai Gadong; SKJBC = Sungai Kejar Base Camp; SKNBC = Sungai Kenarong Base Camp; PB = Pulau [=Island] Bendong; PP = Pulau Pertanian. The numbers represent "number of encounter" in the transects. (*) Found in casual sampling collections but not in standardised transects.

Species	Feeding group	Site							
		NF				DF			
		SK	SM	ST	SG	SKJBC	SKNBC	PB	PP
RHINOTERMITIDAE									
Coptotermitinae									
Coptotermes curvignathus (Holmgren)	W	0	0	0	0	3	0	2	0
Rhinotermitinae									
Schedorhinotermes medioobscurus (Holmgren)	W	4	3	0	0	0	1	0	0
Schedorhinotermes malaccensis (Holmgren)	W	0	2	0	0	0	0	0	0
Parrhinotermes buttel-reepeni (Holmgren)	W	1	0	0	0	0	0	0	0
TERMITIDAE									
Termitinae									
Microcerotermes dubius (Haviland)	W	1	2	0	0	0	0	0	0
Microcerotermes serrula (Desneux)	W	2	0	0	0	1	3	3	1
Microcerotermes crassus Snyder	W	0	1	0	0	0	0	0	0
Globitermes sulphureus (Haviland)	W	0	0	0	0	0	0	0	6
Procapritermes sp. B [sp. nov.]	S	0	0	0	1	0	0	0	0
Procapritermes sp. D [sp. nov.]	S	0	0	0	1	0	0	0	0
Procapritermes prosetiger Ahmad	S	0	1	0	0	0	0	0	0
Pericapritermes latignathus (Holmgren)	S	1	0	0	1	0	0	0	0
Homallotermes foraminifer (Haviland)	SW	0	0	1	0	0	0	0	0
Macrotermitinae									
Macrotermes gilvus (Hagen)	WL(F)	2	4	1	2	2	3	0	0
Macrotermes sp. A [sp. nov.]	WL(F)	0	0	1	0	0	0	0	0
Macrotermes malaccensis (Haviland)	WL(F)	2	3	3	8	2	3	0	0
Odontotermes sarawakensis Holmgren	W(F)	4	5	8	8	5	4	6	5
Odontotermes javanicus Holmgren	W(F)	2	2	2	1	2	0	0	0
Odontotermes grandiceps Holmgren	W(F)	2	1	1	3	1	1	0	0
Odontotermes oblongatus Holmgren	W(F)	0	1	0	0	0	0	0	0
Odontotermes longignathus Holmgren	W(F)	0	2	0	0	0	0	0	0
Hypotermes xenotermitis (Wasmann)	W(F)	4	7	3	3	8	3	0	0
Ancistrotermes pakistanicus Ahmad	W(F)	1	6	4	3	5	4	0	5
Microtermes obesi Holmgren	W(F)	1	0	0	2	0	0	0	0
Nasutitermitinae									
Havilanditermes proatripennis Ahmad	W	0	0	0	0	0	0	2	0
Nasutitermes longinasoides Thapa	W	0	1	0	0	0	0	0	0
Nasutitermes longinasus (Holmgren)	W	0	0	3	3	0	4	0	0
Nasutitermes johoricus (John)	W	0	1	2	0	0	0	0	0
Nasutitermes havilandi (Desneux)	W	3	1	2	1	0	0	0	3
Nasutitermes neoparvus Thapa	W	3	0	2	0	0	0	0	0
Nasutitermes matangensiformis (Holmgren)	W	0	0	2	1	0	0	0	2
Bulbitermes flavicans (Holmgren)	W	0	0	2	0	0	0	0	0
Bulbitermes constrictiformis (Holmgren)	W	0	0	0	1	0	0	0	0
Bulbitermes neopusillus (John)	W	0	0	3	0	0	0	0	0
Longipeditermes longipes Holmgren	W	4	0	0	0	3	0	0	0
**Hospitalitermes hospitalis* (Haviland)	E	0	0	0	0	0	2	0	0
**Hospitalitermes umbrinus* (Haviland)	E	0	0	0	0	0	5	0	0
**Hospitalitermes bicolor* (Haviland)	E	0	0	0	0	3	0	0	0
**Hospitalitermes medioflavus* (Holmgren)	E	0	0	0	0	0	0	4	0
Oriensubulitermes inanis (Haviland)	S	0	0	0	0	1	0	0	0
Total no. of encounters		**36**	**43**	**40**	**39**	**35**	**33**	**17**	**22**
Total no. of species		**16**	**17**	**16**	**15**	**12**	**11**	**5**	**6**

Nineteen species were found only in the natural forest area while eight species were restricted to the disturbed area.

The five categories of termite functional feeding groups that made up the composition of the termite community in BTFC were the wood feeders (W), wood-litter feeders (WL), soil feeders (S), soil-wood interface feeders (SW), epiphyte feeders (E), and fungus growers (F; Fig. 2). The largest group of feeders was the wood feeders, represented by 27 species (67.5%) mainly from the genus *Nasutitermes*, *Odontotermes*, and *Bulbitermes*. The soil feeder group was represented by three species of *Procapritermes*, and one species of *Pericapritermes* and *Oriensubulitermes* each. The subfamily of Macrotermitinae dominated the wood-litter feeder group. However, this group was represented by only three species (*Macrotermes* spp.). There were four species of epiphyte feeders represented by *Hospitalitermes* spp. while the soil-wood interface feeders were only represented by one species (*Homallotermes foraminifer*).

In terms of distribution of these feeding groups, the wood feeders, the wood-litter feeders and the soil feeders can be found at both natural forest (NF) and disturbed forest (DF) sites. However, the species richness of these three groups was higher at the natural forest sites. The number of wood-feeders decreased from 24 species in the NF to 14 species in the DF. Within the wood feeder group, the subfamily Macrotermitinae was the least affected by the forest clearance while some members of the Nasutitermitinae (*Nasutitermes* spp. and *Bulbitermes* spp.) were negatively affected. The soil feeders dropped from four in the NF to one species in the DF area (Fig. 3). Although the wood-litter feeders showed a decline in numbers, the reduction was not notable. Only the soil-wood interface feeders and the epiphyte feeders were exclusive to the natural forest and disturbed forest areas respectively.

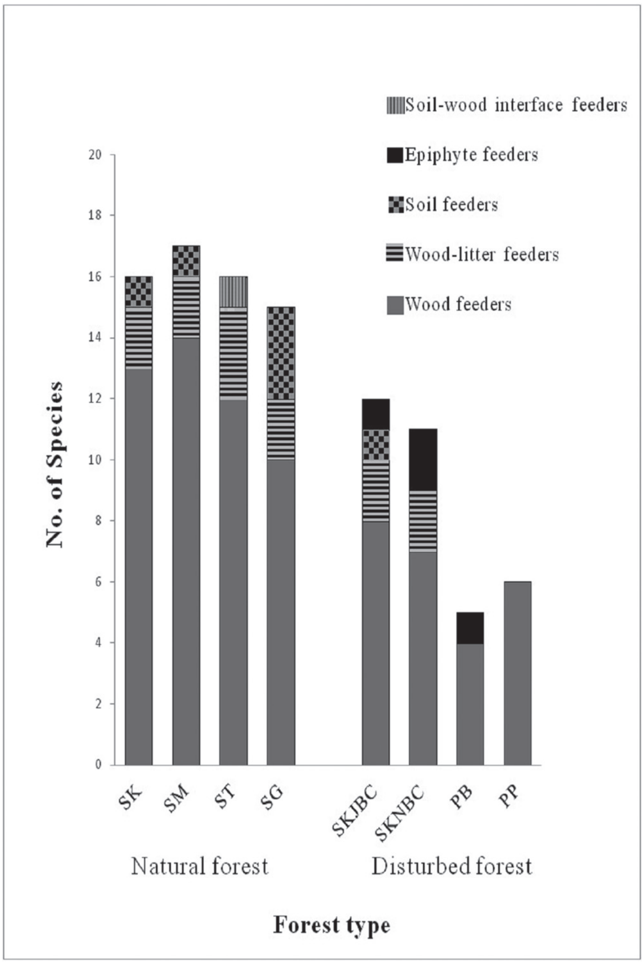

Fig. 3. The different compositions of termite feeding groups in natural forest and disturbed forest areas within the Belum–Temengor Forest Complex.

Table 2 lists the termite species found infesting man-made structures in the disturbed forest (DF) areas within the BTFC. From the total of 21 species found in the DF areas, 12 species from five subfamilies were observed infesting and damaging structures of various conditions and were therefore designated as pest species. All of the species were the wood feeders and wood-litter feeders. Higher termites especially those from the subfamily Macrotermitinae were found to be more important as pests (83.3%) compared to the lower termites. Two species; *Odontotermes sarawakensis* and *Ancistrotermes pakistanicus* were the most common and important pest species in the BTFC.

DISCUSSION

Termite composition in BTFC. The overall species richness of termites in BTFC (40 species) was relatively lower compared to the total number of species reported from several studies conducted in the Sunda region (e.g., Jones & Brendell, 1998 [80 species]; Eggleton et al., 1999 [93 species]; Jones & Prasetyo, 2002 [64 species]). Transects at sites of lowland evergreen forest with altitude below 100 m from previous studies recorded higher species richness per transect such as Pasoh in Peninsular Malaysia (29 species), Danum Valley in Sabah (29 and 33 species), and Jambi in Sumatra (34 species; Table 3). Similarly, a transect in an old logged dipterocarp forest of Tabalong, Kalimantan, also yielded higher species richness (31 species). The assemblages and species richness of this old logged hill dipterocarp forest was relatively unaffected possibly because timbers were logged selectively. Eggleton et al. (1997) had reported no significant difference in termite richness between primary forest and selectively logged secondary forest. Our BTFC transects (15–17 species) were somehow more similar to the two lower montane forest (altitude 1,000 m) transects in Maliau Basin, Sabah (19 and 15 species; Table 3).

A study by Jones & Brendell (1998) in a primary lowland forest of Pasoh Forest Reserve, Peninsular Malaysia listed a compilation of 80 species of termites (52 species from their own collection). Although the species diversity was higher in Pasoh Forest Reserve compared to BTFC, the composition of termites exhibits some similarity in both studies where Termitidae was the dominant family, 90% in BTFC and 85% in Pasoh Forest Reserve. The largest subfamily was the Nasutitermitinae. The family Kalotermitidae was represented by one species in Pasoh Forest Reserve but absent in BTFC. Unlike in BTFC, the soil feeders were richer in Pasoh Forest

Table 2. List of termite species found infesting man-made structures in BTFC. Sites: SKJBC = Sungai [=River] Kejar Base Camp; SKNBC = Sungai Kenarong Base Camp; PB = Pulau [=Island] Bendong; PP = Pulau Pertanian. Feeding group: W= wood feeders; WL(F) = wood-litters feeders (Fungus grower).

Termite species	SKJBC	SKNBC	PB	PP	Feeding Group
Coptotermes curvignathus			+		W
Schedorhinotermes medioobscurus		+			W
Globitermes sulphureus				+	W
Microcerotermes serrula		+	+		W
Macrotermes gilvus		+			WL(F)
Odontotermes sarawakensis	+	+	+	+	W(F)
Odontotermes javanicus	+				W(F)
Hypotermes xenotermitis	+	+			W(F)
Ancistrotermes pakistanicus	+	+		+	W(F)
Nasutitermes matangensiformis				+	W
Nasutitermes havilandi				+	W
Havilanditermes proatripennis			+		W

Table 3. The termite species richness in natural forest sites from studies in Sunda region. Belum–Temengor Forest Complex (BTFC) (present study), Pasoh (Jones & Eggleton, 2000), Jambi (Jones et al., 2003), Danum valley (Eggleton et al., 1997), Tabalong (Jones & Prasetyo, 2002), Maliau basin (Jones, 2000), and Khao Kitchagoot (Inoue, 2006).

Location	Altitude (m)	Species Richness	Habitat Type
BTFC	270–400	16, 17, 16 and 15	Primary hill dipterocarp forest
Pasoh	100	29	Lowland evergreen rain forest
Jambi	76	34	Lowland evergreen rain forest
Danum Valley	50	29 and 33	Lowland evergreen rain forest
Tabalong	630	31	Old logged dipterocarp forest
Maliau Basin	1,000	19 and 15	Lower montane evergreen forest
Khao Kitchagoot	100 and 300	17 and 15	Moist evergreen forest

Reserve (25 species), making them the second largest feeding group after the wood feeders. Lower species richness and relative abundance in BTFC may be related to the differences of altitudes (±200–400 m asl in BTFC) of the study sites which affects the assemblages of termites although the effect may not be as significant.

In term of species richness, the result from our study is more comparable to the work in Thailand by Inoue et al. (2006) in Khao Kitchagoot National Park. The moist evergreen forest of Khao Kitchagoot National Park is located in the mainland of the Sunda Shelf and received almost similar annual rainfall (average of 3,230 mm) and temperature (27.5°C). In their study, Inoue et al. (2006) reported 30 species of termites but recorded only 9–17 species collected in individual transects at different altitudes. Although they concluded that termite species density and abundance had no significant correlation with altitude, they agreed that some termite groups corresponded significantly with altitude. However, other studies in general suggested that termite richness, abundance, and species density decreases with increasing altitude (Collins, 1980; Gathorne-Hardy et al., 2001; Pribadi et al., 2011). As our present study was not designed to address the effect of altitude, no conclusion can be made from our results.

The lower species richness and relative abundance of termites in BTFC may be due to the location of the study sites which were in close proximity of water bodies (river streams and lake), where the belt transects ran in and near riparian forest ecosystem. A study by Vaessen et al. (2011) in peat swamp areas in Sarawak, Malaysia also reports a lack of soil-feeding termite owing to inundated soil. Soil feeders are said to account for more than 60% of the known termite species (Eggleton, 2000). However, only four species were encountered in this study (Table 1). In the event of high water or heavy rainfall, certain parts of the study areas may be flooded or inundated. The occasional soil inundation in riparian forest ecosystem may affect termites' habitat creating unfavourable condition to soil termites especially the soil feeders which probably explains their low richness in this study. High annual rainfall and seasonal flooding have been reported to cause difficulties in termites nesting and foraging (Collins, 1979; Martius, 1994). Dibog et al. (2000) also observed a significant effect of seasonal rainfall on termite diversity and abundance that decline with increasing rainfall.

The response of the termite community toward environmental disturbances in this study demonstrated a typical declining pattern at which most termite groups were negatively affected. Ackerman et al. (2009) reported that disturbance of the natural habitat of termites caused by human activity, often results in declining termite species richness, abundance, and function. However some studies have also shown that some termite groups are less affected, to which some even respond positively to disturbances (Eggleton et al., 1995, 1996; Gathorne-Hardy et al., 2000; Davies, 2002; Jones et al., 2003). Therefore, the changes of termite community structure at the functional group level appears to be more reliable for evaluating the effects of disturbances compared to species richness. In the case of our study, all feeding groups exhibited reduction in species richness with the exception to epiphyte feeders. This feeding group, represented by the *Hospitalitermes* spp., is a common open-air forager that feeds on non-vascular plant tissue with high nitrogen content such as lichen scraped from woody surfaces (Collins, 1979; Miura & Matsumoto, 1997). The absence of this feeding group in the NF transects is likely related to daytime sampling (late morning till afternoon) which does not coincide well with the activity of *Hospitalitermes*. Jones & Gathorne-Hardy (1995) reported colonies of *H. hospitalis* foraging 46–72% of the nights. In our study, *Hospitalitermes* spp. were collected at DF sites at night by casual sampling during our stay there.

The declining trend of species richness in the DF areas can be explained by the lack of suitable nesting and feeding sites. The increasing disturbance gradients in an area provided less structural and physical complexity that may provide microhabitats for termites (Jones et al., 2003). The removal of canopy cover in the DF areas would have exposed the forest floor to direct sunlight which greatly influences soil temperature and moisture level (Dibog et al., 1999; Jones & Prasetyo, 2002; Pribadi et al., 2011). Compared to other feeding groups, soil feeders are especially sensitive and more vulnerable to habitat disturbance and prefer moist soil conditions with dense canopy cover in the forest (Eggleton et al., 2002). The soil-wood interface feeders were absent in the DF areas while there was about 75% reduction of soil feeder richness in the DF area compared to the NF with only one species (*Oriensubulitermes inanis*) encountered in this study. This species was collected from a mound located under an elevated wooden building which may have provided an artificially ideal condition for soil-feeding termite. In the peat soil areas, Vaessen et al. (2011) found that *Oriensubulitermes* sp. inhabited exclusively at cleared sites of a mixed swamp forest. This is possibly due to the ability of *Oriensubulitermes* to tolerate a certain level of disturbances.

In this study, two of the DF transects ran on islands (PB and PP) in the middle of the Temengor Lake. The local termite species in these islands may be the remnant of the surviving species during the flooding of the forest area at the time of Temengor Dam construction in the 1972 that lead to the formation of these islands. The small size of the islands may harbour reduced termite richness resulting from the stochastic extinctions of soil feeders colonies (Davies, 2002). Moreover some parts of these islands in the later years were cleared and developed for ecotourism activity. As transects ran through these sites, some part of the transects were positioned under building and bare earth. This may explain the low number of species collected from these two sites even compared to the DF sites located on mainland; SKJBC and SKNBC (Table 1).

The emergence of pest species. In this study, a staggering number of termite species (12 species from the overall species encountered in BTFC) was designated as pest of structures in BTFC. These species were found infesting and causing damages to man-made structures of various conditions (sound timber to broken and decaying wooden structures) within the DF areas. Wooden structures with direct contact with the ground were observed to be more prone to termite infestation especially those that have started to decay. All of the recognised species were wood feeders except for *Macrotermes gilvus*, which was a wood-litter feeder. The Macrotemitinae, with five representative species, emerged as the most important pest group. In the urban area, *Coptotermes* is considered the most important pest genera, accountable for almost 85% of the total termite infestation on premises in Malaysia (Lee et al., 2007). The only one species of *Coptotermes* found in this study was *C. curvignathus*, which has been reported to occasionally infest houses in Malaysia (Lee et al., 2007). This species is one of the few species that feeds on living trees and considered as a major pest of agriculture and plantation forest in Malaysia (Tho, 1974, 1992; Kirton et al., 1999; Cheng et al., 2008; Aiman Hanis & Abu Hassan, 2011). In contrast, the common pest species identified in this study were the higher termite species especially *Odontotermes sarawakensis* and *Ansictrotermes pakistanicus.* These two species were well distributed in the BTFC and were encountered at both the natural and disturbed forest areas. They are widespread and commonly found throughout the country but *A. pakistanicus* (syn. *Microtermes pakistanicus*) is occasionally encountered in hill dipterocarp forests (Tho, 1992). Previously *Odontotermes sarawakensis* and *A. pakistanicus* have been identified as peridomestic species as well as minor pest in agriculture and agro-forestry industry (Tho, 1992; Lee, 2002; Aiman Hanis & Abu Hassan, 2011). However, in this study these species have emerged as a potentially harmful pest species capable of causing serious damage on structures.

The decline in species richness which leads to lower intra-species competition may allow some tolerant species to surface as key species. The emergence of the wood feeders, which previously feed mainly on dead and decaying wood materials, as pest is most probably related to the clearance of dead wood on the forest floor of the disturbed sites by the ecotourism operators. A number of researches reported the importance of decayed wood and cellulosic litter on the floor of natural forests and human impacted forests as a food source and habitat for termites (Collins, 1983; Inoue et al., 2001; Jones et al., 2003). The limitation of food resources may have forced these termites to consume the wooden structures built in the area as an alternative food source. Most of the wooden stools, benches, and tables made of trees cut down from the area were directly placed on the ground and left unchecked. These slowly decaying woods are especially attractive to some termite species. Damages caused by their feeding and tunnelling activities resulted in significant economic losses to developers. Although the key pest species in forest areas are different compared to the pest of urban and sub-urban area, the threat to structures, especially those made out of wooden materials, is similar. A currently popular termite management program using baiting system was reported to be less effective against higher termites (Lee et al., 2007). The cost to control termites in Malaysia as reported by Lee (2004) was estimated to be at USD 10–12 million in 2003 and the repair cost was estimated to be 3–4 times higher. This significant loss due to termites may become a major factor that could discourage development of the ecotourism industry in highly problematic areas.

CONCLUSIONS

Forest clearance in BTFC for development of the ecotourism industry was found to negatively affect termite diversity and assemblages. From the total of 40 species of termites found in BTFC, 32 species inhabited the undisturbed natural forest areas while only 21 species were encountered in areas disturbed by the construction of buildings and structures. Wood feeders were the dominant feeding group in the BTFC. Among the 21 species of termites found in the disturbed areas, at least 12 of them were found infesting and damaging wooden structures and buildings in the areas and were therefore designated as pest species. *Odontotermes sarawakensis* and *Ancistrotermes pakistanicus* were the most common pest of wooden structures in the BTFC.

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LITERATURE CITED

Abdul Hafiz AM & Abu Hassan A (2008) Preliminary field efficacy of transfer effect of slow acting termiticide (Imidacloprid) on subterranean termites population (Coptotermes Gestroi) (Wasmann) (Isoptera: Rhinotermitidae). Journal of Biosciences, 19: 101–106.

Ackerman IL,Constantino R, Gauch Jr. HG, Lehmann J, Riha SJ & Fernandes ECM (2009) Termite (Insecta: Isoptera) species composition in a primary rain forest and agroforests in Central Amazonia. Biotropica, 41: 226–233.

Ahmad Z (1965) Termites (Isoptera) of Thailand. Bulletin of the American Museum of Natural History, 131: 3–113.

Aiman Hanis J & Abu Hassan A (2011) Termite incidence on *Araucaria* plantation forest in Teluk Bahang, Penang. Insects, 2: 469–474.

Azreen RA, Chan NW & Ahmad Puat MS (2011) The potentials and perils of ecotourism in Belum Temengor Forest Complex. World Applied Sciences Journal, 12 (Special Issue of Tourism & Hospitality): 1–9.

Bignell DE & Eggleton P (2000) Termites in ecosystems. In: Abe T, Bignell DE & Higashi M (eds.) Termites: Evolution, Sociality, Symbioses, Ecology. Kluwer Academic Publishers, The Netherlands, pp. 363–388.

Cheng S, Kirton LG & Gurmit S (2008) Termite attack on oil palm grown on peat soil: identification of pest species and factors contributing to the problem. The Planter, 84: 659–670.

Collins NM (1979) Observations on the foraging activity of *Hospitalitermes umbrinus* (Haviland) (Isoptera: Termitidae) in the Gunong Mulu National Park, Sarawak. Ecological Entomology, 4: 231–238.

Collins NM (1980) The distribution of soil macrofauna on the west ridge of Gunung (Mount) Mulu, Sarawak. Oecologia, 44: 263–275.

Collins NM (1983) Termite population and their role in litter removal in Malaysia rain forests. In: Sutton SL, Whitmore TC & Chadwick AC (eds.) Tropical Rain Forest, Ecology and Management. Blackwell Scientific Publications, Oxford, pp. 311–325.

Collins NM (1984) The termites (Isoptera) of the Gunung Mulu National Park, with a key to the genera known from Sarawak. Sarawak Museum Journal, 30: 65–87.

Davies RG (2002) Feeding group responses of Neotropical termite assemblage to rain forest fragmentation. Oecologia, 133: 233–242.

Dibog L, Eggleton P, Norgrove L, Bignell DE & Hauser S (1999) Impacts of canopy cover on soil termite assemblages in an agrisilvicultural system in southern Cameroon. Bulletin of Entomological Research, 89: 125–132.

Dibog L, Eggleton P & Forzi F (2000) Seasonality of soil termites in a humid tropical forest, Mbalmayo southern Cameroon. Journal of Tropical Ecology, 14: 841–850.

Donovan SE, Eggleton P & Bignell DE (2001) Gut content analysis and a new feeding group classification of termites. Ecological Entomology, 26: 356–366.

Eggleton P (2000) Global patterns of termite diversity. In: Abe T, Bignell DE & Higashi M (eds.) Termites: Evolution, Sociality, Symbioses, Ecology. Kluwer Academic Publishers, The Netherlands, pp. 25–51.

Eggleton P, Bignell DE, Sands WA, Waite B, Wood TG & Lawton JH (1995) The richness of species of termites (Isoptera) under differing levels of forest disturbance in the Mbalmayo Forest Reserve, Southern Cameroon. Tropical Journal of Ecology, 11: 85–98.

Eggleton P, Bignell DE, Sands WA, Mawdsley NS, Lawton JH, Wood TG & Bignell NC (1996) The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest Reserve, Southern Cameroon. Philosophical Transactions of the Royal Society of London B, 351: 51–68.

Eggleton P, Homathevi R, Jeeva D, Jones DT, Davies RG & Maryati M (1997) The species richness and composition of termites (Isoptera) in primary and regenerating lowland dipterocarp forest in Sabah, East Malaysia. Ecotropica, 3: 119–128.

Eggleton P, Homathevi R, Jones DT, MacDonald JA, Jeeva D, Bignell DE, Davies RG & Maryati M (1999) Termite assemblages, forest disturbance and greenhouse gas fluxes in Sabah, East Malaysia. Philosophical Transactions of the Royal Society of London B, 354: 1971–1802.

Eggleton P, Bignell DE, Hauser S, Dibog L, Norgrove L & Madong B (2002) Termite diversity is a cross an anthropogenic disturbance gradient in humid forest zone of West Africa. Agricultural Ecosystem and Environment, 90: 189–202.

Gathorne-Hardy FJ (2001) A review of the South East Asian Nasutitermitinae (Isoptera: Termitidae) with descriptions of one new genus and a new species and including a key to the genera. Journal of Natural History, 35: 1486–1506.

Gathorne-Hardy FJ (2004) The termites of Sundaland: a taxonomic review. Sarawak Museum Journal, 60(81): 89–133.

Gathorne-Hardy FJ, Jones DT & Mawdsley NA (2000) The recolonization of the Krakatau islands by termites (Isoptera), and their origins biogeographical. Biological Journal of the Linnean Society, 71: 251–267.

Gathorne-Hardy FJ, Syaukani & Eggleton P (2001) The effects of altitude and rainfall on the composition of termites (Isoptera) of the Leuser Ecosystem (Sumatra, Indonesia). Journal of Tropical Ecology, 11: 379–393.

Gathorne-Hardy FJ, Jones DT & Syaukani (2002a) A regional perspective on the effects of human disturbance on the termites of Sundaland. Biodiversity and Consevation, 11: 1991–2006.

Gathorne-Hardy FJ, Syaukani, Davies RG, Eggleton P & Jones DT (2002b) Quartenary rainforest refugia in South-East Asia: using termites (Isoptera) as indicators. Biological Journal of the Linnean Society, 75: 453–466.

Gathorne-Hardy FJ, Syaukani & Inward DJG (2006) Recovery of termite (Isoptera) assemblage structure from shifting cultivation in Barito Ulu, Kalimantan, Indonesia. Journal of Tropical Ecology, 22: 605–608.

Inoue T, Takematsu Y, Hyodo F, Sugimoto A, Yamada A, Klangkeaw C, Kirtibutr N & Abe T (2001) The abundance and biomass of subterranean termites (Isoptera) in a dry evergreen forest of north-east Thailand. Sociobiology, 37: 41–52.

Inoue T, Takematsu Y, Yamada A, Hongoh Y, Johjima T, Moriya S, Sornnuwat Y, Vongkaluang C, Ohkuma M & Kudo T (2006) Diversity and abundance of termites along an altitudinal gradient in Khao Kitchagoot National Park, Thailand. Journal of Tropical Ecology, 22: 609–612.

Jones DT (2000) Termite assemblages in two distinct montane forest types at 1000 m elevation in Maliau Basin, Sabah. Journal of Tropical Ecology, 16: 271–286.

Jones DT & Gathorne-Hardy F, 1995. Foraging activity of the processional termite *Hospitalitermes hospitalis* (Termitidae: Nasutitermitinae) in the rain forest of Brunei, north-west Borneo. Insectes sociaux, 42: 359–369.

Jones DT & Brendell MJD, 1998. The termite (Insecta: Isoptera) fauna of Pasoh Forest Reserve, Malaysia. Raffles Bulletin of Zoology, 46: 79–91.

Jones DT & Eggleton P (2000) Sampling termite assemblages in tropical forest: testing a rapid biodiversity assessment protocol. Journal of Applied Ecology, 37: 191–203.

Jones DT & Prasetyo AH (2002) A survey of termites (Insecta: Isoptera) of Tabalong district, South Kalimantan, Indonesia. Raffles Bulletin of Zoology, 50: 117–128.

Jones DT, Susilo FX, Bignell DE, Hardiwinoto S, Gillison AN & Eggleton P (2003) Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia. Journal of Applied Ecology, 40: 380–391.

Kirton LG, Brown VK & Azmi A (1999) The pest status of the termite *Coptotermes curvignathus* in *Acacia mangium* plantation: incidence, mode of attack and inherent predisposing factors. Journal of Tropical Forest Science, 11: 822–831.

Lee CY (2002) Subterranean termite pests and their control in the urban environment in Malaysia. Sociobiology, 40: 3–9.

Lee CY, Ngee PS & Lee LC (2003) Foraging populations and territories of a mound-building subterranean termite, *Microtermes pakistanicus* (Isoptera: Macrotermitinae). Sociobiology, 41: 307–316.

Lee CY (2004) Current termite management in Peninsular Malaysia. In: Tsunoda K (ed.) Proceedings of the First Pacific Rim Termite Research Group Meeting. Kyoto University, Japan, pp. 37–42.

Lee CY, Vongkaluang C & Lenz M (2007) Challenges to subterranean termite management of multi-genera faunas in Southeast Asia and Australia. Sociobiology, 50: 213–221.

Martius C (1994) Termite nest as structural elements of the Amazon floodplain forest. Andrias, 13: 137–150.

Miura T & Matsumoto T (1997) Diet and nest material of the processional Hospitalitermes, and cohabitation of Termes (Isoptera, Termitidae) on Borneo Island. Insectes sociaux, 44: 267–275.

MOCAT (1996) The National Ecotourism Plan, Malaysia – Part 1. Ministry of Culture, Arts and Tourism, Malaysia, Kuala Lumpur, 324 pp.

Ngee PS & Lee CY (2002) Colony characterization of a mound-building subterranean termite, *Globitermes sulphureus* (Isoptera: Termitidae) using modified single-mark recapture technique. Sociobiology, 40: 525–532.

Ohkuma M, Nado S, Hangoh Y & Kudo T (2001) Coevolution of symbiotic systems of termites and their gut microorganisms. RIKEN Review, 41: 73–74.

Pribadi T, Raffiudin R & Harahap IS (2011) Termites community as environmental bioindicators in highlands: a case study in eastern slopes of Mount Slamet, Central Java. Biodiversitas, 12: 235–240.

Syaukani & Thompson GJ (2011) Taxonomic notes on nasutitermes and bulbitermes (Termitidae, Nasutitermitinae) from the Sunda region of Southeast Asia based on morphological and molecular characters. ZooKeys, 148: 135–160.

Thapa RS (1981) Termites of Sabah (East Malaysia). Sabah Forest Record 12. Sabah Forest Department, Sandakan, pp. 1–374.

Tho YP (1974) The termite problem in plantation forestry in peninsular Malaysia. Malaysian Forester, 37: 278–283.

Tho YP (1992) Termites of Peninsular Malaysia. In: Kirton LG (ed.) Malayan Forest Records 36. Forest Research Institute of Malaysia, Kepong, pp. 1–224.

Vaessen T, Verwer C, Demies M, Kaliang H & van der Meer PJ (2011) Comparison of termite assembleges along a landuse gradient on peat areas in Sarawak, Malaysia. Journal of Tropical Forest Science, 23: 196–203.

Whittaker RH (1960) Vegetation of the Siskiyou mountains, Oregon and California. Ecological Monographs, 30: 279–338.

Wong SL (2003) The Royal Belum: Crowning Glory of Peninsula. Perbadanan Taman Negeri Perak, Ipoh, and Sasyaz Holdings Sdn. Bhd., Petaling Jaya, 117 pp.

Wood TG & Sands WA (1978) The role of termites in ecosystems. In: Brian MV (ed.) Production Ecology of Ants and Termites. Cambridge University Press, Cambridge, pp. 245–292.

Wood TG (1988) Termites and the soil environment. Biology and Fertility of Soils, 6: 228–236.

Yamada A, Inoue T, Wiwatwitaya D, Ohkuma M, Kudo T, Abe T & Sugimoto A (2005) Carbon mineralization by termites in tropical forests, with emphasis on fungus combs. Ecological Research, 20: 453–460.

Yamada A, Inoue T, Wiwatwitaya D, Ohkuma M, Kudo T, Abe T & Sugimoto A (2006) Nitrogen fixation by termites in tropical forests, Thailand. Ecosystem, 9: 75–83.