TERMITE ASSEMBLEDGES, NICHE PARTITIONING AND INFESTATION IN NATURAL, DISTURBED AND PLANTATION FOREST IN NORTHERN PENINSULAR MALAYSIA

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By

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ABSTRAK

Pembukaan hutan untuk aktiviti ekonomi menyebabkan kemusnahan habitat semulajadi dan degradisi fungsi ekosistem. Kepelbagaian dan komposisi organism selalunya terkesan secara negatif akibat pembukaan tanah. Peluasan kawasan perladangan seperti ladang kelapa sawit, getah dan ladang pokok balak (Cth: Jati, *Pinus* dan *Araucaria*) memberi ancaman yang lebih besar kepada hutan semulajadi kita. Anai-anai sebagai agen pengurai bahan organik utama dalam ekosistem hutan tropika juga mengalami kesan akibat ganguan pada habitat mereka. Kajian yang dijalan ini bertujuan untuk mengkaji struktur komuniti anai-anai di kawasan-kawasan terpilih dengan jenis guna-tanah dan gangguan yang berbeza. Gangguan pada hutan didapati mempunyai kesan negatif terhadap kepelbagaian anai-anai. Penurunan kepelbagaian species anai-anai dapat dilihat apabila tahap gangguan meningkat daripada hutan primer (purata: 16.5 sp.) > hutan sekunder (purata: 15.5 sp.) > hutan dengan binaan (purata 13.5 sp.) > hutan ladang (purata: 6 sp.). Anai-anai dari kumpulan pemakan kayu (wood feeders) adalah kumpulan pemakanan berfungsi yand dominan dalam kajian ini, meliputi sehingga 70.3% daripada jumlah species terkumpul manakala subfamili Nasutitermitinae yand diwakili oleh 13 species merupakan subfamili terbesar dalam keseluruhan komposisi species kajian ini. Selain itu, kajian ini juga bertujuan untuk mengkaji kesan pengurusan kawasan terhadap kominiti anai-anai dalam hutan ladang (*Araucaria cunninghamii*) bagi tempoh

tiga tahun (2009 – 2011). Komposisi dan kepelbagaian anai-anai di kawasan yang diurus dengan baik didapati lebih stabil berbanding kawasan yang tidak diurus selia yang mana menunjukkan peningkatan jumlah spesis. Sejumlah lima spesis disampel pada Tahun 1, lapan spesis pada Tahun 2 dan 14 spesis pada Tahun 3. Empat kumpulan pemakanan (wood feeders, soil-wood interface feeders, wood-litter feeders and epiphyte feeders) ditemui dalam kawasan hutan ladang yang dikaji. Kumpulan pemakan kayu (wood feeders) merupakan kumpulan terpenting yang diwakili oleh 12 spesis (75%). Objektif terakhir kajian desertasi ini adalah untuk mengenalpasti spesis anai-anai yang muncul sebagai perosak struktur bangunan dalam kawasan hutan semulajadi dan hutan ladang. Enam belas spesis anai-anai daripada 10 genera dan dua famili: Rhinotermitidae and Termitidae, telah dikenalpasti menyerang struktur binaan. Kumpulan famili Termitidae membentuk majoriti dengan diwakili oleh 13 spesis yang mana *Globitermes sulphureus* (18%), *Odontotermes sarawakensis* (16%) dan *Ancistrotermes pakistanicus* (14%) dikenalpasti sebagai perosak utama struktur binaan dalam kawasan kajian. Di kawasan hutan ladang, tiga species dijumpai pada pokok *Araucaria*; *C. curvignathus*, *Schedorhinotermes medioobscurus* and *O. sarawakensis*. Di kalangan spesis ini, *C. curvignathus* merupakan sepsis dominan yang bertanggungjawab terhadap kira-kira 74% daripada kesuluruhan pokok yang diserang anai-anai.

TERMITE ASSEMBLEDGES, NICHE PARTITIONING AND INFESTATION IN NATURAL, DISTURBED AND PLANTATION FOREST IN NORTHERN PENINSULAR MALAYSIA

ABSTRACT

Forest conversion causes the destruction of natural habitat, fragmentation and degradation of an ecosystem functioning. Diversity and assemblages of organisms are often negatively affected by the land conversion. The expansion of plantation forest such as oil palm, rubber tree and forest plantations (e.g. Teak, *Pinus* and *Araucaria*) inflicts a greater threat to our natural forest. Termites as the main decomposer of organic matter in the tropical forest ecosystem are very much affected by the disturbances in their habitat. The present study was conducted mainly to investigate the community structure and assemblages of termites in the selected sites with different type of land-use and disturbances. Forest disturbance was found to have negatively affecting termite diversity and assemblages. The general trend of declining pattern of species richness can be observed along the increasing disturbance gradient of Primary forest (ave: 16.5 sp.) > Secondary forest (ave: 15.5 sp.)> Disturbed forest with building (ave: 13.5 sp.) > Plantation forest (ave: 6 sp.). The wood feeders were the dominant feeding group found in this study, contributing up to 70.3 % of the total species collected while the Nasutitermitinae was represented with 13 species that make up the largest subfamily of the overall species composition in this study. This study also aimed to investigate the impact of area management on the termite community structure within a plantation forest (*Araucaria cunninghamii*) over a three year period (2009 – 2011). The diversity and composition of termite in the managed area were found to be relatively stable while the unmanaged area showed increasing species richness. A total of five species were collected in year 1 followed by eight and 14 species in year 2 and 3 respectively. Four feeding groups (wood feeders, soil-wood interface feeders, wood-litter feeders and epiphyte feeders) were found in the plantation forest. The wood feeders were the most important feeding guild represented by 12 species (75%). The final objective of this study was to identify local termite species that are emerging as economically important pests of structures built in the forest area and an *Araucaria* tree plantation. Sixteen species of termites were identified infesting structures consisting of 10 genera from two families; Rhinotermitidae and Termitidae. The higher termites of Termitidae made up the majority with 13 species in which *Globitermes sulphureus* (18% of occurrences), *Odontotermes sarawakensis* (16%) and *Ancistrotermes pakistanicus* (14%) were identified as the main pest of structures in the study sites. In plantation forest area, three species were found occurring on the *Araucaria* trees; *C. curvignathus, Schedorhinotermes medioobscurus* and *O. sarawakensis*. Among these species, *C. curvignathus* was the dominant species responsible for about 74% of the total number of infested trees.

CHAPTER ONE

GENERAL INTRODUCTION

Forest degradation and disturbance in natural ecosystem has become a very concerning issue over the past decades. This especially has poses great danger to the biodiversity in the tropics. The rainforests of the south-east Asia are known to be among the most diverse in the world (Myer et al. 2000). The biodiversity "hotspot" of the south-east Asia located mainly in the Sundaland region.

Malaysia, located at the centre of the Sunda region, houses a vast area of lowland and upland dipterocarp forests. However, our forest area is rapidly vanishing to give way for development and economic activities. It was estimated that more than 250 000 hectares of Malaysian forest is logged each year (McMorrow & Talip 2001). Large-scale deforestration in Malaysia is mainly contributed by its agricultural sector with the increasing demand for palm oil (Fitzherbert et al. 2008) and continued need for rubber in the global market. Timber logging is another contributor for deforestation. The timber industry known Malaysia as one of the major producer of high-quality tropical log (ITTO 2009) such as Jelutong (*Dyera costulata*, syn. *D. laxiflora*), Keruing mempelas (*Dipterocarpus crinitus* Dyer), Meranti bukit (*Shorea platyclados*) and Merbau (*Intsia palembanica*).

In order to protect the forest area, numerous forest reserves, national parks as well as state parks have been gazetted across the peninsular to conserve and protect these natural rainforests. The Malaysian government, nevertheless through the National Ecotourism Plan in 1996, has identified several locations to be designated as prospective sites for ecotourism development in Malaysia which include the Belum-Temengor Forest Complex in Perak, one of the largest protected areas in Peninsular

Malaysia (MOCAT, 1996). For this reason, several locations within the forest area have to be cleared to give way for the development of necessary facilities. Although this has cause negative impact to the forest area, such development allows business and economic activities to flourish, thus benefit the locals. Therefore the effects of development and forest clearances on the natural ecosystem need to be monitored and kept at a minimal.

The use of termite assemblages and compositional changes has been studied as a model to evaluate the ecosystem functioning and disturbance effects on an ecosystem (Eggleton et al. 1999; Davies et al. 1999; Davies, 2002) as well as potential indicator to investigate climatic change in a given area (Gathorne-Hardy, 2002b). In general, termite species richness declines along disturbance gradients and the trophic structure of termite assemblages changes with the environmental changes (Eggleton et al., 1996, 1999; Jones & Eggleton, 2000; Davies, 2002). However, while some species responds negatively to disturbances, more tolerant species strive very well in new environments (Eggleton et al. 2002; Jones et al. 2003).

Some opportunistic species of termites may emerge as economically important pest in the area. Termite pest species generally come from the wood-feeders group. They become serious problem when their feeding activity compromises the integrity of a structure especially those made up of wood and cellulosic materials. Among the common pest species of termites in Malaysia are *Coptotermes* spp., *Schedorhinotermes* spp., *Macrotermes* spp., *Microtermes* spp., *Odontotermes* spp. and *Globitermes sulphurous* (Haviland) (Tho 1992; Lee 2002a; Lee et al. 2007; Abdul Hafiz & Abu Hassan 2009, 2011). The *Coptotermes* spp. was considered the most important pest species accountable for almost 85% of the total termite infestation on premises in Malaysia (Lee et al., 2007) while the *Coptotermes curvignathus* (Holmgren)was found to be the key pest species in Malaysian plantation forest (Tho, 1974, Kirton et al., 1999, Cheng et al., 2008).

Understanding the basic biology and ecological functions of termites will help in determining the best possible management program that can be used to avoid or control termite infestation in a given area.

The objectives of this study are:

1. To study the responses of termite community toward different habitat disturbance level.
2. To investigate the compositional changes of wood-feeding termites in an *Araucaria* plantation area.
3. To determine the pest status of some termite species in the natural forest area as well as the plantation forest.

CHAPTER TWO

LITERATURE REVIEW

2.1 Termite Diversity and Taxonomy

2.1.1 **Termite taxonomy and classifications**

Termites (Class: Insecta) or commonly known as the white ants, are eusocial insects that were classified under order of Isoptera. However, a molecular phylogenetic study by Inward et al. (2007) proved that termites are social cockroaches that are closely related to wood-eating cockroaches and should be placed under the order of Blattodea. Consequently, termites are now classified as infraorder Isoptera under the order of Blattodea (Krishna et al. 2013). In family level classifications, there have been a number of family names suggested, recognized or dropped over the past few decades. Based on some of the most recent literatures, seven families of termites (i.e: Mastotermitidae, Kalotermitidae, Termopsidae, Hodotermitidae, Termitidae, Serritermitidae and Rhinotermitidae) (Kambhampati & Eggletion 2000, Engel & Krishna 2004) were generally accepted. However, Krishna et al. (2013) listed three more families; Archotermopsidae, Stylotermitidae and Stolotermitidae while delisting the Termopsidae.

There are 3106 species of termites recorded by Krishna et al. (2013). Termites have been suggested to be "taxonomically tractable" (Brown, 1991) which indicates that most of the termites species are presumably have been discovered and described. However, Eggleton (1999) reported a steady increase in the rate of termite species description per year in various regions around the world although the rate differs regionally.

Termite taxanomic classification and nomenclature has also undergone several changes and constantly reviewed up till the species level especially due to synonymies and the recent advancement on the use of molecular approach in termites' phylogeny. The most recent reviews among others are by Gathorne-Hardy (2001, 2004), Engel & Krishna (2004), Inward et al. (2007), Engel (2011) and Krishna et al. (2013).

2.1.2 **Diversity of termites in Sundaland and Peninsular Malaysia**

The Sundaland is a biogeographical region located on the Sunda shelf that comprises the Malay peninsula of the Asian Mainland as well as the Indonesian islands of Borneo, Sumatra, Java, Bali and its surrounding islands (Figure 1).

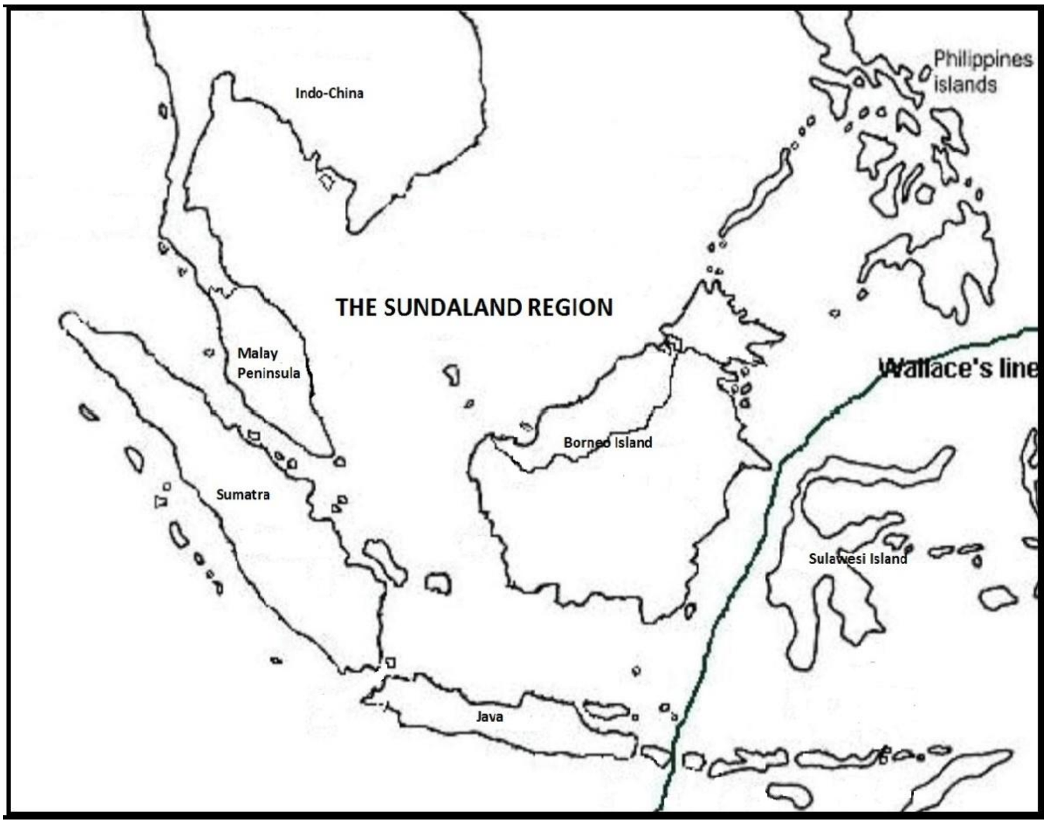

Figure 2.1: The Sundaland region

Although the Sundaland region is recognized as biodiversity hotspot (Myers et al., 2000), the termite richness and its biomass is relatively lacking compared to the Afrotropics regions (Eggleton et al. 1999). However, numerous studies have been conducted in this region making it one of the best studied areas for termites of tropical ecosystem in the world (Eggleton 1999). Early studies of termites in Sunda region were pioneered by among others; G. D. Haviland whose work on termite samples collected from South Africa, the Malay Peninsula and Borneo island, published in The Journal of the Linnean Society of London in 1898; N. Holmgren (1913, 1914) worked on termites of Java, Sumatra, Malacca and Ceylon; John (1925) worked on termites of Ceylon, Malay Peninsula, Sumatra Java and Aru island; N. A. Kemner who worked on Termitidae of Sumatra (1930) and the systematic and biological study of termites in Java and Celebes (1934).

In the Peninsular Malaysia, Tho (1992) listed approximately 175 species of termites from 42 genera and three families (Kalotermitidae, Rhinotermitidae and Termitidae) in which he also provided a reliable taxonomic account for termites of 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 peninsular. Gathorne-Hardy (2004) also reported a total of 226 species of termite recorded all over the Sunda region.

One of the most intensive works to study termite diversity in lowland forest of Sundaland region is by Jones & Brendell (1998) in Pasoh Forest Reserve of Peninsular Malaysia. A total 80 species of termites were documented by compiling their own collection and the previous studies done in the area (e.g: Abe & Matsumoto 1979, Matsumoto & Abe 1979, Tho 1982). In the East Malaysia, Collin's (1980,

1983) work on Gunung Mulu, Sarawak and work in Danum Valley, Sabah (Eggleton et al. 1997, 1999) are two of the most well studied sites. The work by Eggleton et al (1999) which was conducted under the Darwin Initiative grant funded by the UK government had reported a total of 93 species of termite fauna, the highest record of termite diversity of any sites in the region (Jones & Eggleton 2000). Other than Malaysia, studies of termite assemblages have been conducted in several other sites across the Sundaland such as in Indonesia (Gathorne-Hardy et al. 2000a, 2000b, 2001; Jones & Prasetyo 2002) and in Thailand (Davies 1997, Inuoe et al. 2001).

2.1.3 **Works on termites' identification key.**

Apart from studies conducted to provide termites inventory in the Sunda region, a good number of works was dedicated to provide taxanomic key for termite identifications. In Malaysia, two works are considered the most important. The work of Tho Y.P. on the illustrated key and brief description of termites of Peninsular Malaysia was compiled and edited by Kirton L.G. and published by Forest Research Institute Malaysia in 1992. This record has been referred by many researchers that work on termite of Sunda region (i.e: Jones & Brendell 1998,Eggleton et al. 1999, Gathorne-Hardy et al. 2001, 2002, Jones & Prasetyo 2002, Pribadi et al. 2011). Another work is on termite of Sabah (East Malaysia, Borneo Island) by Thapa R. S. published in 1981. Unlike Tho (1992), this work provided both systematic key, morphological descriptions and illustration to termite species found in Sabah amounting to 103 species described.

Early work on Malaysian termites also include work by Ahmad M. (1968) that discuss the nasute genera related to *Subulitermes* from the subfamily Nasutitermitinae and work by Ahmad M. & Aktar M. S. (1981) that described a new termite genera of the *Capritermes* complex from Malaysia. Gathorne-Hardy (2001) reviewed the subfamily Nasutitermitinae of South East Asia in 2001 along with description of one new genus *Snootitermes* and a new species, *Hirtitermes brabazoni*. In 2004, Gathorne-Hardy produced a taxonomic review and checklist of termites of Sundaland. He also described *Leucopitermes thoi*, a new species found in Borneo, Peninsular Malaysia and Sumatra and provided a revised key to the soil feeding Nasutitermitinae of Sundaland. In a more recent study, Syaukani & Thompson G. J. (2011) published taxonomic notes on *Nasutitermes* and *Bulbitermes* (Termitidae, Nasutitermitinae) of the Sunda region based on morphological and molecular characters.

2.2 Termite Biology and Ecology

2.2.1 Termite biology

Termites are eusocial insect that undergo incomplete metamorphosis or hemimetabolous. Their colony is made up of various functional groups which can be divided into three major castes; the reproductives, the sterile castes and the immature (Krishna & Weesner 1969). The life cycle of termite consist of a number of pathways which produce individuals of different castes to participate in the various tasks for the colony to function. The castes of the nymphs are determined by factors such as hormones and pheromones based on the need of the colony (Homathevi & Noel 2003). The termite larvae is an immature termite individual that has no external sign of wing buds or of the soldier morphology (Roisin, 2000), a stage prior to the differentiation of immature termite into either, nymph, soldier or worker castes.

The reproductives castes include the royal pair or the primary reproductive, secondary reproductive, supplementary reproductive and alates. The number of reproductives is usually very low, increase during the development of alates before swarming season. Secondary reproductives in an established colony are called supplementary reproductives which may or may not succeed and replace the primary reproductives. In some large termite colony, the supplementary reproductive produces eggs even when the primary reproductive or the queen is still present which further increase the colony size (Hopkins 2003, Suiter et al. 2009.).

The sterile castes are the soldiers and workers that made up of sexually immature male and female, wingless and blind in most species. Some species of termites exhibits polymorphism in both or either one of these two castes. For example, *Macrotermes* sp., and *Odontotermes* sp. have dimorphic soldiers and workers (major caste bigger in size), species like *Ancistrotermes pakistanicus* consist of dimorphic soldiers but monomorphic workers, while *Hospitalitermes* sp. is an example of genera with monomorphic soldiers but dimorphic workers. This characteristic may be used to differentiate and effectively separate a closely related genera and even species. The open-air foragers of *Longipeditermes* sp. and *Hospitalitermes* sp. can be separated by observing the distinctly dimorphic soldier in *Longipeditermes* sp. (Tho 1992).

The workers made up the majority of the colony member. They are accountable to various kind of work such as foraging for food, feeding and grooming other castes, tending the eggs and maintaining and building nest structures (Weesner 1969, Krishna 1969). In some termite families (e.g. Mastotermitidae, Kalotermitidae, Termopsidae) the workers are absent and replaces by the pseudergates (Krishna 1989, Roisin 2000), “false worker”, temporarily non reproductive helper characterized by reduced wing buds (Thorne 1996). The soldiers usually that equipped with heavily sclerotized head capsule and mandibles for defending the colony against intruders, made up the second largest castes (Weesner 1969).

2.2.2 **Feeding ecology**

Based on their feeding ecology, termites can be divided into two main groups, the “lower” and “higher” termites. Lower termites consist of all termite families other than Termitidae. The gut of lower termites contains highly diverse prokaryotes and eukaryotic flagellated protists population while the higher termites of Termitidae family typically lack eukaryotic flagellated protists. However, the higher termites are considered as the most evolved lineage of termite family which exhibit a variety of feeding ecology (Miura et al. 1998, Ohkuma et al. 2001). The Termitinae and Nasutitermitinae are the two largest subfamily among the higher termites known to have more than 647 species from 62 different genera and 614 species from 77 genera respectively (Krishna et al. 2013))represented by a number of feeding guilds such as wood-feeders, fungus-growers, epiphyte-feeder as well as soil feeders.

Termites generally known to the public as wood feeders that feeds on wooden or cellulosic materials. Nevertheless there are a number of species that feed on living plant materials (e.g. *Coptotermes* and *Microcerotermes*) to dead plant of various decomposing stages including highly decayed materials as well as minerals in the soil (e.g. *Termes*-group). There are five feeding groups based on classification given in Collins (1984) and Eggleton et al. (1997). The feeding groups are as follows:

- Wood feeders: Termites that feed on living or dead wood.
- Wood-litters feeders: Foraging termites that feed on leaf litters and woody materials.
- Soil feeders: Termites that feed on humus and mineral soil
- Soil-wood interface feeders: Termite that feed on highly decayed wood that has become friable and soil-like.
- Epiphyte feeders: termites that feed on lichens, epiphytes and other free living non-vascular plants.

Other than these, the mound-building termites of Macrotermitinae that grow fungus in their nest know as fungus growers. These termites are also wood feeders or wood-litter feeders.

Another grouping of termites based on their feeding ecology was presented by Donovan et al. (2001). Termites are designated into groups I to IV in increasing order of humification of the feeding substrate as follows:

- Group I consist of lower termites of dead wood and grass-feeders.
- Group II contains Termitidae with a range of feeding habits including dead wood, grass, leaf litter, and micro-epiphytes;
- Group III contains Termitidae feeding in the organic rich upper layers of the soil;
- Group IV contains the true soil-feeders (again all Termitidae), ingesting apparently mineral soil.

As social insect, the division of labor within a termite colony allows the colony to function effectively. The workers are responsible for finding foods for the colony and distributing it to the other members of the colony through a process called trophallaxis. It involves the exchange of partially digested food secretion from mouth to mouth (stomodeal feeding) or from anus (proctodeal feeding).

Termites are incapable of producing cellulose enzyme needed for digesting cellulosic compound on their own. Thus, they symbiotically depend on other organisms to digest cellulose for them. This relationship with microorganism in termites' gut allows efficient functioning of their digestive system which enables them to survive on low nutrition diet such as cellulosic material (Waller & LaFage 1987). The protozoa or bacteria are not present in the newborn but obtained from the older workers through trophallaxis. The breaking down of cellulosic materials in lower termites is facilitated by the flagellated protozoa in the hind gut as the primary digestive site (Varma et al. 1994, Inoue et al. 2000) although endogenous cellulase has been reported to be produced the salivary glands of *Reticulitermes* sp. (Watanabe et al., 1997, 1998).

While in higher termite, the digestive process is different among the diverse functional feeding group. The cellulose consumed is generally assumed to be digested by bacteria (Noirot & Noirot-Timotheé, 1969, Bignell et al. 1980). Termites in subfamily Macrotermitinae grow fungus (*Termitomyces* sp.) in the fungus chamber of their nest to help them digest the cellulose (Mueller & Gerardo 2002). Semi-digested cellulose will pass through the digestive system and deposited as pellets on the fungus comb (Wood & Thomas 1989). The cellulose will be broken down by the fungus and reingested by termite (Rouland-Lefèvre 2000).

2.2.3 **Population dynamics of termite**

Population dynamics deals with the fluctuation of size and age of a population in addition to the factors influencing the population development. In termites, it engages the changes within the colony which related to colony structure and caste differentiation as well as within an ecosystem which involve species diversity and the community ecology (Lapage & Darlington 2000). The population growth or population dynamic of a termite colony is in synchronization with the functional activities of the colony as well as favourable environmental conditions. Baneerjee (1971) suggested that the homeostatic mechanism is responsible in regulating the soldier-worker ratio in the colony thus, the population dynamics. The ability of termites to stabilize the microclimate inside their colonies to the optimum making the weather seasonal changes a less important regulating factor. However, Sattar et al. (2013) reported different environmental factor give different effect on the population of different termite species.

The number of individual within a colony increases as the foraging activity of termite peaks during the alate production state (Schuur-man 2006). The production of alates is regulated by pheromones and affected by the environmental conditions. The foraging activities of termites correlated with temperature and rainfall (Evans & Gleason 2001). The flight season or swamming by termite alates is different among species and its topography. Neoh & Lee (2009) found that *M. gilvus* swarming correlate significantly on rainfall and atmospheric pressure. The flight of this species occurs mostly on rainy days while the *M. carbonarius* swarms on non-rainy days (Neoh & Lee 2009). Following the swarming of the alates, the population of various castes in the colony decline and stabilized (Banerjee 1966) before the population continues to grow.

The use of resources within the colony also regulated the nest density and seasonal fluctuation of different castes proportions. The resources and energy produced are dedicated to castes in accordance to the need of the colony (Lapage & Darlington 2000). For example, in the early stage of colony establishment, the main used for energy and gathered resources is to increase sterile population to collect more forage and fortifying the nest. The maturation of numerous nymphs during the dry season requires highest demand for food pending the swarming in the wet season. Su & Schefferahn (1987) collected an estimated sum of 68, 729 Formosan termites's alates in a 5 days swarming period. While the amount of alates produced varies between species, larger colony produces more alates.

Major limiting factors for termites' population dynamics are intraspecific competition, predation and extremely unfavourable environmental conditions that impose stress and disturbance to the colony (Lapage & Darlington 2000).

2.2.4 **Termite responds to environmental changes**

Insects' quick responses to their environmental changes allow them to be utilized as a reliable bioindicator to monitor the health of an ecosystem (McGeoch 1998). Termites in general are rather responsive to habitat disturbance and environmental changes which may allow the utilization of termite composition and assemblages in an area as a model to assess the effects of the disturbances and change on an ecosystem (Davies, 2002). Previous studies have reported that termite species richness decline along the disturbance gradients and the trophic structure of termite assemblages changes with the environmental changes (Eggleton et al. 1996, 1999; Jones & Eggleton, 2000; Davies, 2002). The responds however, differs among termites species or groups. Some species may responds negatively to disturbances while the more tolerant species may strive very well in new environments (Eggleton et al. 2002; Jones et al. 2003).

Environmental changes by natural cause also affect the richness and abundance of termites. For example, termite richness generally decline with increasing altitude which correspond with increasing temperature (Collins, 1980; Gathorne-Hardy et al., 2001; Inoue et al. 2006, Pribadi et al., 2011). The decrease in termite richness due to this factor can be properly observed at the functional feeding group level. Other than temperature as the important factor influencing the termite diversity, high annual rainfall may have negative effect on the overall termite richness and abundance due to the inundation of microhabitats which may lead to colony death (Dibog et al. 1998, Bignell & Eggleton 2000).

Habitat loss and forest degradation due to human activities has great impact on the assemblages of termites in an area (Gathorne-Hardy et al. 2002a, Jones et al. 2003). The lack of suitable nesting and feeding sites such as dead log, forest litter and tree stump in disturbed forest cause termite fauna to decline (Eggleton & Bignell 1997). Jones et al. (2003) reported woody plant basal area as a strong influencing factor affecting termite richness and relative abundance. Lower structural complexity in an area results in lesser microhabitats for termite to occupy (Jones 2000).

Canopy height affect the species richness of termite (Jones et al. 2003) and dense canopy cover increase the richness and abundance of termites (Eggleton et al.

1996, 2002). The loss of canopy cover alters the microclimate conditions of the forest floor (Chen et al. 1999) causing some species with low tolerant to decline. The soil-feeders were reported to be more affected by the canopy loss compared to the wood feeders (Eggleton et al. 1998, Dibog et al. 1999) and were more vulnerable to disturbance (De Souza & Brown 1994, Eggleton et al. 1997). This is said to be due to the energetic limitation of the soil-feeders as they consume mineral soil that has low amount of cellulosic materials (Eggleton et al. 1998).

2.3 Termites as beneficial insect in natural ecosystem

Termites feed on a wide range of organic material such as plant litter, dead wood, and soil organic matter (Donovan et al. 2001). They play an important role in the decomposition of such matter in the tropical forest ecosystem (Matsumoto 1976, Wood & Sand, 1978) and were reported to consume approximately14% - 50% of the dead plant biomass in tropical ecosystems (Matsumoto & Abe 1979, Bignell & Eggleton, 2000). Matsumoto and Abe (1979) observed and estimated more than 30% of the tree leaf litter in Pasoh Forest (Malaysia) consumed by termites. Collins (1989) has estimated the production of termite in the Sunda region at about 300 kg ha^{-1} per year.

In the event of habitat disturbances, termites were thought to help the recovery of the soil fertility (Davies et al 1999). Through their feeding, tunneling and mound-building activities, termites contribute significantly on the soil formation, texture, quality and nutrient enrichment in the soil (Wood, 1988; Yamada et al. 2005, 2006). Evans et al. (2011) reported increase of wheat yield in dry climate region by

36% in a field experiment with ants and termites due to the increased water infiltration in the soil by the tunneling activity and improved soil nitrogen.

Most termite species consumed plant material that is low in nitrogen content (Collins 1983). Their supplement of nitrogen comes from the symbiotic bacteria in their gut that fix atmospheric nitrogen using the dinitrogenase reductase (*nifH*) (Ohkuma et al. 1999).Termite faeces contain high level of nitrogen which they then use the mixture of their saliva and faeces to construct tunnel walls resulting in increase of nitrogen content in the soil. The gas flux produce by termites and their nests contributes about 2%–5% of the world's methane in the atmosphere (Sugimoto et al., 2000). However, a study by Eggleton et al. (1999) suggested that methane production by South-East Asian termites does not contribute significantly to the world's methane fluxes as the soils are methane sinks.

In term of carbon mineralization, a number of studies (e.g: Wood & Sands 1978, Bignell et al. 1997, Eggleton et al. 1999) attempted to quantify the decomposition process by using termites' abundance and biomass and measuring the respiration rates of termites. The measurements of respiration enable the quantification of the carbon mineralization by termite populations, although the mineralized by the fungus-combs in mound of higher termites is usually not included.

2.4 Economic importance of termites

2.4.1 Pest of structures

Termites are well known worldwide as one of the most destructive group of pest on structure and building made up of wood. Su (2003) reported an estimation of more than USD 20 billion annually used for termite control and repair cost of termite damages around the world. In 2012, Rust and Su estimated about USD 40 billions were spent annually. As much as 183 species of termites, mostly subterranean termites were recognized as pest of structure with 83 of them cause significant loss and damages (Edwards & Mill 1986). Krishna et al. in 2013 noted a sum 371 species of termites has been reported as pest of structures as well as agriculture with 104 species were considered as of serious threat. In Malaysia, in year 2000, the cost of subterranean termite control was estimated to be USD 8-10 million, which was 50% of the total business turnover of the Malaysian pest control industry in 2000 (Lee 2002a). In year 2003, this number increased to USD 10-12 million (Lee 2004). Most termite control services by pest control operator in Malaysia were carried out in residential premises, as to 20% in the industrial sectors, 10% in commercial buildings and 5% in other locations (Lee 2002a).

Of all the species of subterranean termites, *Coptotermes* spp. is the most destructive and widely distributed throughout the tropics and subtropic area. The *Coptotermes* spp. was considered the most important pest species on premises in Malaysia (Sajap & Wahab, 1997; Mohd Yusri et al., 2005; Lee et al., 2007; Abdul Hafiz & Abu Hassan, 2009). The *Coptotermes gestroi* (Wasmann), or commonly known as the Asian Subterranean Termite is the most important pest species in both urban and semi-urban area accounted for 85% and 40 % of all building infestations in the respective areas (Kirton & Azmi 2005) while infestations by *C. curvignathus* are common in premises built on ex-agricultural land or plantations with history of *C. curvignathus* infestation (Lee 2002a, Lee at al. 2007).

Other species that were reported as the secondary pest of premises in Malaysia are *Macrotermes gilvus* (Hagen), *M. carbonarius* (Hagen), *Globitermes sulphureus*, *Microtermes pakistanicus* Ahmad, *Schedorhinotermes* spp., *Odontotermes* spp., *Nasutitermes* spp., and some arboreal nesters such as *Microcerotermes* spp. (Lee, 2002a, Kirton & Azmi 2005, Abdul Hafiz & Abu Hassan 2009). Lee et al. (2007) also reported that case of several termite species infesting premises at any one time is common especially in area with high termite diversity. The population size of some of the pest species within the area can be very high with millions of individuals per colony with their wood consumption rate exceeding 500 gram per month; and foraging territories more than 100 m^2 with high tunneling activities (e.g: *G. sulphureus*, *C. gestroi* and *C. curvignathus*) (Lee 2002b, Ngee & Lee, 2002, Yeoh & Lee 2007, Abdul Hafiz & Abu Hassan 2008).

2.4.2 **Pest of agriculture**

Exotic trees seem to be more susceptible to termite infestation. In Malaysia, most of the exotic conifer trees such as *Araucaria cunninghamii*, *Araucaria hunsteinii*, *Pinus caribaea* and *Pinus patula* are under threat of termite attack (Tho, 1974). The incidence of termite attacks have been reported to be high in Malaysian conifer plantations (Benedict 1971, Thapa & Shim 1971) with severe infestations that lead to complete losses in some plantations (Tho 1974). Other plantation forests in

Malaysia attacked by the termite include *Acacia mangium* (Hamid 1987, Tho & Kirton 1990), *Tectona grandis* (Chey 1996) and *Eucalyptus deglupta* (Hamid 1982). Economically important crops in Malaysia such as oil palm (Cheng et al. 2008) and rubber tree are also now under serious threat due to termite attack. Plantation areas developed on peat swamp land are particularly vulnerable to attack by the wood feeder *Coptotermes* spp.

The *Coptotermes curvignathus* was found to be the key pest species in the plantation forests (Tho, 1974, Kirton et al., 1999, Cheng et al., 2008,). Lower termite richness in plantation forest reduces competition for food and territory thus allowing the *C. curvignathus* to utilize food resources efficiently (Tho, 1974). This situation may worsen when the environmental conditions favors the termites. Improper management of a plantation, inadequate drainage (Thapa & Shim 1971, Chew 1975) and presence of logs, stumps and organic litters on the ground may increase the risk of termite infestation. Collins (1980) reported termite occupancy in dead wood on forest floor of different forest types in Gunung Mulu National Park, Sarawak to be up to 50% and that all wood at some stage was attacked by termites. High amount of timber residues due to incomplete forest clearing was said to be a contributing factor for *C. curvignathus* problem in pine plantations grown on mineral soils (Thapa & Shim, 1971; Tho, 1974). However, more recent studies reported that wood residue on the forest floor have little contribution to termite problem (Kirton et al. 1999, Cheng et al. 2008). Host susceptibility (Chew 1975, Tho & Kirton 1998) and the presence of remaining termite pest species populations following the forest conversion (Kirton et al. 1999) were concluded to be the main factors that determine the severity of attack in plantations.

2.5 Management strategies for termite problems

Termite infestations especially on wooden structures compromised the structures integrity. Damages caused by termite infestation resulted in huge economic loses. Apart from the cost needed to repair the damages, the applications of termite control strategies to avoid or prevent further damages are very costly. In the United States, Su (1994) estimated the cost of termite control exceeding $1.5 billion annually while in Malaysia, Yap & Lee (1996) reported the cost of termite control and related services was at US$5 million in 1995. Structures that lie within the foraging territory of a wood-feeders colony usually become infested. The damages by termites are caused by the feeding and foraging behaviour of the worker castes, thus the termites population control usually targets the worker castes. Various methods have been developed to stop the occurring infestation and preventing new infestation of termite.

Creating barrier on the site before construction of premise by physical or chemical meant to prevent termites from reaching a structure. Installation of uniform-sized particles such as sand (Ebeling &Forbes 1988, Su et al. 1991, Su & Scheffrahn 1992) or stainless steel screening (Lenz & Runko 1994, Grace et al. 1996) during construction is the most common and commercially available method for creating physical barrier. Although they are rather expensive and difficult to install, these methods are gaining more attention and preferred in the recent years due to the growing environmental impact of chemical termiticides.

Soil treatment using liquid termiticides have been widely used to control subterranean termites. The organochlorines, which were mainly used in soil treatment thanks to their lower cost and persistency in the soil, have been banned due to health and environmental concerns. With this, organophosphates (e.g. chlorpyrifos and isofenphos) which were reported to be effective in creating barrier (Su & Scheffrahn, 1990) have been used in soil treatments although they are less persistent. Other currently available termiticides in the market are pyrethroids-based termiticides (i.e. permethrin, cypermethrin, bifenthrin), neonicotinoid (imidacloprid) and fipronil (Su 2000).

In Malaysia, management strategies for subterranean termites commonly rely on the use of soil insecticides (Chung & Lee 1999). Due to the banning of organochlorines, chlordane in 1998, chlorpyrifos termiticides have been widely utilized (Lee 2002a). Currently, imidacloprid are widely use in liquid soil treatment in urban area for termite control as it has now become available in generic formulation. Termite population control using baiting system incorporated with chitin synthesis inhibitors (CSI), hexaflumuron as the active ingredient by pest control operators started in October 2000 (Lee 2002a, 2002b) first introduced by Dow AgroSciences LLC and has then been quite popular for termite control in residential area. Other CSI products are baits with diflubenzuron, chlorfluazuron, and noviflumuron.

CHAPTER THREE

ASSEMBLAGES OF TERMITES IN PRIMARY, SECONDARY AND DISTURBED FORESTS IN NORTHERN PENINSULAR MALAYSIA: A COMPARATIVE STUDY[1].

3.0 Introduction

Forest conversion causes the destruction of natural habitat, fragmentation and degradation of an ecosystem functioning. Diversity and assemblages of organisms are often negatively affected by the land conversion. The Peninsular Malaysia accommodates area of lowland and upland dipterocarp forests. However the highly diversified rainforests are being subjected to high level of habitat loss (Myers et al. 2000). Over 250 000 hectares of Malaysian rainforest is logged every year (MacMorrow & Talip 2001) mostly due to the expansion of plantation forest (especially oil palm plantation).

Therefore, forest reserves, national parks as well as state parks have been gazetted across the Malaysia to conserve and protect these natural rainforests. One of them is the Belum – Temengor Forest Complex (BTFC) in the northern Perak. The northern part of this forest complex is currently known as the Royal Belum State Park (RBSP), gazetted on 17 April 2007. It stretches across about 117,500 hectares of primary upland dipterocarp forest.

The lower section of the forest 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).

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In 1996, the National Ecotourism Plan has identified the BTFC as a prospective site for ecotourism development in Malaysia (MOCAT 1996). To accommodate such activity, some of the forest areas were cleared for the construction of offices and living quarters of the Forestry Department as well as facilities for eco-tourism industry within the area.

The expansion of plantation forest such as oil palm plantation, rubber tree plantation and timber trees plantation (e.g. Jati, *Pinus* and *Araucaria*) inflicts greater threat to our natural forest. Most of these monoculture plantation forests do not support forest-specialist species and tend to be depauperate (Gathorne-Hardy et al. 2002b, Peh et al. 2006, Bruhl & Eltz 2009,). Timber trees plantation forests especially in the Peninsular of Malaysia are mainly test plots to study the feasibility of the exotic trees to be planted commercially in Malaysia, in most cases not pursued.

Termite composition and assemblages in an area may be used as a model to evaluate the disturbance effects on an ecosystem as they are very responsive to habitat disturbance and environmental changes (Davies 2002). Their populations within the area can be very high with millions of individuals per colony in some species of termite (e.g: *Globitermes sulphureus*, *Coptotermes gestroi*) (Ngee & Lee 2002, Abdul Hafiz & Abu Hassan 2008). In term of richness, Tho (1992) reported 175 species of termites from 42 genera and three families (Kalotermitidae, Rhinotermitidae and Termitidae) all across Peninsular Malaysia.

The species richness of termite and the trophic structure of termite assemblages generally decline along disturbance and land-use intensification gradients (Eggleton et al., 1996, 1999; Jones & Eggleton, 2000; Davies 2002, Jones et al. 2003). However, while some species responds negatively to disturbances, more