TAXONOMIC STUDY OF *BULBITERMES* (BLATTODEA: TERMITIDAE: NASUTITERMITINAE) IN SABAH, MALAYSIA

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INSTITUTE FOR TROPICAL BIOLOGY AND CONSERVATION
UNIVERSITI MALAYSIA SABAH
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ABSTRACT

This research was focused on the taxonomic studies of the genus *Bulbitermes* (family Termitidae and sub-family Nasutitermitinae) of Sabah. This study is important as morphological existing taxonomic information of *Bulbitermes* is not sufficient to separate the species. The objectives of this research were; 1) to study the morphological characters and revise the genus *Bulbitermes* of Sabah, and 2) to construct a pictorial identification key for the genus *Bulbitermes* of Sabah. Fresh specimens were collected manually at 11 different locations around Sabah using standardised belt transect method (100mx2m) and casual collection. In addition, preserved specimens of *Bulbitermes* from existing collection in BORNEENSIS, Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah were also analysed. A total of six described *Bulbitermes* species and nine morphospecies were examined in this study. Of these, a total of nine *Bulbitermes* species, one species from genus *Ceylonitermes* and one species from genus *Lacessititermes* were identified after revision. Of seven examined *Bulbitermes* morphospecies, four were confirmed to be similar with described species. *Lacessititermes* sp. and *Ceylonitermes* sp. were previously misidentified as *Bulbitermes* sp. G and *Bulbitermes* sp. F, respectively. This result gives rise to the 50% of *Bulbitermes* species in Sabah, comprising 27% of *Bulbitermes* species worldwide. Morphological characteristics of the species were analysed and the description of soldier caste and worker caste were given. Observation on the specimens from 425 colonies and cluster analysis using MultiVariate Statistical Package, (MVSP) showed that *Bulbitermes* sp. A and *Bulbitermes* sp. B are similar to *B. constrictus*. Meanwhile, *Bulbitermes* sp. C is similar to *B. sarawakensis* and *Bulbitermes* sp. D is similar to *B. borneensis.* These grouping clades have highest similarity value in cluster analysis. *Bulbitermes* sp. 1 is slightly similar to the *B. germanus* which have been recorded in Peninsular Malaysia but differs in the soldier mandible character where a distinct marginal teeth is present on both mandibles of *Bulbitermes* sp. 1 while this character is absent in the *B. germanus*. *Bulbitermes* sp. 2 and *Bulbitermes* sp. E could not be related with other *Bulbitermes* species which have been recorded in Malaysia. *Bulbitermes* sp. 2 comes closer to *B. prabhae* which have been identified in Thailand. *Bulbitermes* sp. E could not be related to any other *Bulbitermes* species due to the limitation in the morphological information and samples. Using the confirmed *Bulbitermes* species after revision, a pictorial identification key for the genus level and *Bulbitermes* species level were constructed. In conclusion, taxonomic status and list of *Bulbitermes* species for Sabah have been updated through this study. Hence, all these species give a rise to the total number of species and genera for Sabah. Research in molecular phylogeny could be conducted in the future to identify the genetic variance among these *Bulbitermes* species.

ABSTRAK

KAJIAN TAKSONOMI BULBITERMES (BLATTODEA:TERMITIDAE:NASUTITERMITINAE) DI SABAH, MALAYSIA

Penyelidikan ini memfokuskan kajian mengenai taksonomi anai-anai genus Bulbitermes (Famili Termitidae dan sub-famili Nasutitermitinae) di Sabah. Kajian ini adalah penting kerana kurangnya maklumat morfologi taksonomi bagi Bulbitermes untuk membezakan spesies tersebut. Objektif kajian ini adalah; 1) untuk mengkaji karakter morfologi dan menyemak genus Bulbitermes di Sabah, dan 2) membina kekunci identifikasi bergambar untuk Bulbitermes di Sabah. Spesimen hidup telah dikutip dari 11 kawasan kajian di sekitar Sabah dengan menggunakan kaedah transek (100mx2m) serta koleksi secara kasual. Tambahan pula, spesimen Bulbitermes yang sedia ada dari koleksi BORNEENSIS, Institut Biologi Tropika dan Pemuliharaan, Universiti Malaysia Sabah juga telah dianalisis. Sejumlah enam spesies Bulbitermes dan sembilan morfospesies telah dikaji dalam kajian ini. Daripada ini, sejumlah sembilan spesies Bulbitermes, satu spesies Ceylonitermes dan satu spesies Lacessititermes telah direkod selepas penyemakan spesies. Tujuh daripada morfospesies yang dikaji, empat morfospesies telah dikenalpasti serupa dengan Bulbitermes yang pernah dihuraikan. Lacessititermes sp. dan Ceylonitermes sp. adalah spesies yang disalahtafsirkan masing-masing sebagai Bulbitermes sp. G dan Bulbitermes sp. F. Keputusan ini meningkatkan jumlah species Bulbitermes di Sabah sebanyak 50% dan merangkumi 27% daripada jumlah keseluruhan Bulbitermes di dunia. Ciri-ciri morfologi bagi spesies-spesies tersebut telah dianalisa dan huraian bagi kasta askar dan pekerja telah diberikan dalam kajian ini. Selepas pemerhatian morfologi terhadap 425 koloni dan analisa kluster dilakukan terhadap semua spesies Bulbitermes, didapati bahawa Bulbitermes sp. A dan Bulbitermes sp. B mempunyai morfologi yang sama dengan B. constrictus. Bulbitermes sp. C pula serupa dengan B. sarawakensis manakala Bulbitermes sp. D sama dengan B. borneensis. Kesemua kumpulan spesies ini mempunyai nilai kesamaan yang tinggi dalam analisa kluster. Bulbitermes sp. 1 adalah sama dengan B. germanus yang pernah direkodkan di Semenanjung Malaysia tetapi ciri mandibel membezakan kedua-dua spesies tersebut. Satu gigi marginal dapat diperhatikan di kedua-dua mandibel Bulbitermes sp. 1. Walaubagaimanapun ciri ini tidak kelihatan pada B. germanus. Bulbitermes sp. 2 dan Bulbitermes sp. E tidak dapat dikaitrapatkan dengan spesies Bulbitermes yang pernah direkodkan di Malaysia. Bulbitermes sp. 2 hampir sama dengan B. prabhae yang pernah direkodkan di negara Thailand. Bulbitermes sp. E pula tidak dapat dikaitkan dengan Bulbitermes spesies yang lain kerana batasan dalam maklumat morfologi dan bilangan sampel. Kekunci identifikasi bergambar bagi peringkat genus dan juga spesies telah dibina dengan menggunakan spesies Bulbitermes yang telah disemak. Secara kesimpulan, status taksonomi dan senarai spesies Bulbitermes di Sabah telah dikemaskini melalui kajian ini. Oleh itu, kesemua spesies yang dikaji menambahkan lagi bilangan spesies dan genera yang terdapat di Sabah. Penyelidikan dari segi genetik (DNA) boleh dibuat pada masa akan datang bagi mengenalpasti perbezaan genetik antara spesies Bulbitermes.

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%	Percentage
†	Fossil
m^{-2}	one per meter square
gm^{-2}	gram per meter square
Alt.	Altitude
CA	Conservation Area
Dbh	Diameter at breast height
FR	Forest Reserve
ha	hectare
m	meter
mm	millimeter
Seg.	Segment
Sg.	Sungai

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CHAPTER 1

INTRODUCTION

1.1 Termites

Termites are important inhabitants of tropical rain forest and they are common in tropical soils especially in the tropical rain forest (Acda, 2007). Termites can also be found in some temperate regions and rain forests of Africa, South America and Southeast Asia continents (Eggleton, Williams and Gaston, 1994). They are eusocial insects which was previously grouped under the order Isoptera. The term Isoptera derived from the Greek words, of which '*isos*' means equal and '*pteron'* means wing. However, a recent molecular phylogenetic study proved that termites are sosial cockroaches. Hence, termites were reclassified under the order Blattodea and epifamily Termitoidea (Eggleton, Beccaloni and Inward,2007; Inward, Beccaloni and Eggleton, 2007; Zhang, 2011). Termites are also known as "white ants" in general even though they are not related to ants.

It has been known that termites have existed on this planet over 120 million years ago (Triplehorn and Johnson, 2005). They have similar characteristics as cockroaches. This can be seen in *Mastotermes darwiniensis* Froggatt, the primitive species of termite from Australia which have some similar characteristics with some cockroaches (Triplehorn and Johnson, 2005). The most noticeable similarity is the present of styli in the rear end of the abdomen in termites and cockroaches (Harris, 1957). Both termites and cockroaches are also hemimetabolus where they have incomplete life cycle with absence of pupal stage (Homathevi, 2003). Furthermore, the folded anal lobe in the hind wing and an egg mass of the termites also resemble the wings and oothecae of the cockroaches. The relationship between termites and cockroaches gives an idea that termites have evolved during the late Permian, approximately 200 million years ago (Triplehorn and Johnson, 2005).

Termites are insect with great importance in tropical terrestrial ecosystem especially in the decomposition process (Wood and Johnson, 1986). They also facilitate to improve the structure and also the quality of soil (Jones and Prasetyo, 2002) and mediate the ecosystem processes such as carbon and nitrogen cycles (Inoue, Takematsu, Yamada, Hongoh, Jojima, Moriya, Sornnuwat, Vongkaluang, Ohkuma and Kudo, 2006). Termites are also known as soil engineers where, they move through soils and mix organic and mineral materials (Bignell and Eggleton, 2000). Termites also play important role in the food chain. They are food source for many other organisms especially ants. Some, specialized vertebrate predators such as sun bears, aardvark, aardwolf, pangolins, armadillos, anteaters, sloth bears and echidnas have termites as their food (McGavin, 2001). Despite having positive functions in the ecosystem, termites can be either beneficial or destructive to man. There are certain species of termites that act as pests and cause serious damage to buildings, crops and even plantation forests (Kirton, 2005).

In a termite colony, several millions of termite individuals can be found. The main caste which can be found in the colony are the nymphs, workers, soldiers and reproductives. The entire individuals in a colony are dependent on each other. Hence, the disappearances of either one of the caste will affect the entire colony greatly (Wilson, 1971). At present, 3106 living and fossil termite species have been identified across the world, consisting of 330 living and fossil genera, and 12 families (Krishna, Grimaldi, Krishna and Engel, 2013a). There are only four families (Kalotermitidae, Rhinotermitidae, Stylotermitidae and Termitidae) which have been recorded in Malaysia. Published record showed that 175 species from 42 genera and three families have been identified in Peninsular Malaysia (Tho, 1992) while only 103 species from 33 genera and four families have been recorded in Sabah (Thapa, 1981). The termites can also be classified into five different groups as wood-feeders, litter foragers, micro-epiphyte feeder, soil-feeders and soil-wood interface-feeders according to their feeding behavior (Eggleton, Homathevi, Jeeva, Jones, Davies and Maryati, 1997).

It has been known that the digestion process in termites are assisted by the symbiotic protists and bacteria living in their gut (Krishna *et.all*, 2013a). This can be observed in the 'lower' termite which comprises all of the termite families except family Termitidae. Presence of symbiotic flagellate protozoans in this group enables the cellulose digestion in termite gut and the digested food is passed on to other colony members by trophallaxis, through oral or anal feeding (McGavin, 2001). The family Termitidae is classified as 'higher termite' due to the termite's capability to degrade cellulose without the presence of symbiotic protists in their gut (Ohkuma, 2003). The family Termitidae consists about 75% to 80% of the entire termite species of world (Tho, 1992; Brandl, Hyodo, Korff-Schmising, Maekawa, Miura, Takematsu, Matsumoto, Abe, Bagine and Kaib, 2007). Sub-family Nasutitermitinae which consist of 11 genera in Sabah is one of the sub-family categorised under the family Termitidae (Thapa, 1981). Species of this sub-family are said to be the most advanced termite species because of their highly specialized and effective chemical defense. Moreover, the caste of soldiers have a long pear-shaped rostrum (nasus), which is used as a defence mechanism (Lommen, Arnold and Ahmad, 2004).

Genus *Bulbitermes* is classified under the sub-family Nasutitermitinae and was erected by Emerson in 1949 (Synder, 1949). There are 33 known species of this genus which are restricted to Indo-Malayan and China region with six species recorded in Sabah (Synder, 1949; Thapa, 1981; Tho, 1992; Ahmad, 1965; Krishna, Grimaldi, Krishna and Engel, 2013c). This genus is separated from other genus in the sub-family Nasutitermitinae by having constrictions behind base of antennae, not greatly elongated legs and shorter hind femora compared to abdomen in the soldier caste (Thapa, 1981; Tho, 1992).

Bulbitermes is known as wood feeder, feeding on dead branches attached to or detached from living trees, dead standing trees and wood in early stage of the decaying process (Swift and Bignell, 2001; Syaukani and Thompson, 2011). They are also known as arboreal nesters, where their nest attached to tree. Even though the nest is attached to trees, they are not known as pest. They only feed on dead and decaying woods (Chey, 2012). Updated taxonomy information of the genus *Bulbitermes* of Sabah in the sub-family Nasutitermitinae is still lacking at present.

Taxonomic revision of *Bulbitermes* is required to furnish further details for species identification. This study will provide reliable and updated taxonomic information of genus *Bulbitermes* in Sabah.

1.2 Justification

Sabah a state of Malaysia has a total area of 7,487,564 ha and diverse with flora and fauna. Many studies on termites had been conducted in Sabah but most of the researches are ecological based studies. As an example, ecological studies have been conducted in Danum Valley Conservation Area (Eggleton *et.all*, 1997; Eggleton, Homathevi, Jones, MacDonald, Jeeva, Bignell, Davies and Maryati, 1999; Donovan, Griffiths, Homathevi and Winder, 2007), Maliau Basin Conservation Area (Jones, Jeffrey and Bakhtiar, 1998), Tabin Wildlife Reserve (Homathevi and Bignell, 1999), Kimanis-Keningau Road, Crocker Range Park (Homathevi, Tawatao, Mizan, Beterin and Matajim, 2004) and Malua Forest Reserve (Donovan *et.all*, 2007). Taxonomic studies have been solely concentrated on certain group of termites such as *Homallotermes* by Krishna (1972) and *Termes-Capritermes* group by Homathevi (1999).

Genus *Bulbitermes* of Sabah has less updated taxonomic information and the last revision done for this genus was about 33 years ago by Thapa (1981). Moreover, few studies related to *Bulbitermes* have been done for certain *Bulbitermes* species of Southeast Asia and Malaysia. These studies were more focused in caste biology, behaviour, defense secretions and molecular (Lommen *et. all*, 2004; Chuah, 2005; Syaukani and Thompson, 2011). Taxonomic revision of *Bulbitermes* is still lacking in Malaysia. Hence, this study aimed to provide reliable and updated taxonomic information of *Bulbitermes* in Sabah.

Identification key is very important to identify the termite until species level. Ahmad (1965), Krishna (1972), Thapa (1981), Tho (1992), Gathorne-Hardy (2001), Scheffrahn, Jones, Krecek, Chase, Mangold and Su (2003), Sornnuwat, Vongkaluang and Takematsu (2004) and Krishna *et.all* (2013a) are few examples of identification keys which have been developed by termitologist in order to aid in termite identification to family, genus and species level. As for Sabah, the

Bulbitermes species identification key was last published by Thapa in 1981. Up to date after 33 years, through ecological studies many species of *Bulbitermes* have been discovered around Sabah which does not tally with the species as stated by Thapa (1981). Problems were encountered by the researchers during the process of identification to species level. Many species were identified as morphospecies and named as *Bulbitermes* sp. A, *Bulbitermes* sp. C, *Bulbitermes* sp. E, and *Bulbitermes* sp. G (Eggleton *et.all*, 1997; Jones *et.all*, 1998; Eggleton *et.all*, 1999; Homathevi and Bignell, 1999; Homathevi *et.all*, 2004). Hence, this study will provide revised identification key to species level to ease the identification process for *Bulbitermes*.

Furthermore, the *Bulbitermes* identification key in Thapa (1981) also lacks figures explaining each of the termites' character in the form of a visual aid. It causes difficulty for the non-taxonomist and other researchers to identify the termite species easily as it is very technical for the general use. In this study, a pictorial identification guide for the genus *Bulbitermes* will be developed. Other than that, this study is also an effort to increase identification guides for insects in Sabah focussing on termite.

1.3 Objectives

The objectives of this study are:

a) To study the taxonomy and revise the genus *Bulbitermes* of Sabah.
b) To construct a pictorial identification key for the genus *Bulbitermes* of Sabah.

CHAPTER 2

LITERATURE REVIEW

2.1 Systematic Classification of Termites

Taxonomy and systematic are normally defined synonymously by researchers. However, these two fields can be separated from each other. According to Quicke (1993), taxonomy includes different range of areas such as nomenclature, classification and construction of identification key for particular groups of organisms while systematic is the combination of traditional taxonomy with the addition of theoretical and practical aspects of evolution, genetics and speciation. These two fields are also have well developed for termites.

2.1.1 General Classification

There were several attempts made by taxonomist in order to identify the phylogeny of termites over the course of time. Phylogenetically, termites are classified in the order Isoptera which is said to be a sister group with a primitive group of wood-dwelling cockroaches (Blattaria) (Thorne, Grimaldi and Kumar, 2000). This is due to the similar characteristics found between termites and cockroaches. Both termites and cockroaches are hemimetabolus. Termites have styli in the rear end of the abdomen as in cockroaches (Harris, 1957). Furthermore, termites enclosed their eggs in a specialized case known as ootheca similar as cockroaches (Triplehorn and Johnson, 2005). Recently, a molecular study on termite proved that termites are eusocial cockroaches (Inward *et.all*, 2007). In the molecular phylogenetic, termites nest within the cockroaches. Moreover, woodroach *Cryptocercus* form sister group with termites. This group clade as sister to Blattidae. Hence, termites were reclassified under the order Blattodea replacing the original classification of termites which was from the order Isoptera. Termites are now grouped under the superfamily Blattoidae and epifamily Termitoidae (Eggleton *et.all*, 2007; Zhang, 2011). The detail classification of termite is as shown in Table 2.1.