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THE IMPORTANCE OF ACCURATE TERMITE TAXONOMY IN THE BROADER PERSPECTIVE OF TERMITE MANAGEMENT

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Abstract The species of termites that have an impact on urban dwellings in Southeast Asia are reviewed. Termites of the genus *Coptotermes* are considered, by far, to have the greatest economic impact on urban dwellings. In Peninsular Malaysia, where the species of *Coptotermes* have been relatively well studied, five species are known, of which one, the Asian Subterranean Termite (*Coptotermes gestroi*), is responsible for most of the damage to wood in buildings in urban areas. Correct recognition of the pest species of *Coptotermes* originating from Southeast Asia has been largely hampered by confusion over the identity of the primary pest species, due to long-standing confusion in the literature on these species and the difficult taxonomy of the genus. It has been recently shown that there is a single primary pest species of *Coptotermes*, that is, *C. gestroi*, and not three, as previously thought, occurring from northeast India through Burma, Thailand, Malaysia and the Indonesian archipelago. As a result, the species once known as *C. havilandi*, thought to have been introduced from this region to North America, Brazil and various other countries, should be known as *C. gestroi*. In addition, contrary to what was previously thought, *C. havilandi* is now known to be a forest dwelling species that has not been recorded infesting buildings in Peninsular Malaysia or other areas in which it occurs. The true pest species in these geographical areas is *C. gestro*i, which was previously thought to occur only in Thailand, Burma and northeast India. Uncertainties continue to exist as to the status of a number of very similar species of *C. havilandi*, such as *C. vastator* in the Philippines and *C. heimi* in India. In addition, a number of species descriptions in older literature may eventually prove to be based on species better known now by a different name. These problems pose difficulties for researchers and practitioners in the field of termite management. However, the benefits of fundamental research on the identities of the various termite pest species occurring in the region are clearly exemplified in the case of Asian Subterranean Termite. The paradox of inconsistencies in the economic impact of the three supposed species in different parts of the world was resolved with the recognition of a single species. As a result of the findings, scientists and industry alike are now able to work toward common solutions to a single pest problem occurring in most of the Southeast Asian region, as well as in countries to which it was introduced.
Key Words *C. havilandi*, Southeast Asia, identification, urban pests

INTRODUCTION

Termites are social insects that are primarily wood-feeders, but also feed on a variety of other organic substrates, such as living trees, leaf litter, soil, lichens and animal faeces. They occur throughout the tropics and subtropics, as well as in many temperate areas of the world. In natural ecosystems, they perform a beneficial role in nutrient cycles by accelerating decomposition. However, a number of species can be important pests in man-made ecosystems, such as agricultural and forest plantations (Cowie et al., 1989), as well as in urban and rural areas inhabited by man. They cause damage to trees, wooden structures, earthen dams, underground electrical cables, wooden buildings, wooden furnishings and items made of paper.

Damage to human habitations by termites varies in its impact. When buildings are built of timber, their structure can sometimes be severely compromised. In what may be the most extreme example of damage by termites, an entire township in India was gradually destroyed by the termite, *Heterotermes indicola*, and eventually resembled a bombed-out ghost town (Roonwal, 1955; 1970). In buildings constructed from concrete, brick and mortar, however, termites often cause damage to decorative timber used in the interior of the building. They also commonly damage wooden furniture and paper items such as books. While rarely affecting the structural integrity of the building, the economic losses can be considerable. The high frequency of damage caused by termites in such buildings and the high losses sustained have resulted in multi-million dollar pest control industries in many major cities of the world in which termites occur.

The species of termite that cause damage to buildings vary according to geographical region. In temperate and subtropical areas of the world, where termite diversity is relatively low, the pest species are more readily identified and better documented. In tropical areas, where the diversity of termites is high, a complex of different species have usually been recorded causing damage in buildings, but there is usually little data on the relative importance of these species. In addition, problems in the taxonomy and identification of the diverse tropical termite fauna have sometimes led to confusion over the pest species associated with buildings in the tropics.

In this paper, the pest species of termites affecting buildings in Southeast Asia are reviewed, and problems in the taxonomy and identification of the species are highlighted. Specific reference is made to the Asian Subterranean Termite, for which recent taxonomic work has clarified a paradox that existed with regard to its pest status, and this is used to exemplify the importance of accurate taxonomy in the broader perspective of termite management. In addition, unresolved taxonomic problems that could have an impact on our perspectives on termite management are discussed.

PEST SPECIES OF TERMITES IN SOUTHEAST ASIA

Southeast Asia is the sub-region of Asia bound roughly by the Indian subcontinent on the west, China on the north, and the Pacific Ocean on the east. It comprises ten independent countries, that is, Myanmar (formerly Burma), Thailand, Laos, Cambodia, Vietnam, Malaysia, Singapore, Indonesia, Brunei and the Philippines. Southeast Asia is not strictly a biogeographical zone, that is to say, its fauna and flora are not characterised or delimited by this geographical entity. Instead, it is part of a wider biogeographical zone known as the Oriental (or Indomalayan) Region, which stretches from India to southern China and includes Southeast Asia (Roonwal, 1970). In this sense, the termite fauna of Southeast Asia has affinities to that of South Asia (India, Pakistan, etc.) and southern China, and this is reflected in the pest species known from these regions. A number of Southeast Asian termites have also been inadvertently introduced through transport to other parts of the world. An example is the Asian Subterranean Termite, *Coptotermes gestroi*, which is now found in Florida, Brazil and a number of Caribbean islands (Su et al., 1997a; Su et al., 1997b; Constantino, 2002; Scheffrahn et al., 1990; Scheffrahn et al., 1994).

The pest species of termites affecting human habitations have been documented in a number of countries in Southeast Asia, notably Thailand, Peninsular Malaysia, Singapore, the Philippines, and to a lesser extent, Indonesia. Information from Burma, Indo China and Brunei is largely lacking. Two major groups of termites that affect houses in Southeast Asia are drywood termites and subterranean termites. Drywood termites nest in the wood on which they feed, while subterranean termites usually nest in the ground outside the building, and are generally more destructive. Species of *Cryptotermes* are the only drywood termites responsible for damage to wood in buildings in Southeast Asia, particularly *C. domesticus* and *C. cynocephalus* (Roonwal, 1970; Tho and Kirton, 1992).

Subterranean termites that have been reported affecting buildings in Southeast Asia are *Heterotermes philippinensis*, *Coptotermes* spp., *Prorhinotermes tibiaoensis*, *Schedorhinotermes* spp., *Macrotermes gilvus*, *Odontotermes* spp., *Microtermes* spp., *Globitermes sulphureus*, *Microcerotermes* spp. and *Nasutitermes* spp. (Roonwal, 1970; 1979; Tho, 1992; Tho and Kirton, 1992; Lee, 2002a; Sornnuwat, 1996; Ahmad Said and Yaacob, 1997; Kirton and Wong, 2001). *Heterotermes philippinensis* and *Prorhinotermes tibiaoensis* are pest only in the Philippnes (Roonwal, 1979). In a study conducted in Thailand on subterranean termites, *Coptotermes* vastly dominated infestations of houses in urban areas (Sornnuwat, 1996). Other genera were found to be more frequently associated with houses in rural areas, where *Coptotermes* was less dominant. *Microcerotermes crassus* was the most commonly encountered species in rural dwellings, exceeding *Coptotermes* in incidence.

Of the five species of *Coptotermes* known from Peninsular Malaysia, three are known to enter buildings (Kirton, 1995). *Coptotermes kalshoveni* and *C. curvignathus* occasionally affect houses in West Malaysia (Lee, 2002a; Lee, 2002b; Kirton, 1995; Tho and Kirton, 1992), and the former has also been reported occasionally affecting buildings in Thailand (Sornnuwat, 1996). The latter is primarily a pest of agricultural, forestry and urban tree species, causing the death of both young and mature trees (Tho, 1975; Tho and Kirton, 1992; Tho and Kirton, 1998; Kirton et al., 1999). However, the most serious pest termite in urban areas in Southeast Asia is evidently the Asian Subterranean Termite, *C. gestroi*, which is responsible for most of the damage to urban buildings in Thailand, West Malaysia and Singapore, and is probably also the most significant pest species throughout the rest of its range in Burma, Indo China, East Malaysia, Brunei and Indonesia (Kirton and Brown, 2003). In the Philippines, the species is replaced by a very similar and equally destructive species, *C. vastator* (Light, 1929).

THE ASIAN SUBTERRANEAN TERMITE: A PARADOX RESOLVED

Until recently, confusion existed as to the identity of the primary pest species of *Coptotermes* in Southeast Asia. *Coptotermes gestroi* was thought to occur only in Northern India, Burma and Thailand (Roonwal and Chhotani, 1962). *Coptotermes havilandi* was supposed to have been introduced from Southeast Asia to parts of South and North America and to a number of Carribean Islands, where it became known as a serious pest of woodwork in buildings (Gay, 1967; Gay, 1969; Scheffrahn et al., 1990; Scheffrahn et al., 1994; Su et al., 1997b; Su et al., 1997a). However in the countries from which it was supposed to have originated, it was never considered a serious pest. Instead, two apparently different species held a reputation as pests. One of these was *C. gestroi* in Thailand (Sornnuwat, 1996) and the other *C. travians* in Malaysia, Singapore and Indonesia (Harris, 1957; Tho, 1992).

However, on comparison of the alates and soldiers with the type specimens and examination of the degree of variation within populations, it was found that *C. havilandi* and *C. gestroi* were, in fact, the same species (Kirton and Brown, 2003). *C. gestroi* had been described from the soldier form of the termite by Erich Wasmann in 1896, while *C. havilandi* had been described later by Nils Holmgren in 1911 from the flying form of the same species of termite. The difficulty of matching alates to soldiers had led to this situation, since most termite samples usually have only one or the other. Over time, various authors reported size differences and slight differences in shape that distinguished the two supposedly different species. However, when the size and shape of the soldiers were examined in samples of a large number of populations from all over Peninsular Malaysia, then compared with the size ranges reported by the various authors and specimens from other countries, it became evident that there was continuous variation in size and shape that had to be attributed to the existence of only a single species (Kirton and Brown, 2003). Thus, it is now known that the species occurring in Thailand, which was called *C. gestroi*, is the same as the species introduced to America. As a result, what used to be known as *C. havilandi* in countries like the USA and Brazil is now referred to as *C. gestroi*.

In Peninsular Malaysia, the primary pest species of *Coptotermes* affecting buildings was thought to be *C. travians*. As early as the species's description by George Haviland in 1898, it was thought to be a pest of woodwork in buildings (Haviland, 1898). It was later described as a pest affecting woodwork in buildings all over Peninsular Malaysia, Singapore, Borneo, Java and Sumatra (Harris, 1957). In the book, Termites of Peninsular Malaysia (Tho, 1992), it was again listed as infesting woodwork in buildings. However, an examination of the original specimens on which Haviland based his description (the type series) showed that *C. travians* was a species that had not been found in houses, but instead occurred only in forested areas (Kirton and Brown, 2003). The species referred to by Harris and Tho as infesting woodwork in buildings was in fact *C. gestroi* (formerly called *C. havilandi*), which had been wrongly identified as *C. travians*. In addition, in Peninsular Malaysia, the true *C. travians* had been wrongly called *C. havilandi*, while in Borneo, it had been described again under a different name, *C. borneensis* (Oshima, 1914; Davis, 1929; Thapa, 1981). Thus, the name *borneensis* is a junior synonym of *travians* (Kirton and Brown, 2003). Haviland himself, however, in his description of *C. travians*, said it was a pest of woodwork in houses. This was because Haviland had not differentiated between *C. gestroi* and *C. travians*, and assumed that the species affecting houses and the species he named *C. travians* were one and the same (Kirton and Brown, 2003).

With the resolution of this paradox, it has become apparent that 1) the species referred to as *C. havilandi* in parts of North and South America and the Caribbean, 2) the species referred to as *C. gestroi* and *C. havilandi* in Thailand, and 3) the species wrongly identified as *C. travians* in Peninsular Malaysia (Tho, 1992), are in fact one and the same species, and should be known as *C. gestroi*, the Asian Subterranean Termite. The species once wrongly referred to as *C. havilandi* in Peninsular Malaysia (Tho, 1992) should be called *C. travians*.

TAXONOMY'S IMPACT ON INDUSTRY

While taxonomy is sometimes viewed by industry as a theoretical science with little applied value, the example of the Asian Subterranean Termite provides one of many clear examples of taxonomy's impact on industry. Other examples can be found on the website, *Why Taxonomy Matters*, hosted by BioNet International (BioNET INTERNATIONAL, 2004). With the recognition of a single pest species in Southeast Asia that was introduced to the Americas, information available about this species in different parts of the world can now be pooled into a common body of knowledge. This common pool of information will form the basis from which effective management strategies can be developed (Kirton and Brown, 2003). Industry is also able to avoid duplicative testing of termite management strategies for what was once thought to be three different pest species in different geographic areas. Instead, results of testing new technologies, such as baiting systems, obtained in one country, may be able to be applied or adapted in other countries, saving time, resources and finances (Kirton, 2004a;

2004b; 2004c). In addition, the recognition of a single species provides the different countries a common platform on which to share mutually beneficial information that could be helpful in managing the pest species.

Taxonomy is the science of recognizing and classifying biological life-forms. Though not often realised, what we know about a species is only as good as the name that is applied to it, because the information about a species is linked to the name that it is given. If there is taxonomic confusion, or the wrong name is applied to the species, then the pest management decisions we make could be based on misleading information or may not make use of the full body of information available about that species (Kirton, 2004c). Thus, the confusion filters down to the level of industry, and may have serious economic consequences or, in extreme cases, even direct effects on the well being of human beings. Fundamental taxonomic research can, therefore, have far reaching impacts on science, industry and society across the world. In spite of this, there is reluctance on the part of scientific institutions to undertake taxonomic research because of the poor funding opportunities associated with such research. It is hoped that examples such as that of the Asian Subterranean Termite will encourage industry and funding agencies to invest in good taxonomic research.

DIFFICULTIES IN THE TAXONOMY OF PEST SPECIES OF TERMITES

It needs to be borne in mind that there are a number of difficulties associated with the taxonomy of the pest species of termites in tropical areas where termite diversity is high. Each taxonomist worked within the limitations of the tools, specimens and information available at the time, and provided a greater understanding of termites than we had before. Among the difficulties associated with the taxonomy of pest species of termites in Southeast Asia are the following:

Inherent Difficulties In Termite Morphology

Termites are social insects with a caste system. Much of termite taxonomy is based on the soldier caste or, in the case of soldierless termite groups, the worker caste. This is because these castes are the most readily encountered in the field, as they often forage away from the nest and are, therefore, the forms associated with damage to wood. The adult reproductive forms of termites are the alates, which can usually be collected at light, but are rarely found together with the workers and soldiers collected in the field, because they remain in or close to the nest. As a result, it is often difficult to match the alate form with other castes of the same termite species, particularly where termite diversity is high. The soldier and worker castes are derived from developmental pathways regulated chemically by hormone balances within the colony. Their development and, hence, their morphology can be influenced by the age and state of the colony, or their environment, such as the habitat in which they occur, particularly in the lower termites (Miller, 1969), to which many termite pest species belong (e.g., *Reticulitermes* and *Coptotermes*). It is, therefore, common to find a high degree of variation in morphology among different colonies of the same species, and between populations in different habitats or vegetation-types (e.g., Kirton, 1995). Natural variation also occurs within a species in different parts of its geographic range. These sources of variation poses problems for taxonomists, as it means that species can often only be properly delineated when sufficiently large samples across a large geographical range are obtained and studied. Added to this is the common problem of the lack of clear distinguishing features between different species, and the high degree of overlap in size ranges and shape. To overcome such problems, taxonomists often have to rely on multiple characters to distinguish species.

Historical, Geographical And Political Limitations

Many tropical species of termites were described in various languages late in the 19th century or early in the 20th century after expeditions by European explorers to these areas. Since the extent of termite diversity was not well known at the time, multiple species were sometimes unknowingly grouped under a single species name. Conversely, the same species was sometimes given different names in different parts of its geographic range, or based on different castes, as termite samples were limited and, thus, the extent of variation within a species was not fully studied.

Though our understanding of biological species systems has since grown, for many groups of termites, the state of their taxonomy and classification has often remained much as it was 50 to 100 years ago, because of a growing shortage of taxonomic expertise and the difficulties of accessing specimens used by early taxonomists. The procedures used by taxonomists in the naming, classification and revision of animal groups and species are governed by the International Code of Zoological Nomenclature (International Commission on Zoological Nomenclature, 1999). This Code is intended to provide consistency and stability in the naming and classifying of zoological organisms. Of importance in the correct assignment of a species name are the type specimens, which are the original specimens (or specimen) on which a taxonomist based his description of a species. These type specimens provide authority and stability to species names in cases of doubt. However, many early descriptions of the types are not adequately specific by comparison to our modern understanding of termite morphology. As such, they are often of little help in ascertaining the species an author was describing. Reference, therefore, has to be made by taxonomists to the actual type specimens, which are often housed in different museums throughout Europe and America. Among the difficulties faced by taxonomists dealing with termite species described many years ago are: the large number of museums that have to be dealt with to undertake a study of a single group of termites; the lack of clear information on the museum or museums in which the type specimens reside; the difficulty of ascertaining which specimens the describer referred to; the under-staffing of large museums that sometimes results in unattended specimen loan requests; and the difficulty of obtaining financial and administrative support to visit museums that are potential repositories of type specimens.

Sometimes, political obstacles may prevent taxonomists from accessing specimens in countries such as China. The same obstacles often prevent taxonomists in China from accessing specimens outside the country, a situation that has probably contributed to a proliferation of independently described species in this country and, consequently, the isolation of its taxonomic information from the mainstream of taxonomic science (Crosland, 1995; Ruelle, 1996). In other countries, political instability and civil strife has sometimes hampered the collection of adequate specimens for taxonomic research, resulting in missing links in our understanding of the degree of geographical variation in populations of termites.

MODERN TOOLS THAT AID IN THE TAXONOMY OF TERMITES

Today, the modern taxonomist has access to tools that were not available to predecessors in this field. Numerical and statistical methods that have been developed and used in taxonomic research have helped provide more objective means of defining species limits and studying variation within and between populations (Hebrant, 1981; Mayr and Ashlock, 1991). Techniques for identifying chemicals such as cuticular hydrocarbons have been useful in differentiating some species that differ little in morphology (e.g., Haverty et al., 1988; Watson et al., 1989; Brown et al., 1990; Brown et al., 1994).

The advent of molecular techniques has provided taxonomists with an invaluable tool for studying populations and species at the genetic level, as has been demonstrated for a few termite genera, particularly *Reticulitermes* (e.g., Clement et al., 2001; Austin et al., 2002; Szalanski et al., 2003). Through these techniques, taxonomists are now able to match castes reliably and better determine species boundaries. It has also provided a supplementary tool to study relationships between species and to test the strength of classification systems. However, it is a common misconception that molecular techniques are able to provide all the answers to taxonomic problems, and that they are a convenient substitute for morphological techniques. In reality, although molecular methods are able to provide information not readily available from morphology, they remain only one of many tools needed by taxonomists to address questions about species and populations. As with morphology, genetic information has to be analysed on a sufficiently large geographic scale to provide answers to questions on the limits of species variation. In addition, the identities of species are still tied to the type specimen concept, with its associated problems of museum access and specimen tracing. Morphology also provides a relatively convenient and inexpensive technique for identification and description of species. However, when morphology is studied hand-in-hand with genetic structure, it provides a powerful tool in the recognition, characterisation and classification of species (e.g., Clement et al., 2001). Together with the increasing degree of networking and increasing ease of communication between scientists in different parts of the world, molecular taxonomy coupled with conventional methods are set to enable great advances in our understanding of the pest species of termites in the world.

Table 1. Described pest species of *Coptotermes* belonging to the *C. gestroi* complex.

Species of *Copotermes*	Synonyms	Country / Region
C. gestroi	*javanicus, havilandi*	Myanmar, Thailand, Malaysia, Indonesia
C. vastator		Philippines
C. heimi	*parvulus*	India, Pakistan
C. ceylonicus		Sri Lanka

PROBLEMS THAT CONTINUE TO EXIST IN THE TAXONOMY OF TERMITE PEST SPECIES

Although the paradox of the pest species of subterranean termites entering buildings in Southeast Asia has been resolved with the discovery that there is but a single primary pest species in most of Southeast Asia, a number of unresolved questions still remain. As pointed out by Kirton and Brown (2003), a number of important pest species of *Coptotermes* in neighbouring regions are very similar to the Asian Subterranean Termite and could be the same species described under different names. This species complex stretches from India in the west to the Philippines in the east and involves such taxa as *C. heimi*, *C. ceylonicus* and *C. vastator* (Table 1), which differ only slightly from *C. gestroi* and overlap with this species in morphological characteristics. Resolving questions pertaining to this species complex would require investigating adequate samples of populations from across intermediate geographic ranges. At present, it is probably best that these populations continue to be considered as different species until a comprehensive investigation can be carried out. However, understanding the close relationship of these species will enable industry and governments to better formulate management strategies for the control of these pest species, using data and experience gained from research on related termite species in neighbouring regions of the world. When these taxonomic problems have been fully investigated and resolved, they could result in pest species name changes that may be confusing to both scientists and members of industry, as has been the case in the Asian Subterranean Termite. However, the benefits of the resolution of these problems to industry and science greatly outweigh the inconveniences.

CONCLUSION

Many aspects of the management and control of termites are dependent on reliable and accurate information on the taxonomy of the pest species of termites targeted. This is illustrated in the case of the Asian Subterranean Termite, which has been shown to be a single important pest species in Southeast Asia, where it was previously thought that three pest species existed. The taxonomy of the pest species of termites is constrained by inherent difficulties in the morphology of termites, as well as by historical, geographical and political factors. However, modern tools available to the taxonomist, such as numerical, chemical and molecular techniques, and increased inter-regional cooperation, are enabling advances in our understanding of the taxonomy of termite pest species, when combined with conventional methods. There remain unresolved questions as to the status of some termite pest species, particularly in the genus *Coptotermes* and in the *C. gestroi* complex. Resolving these questions will require genetic and morphological variation in populations of the species complex to be studied on a wide geographic scale.

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