DO FOREST-FLOOR WOOD RESIDUES IN PLANTATIONS INCREASE THE INCIDENCE OF TERMITE ATTACK?—TESTING CURRENT THEORY

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KIRTON, L. G., BROWN, V. K. & AZMI, M. 1999. Do forest-floor wood residues in plantations increase the incidence of termite attack?—Testing current theory. The incidence of attack by the termite, *Coptotermes curvignathus* Holmgren, in four- to eight-year-old *Acacia mangium* forest plantations is examined and discussed in relation to 1) the occurrence of the termite on wood material on the forest floor of plantations and dipterocarp forest, and 2) the severity of attack reported in four-year-old conifer plantations. Although *A. mangium* plantations had a much greater number of large stumps and logs on the forest floor than dipterocarp forests, due to incomplete clearing and burning of the original forest, numbers of forest floor wood material in which the termite occurred averaged 5.3 per ha and 8.0 per ha respectively for these habitats. The number of living *A. mangium* trees with infestations averaged 13.3 per ha, while there were no infestations of living trees sampled in dipterocarp forests. The incidence of attack on *A. mangium* trees was greater than that reported for *Pinus caribaea, P. merkusii, P. oocarpa* and *Agathis macrophylla*, but lower than that reported for *Araucaria cunninghamii* and *A. hunsteinii*. However, reported rates of mortality among these conifers in plantations greatly exceeded that of *A. mangium*. The results of the study suggest that, although populations of the termite *C. curvignathus* are neither eliminated nor greatly reduced by the practice of clear felling and burning of wood debris, contrary to current theory, large stumps and logs left behind by this site preparation practice do not contribute much to increases in the termite population. Susceptibility of the tree species appears, therefore, to be the major factor affecting the incidence of attack and mortality in plantations. It is suggested that this pest be managed by selection of plantation tree species which are less susceptible to attack and planting of susceptible species, such as conifers, at low-risk sites.

Key words: Plantation site preparation - tree species susceptibility - termite attack - *Coptotermes curvignathus*

KIRTON, L. G., BROWN, V. K. & AZMI, M. 1999. Adakah sisa-sisa kayu di lantai ladang-ladang hutan meningkatkan insidens serangan anai-anai?—Menguji teori semasa. Insidens serangan anai-anai *Coptotermes curvignathus*, ke atas pokok-pokok *Acacia mangium* berumur empat hingga lapan tahun di ladang-ladang hutan dikaji dan dibincangkan berasaskan 1) kehadiran anai-anai tersebut pada bahan kayu di lantai hutan di ladang-ladang dan hutan dipterokap dan 2) keamatan serangan yang dilaporkan berlaku di ladang-ladang pain yang berumur empat tahun. Walaupun ladang-ladang *A. mangium* mengandungi lebih banyak tunggul dan batang balak besar di lantai hutan berbanding dengan hutan-hutan dipterokap, yang disebabkan oleh pembersihan dan pembakaran hutan asal tidak sempurna, bilangan bahan kayu yang terdapat anai-anai di lantai hutan secara purata masing-masing adalah 5.3 ha^{-1} dan 8.0 ha^{-1} di habitat-habitat ini. Bilangan pokok-pokok hidup *A. mangium* dengan infestasi secara purata adalah 13.3 ha^{-1}, manakala tiada infestasi pada pokok-pokok hidup yang disampel di hutan-hutan dipterokap. Insidens serangan ke atas pokok-pokok *A. mangium* melebihi insidens yang dilaporkan berlaku kepada *Pinus caribaea*, *P. merkusii*, *P. oocarpa* dan *Agathis macrophylla*, tetapi lebih rendah daripada yang dilaporkan berlaku kepada *Araucaria cunninghamii* dan *A. hunsteinii*. Bagaimanapun, kadar kematian yang dilaporkan di kalangan pain itu di ladang-ladang jauh melebihi *A. mangium*. Keputusan kajian ini menunjukkan bahawa, walaupun populasi anai-anai *C. curvignathus* tidak dihapuskan dan tidak banyak dikurangkan dengan tebang bersih dan pembakaran bahan-bahan kayu, berlawanan dengan teori semasa, tunggul-tunggul dan batang-batang balak besar yang tinggal selepas amalan penyediaan kawasan ladang ini tidak banyak menyumbang kepada peningkatan populasi anai-anai tersebut. Oleh itu, kerentanan spesies pokok merupakan faktor utama yang memberi kesan ke atas kejadian serangan dan kematian pokok di ladang-ladang. Disarankan supaya serangga perosak ini diuruskan dengan pemilihan spesies-spesies pokok yang kurang rentan kepada serangan untuk ladang hutan dan penanaman spesies pokok yang mudah diserang seperti pain, di kawasan yang berisiko rendah.

Introduction

Coptotermes curvignathus Holmgren is a termite species that kills trees, and has long been a pest of plantations in Southeast Asia. The species has also been called *C. gestroi* in much early literature, probably because Haviland (1898) referred to it as *gestroi* before it was recognised and named as a different species in 1913. It has been recorded attacking a large range of hosts (for example, Ridley 1909, Richards 1917, Kalshoven 1963, Dhanarajan 1969), but its economic impact has been highlighted most in rubber (*Hevea brasiliensis*) plantations (Robinson 1905, Rao 1974) and conifer plantations (Benedict 1971, Thapa & Shim 1971, Tho 1974, Khamis 1982, Yoshii 1982), particularly in the early years of the establishment of these industries. In conifer plantations, very high mortality has been reported, with complete losses in some plantation plots (Tho 1974). As a result, it became necessary to practise prophyllactic treatment of the soil with granular heptachlor, which was applied into the planting hole during transplanting (Tho 1976). Other forest plantation trees, currently planted in Malaysia, that are attacked by the termite include *Acacia mangium* (Mori 1986, Hamid 1987, Tho & Kirton 1990), *Gmelina arborea* (Chin & Hamid 1979, Hamid 1982, Mori 1986), *Cedrela odorata* (Chin & Hamid 1979) and *Eucalyptus deglupta* (Chin & Hamid 1979, Hamid 1982). In some overviews of plantation forest pests, the termite has also been listed affecting *Tectona grandis* in Indonesia (Browne 1968) and Malaysia (Chey 1996).

The termite attacks and kills young, small trees as well as older, large trees (Tho 1974). Trees with no apparent symptoms of disease can be killed (Sharples 1936), but some reports suggest stress factors such as poor drainage can predispose trees to attack (Thapa & Shim 1971, Chew 1975). The effect of *C. curvignathus* on living trees has been reviewed by Tho and Kirton (1990). Normally, it plasters or encases the base of the trunk of living trees with soil and faecal matter, causing extensive damage beneath the plaster to the bark, cambium and outer wood and, eventually, death of the tree. However, it occasionally gains access to the core of the tree through the roots, showing no external signs of its presence until attack spreads to the living wood surrounding the heartwood and the tree withers and dies.

The scarcity of *Coptotermes* and attack by *C. curvignathus* in lowland dipterocarp forest have been noted by Abe (1979), who studied termite communities in this habitat. This contrasts with the high incidence of attack by *C. curvignathus* reported in some tree plantations established in areas cleared of logged-over lowland dipterocarp forest. A number of hypotheses have been put forward to explain the severity of attack in plantations. Changes in the environment linked to conversion of the original forest to a plantation have been the most frequently suggested explanations. Most widely advocated is that incomplete clearing or burning of wood material from the original forest at planting sites leaves food and breeding grounds for the termite, resulting in a build-up of populations (Thapa & Shim 1971, Tho 1974, Chew 1975). This has been stated even in early literature on attack in rubber plantations (e.g. Pratt 1909, Richards 1917). Forest plantations have generally been established on undulating or hilly lowland areas cleared of existing secondary or logged-over dipterocarp forest. The prescribed procedures for site preparation prior to planting are described in detail by Fielding (1972) and the Forest Department of Malaysia (Anonymous 1989). A brief outline is given here. Undergrowth in the original forest is slashed, and all the trees are then felled using chain saws (clear felling). A first burn is then carried out, after which logs and branches are either cut up and stacked by hand or heaped into windrows using a light bulldozer. The heaps of wood debris are then burned again. This process does not result in elimination of all wood material. Smaller wood pieces are usually burnt to ash or are completely charred, but larger material remains intact with some superficial charring. The forest plantation floor, therefore, typically has charred stumps, logs and large fragments of wood remaining. In view of this, recommendations for the management of this pest problem have advocated the total elimination of large wood remnants at the planting site, prior to seedling transplantation and plantation establishment (Thapa & Shim 1971, Tho 1974, Chew 1975). More thorough clearing of wood material is practised in the agricultural plantation sector to enable frequent and unobstructed access by workers or machinery (Fielding 1972, Anonymous 1989).

It has also been suggested that populations of *C. curvignathus* build up in plantation forests because plantations provide a more open and thus more favourable environment, or a low diversity habitat with less competition, enabling *C. curvignathus* to utilise more food resources (Salick & Tho 1984). In response to these hypotheses, it has been proposed that populations of *C. curvignathus* might be reduced by silvicultural management that creates a less favourable environment and encourages competitive displacement by populations of non-pest termite species (Tho 1974, Salick & Tho 1984, Tho & Kirton 1990).

Host susceptibility is an intrinsic non-environmental factor that has been alluded to as a possible cause for the severity of attack in plantations, particularly in the context of exotic tree species which are thought to be more susceptible than indigenous species (e.g. Kalshoven 1963, Dhanarajan 1969, Collins 1983, Tho & Kirton 1990). Studies in conifer plantations suggest that some species may be more susceptible than others (Chew 1975, Tho & Kirton 1998).

In view of the impact of these hypotheses on silvicultural practices, we tested whether environmental and habitat changes increase the severity of attack in forest plantations by enumerating the density of wood material and termite infestations in wood on the ground as well as the density of attack on trees in both lowland dipterocarp forests and plantations. If wood remnants, an open environment or reduced competition are major contributory factors to the severity of attack in plantations, then wood material and infestations of it would be expected to be higher in plantations than in dipterocarp forests.

Acacia mangium Willd. plantations were used in the field sampling, but a comparison is made with reported incidences of attack and tree mortality in conifer plantations, to examine the role of host susceptibility. *Acacia mangium* is an exotic leguminous tree that has been introduced from Australia to Southeast Asia for the establishment of fast-growing forest plantations. The introduction of *A. mangium* to Malaysia and the development of forest plantations of this species are discussed by Yap (1986) and Udarbe and Hepburn (1986). The species is presently one of the most widely planted forest plantation tree species in Malaysia.

Methods

Study sites

Three sites were selected for each of the two habitats, that is primary lowland dipterocarp forest and *A. mangium* plantations established in areas cleared of logged-over lowland dipterocarp forest. The number of sites sampled was restricted by the large sampling effort required. However, the use of a substantial number of large plots enabled a reliable estimate of the abundance of *C. curvignathus* to be obtained for each site, in spite of its scarce and patchy distribution. The geographic location of each of the six sites is shown in Figure 1.

The three *A. mangium* plantations were located in Kemasul, Ulu Sedili and Batu Arang. In Kemasul, the land was undulating with a few swampy patches in low-lying areas. Trees in the sampling area were three to four years old. In many areas, the tree crowns were thin resulting in a thick undergrowth of tall grasses and bushes. Very little pruning had been carried out, so most of the wood material on the ground was logs and stumps remaining from the original forest. Ulu Sedili had undulating and sometimes hilly terrain with occasional gullies. Sampling was carried out among approximately four-year-old trees. Although they were approximately the same age as trees in Kemasul, the crowns were generally thicker resulting in less dense undergrowth. Death of trees as a result of debarking by elephants was common, resulting in gaps. A large number of trees had developed multiple leaders or side branches at a young age, but had only been pruned after these had reached a significant size. As a result, there were many more pruned branches on the forest plantation floor in comparison to Kemasul. Sampling was carried out in Batu Arang on the border of an approximately eight-year-old stand. Undergrowth tended to be thinner than in Kemasul and Ulu Sedili because of a thicker canopy. There was also comparatively little wood material remaining from the original forest. The original forest could have been bush-like secondary forest, as was the forest adjacent to the planting. On the other hand, the lack of remnant wood material could have been a result of more thorough clearance and burning, or decomposition of the wood with time. Although systematic thinning had not yet been carried out, *A. mangium* logs and stumps were fairly abundant on the forest floor, as unhealthy or dead trees had been felled. The trees were sometimes sectioned into small logs which were occasionally heaped together. Granular heptachlor had been applied into the planting hole during transplanting in the three plantations. The treatment does not provide long-term protection (Chew 1987 in Weinland & Ahmad Zuhaidi 1992), lasting only about two years (Yong 1985), and is, therefore, unlikely to have had an impact on the results of the study.

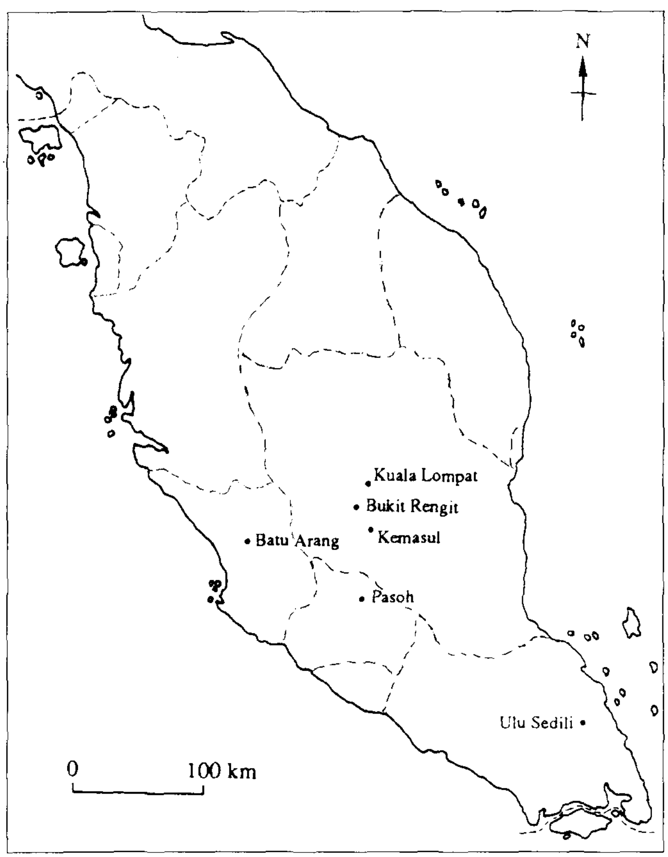

Figure 1. Map of Peninsular Malaysia, showing the approximate geographic locations of the sampling sites

Lowland dipterocarp forest, which occurs inland at altitudes below 300 m in the Peninsula, was represented by sites at Bukit Rengit, Pasoh and Kuala Lompat. This forest formation is discussed in Symington (1943) and Wyatt-Smith (1964). The sites at Bukit Rengit and Pasoh were undulating and hilly, whilst the terrain was flat at Kuala Lompat. The sites at both Bukit Rengit and Kuala Lompat were situated in the borders of the large Krau Game Reserve. Pasoh Forest Reserve, on the other hand, is a relatively small fragment of forest comprising 600 ha of virgin forest surrounded by 1300 ha of logged forest in the midst of oil palm plantations. Pasoh is the site of the Forest Research Institute Malaysia field research station, and the area that was sampled was within a 50-ha permanent ecological plot.

Sampling plots

Sampling was carried out in each site using 25 10 × 10 m plots (a total of 0.25 hectares) located at random distances along a sampling zone of 0.9–1.3 km, such that no two distances were less than 20 m apart, to ensure that the perimeters of the plots were separated by at least 10 m. Each plot was measured with the aid of a cord and demarcated with flags at its four corners. A one-kilometre transect was used following access routes, such as roads or paths, into the site and the plots were randomly assigned to either side of the transect. In Batu Arang, plots were assigned to one side, as the transect was along a road on the border of the plantation. The distance between the outer perimeter of the plots and the edge of the path or road was varied to accommodate local conditions, but was kept as consistent as possible within each site. Plots in dipterocarp forest were placed one to three metres from the edge of the narrow paths, as the vegetation was dense and there was little or no transition zone at the edge of the path. It was only exceptionally necessary to place the plots further from the edge to avoid large gaps. In Pasoh Forest Reserve, however, plot locations were rounded to the nearest five metres to match the grid layout in the 50-ha plot, and the edge of the plot was similarly placed on the nearest grid more than 1 m from the edge of the path. There was a much more marked transition in vegetation at the edges of the wide access roads into *A. mangium* plantations (Figure 2) and, as such, the plots generally had to be placed 10–40 m from the edge. A fixed distance was used for each site, but was increased by a multiple of five metres or ten metres when necessary to avoid greater edge effects.

The plots had to be in natural but workable terrain and, thus, plots that fell in unnatural gaps or inaccessible areas, such as gullies, were repositioned using a set of conventions. If possible, the plot was placed on the other side of the transect. Otherwise, the plot was shifted to the nearest possible location, either backwards or forwards, as long as a distance of at least 10 m was maintained from other plots. In *A. mangium* plantations, the plot was shifted along the transect only if it was not possible to overcome the problem by moving the plot further from the edge of the road, using the same principles described earlier for placing the plots clear of unusually large edge effects in this habitat. If minor shifting of the plot did not solve the problem, or was not possible because of adjacent plots, a new distance was generated randomly within the previous and next plots or within the entire transect.

Figure 2. Four-year-old *Acacia mangium* plantation bordering an access road, showing the marked transition in vegetation at the edge of the plantation (Kemasul)

Sampling of wood material and termite infestations

Trees and wood material on the ground within the plot were inspected for the presence of *C. curvignathus*, dissecting material whenever necessary with the aid of a heavy knife. Each tree or individual piece of wood material colonised by *C. curvignathus* was considered a discrete infestation which was, as far as possible, verified with a small voucher collection of soldiers and categorised according to the type of material colonised and the estimated size class as defined in Table 1. These classes enabled the large quantities of wood material distributed over large sampling areas to be categorised within a reasonable time frame. Except for standing or fallen trees killed by the termite, or the stumps of such trees, remnant wood material from the original forest was not differentiated from wood originating from the plantation trees, as it was not always possible to identify reliably the origin of partially decomposed material. All wood material in a plot, down to a diameter of 5 cm, was examined. Material smaller than this, to a diameter of 1.5 cm, and material less than 1.5 cm in diameter, was sub-sampled using five 75 × 75 cm quadrats and seven 50 × 50 cm quadrats respectively. Diagonally opposite corners of each of these types of quadrat were placed equidistant from each other along a cord placed along the diagonal of the plot beginning at the corner nearest the origin of the site transect. Perimeters of quadrats on extreme ends of the cord were partially bounded by the plot. Two cardboard strips were used to form the diagonals of the quadrat from which the boundary could be gauged. This technique was used because placement of boxed-in quadrats would have been obstructed by vegetation.

Table 1. Definitions for classes of wood material sampled in *A. mangium* plantations and lowland dipterocarp forest

	Category	Definition
Type:	Tree	Living plants (subcategorised as living), or dead standing plants with branches present, or dead material attached to or forming part of living trees (subcategorised as dead)
	Stump	Base of the tree or standing bole which lacks a crown
	Log	Fallen bole of a tree of any size
	Branch	Any offshoots of the main stem
Size:	Very big	Diameter ≥ 30 cm
	Big	30 cm > diameter ≥ 12 cm (approximates to the maximum width encircled by the thumb and second finger of both hands)
	Medium	12 cm > diameter ≥ 5 cm (approximates to the maximum width encircled by the thumb and second finger of one hand)
	Small	5 cm > diameter ≥ 1.5 cm (approximates finger width)
	Twig	Diameter < 1.5 cm

Each resource category available was estimated with a visual count in each plot. Living trees and dead material attached to or forming part of living trees were excluded from the count. As such, occurrences on such material were excluded when considering the proportion of available resources utilised. A count was, however, made of the number of *A. mangium* trees in each plot in plantations.

Analysis

Since the large plots were randomly located over a long transect, the proportion of plots in which *C. curvignathus* occurred could be taken as an indication of colony abundance. Direct counts and categorisation of wood material available and colonised by the termites are used in comparisons between lowland dipterocarp forest and *A. mangium* plantations.

The incidence of attack is compared with reported incidences in four-year-old conifer plantations (Tho & Kirton 1998). Sampling such plantations in the present study was not possible, as only old stands of conifer plantations remain in the country, and the original conifer plantations surveyed by Tho and Kirton have been harvested and converted to oil palm plantations. To make results comparable with the reported incidences in conifers, the following indices defined by Tho and Kirton have been used:

$$\textit{Current attack} = \frac{N_B}{N_A + N_B} \times 100$$

and

$$Recent\ attack = \frac{N_B + N_C}{N_A + N_B + N_C} \times 100$$

where

N_A = number of standing, living trees not attacked by termites
N_B = number of living or dead standing trees with active termite infestations or attack
N_C = number of fallen or broken trunks (or remaining stumps) of trees that had died as a result of termite attack

Current attack is indicative of early infestations on living trees, as it incorporates only infestations on dead or living standing trees. Since recent attack includes the incidence on stumps or fallen boles of trees which were killed by the termite, it reflects the tree species mortality rate attributable to the termite.

The terms incidence of attack, density of infestations and severity of attack, as used in the present study, are defined as follows:

Incidence of attack:	the proportion of trees attacked
Density of infestations:	the number of infestation per unit area
Severity of attack:	the degree of damage to a tree with an infestation

All data for the density of trees, wood material or termite infestations are expressed as numbers of occurrences per hectare, for comparability with other studies.

Results

Quantity of wood material on the forest floor

The quantity of different classes of wood material in lowland dipterocarp forest and *A. mangium* plantation sites is shown in Table 2. In dipterocarp forests, branch-wood was the most abundant wood resource, whilst in the plantations, logs were much more abundant than any other resource above 5 cm in diameter. Both dipterocarp forests and plantations showed increasing counts with decreasing size of wood material. The maximum number of medium-sized wood material in any one site was just over a thousand per hectare. In contrast, estimates of material classed as small ranged from about 10 to 20 thousand per hectare, and material classed as twig-sized ranged from about 50 to 180 thousand per hectare. Infestations of *Coptotermes curvignathus* were found only on wood material classed as medium-sized or larger, in spite of the far greater abundance of small- and twig-sized material. Figure 3 summarises the quantity of different classes of wood material found in dipterocarp forests and plantations, for material above the size class small (i.e. classes colonised by the termite). Plantations had a significantly greater quantity of stumps (*t*-test on square root transformed data, $t_{(4)} = 6.16$, $p < 0.005$) and logs (*t*-test on log transformed data, $t_{(4)} = 6.00$, $p = 0.005$) than dipterocarp forest.

Table 2. Quantity of wood resources on the forest floor in sites representing lowland dipterocarp forests and *Acacia mangium* plantations. Mean numbers per plot ± standard error are expressed in numbers per ha.

	Lowland dipterocarp forest			*Acacia mangium* plantation		
	Pasoh	Bukit Rengit	Kuala Lompat	Kemasul	Ulu Sedili	Batu Arang
Dead tree	8 ± 6	8 ± 6	4 ± 4	8 ± 6	16 ± 7	12 ± 9
Stump	60 ± 16	52 ± 15	16 ± 9	268 ± 62	188 ± 35	280 ± 33
Log	248 ± 58	144 ± 32	120 ± 29	640 ± 75	1216 ± 127	1468 ± 129
Branch	516 ± 82	532 ± 63	440 ± 66	376 ± 55	184 ± 36	372 ± 62
Very big	68 ± 15	140 ± 32	44 ± 18	180 ± 40	172 ± 54	28 ± 11
Big	156 ± 28	140 ± 44	100 ± 27	280 ± 57	488 ± 67	976 ± 80
Medium	608 ± 94	456 ± 45	436 ± 61	832 ± 121	944 ± 101	1128 ± 113
Small (× 10^3)	12.5 ± 1.5	18.5 ± 2.9	10.4 ± 1.3	14.9 ± 2.8	15.8 ± 2.2	22.5 ± 2.3
Twig (× 10^3)	55.8 ± 6.7	122.3 ± 13.8	67.4 ± 7.3	51.4 ± 8.0	89.8 ± 8.9	178.3 ± 11.5

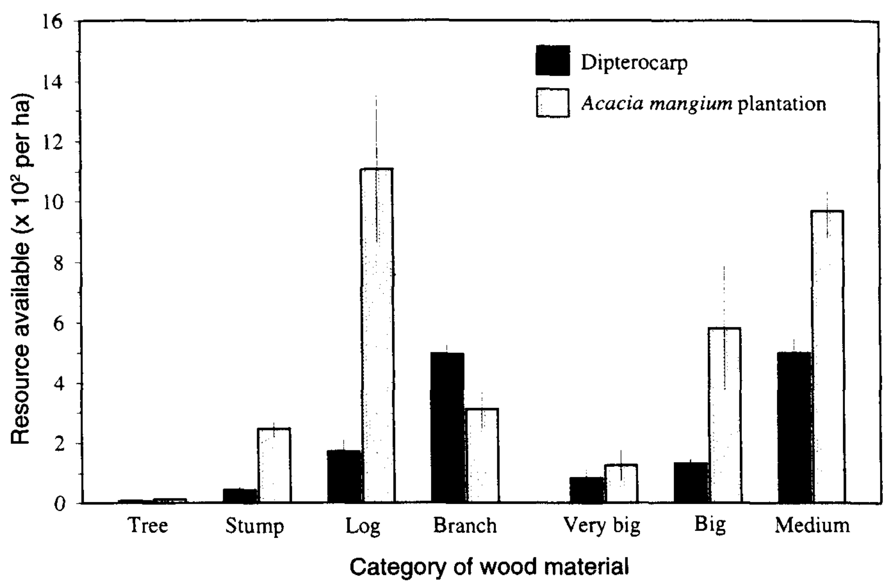

Figure 3. Quantities of different types and size classes of wood material on the forest floor of dipterocarp forest and *Acacia mangium* plantations. Means of three sites and standard error bars (expressed in numbers per ha) are shown for each forest-type.

Density of termite infestations

The density of infestations by *C. curvignathus* is shown in Table 3. Infestations occurred, on average, in 5.3% of the plots in dipterocarp forests. Although *A. mangium* plantations had a slightly higher rate of occurrence in 10.7% of the plots, there was no significant difference between dipterocarp forests and plantations (*t*-test on arc sine transformed data, $t_{(4)} = 1.14$, $p > 0.3$).

The average total density of infestations in dipterocarp forests was 8.0 per hectare, and all the infestations were on wood on the forest floor; there were no infestations of living trees in the plots in dipterocarp forest (Table 3). *Acacia mangium* plantations had an average total density of 18.7 infestations per hectare. More than two thirds of these (13.3 per hectare) were infestations of living *A. mangium* trees. There was an average of 5.3 infestations of wood per hectare on the plantation forest floor, which was below the density of such infestations in dipterocarp forest. Although total density of infestations averaged higher in *A. mangium* plantations than in dipterocarp forests, the difference was not significant, controlling statistically for inherent differences in termite population between sites reflected in the proportion of plots in which the termite occurred (analysis of covariance using arc sine transformed proportion of plots and square root transformed densities, $F_{(1,3)} = 0.001$, $p > 0.9$).

Table 3. Abundance of *C. curvignathus* in dipterocarp forest and *A. mangium* plantations, showing percentage of plots in which the termite was present and the density of infestations (expressed as numbers of wood material or living trees per ha in which the termite occurred). Values for forest-type are shown as mean of three sites ± standard error. A breakdown by site is given below each forest-type.

Habitat	Occurrence in plots (%)	Density of infestations (per ha)		
		Wood on forest floor	Living trees	Total
Dipterocarp forest	5.3 ± 3.5	8.0 ± 6.1	0.0	8.0 ± 6.1
Bukit Rengit	4	4	0	4
Pasoh	12	20	0	20
Kuala Lompat	0	0	0	0
A. mangium plantation	10.7 ± 3.5	5.3 ± 1.3	13.3 ± 8.1	18.7 ± 8.1
Kemasul	12	8	12	20
Ulu Sedili	16	4	28	32
Batu Arang	4	4	0	4

Relative incidence of attack on different tree species

Current and recent attacks, as defined by Tho and Kirton (1998), did not differ in the *A. mangium* plantations, and was 2.6% on average. The incidence of attack by *C. curvignathus* on six conifer plantation tree species is summarised in Figure 4 from the data of Tho and Kirton (1998), and is compared with that on *A. mangium* in the present study. Recent attack exceeded current attack in all the conifer species. In *Araucaria cunninghamii, Agathis macrophylla* and all *Pinus* spp., that is all but one of the six conifer species studied, recent attack was more than twice current attack. This contrasts with the absence of any difference between current attack and recent attack in *A. mangium.*

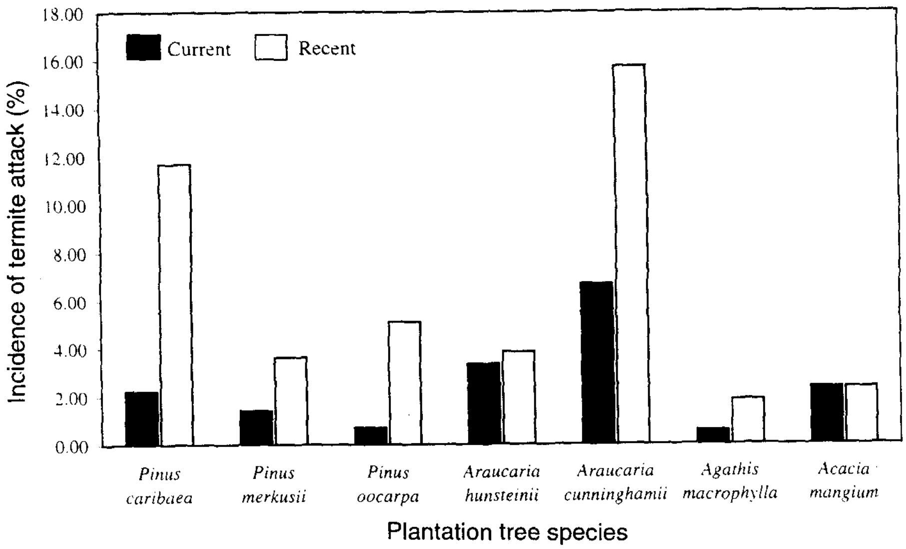

Figure 4. Incidence of termite attack on six conifer plantation tree species (Tho & Kirton 1998) compared with that on *Acacia mangium.* Indices of attack are defined in the text. The values for conifer species are the averages of the two blocks, 1.4 km apart, used by Tho and Kirton. Each block comprised 8.1 ha with 240–2601 trees of each conifer species at the time of planting.

Discussion

The incidence and severity of attack in plantations are the result of a number of factors shown in Figure 5. The main factors are the existing population level of the termite pest species, availability of suitable wood material as a food resource and susceptibility of the tree species planted. The results of the present study are discussed in relation to these factors, and their implications for the management of the pest.

Existing pest population level

The existing population level of the pest termite species is an important factor that determines the incidence and severity of attack. The population level is influenced, firstly, by the type of habitat that was cleared for plantation establishment. For example, grasslands and other habitats long devoid of wood do not support populations of *C. curvignathus* (Tho 1974). Lowland dipterocarp forests have very low population levels of *C. curvignathus*, as noted by Abe (1979) and evident from the sites sampled in the present study. Besides the influence of forest type, the presence and abundance of a termite species in identical forest types are also patchy, and give rise to differences between sites (De Souza & Brown 1994). Such variation in populations can occur on an even smaller geographical scale, such that the termite may range from being absent to very abundant in different areas within the same site. Thus, attack on trees by *C. curvignathus* in a uniform plantation is known to be isolated or patchy and aggregated (Tho 1974, Tho & Kirton 1990, 1998), and sometimes locally severe (Chew 1975). In the present study, replication with three different sites, and the use of a long transect of one kilometre for sampling plots, minimised the effects of such variation on statistical comparisons of the two forest types so that the importance of other factors could be investigated.

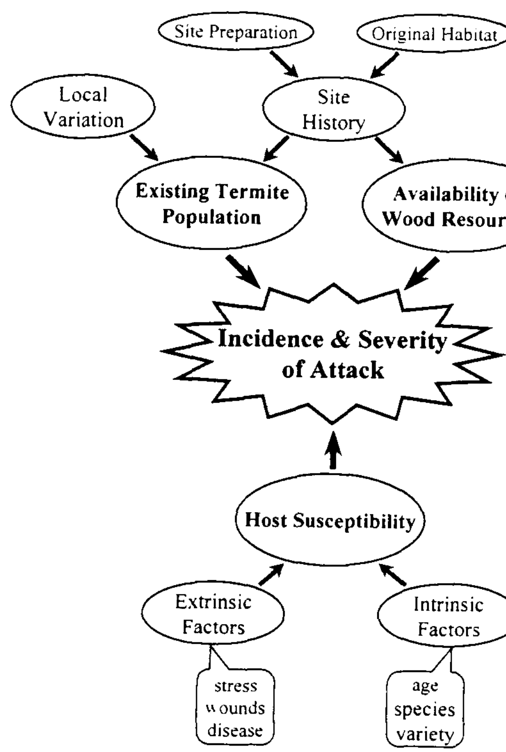

Figure 5. Factors influencing the incidence and severity of attack by *C. curvignathus* in forest plantations

The termite population is influenced, secondly, by the preparation of a site for planting. Clearing the original forest and burning wood remnants may eliminate some foraging parties of termites and very young colonies nesting in wood material, thus reducing the population. However, since *C. curvignathus* is subterranean in nesting and foraging habit, the impact on this termite species is not great, as is evident from the serious damage and losses which have been attributed to this termite species in some plantations which practised this form of site preparation (Thapa & Shim 1971, Tho 1974).

Availability of suitable wood material on the forest floor

Wood material available on the plantation forest floor could contribute to an increase in the pest termite population if the wood is a suitable food resource. Such wood material may be utilised by termites that survive the clearing of the original forest, enabling the colonies to grow in size. Some of the remnant wood material could also provide suitable nesting sites for the establishment of new colonies. The quantity and type of this material on the plantation forest floor is determined by the forest type cleared for planting and the site preparation practice. Both the *A. mangium* plantations in the present study and the conifer plantations studied by Chew (1975) and Tho and Kirton (1998) were established in sites which had been cleared of lowland dipterocarp forest.

The site preparation practice of clearing and burning the forest left more large wood remnants on the ground in *A. mangium* plantations than there were in the original forest. This is most clearly seen in data for Kemasul. Since hardly any thinning, and little pruning, had been carried out in this site, the densities of medium and big wood material were much lower than in the other two plantation sites but, nevertheless, still much higher than in the lowland dipterocarp forest sites (Table 2). Thinned trees, some of which had been sectioned and left to decompose on the ground, were found in Batu Arang, whilst in Ulu Sedili, there were numerous pruned multiple stems remaining beside the trees. Such thinnings and pruned multiple stems would have been classed as medium-sized or, to a lesser extent, big, but would never have approached the very big size class, which encompassed only remnants from the original forest. The higher density of very big wood material in plantations than in lowland dipterocarp forest, therefore, further verifies that the site preparation practice left more large wood remnants on the ground than there were in the original forest. Figure 6 shows examples of such wood material that remained on the forest floor. Most of the material classed as small- and twig-sized in the plantations would have been small branches and twigs of *A. mangium*, since the burning during site preparation would have eliminated most of the original forest wood material in these size classes. However, wood material in these size classes was not favoured as a food resource of *C. curvignathus*, as the termite was not found on small- or twig-sized material in the plot sub-samples.

The similar densities of C. *curvignathus* infestations in wood material on the forest floor of *A. mangium* plantations and lowland dipterocarp forest indicate that the increase in wood material after conversion of the original forest to a plantation did not lead to a significant rise in colonisation of these food resources. Thus, although populations of the termite are not eliminated or even greatly reduced by the practice of clear felling and burning of wood debris, large stumps and logs left behind by this site preparation practice do not contribute much to increases in the termite population, at least in the first four years after plantation establishment.

The hypothesis that excess wood material in plantation forests provides breeding grounds for the termite (Thapa & Shim 1971, Tho 1974, Chew 1975) is not, therefore, supported by the results of the present study. Contrary to the suggestion of Salick and Tho (1984), reduced competition for wood material in plantations, if it occurs, also has little bearing on a high incidence of attack. Furthermore, a high incidence of attack is not likely to be the result of a more favourable physical environment in plantations. It has been argued that faster canopy closure of *A. mangium* than conifers results in a less favourable physical environment for *C. curvignathus* or increased competition from other termite species (Tho & Kirton 1990). However, the canopy of *A. mangium* plantations is much more open than the tiered canopy of natural lowland dipterocarp forest, yet there was no evidence of an increase in infestations of the termite on wood material on the forest floor in the plantations sampled.

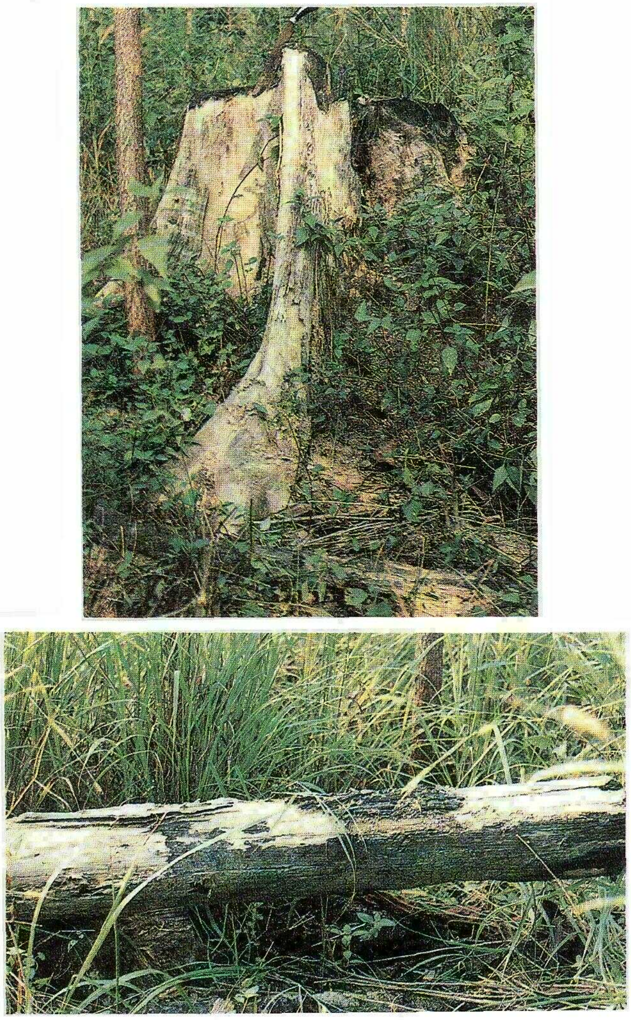

Figure 6. Partially burnt, large wood remnants of the original forest, typical of the forest floor in plantations (Kemasul, *A. mangium* plantation)

It is necessary to establish whether the site preparation methods for *A. mangium* and the conifer plantations studied by Tho and Kirton (1998) were sufficiently similar to enable the effect of host susceptibility to be determined. The site preparation practice for the conifer and *A. mangium* plantations differed in one respect, that is, the manner in which wood remaining after the first burn was heaped prior to being burned a second time. The method used in *A. mangium* plantations (Anonymous 1989), termed semi-manual clearing, involves the use of light bulldozers to windrow wood material other than stumps. The second burn is carried out on the heaps of wood. In the conifer plantations, the recommended practice at the time (Fielding 1972, Chew 1975), known as manual clearing, requires wood material other than stumps and large logs to be cut and stacked by hand. These stacks are then re-burned. Manual clearing is also employed for areas in *A. mangium* planting sites where topography or soil conditions make the use of a light bulldozer inadvisable (Anonymous 1989). Planting sites prepared by each method are figured by Fielding (1972) and the Forest Department of Malaysia (Anonymous 1989). This difference in site preparation could have resulted in dissimilarities in the distribution pattern of wood material and the degree to which it was eliminated by the second burn in conifer and *A. mangium* plantations. However, it is unlikely that any difference which might arise would be significant enough to cause a build-up of the termite population in conifer plantations.

Susceptibility of plantation trees

The susceptibility of plantation trees has a direct effect on the incidence and severity of attack. Differing susceptibility has been noted among different conifer species, for example, under identical site and growing conditions (Chew 1975, Tho & Kirton 1998). Host factors that influence susceptibility may be intrinsic attributes like the tree species, variety or age, or extrinsic factors, such as physiological stresses on the tree, wounds or disease. Susceptible hosts are easily killed by the termite and, thus, become a food resource that can sustain populations and enable population build-up, even in the absence of alternative wood resources on the forest floor.

The higher recent than current attack in the conifers studied by Tho and Kirton (1998) indicates that there was high tree mortality among conifer species. Since current attack represents the incidence of infestations on dead or living standing trees, while recent attack includes the incidence on stumps or fallen boles of trees which were killed by the termite, the latter reflects the tree species mortality rate attributable to the termite. High mortality rates in conifers due to *C. curvignathus* has been found in other plantation sites in Malaysia (Benedict 1971, Thapa & Shim 1971, Tho 1974). Although the incidence of infestations on *A. mangium* was comparable with that on most conifers (Figure 4), there was relatively little mortality of the trees. This was reflected by recent attack being no higher than current attack. Although the *Acacia mangium* trees were observed to be predisposed to infestations, for example, through pruning wounds and abscission scars on the bole, few of the trees were killed, as infestation appeared usually to be restricted to the heartwood. The mode of attack and inherent predisposing factors are discussed in greater depth by Kirton *et al.* (submitted). There is some indication that heart rot in *A. mangium* may also predispose the trees to invasion of the heartwood by termites (Mahmud *et al.* 1993).

Values for recent attack can be influenced by the decomposition rate of the different tree species attacked by the termite. Tree species, which are consumed more rapidly by the termite, or that deteriorate faster, are likely to have lower counts for infested dead, fallen trees than trees which persist longer on the ground. Misleading comparisons can result if wood decomposition rates between tree species greatly differ. Conifers are reputed to decompose rapidly. *Pinus caribaea*, *P. insularis* and *Agathis borneensis* have wood classified as non-durable in ground contact (Jackson 1957, Mohd. Dahlan & Tam 1985). The wood of *Acacia mangium* and *Pinus caribaea* are equally susceptible to *Coptotermes* and other subterranean termites (Grace *et al.* submitted). Therefore, it is unlikely that the wood of *A. mangium* decomposes any faster than conifers, and the absence of infested dead, fallen *A. mangium* trees is not likely to have been due to more rapid decomposition. It is also probable that external manifestations, such as the termites and their carton, which make infestations by *C. curvignathus* recognisable, disintegrate before the wood completely decomposes.

In the present study, the incidence rather than the density of attack has been used as an indication of the abundance of the termites in comparisons between plantations. The rationale for this is that, since the termite infestations are known to be aggregated, and the foraging range of the termite colonies is limited, the area over which infestations occur (to which the incidence of attack is proportional) would be more indicative of the abundance of the termite than the density of attack. The density of trees in plantation sites can have an effect on the density of attack. Table 4 shows the initial planting densities for the *A. mangium* and conifer plantations and the estimated density at the time of sampling. The planting density for *A. mangium* recommended by the Forest Department of Malaysia (Anonymous 1989) and reviewed in Weinland and Ahmad Zuhaidi (1991) is 900 stems per ha, and the overall density of living or dead standing trees in the plantations studied was about 600 per ha. Planting densities for conifers were higher. Chew (1975) reported, for the same sampling sites used by Tho and Kirton (1998), that the conifers were planted at a spacing of 2.44 × 2.44 m, which is an estimated 1680 per ha. This spacing and density is based on the guidelines of Fielding (1972). Based on the percentage of dead or living standing trees given by Tho and Kirton, the estimated density for different conifer species in each of the two blocks at the time of sampling ranged from about 950 to 1600 per ha. Thus, the density of conifer trees was, on average, about 87% higher than the density of *A. mangium* at the time of planting and about 118% higher at the time of sampling, which would imply that, relative to *A. mangium*, the density of attack in conifers was, on average, proportional to approximately twice the incidence of attack. The number of trees infested per unit area in *Pinus caribaea* and *Araucaria hunteinii* would, therefore, be clearly higher than that in *A. mangium*, even though the incidence of attack in these trees was close to the incidence in *A. mangium*. However, this would be due to the shorter planting distance, which makes it easier for foraging groups of termites to locate and attack the trees in the vicinity of the nest. The abundance of the termite in each plantation is, therefore, better represented by the incidence of attack, since it is indicative of the area over which infestations occur.

Table 4. Densities of *A. mangium* and conifer stands (to the nearest 10 trees) at the time of planting and sampling. The ranges given for A. *mangium* are site ranges for living trees, whilst that given for conifers is within-block species ranges for standing, dead or living trees. The latter is estimated from the proportion of dead or living standing trees for each species multiplied by the initial species planting density.

	Acacia mangium	Conifers
At time of planting		
Spacing (m)	3.7 × 3.0	2.44 × 2.44
Planting density (per ha)	900	1680
At time of sampling		
Average density (per ha)	600	1310
Range (per ha)	460–740	950–1600

Although attack by *C. curvignathus* was observed on trees outside the sampling plots in the site at Pasoh, the incidence and density of attack in lowland dipterocarp forests were too low to be detected by the plots. This low density of attack could not have been due to a low density of trees. The 50-ha permanent ecological plot in Pasoh, in which all trees 1 cm and above in diameter at breast height (dbh) have been measured, mapped and tagged (Manokaran *et al.* 1990), provides further evidence. Kochummen *et al.* (1990) reported a density of 530 trees per ha above 10 cm dbh. The density of trees above 2 cm dbh was just over 3900 per ha, with an exponential decline in tree density with increasing dbh (Manokaran & LaFrankie 1990). However, there was a high species diversity of 820 species from 294 genera and 78 families in the plot, with trees above 10 cm dbh representing about 210 species (Kochummen *et al.* 1990). The forest in Pasoh has been described as representative of primary lowland rain forest in Peninsular Malaysia in both its floristic composition (Kochummen *et al.* 1990) and stand structure (Manokaran & LaFrankie 1990). Thus, lowland dipterocarp forest has a range of species of different age and size, unlike the uniform stands of trees that occur in plantations. Since termite attack may be influenced by tree species, size and age, it is likely that the incidence and density of attack in a forest type of such high diversity are reduced by the presence of unsuitable hosts and the difficulty of locating non-uniformly distributed susceptible tree species.

Implications for management of the pest

Residual stumps and logs that remain after site preparation by clearing and burning of logged-over lowland dipterocarp forest do not appear to contribute to termite pest population build-up and increased incidence of attack. In view of this, the total elimination of large wood remnants at such planting sites prior to plantation establishment, which has been frequently recommended for the management of this pest problem (Thapa & Shim 1971, Tho 1974, Chew 1975), is unnecessary, as it will not have an impact on the incidence or severity of attack. The termite pest population would not be suppressed if the tree species planted was susceptible to infestation or attack. Site preparation techniques that leave large wood residues, but do not employ burning, are becoming more widely advocated and adopted because of their lower environmental impact and improved plantation performance (Nykvist *et al.* 1996). Although the effect of this site preparation practice on the termite pest population has yet to be ascertained, the findings of the present study are an encouraging indication that it may have little or no impact on the incidence or severity of termite attack.

Susceptibility of tree species was the major factor affecting the incidence of attack and tree mortality in conifer plantations. The termite problem in plantation forests could, therefore, be managed by selection of plantation tree species which are less susceptible to attack. Where plantations of susceptible species such as conifers are to be established, these should be located in low-risk sites known to have low termite pest populations. Such sites would include areas long occupied by bushy secondary growth or grassland (Sharples 1936, Tho 1974), which would be devoid of wood material and susceptible tree species needed for the establishment and growth of the termite population. Sites cleared of lowland or hill dipterocarp forest pose a moderate risk to susceptible plantation tree species, while sites cleared of peat swamp forest would pose a high risk (e.g. Pratt 1909, Kalshoven 1963, Mariau *et al.* 1992). The susceptibility of new plantation tree species should be investigated from available literature or by experimental planting before wide-scale planting is undertaken, so that appropriate sites can be selected.

The hypothesis of competitive displacement of *C. curvignathus*, by under-planting or other silvicultural practices that may increase populations of non-pest termite species (Tho 1974, Salick & Tho 1984, Tho & Kirton 1990), is not borne out by the results of the present study. The ability of *C. curvignathus* to kill living trees provides it with a food resource not accessible to most other termite species, enabling it to compete well in an environment where susceptible trees are present. Nevertheless, there may be some benefit in under-planting, inter-planting or other methods which incorporate a wider variety of plant species, if some of the tree species planted are not susceptible to attack. The reduced density of susceptible tree species could make the location of suitable hosts by the termite more difficult, as may be the case in a natural forest.

The question of whether elimination of wood material on the ground has long-term benefits through the reduction of nesting sites for new colonies needs to be addressed. It is apparent from the present study that, in the early years of plantation growth, termite attack on trees is a product of tree susceptibility and the existing population of the termite that is largely unaffected by clearing and burning the original forest. Each termite colony may grow in a number of individuals as they infest or kill susceptible trees. However, the experience of the rubber plantation industry has been that, in the long term, termite attack declines with time. This has been attributed to gradual decomposition of wood remnants (Pratt 1909, Sharples

1936), which probably eliminates nesting sites. It is, therefore, likely that natural decomposition produces the same long-term effect that may have been achieved by manual elimination of wood remnants on the ground, making the latter unnecessary. In this respect, competitive displacement by the colonisation of potential nesting sites by other termite species could be contributing to the decline of the population of *C. curvignathus* in the long term. This presupposes, however, that the winged reproductives are able to establish new nests in wood material on the ground in plantations. In fact, the nesting behaviour of *C. curvignathus* is still poorly understood. Mature nests occur underground, and it is thought that new colonies are established in wood on the ground (Tho & Kirton 1990), the nest presumably moving underground as the colony expands and depletes the food resource. The effect of forest clearing on the founding of new nests in *C. curvignathus* is not known. Akhtar and Ali (1979) have shown that wood species that are readily fed on by well established colonies of a termite species are not always suitable for the development of new colonies. It is possible that *C. curvignathus* has close associations with particular hosts in its natural habitat. If this were the case, the long-term decline in the population of *C. curvignathus* in plantations may be due to an unsuitable habitat for colony establishment rather than a result of diminishing wood resources.

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