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Stem Borers of Teak and Yemane in Sabah, Malaysia, with Analysis of Attacks by the Teak Beehole Borer (*Xyleutes ceramica* Wlk.)

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Abstract

Infestations by stem borers in teak (*Tectona grandis*) and yemane (*Gmelina arborea*) plantations were surveyed at seven locations in Sabah, Malaysia in March, 1998. The teak beehole borer (*Xyleutes ceramica*) and the collar ring borer (*Endoclita aroura*) were found to attack teak and yemane. *X. ceramica* accounted for most of the boring attacks in teak plantations, damaging 10.3–65.2% of the planted trees, except at one location where no stem borer attack was detected. The number of past and present attacks per tree ranged from 0.27–1.28 and 0.01–0.62, respectively. In contrast, *E. aroura* was of minor importance, attacking 6.9% or less of the planted trees. Analysis of spatial distribution of past attacks by the teak beehole borer in young teak stands revealed a contagious pattern. The past attacks were heavier on bigger trees. Both past and present attacks were concentrated in the lower part of the trunk, less than 1 m from the ground level. In young stands of yemane, an unidentified lamiine cerambycid damaged 0.0–14.1% of the trees, whereas the teak beehole borer damaged 7.6–12.2% of the trees.

Discipline: Forestry and forest products
Additional key words: *Tectona grandis*, collar ring borer (*Endoclita aroura*), Cerambycidae, *Gmelina arborea*

Introduction

Teak (*Tectona grandis* Linn., Verbenaceae) is an exotic species in Sabah, which was first introduced from Java to Bandau, Kota Marudu by the Dutch Tobacco Company in 1922[13]. Thereafter, teak was planted at several different sites, but most of these earlier trials were unsuccessful due to the lack of silvicultural information and experience on the tree[11]. Teak has thus long been out of consideration in plantation establishment programs in Sabah. In recent years, however, teak planting has been resumed by foresters and estate plantation holders in Sabah, motivated by research and timber technology development, in addition to the high value of the wood and the predicted hardwood shortage in the near future. Since 1992, teak plantations have been set up on a commercial basis at Sejati (Telupid), Boonrich (Lahad Datu) and Balung (Tawau)[16] , and the trees are growing profusely under suitable climatic and soil conditions.

Teak is, however, susceptible to attacks by various insect pests[5,9]. Stem borers are economically important, causing serious degradation of the wood quality. The teak beehole borer (*Xyleutes ceramica*: Lepidoptera, Cossidae) is especially destructive, causing a “beehole”, a tunnel made by the larva, which was formerly mistaken for the burrow of a carpenter bee. Beehole accumulation over the felling period results in the loss of the timber value. This insect is naturally distributed in Sabah, feeding on wild species of Verbenaceae[1]. Teak plantations are, therefore, subject to attacks by teak beehole borers. In Sabah, it has been reported that 20–30% of planted teak trees were attacked by *X. ceramica* in various areas[5]. But the number of beeholes per tree, which is directly

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related to the wood quality, has never been determined. Yemane (*Gmelina arborea*) also belonging to Verbenaceae, which is another popular forestry tree in Sabah, is attacked by insect pests. Besides the teak beehole borer, a hepialid moth (*Endoclita aroura* Tindale) known as the teak collar ring borer, and two cerambycid beetles (*Acalolepta cervina* Hope and *A. rusticator* Fab.) have also been reported to attack teak and yemane in Sabah[5].

The objective of the present study was to determine the relative importance of the borers by evaluating their infestation intensity in teak and yemane plantations in Sabah.

Materials and methods

Field surveys were carried out for 9 teak and 2 yemane stands in the following 7 plantations during the period 14–28 March, 1998:

(1) Luasong Forestry Centre (LFC; trial and demonstration plantations of Innoprise Sdn. Bhd.), Tawau,
(2) Trial plantation of Sabah Forest Department at Apas, Tawau,
(3) Taliwas Experimental Plantation of Innoprise Sdn. Bhd., Lahad Datu,
(4) Commercial Plantation of Sejati Sdn. Bhd. at Boonrich, Lahad Datu,
(5) Commercial Plantation of Sejati Sdn. Bhd. at Sejati, Telupid,
(6) Trial Plantation of Sabah Forest Department at Segaliud-Lokan, Sandakan,
(7) Teak Plantation Forest Reserve of Sabah Forest Department at Bandau, Kota Marudu.

Diameter at breast height (DBH) was measured for each sample tree and mean annual increment (DBH/year) was calculated for each stand. The stand parameters and the number of sample trees are shown in Table 1. The number of holes bored by stem borers and their height from the ground level were recorded for each sample tree. In addition, we felled teak and yemane trees and identified the attacking insects and determined their developmental stages at Luasong (1 yemane tree), Taliwas (2 teak trees), Segaliud-Lokan (1 teak tree) and Kota Marudu (1 wilding of teak).

Patterns of attack by *X. ceramica* in young stands were analyzed mainly based on the data from Sejati and Taliwas, where the infestation rates were rather high. Spatial distribution of attacks in teak stands was analyzed by Iwao's mean and mean crowding regression method[10]. Mean crowding ($\overset{*}{m}$) is defined as the mean number of other individuals per individual per quadrat and is computed as follows:

$$\overset{*}{m} = m + (\sigma^2/m - 1),$$

where m indicates the population mean and σ^2 the variance. The mean crowding linearly changes with mean:

$$\overset{*}{m} = \alpha + \beta\, m,$$

where α and β are constants characteristic of the various theoretical distributions, e.g., $\alpha = 0$ and $\beta = 1 + 1/k$ in the case of a negative binomial distribution with a common k (a parameter used as a measure of aggregation). The intercept of the regression (α) indicates

Table 1. Stand parameters and number of samples

Stand	Age (year)	Mean DBH (cm ± s.d.)	Spacing (m)	Mean annual increment (cm)	No. of sample trees
Teak (*Tectona grandis*)					
Luasong	4	18.1 ± 3.5	2.8 × 3.2	4.5	66
Apas	29	23.4 ± 10.6	1.8 × 1.8	0.8	163
Taliwas	4	19.9 ± 3.3	3.7 × 7.0	5.0	102
Boonrich 1	4	12.4 ± 1.9	2.1 × 4.3	3.1	78
Boonrich 2	5	16.1 ± 2.8	2.1 × 4.3	3.2	70
Sejati 1	5	13.2 ± 3.2	2.1 × 4.3	2.6	50
Sejati 2	4	14.9 ± 3.3	2.1 × 4.3	3.7	70
Segaliud-Lokan	3	8.8 ± 2.6	4.0 × 4.0	2.9	40
Kota Marudu					
planted	76	57.5 ± 18.6	1.5 × 8.9	0.8	61
wilding and coppice	unknown	8.7 ± 5.9	–	–	63
Yemane (*Gmelina arborea*)					
Luasong	7	21.5 ± 9.3	–	3.1	78
Taliwas	20	37.8 ± 8.7	3.7 × 7.0	1.9	49

whether the basic component of the distribution is a single individual ($\alpha = 0$) or a group of individuals ($\alpha > 1$). The slope of the regression (β) indicates the manner in which individuals or groups of individuals distribute themselves in their habitat with a change in the mean density.

In the present study, m and σ^2 were replaced with their unbiased sample estimates x and s^2. Mean (x) is the mean number of attacks per tree. Mean crowding ($\overset{*}{x}$) is the mean number of other attacks per attack per tree and is computed for each stand as follows:

$$\overset{*}{x} = x + (s^2/x - 1)$$

Statistical tests were conducted based on the method of Zar[17].

Results

1. Incidence of stem borer attacks in teak and yemane plantations

Three species of stem borers were detected in the teak and yemane plantations, i.e. *X. ceramica* (Fig. 1 A, E), *E. aroura* (Fig. 1 F) as well as an unidentified cerambycid beetle (Fig. 1 H). Holes of *X. ceramica* (Fig. 1 D) were characterized by the ejection of wood particles (a sign of the presence of an active larva) or sealing with a silk wad (pupa or prepupa) or the presence of a pupal exuvia (indicating recent adult emergence) (Fig. 1 C). Traces of old attacks by *X. ceramica*, or beeholes which appeared as scars with a longitudinal median furrow, were also found (Fig. 1B, lower arrow). Hereafter, current and recent attacks represented by open beeholes will collectively be referred to as "present attacks" and the traces of old attacks as "past attacks". Attacks by *E. aroura* were identified by the presence of silk-spun frass covering the wound (Fig. 1 B, upper arrow) and ring-girdling of the stem (Fig. 1 G). Attacks by cerambycids were readily differentiated by the presence of fibrous frass from attacks by *X. ceramica* and *E. aroura*. Head capsules of the cerambycid larvae collected from yemane in Luasong had one occipital foramen with a greater length than width. These characters indicated that they belonged to the subfamily Lamiinae.

Incidence of the attacks by the stem borers is summarized in Table 2. For teak, attacks by *X. ceramica* were observed in 8 of the 9 stands with damaged trees ranging from 10.3% to 65.2%, and those by *E. aroura* in 2 stands, with damage ranging between 2.5% and 6.9%. No attacks by the cerambycid were detected in the teak stands examined here.

The number of past and present attacks per tree (density) by *X. ceramica*, ranged from 0.27–1.28 and 0.01–0.62, respectively. Density of the present attacks was very low at Boonrich, although the past attacks were noticeable (Table 2). According to the manager of this plantation, damaged trees were logged and thus the borer population could be artificially controlled. The most

Table 2. Incidence of attacks by the teak beehole borer, the collar ring borer and a cerambycid in teak and yemane plantations in Sabah

Stand	Teak beehole borer					Collar ring borer	Cerambycid
	No. of attacks per tree		% of trees with			% of trees attacked	% of trees attacked
	Past	Present	Past attacks	Present attacks	Attacks*		
Teak (*Tectona grandis*)							
Luasong	0.62	0.48	37.9	37.9	65.2	3.0	0.0
Apas	0.00	0.00	0.0	0.0	0.0	0.0	0.0
Taliwas	0.85	0.16	53.9	13.7	60.8	0.0	0.0
Boonrich 1	0.27	0.04	20.5	3.9	23.1	0.0	0.0
Boonrich 2	0.39	0.01	31.4	1.4	32.9	0.0	0.0
Sejati 1	1.28	0.62	48.0	38.0	62.0	0.0	0.0
Sejati 2	0.71	0.20	42.9	15.7	48.6	0.0	0.0
Segaliud-Lokan	0.45	0.38	30.0	32.5	52.5	2.5	0.0
Kota Marudu (wilding and coppice)	0.00	0.12	0.0	10.3	10.3	6.9	0.0
Kota Marudu (planted)	0.00	0.00	0.0	0.0	0.0	0.0	0.0
Yemane (*Gmelina arborea*)							
Luasong	0.00	0.08	0.0	7.6	7.6	0.0	14.1
Taliwas	0.04	0.08	4.1	6.1	12.2	0.0	0.0

*% of trees with at least one past and/or one present attack.

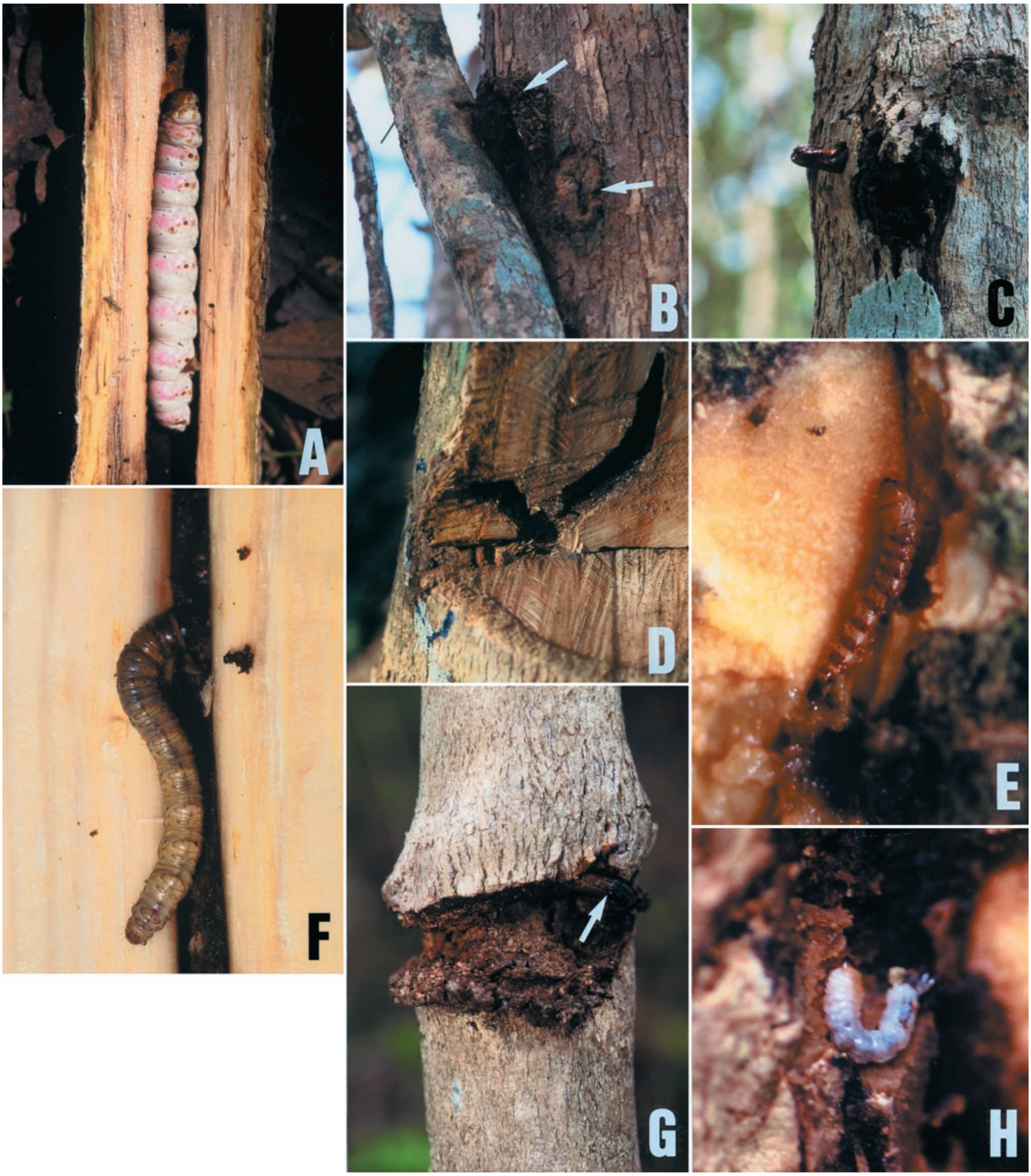

Fig. 1. Borers observed in the teak and yemane plantations

A-E: *X. ceramica*, F-G: *E. aroura,* H: Unidentified cerambycid. A: Mature larva, B: Past attack (lower arrow) by *X. ceramica* and present attack by *E. aroura* (upper arrow), C: Pupal exuvia left intact on the trunk, D: Beehole inside the trunk, E: Young larva feeding inside bark of yemane, F: Mature larva, G: Teak damaged by ring-girdling of stem (arrow indicates pupal exuvia), H: Larva infesting inner bark of yemane.

severe infestation was observed at Sejati 1. The density of the present attacks at Luasong was rather high, but the holes were small, indicating that the larvae were young and a number of them could not develop successfully enough to construct beeholes with usual sizes. On the other hand, there were no traces of attacks at Apas. Signs of attack by *X. ceramica* were not observed on the old trees in Kota Marudu, including 2 large trees, which had recently fallen by accident, and thus could be inspected up to the tree top, whereas present attacks were found with a low incidence in young trees (wilding and coppice).

In yemane, the percentage of the trees damaged by *X. ceramica* was 7.6–12.2%, but no infestation by *E. aroura* was observed. On the other hand, attacks by a cerambycid species were noticeable in the young stand at Luasong, with an incidence of 14.1%. The cerambycid attacks were confined to the lowermost 1 m part of the stem.

2. Analysis of attacks by the teak beehole borer in young teak stands

(1) Incidence of attacks in relation to stem growth and size

There was no significant correlation between the density of past attacks per year and mean annual increment (Fig. 2). On the other hand, the densities of past attacks were significantly different among DBH classes within the Sejati 1 and Taliwas stands (Kruskal-Wallis test, Sejati 1, Hcor = 10.18, $p < 0.01$; Taliwas, Hcor = 13.88, $p < 0.001$)(Fig. 3). On an individual tree basis, the number of past attacks was positively correlated with DBH in both plots (Fig. 4). But there was no significant correlation between the number of present attacks and DBH at Sejati 1($r = -0.056$, $p > 0.5$ n.s.). At Taliwas, an individual tree had seldom experienced one present attack.

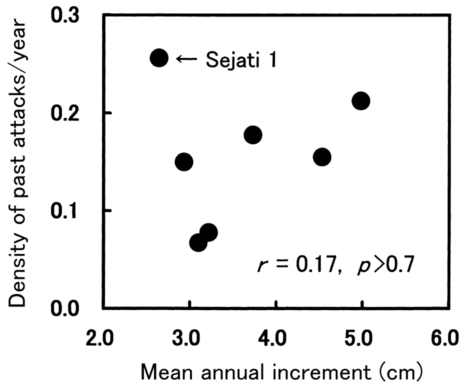

Fig. 2. Relationship between density of past attacks per year by *X. ceramica* and mean annual increment

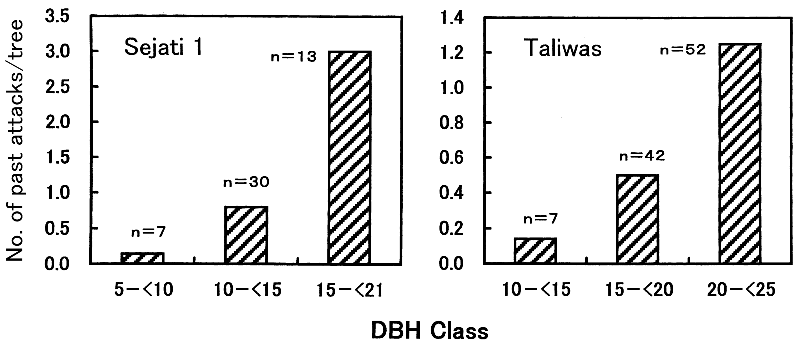

Fig. 3. Difference in density of past attacks by *X. ceramica* among 5 cm DBH classes

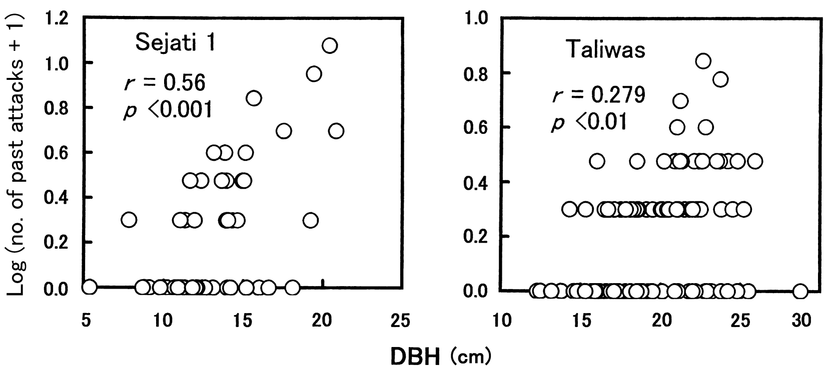

Fig. 4. Relationship between the number of past attacks by *X. ceramica* per tree and DBH of teak tree

(2) Spatial distribution of attacks

The relationship between mean crowding ($\overset{*}{x}$) and mean (x) was described by a linear regression for both past and present attacks (Fig. 5). In the past attacks, the slope of regression was significantly greater than 1 (t = 3.372, $p < 0.05$) and the intercept was not significantly different from 0 (t = 1.531, $p > 0.1$ n.s.), indicating the existence of a contagious distribution of individual attacks. In the present attacks, on the other hand, the slope was greater than 1 but not significantly different from 1 (t = 1.859, $p > 0.1$ n.s.) and the intercept was nearly equal to 0 (t = 0.265, $p > 0.5$ n.s.), suggesting the existence of a random or somewhat contagious distribution of the attacks.

The frequency distribution of the number of past attacks per tree at Sejati 1 and Taliwas fitted well to the negative binomial distribution, without significant differences (Sejati 1, $X^2 = 0.31$, $p > 0.1$; Taliwas, $X^2 = 2.098$, $p > 0.1$)(Fig. 6). The trees with more than 3 past attacks accounted for only 4.9% at Taliwas and 16.0% at Sejati 1, while those free from past attacks accounted for 46.1% at Taliwas and 52.0% at Sejati 1.

(3) Vertical distribution of attacks on the trunk

The frequency distribution of the number of attacks per 0.5 m vertical section along the trunk for 7 stands is shown in Fig. 7. The vertical distribution patterns of the attacks were similar among the plots, in that the majority of both present and past attacks occurred in the lowermost 1 m part of the trunk, and the number of attacks either steadily or suddenly decreased along with an increase in height.

3. Developmental stages of the teak beehole borer in late March

Developmental stages of the teak beehole borer in late March in Sabah were not uniform (Table 3). Holes made by mature larvae ejecting large frasses were found in every plot. At Taliwas, Segaliud-Lokan and Kota Marudu, the occurrence of mature larvae was directly confirmed by splitting the stems of the trees felled in the sample plots. Presence of pupae and adults was also indicated in some plots by the observation of holes sealed with silk wads and pupal exuviae, respectively. At Sejati, adult emergence had already taken place in 48.9% of the

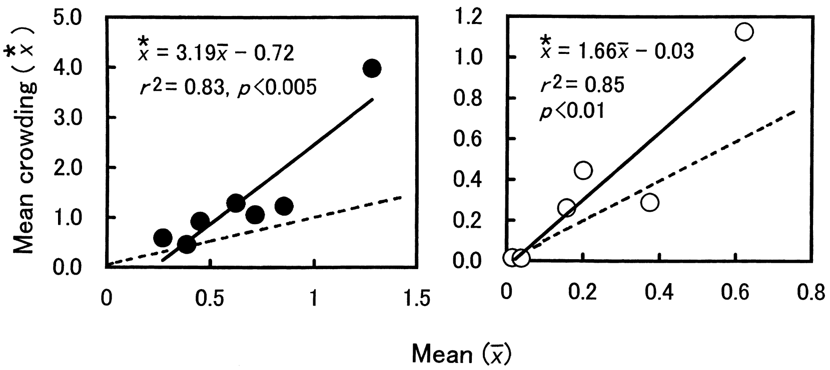

Fig. 5. Regression of mean crowding on mean number of attacks on teak by *X. ceramica*
Left: past attacks. Right: present attacks (data from Luasong were omitted due to predominantly early stages of present attacks). Dotted line shows the Poisson distribution.

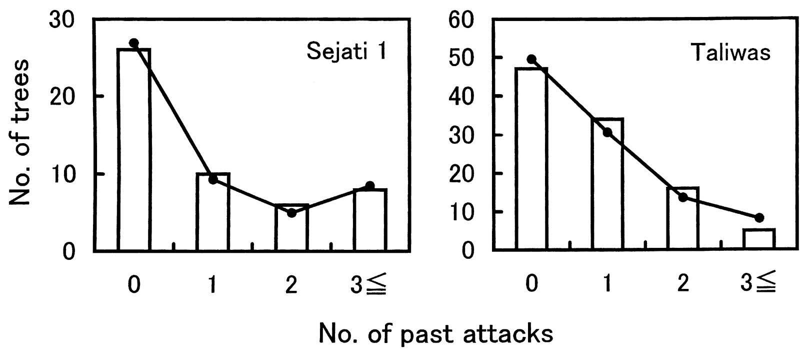

Fig. 6. Frequency distribution of the number of past attacks on teak by *X. ceramica*
Solid line indicates expectation from negative binomial distribution.

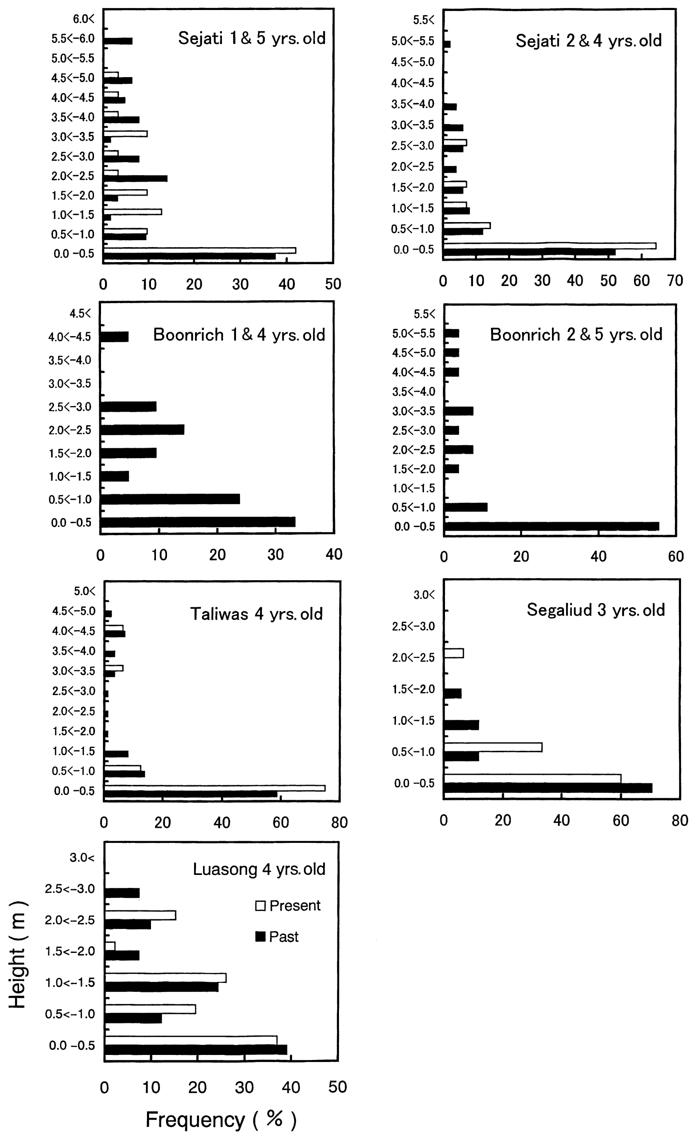

Fig. 7. Vertical distribution of attacks by *X. ceramica* on the trunks of teak trees

Table 3. Tentative estimation of developmental stages of *X. ceramica* in the teak plantations (late March, 1998, Sabah)

Plantation	No. of holes with			
	Young larva	Mature larva	Pupa	Pupal exuvia
Luasong	34	10	0	0
Taliwas	0	10	5	1
Boonrich (combined)	0	2	0	2
Sejati (combined)	0	21	2	22
Segaliud-Lokan	1	12	2	0
Kota Marudu	0	2	1	0

present attacks. Although no pupal exuviae were observed on teak trees in the Luasong plantation, a few exuviae were found on ornamental yemane trees in the garden of the Center, suggesting the occurrence of adults. In the Luasong plot, many small holes with fresh sap flow and/or a fine film of black frasses were found on the teak trees, indicating that the young larvae of the succeeding generation had already hatched.

Discussion

1. Relative importance of borers

The present study revealed that *X. ceramica* is the major stem-boring pest now prevalent in teak plantations in Sabah. *E. aroura* and the cerambycid are, on the other hand, of minor importance and are unlikely to become a serious problem in the teak plantations.

The incidence of *X. ceramica* attacks in young stands of teak in Sabah appears to be very high, compared to reported cases in Myanmar, where the density of beeholes was less than 0.3 until 4 years after planting even in best-grown stands[2]. Such a high incidence in Sabah may be related to the profuse growth of teak trees, since vigorous trees showed more beeholes than weak ones[4]. In fact, the average DBH in all the young stands examined here exceeded that in the best-grown class (class I) in the *Radius-Age Curves* presented by Atkinson[2]. In addition, since the community of natural enemies may still be small in the new teak stands in Sabah, the migrant borers could easily become established and the population could increase.

In the yemane plantations studied, *X. ceramica* and *E. aroura* seemed to be minor pests. In peninsular Malaysia, however, 2% to 50% of the trees were reported to show exit holes of *X. ceramica*[15]. On the other hand, the cerambycid could cause considerable damage in young stands. Since the present results were based on only 2 stands, more field data are needed to draw a conclusion on the relative importance of borers in yemane plantations.

2. Characteristics of attacks by the teak beehole borer

Although increment-incidence analysis did not yield statistically significant results in the present study (Fig. 2), it has been reported that the fast growth of a plantation is conducive to the age-beehole incidence (mean annual incidence of beeholes per tree)[2,3]. The exceptional result from Sejati 1 (very high incidence despite a low increment (Fig. 2)) suggests that there must be a certain factor(s) other than the tree growth rate that strongly affects the intensity of attack. The investigation of such a factor(s) at a particular site would yield useful information for development of a protection method. The results of DBH-incidence analysis (Fig. 3) clearly showed that large-sized (fast-growing) trees were more susceptible to attacks by the teak beehole borer than slow-growing ones in a given stand. It was also pointed out that the number of beeholes per tree was directly proportional to its girth in a stand of even-aged trees[3,6]. This may be due to the lower mortality of the larvae on vigorous trees where better food supply is available, and/or to selection of vigorous trees by female adults for oviposition.

Analysis of the spatial distribution of the past attacks showed that the spatial distribution unit corresponded to a single attack and that the attacks were aggregated. The aggregation of past attacks could be attributed to the fact that fast-growing trees are more susceptible to attacks than the slow-growing ones. On the other hand, it was shown that the present attacks followed a random or only weakly contagious distribution. It was, however, reported that the newly emerged holes followed a negative binomial distribution with a common k[14]. In the current study, the number of data sets for the present attacks was too small to calculate the common k.

It was shown that the attacks occurred exclusively in the lower part of the tree in stands of 3–5 year-old trees, presumably because the larvae wander in search of suitable boring sites where sufficient food for growth is available[3], and the attacks eventually become concentrated in the region with large diameter growth, which may be located in the lower part in young teak trees. In general, young trees in managed plantations are known to show a gradual increase in thickness of the annual increment of new wood from the top to the base of the stem[12]. On the other hand, the observed vertical distribution of the attacks may reflect the distribution of the oviposition sites, although the oviposition behavior of the female adult has not been fully documented.

3. Variations in developmental stages

The developmental stages of the teak beehole borer varied among the plantations in Sabah in March, 1998. Adults emerged earlier at Sejati than in the other plantations, as suggested by the greater proportion of pupal exuviae. Many young larvae of the succeeding generation had already appeared at Luasong, in contrast to the other plots. Such seasonal variations in developmental stages may be related to differences in the local climatic conditions.

The life cycle of the teak beehole borer in Sabah seems to be considerably different from that in Myanmar and Thailand. Adults and mature larvae occurred at the same time at Taliwas, Boonrich and Sejati. In contrast, these two stages were clearly separated by seasons in

Myanmar and Thailand due to the close synchronization between developmental stages of the teak beehole borer and teak phenology[3,7,8]. In Thailand, for example, mature larvae occur in November when the dry season begins and teak ceases to grow. Adults emerge mostly in March just before the beginning of the rainy season when teak resumes growth. It would be worth clarifying the life cycle of the beehole borer in relation to the teak growth pattern under the local climatic conditions in Sabah.

4. Implications for control of the teak beehole borer

The density of the present attacks was very low in spite of the rather intensive past attacks in the Boonrich plantation, suggesting the effectiveness of the removal of infested trees, which is being employed here as a control measure for lessening present attacks. In case this method of control is practiced, timing would be an important factor; the attacked trees must be removed before the emergence of the adult borer. Since mature larvae, pupae and adults were observed in late March in the present study, the larvae may begin to develop into prepupae in January (when precipitation starts to decrease)[11]. Therefore, we consider that the attacked trees must be logged by the end of December.

On the other hand, there was no infestation by the teak beehole borer in the plantation of Apas, probably because the plantation was isolated, without natural forests in proximity where the borer may occur. It may be possible to avoid colonization of the teak beehole borer in a plantation by establishing the plantation away from natural forests and infested plantations.

Outbreaks of the teak beehole borer may occur in future, as has been recorded in Myanmar[2–4] and Thailand[14], and therefore, the teak beehole borer can be a real threat to teak plantations in Sabah. Since the risk of outbreak increases as trees become older, as observed in Myanmar and Thailand, long-term monitoring of populations should be conducted at several plantations.

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