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Structure and Composition of a Teak-bearing Forest under the Myanmar Selection System: Impacts of Logging and Bamboo Flowering

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Abstract

The impact of selective logging on a natural teak-bearing forest was examined in the Kabaung reserve forest, Bago Division, Myanmar. The examined forest was under selective logging from 2001 to 2002. In the area, a bamboo, *Cephalostachyum pergracile*, flowered in 2002 and then died back in 2003. Thirty-seven circular plots of 20 m radius (4.65 ha in total) were set in the forest and 837 tree stems (DBH$\geq$ 10 cm) and 1809 bamboo clumps were enumerated in the plots. The average basal area density was 30.2 m^2 ha^{-1}, and bamboo accounted for 33% of the basal area. Trees with a DBH $\geq$ 10 cm and 60 cm were 180 ha^{-1} and 10.1 ha^{-1}, respectively. The 37 plots were classified into four stand types, *Tectona grandis* type, *Xylia xylocarpa* type, *Bambusa polymorpha* type, and *Dipterocarpus alatus* type. The felling operation was conducted only in 10 of the 37 plots sampled and 11.7% of the basal area of trees over 10 cm DBH was removed during the logging. The percentage of extracted basal area (%-extracted) varied from 6.9 to 51.0% among the 10 plots. The highest %-extracted was recorded in *D. alatus* stands (38.7–51.0%), while the %-extracted in the other stand types was rather smaller (6.9–36.5%). As a result, the impact of harvesting was minimal except in the case of *D. alatus* stands. Teak was most abundant in the sapling layer (427 ha^{-1}). The combination of the logging operation and bamboo dieback enabled the sapling bank to accelerate height growth and to enter the pole size class, while logging or bamboo dieback alone had no significant effect. In the bamboo dieback sites with the logging operation, 84–96% of tree saplings overtopped bamboo seedlings, but the value decreased to between 53 and 56% in non-logged stands. The combination of logging operations and bamboo flowering thus had remarkable effects on the sapling banks of tree species and enhanced recruitment of pole-size trees.

Keywords: bamboo flowering, recruitment, selective logging, sustainability, *Tectona grandis*

I Introduction

Teak (*Tectona grandis*) mostly occurs in mixed deciduous forests (MDFs) consisting of many deciduous tree species such as legumes, *Lagerstroemia* spp., *Terminalia* spp., and bamboos. Teak-bearing MDFs range from India to Thailand and comprise one of the

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most widespread biomes in the monsoon tropics of Asia [Stamp 1925; Davis 1964; Ko Ko Gyi and Kyaw Tint 1998; Ashton 1991]. MDFs are also important sources of many commercial timbers, including teak and other hardwoods, and also produce bamboos and numerous non-timber forest products. Among these commercial timbers, teak commands the highest market price because of its durable and workable wood with high resistance to rotting and termite damage. The main target of the management of teak-bearing natural forests in Myanmar has been teak extraction from the forests [Bryant 1997]. Timber extraction from natural teak forests has been conducted using a selective logging system in Myanmar, Thailand, Laos and partly in India [Kaosa-ard 1992; Phengdouang 1992; Bryant 1997; Nyi Nyi Kyaw 2003]. Teak in the natural forests of Thailand and Laos, however, has been overexploited in commercial logging and extraction of teak from the natural forests has been stopped before 1990 [Sumantakul and Sangkul 1998].

Most natural teak-bearing forests in Myanmar have been under a selective logging system since the middle of the nineteenth century [Bryant 1997]. The Myanmar Selection System (MSS; formerly called the Brandis Selection System) sets the harvestable girth limit at 73 cm DBH in moist sites and 63 cm DBH in dry sites and sets the felling cycle at 30 years [Myanmar, Forest Department 1998]. This logging system was designed to enable the smooth recovery of teak stocks during the rotation time [*ibid.*; Ko Ko Gyi and Kyaw Tint 1998], and Myanmar still retains a high percentage of forest cover compared to other countries with teak-bearing forests [FAO 2001]. The national level tree inventories, however, indicate a decline in teak and other commercial wood stocks in the natural forests of Myanmar [Saw Kelvin Keh 1997; Myanmar, Forest Department 1998]. In general, the decline in natural forest resources has resulted from inappropriate logging methods, ignorance of logging rules, encroachment of cropland, and/or illegal logging. The MSS holds the premise that the logging operation should enhance the regeneration of commercial species in the forest. The first objective of this study was to examine whether logging in a teak-bearing forest is properly practiced.

The extraction of larger canopy trees from a stand will improve light conditions for the understory trees and is expected to effectively improve growth of trees and saplings below the canopy layer. Another major event that strongly influences tree regeneration in teak-bearing forests is the gregarious flowering and dieback of bamboos, which are monocarpic and flower periodically with a rotation time of several decades. The second objective of this study was to examine the impact of these two events, removal of canopy trees and gregarious flowering of bamboos, on the regeneration of tree species in the teak-bearing forest.

II Research Site and Methods

1. *Research Site*

Our study was conducted in the Kabaung reserve forest, Oktwin Township, Taungoo District, Bago Division, Myanmar. The site is located on the Bago mountain range (300–800 m elevation). The area is mainly covered by Ultisols originating from sedimentary rocks, mostly tertiary sandstones. The average annual minimum and maximum temperatures are 21.4℃ and 32.7℃, respectively, and the average annual rainfall is 1,966 mm, ranging from 1,363 to 2,571 mm over a 10-year period (measured from 1993–2002 at the Taungoo Weather Station at around 50 m elevation in the foothills of the Bago range and 40 km east of the research site). Most of the rainfall occurs during the rainy season (May–October). The species composition of the forest indicates that the forest is an upper moist mixed deciduous forest [Stamp 1925; Ko Ko Gyi and Kyaw Tint 1998], the prevalent type of mixed deciduous forest in Myanmar.

2. *Field Methods*

We examined Compartments 103 and 105 of the Kabaung reserve forest (18°48′ N, 96°03′ E, 226–377 m elevation). These two compartments were logged from 2001 to 2002 (referred as the logging 2001 hereafter). Thirty-seven circular plots of 20 m radius (Fig. 1) were set in the compartments in November to December 2002. Before the latest extraction (2001–02), the compartments had experienced at least three previous selective loggings in 1926, 1961, 1979, according to past extraction records of the Forest Department (Zaw Min, personal communication). Teak and other hardwood species, such as *Xylia xylocarpa*, were extracted during the logging in 2001.

Basically, the plots were set systematically at a spacing of 200 m, both in terms of latitude and longitude. However, areas with cliffs or those that were close to roads or in fallow land were avoided. In addition to the 31 systematically located plots, we set 6

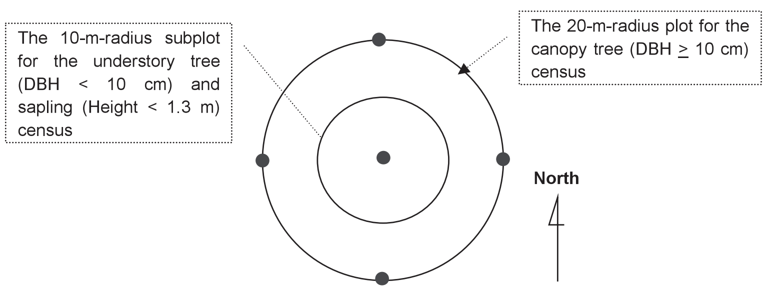

Fig. 1 Design of the circular plot. Black dots indicate the positions at which the relative elevation was obtained during the survey work.

supplemental sampling plots to cover variations in species composition and stand structure of the study site.

Trees over 10 cm DBH (canopy trees) were tagged, identified, and their DBHs were measured. Stumps of extracted stems were also measured for stem diameter at cut height, and wood samples were collected from the stumps for species identification. The wood samples were identified by the wood anatomy laboratory, Forest Research Institute, Yezin, Myanmar. The DBH of extracted trees was estimated using the stem shape model based on measurement of stem shape of several teak trees,

$$\mathrm{DBH} = D(h)/(1.028\, h^{-0.114}),$$

where h is the height of the diameter measuring point and $D(h)$ is the diameter of the stump. Bamboo clumps were also recorded in the circular plots. All the bamboo clumps in the plots were recorded as the number of culms per clump (n), the maximum culm diameter ($d_{\max}$), and the minimum culm diameter ($d_{\min}$) in the clump. The basal area of a bamboo clump was calculated as $n \cdot d_{\max} \cdot d_{\min} \cdot \pi/4$. Within each 20-m-radius circular plot, we set a 10-m-radius circular subplot (Fig. 1) and trees smaller than 10 cm DBH and taller than 1.3 m (understory trees) were tagged, identified, and their DBHs measured within the subplot from November to December 2002.

To examine the impact of logging and bamboo dieback on saplings, we selected 12 subplots for sapling census. The selected stands consisted of two logged stands, two bamboo dieback stands, three stands subjected to logging and bamboo flowering, and five intact stands (without logging and bamboo dieback). Saplings shorter than 1.3 m were enumerated and identified to species in the 12 subplots in November 2003, 1 year after the tree census. Canopy openness in each subplot was estimated from fisheye photos taken at the center of the plot using Gap Light Analyzer (Simon Fraser University).

3. *Analytical Methods*

The *topography* of each plot was expressed in terms of slope inclination, orientation, elevation, and slope convexity. The first three variables were defined as those of a regression plane, which was determined by five surveyed points in the plots (Fig. 1). The convexity of the slope was defined as the difference between the elevation at the center of the plot and the averaged elevation of the five surveyed points.

The 37 stands were classified by cluster analysis based on the relative basal area data of the canopy tree composition. We adopted Ward's method and relative Euclidean distance in the analysis. Indicator species analysis [Dufrene and Legendre 1997] was applied to the stand types obtained from the cluster analysis. Detrended correspondence analysis (DCA) for the species composition data was also applied to the relative basal area data. These numerical analyses were conducted using PC-ORD ver. 4.17 (MjM Software). Multiple regression analysis was employed to test for the topographical dependency of the species composition using SPSS ver. 10.0.7 J.

III Results and Discussion

1. *Species Composition and Diversity*

In the 37 plots (4.65 ha in total), 837 living tree stems (DBH $\geq$ 10 cm) and 1,809 bamboo clumps were counted. Average basal area density was 30.2 $m^2 ha^{-1}$ and bamboo accounted for 33% of the basal area. Trees with DBH $\geq$ 10 cm and 60 cm amounted to 180 ha^{-1} and 10.1 ha^{-1}, respectively.

The total number of species in the canopy layer of the 37 plots was 99. Species diversity indices calculated from the tree density data and basal area data are shown in Table 1. Fisher's alpha calculated from the pooled data of the 37 plots was 29.2, indicating high species diversity of the forest compared to other teak-bearing forests of Myanmar (10.5–25.4) [Nyi Nyi Kyaw 2003] and India (5.5) [Sukumar *et al.* 2004]. The jackknife estimators (an estimate of total number of species in an area [Heltshe and Forrester 1983; Burnham and Overton 1979] were 144 (first-order estimator) and 166 (second-order estimator).

2. *Community Diversification*

We attempted to explain the diversity of species composition among the plots in terms of topographical and regeneration niche differentiation among species. Such approaches have successfully explained habitat differentiation of component species in many tropical forests [e. g., Yamada *et al.* 1997; Svenning 1999; Sri-ngernyuang *et al.* 2003]. We applied multiple regression analysis to explain the Axis 1 score obtained by DCA. The objective variable used was the DCA score of plots and the explanatory variables were the slope inclination, orientation, elevation, convexity index, and basal area density (BA density) of each plot. The last variable, basal area density, was used to indicate the developmental stage of the stand. The multiple regression analysis yielded no significant model (Table 2). The topography and BA density could not explain the variation in

Table 1 Species diversity of teak-bearing forest based on the canopy tree census for trees over 10 cm DBH in 37 plots.

Diversity Index	Density Data	Basal Area Data
Average of 37 plots (each 0.126 ha)		
Number of species	13.5	—
Fisher's alpha	5.20	—
Shannon-Wiener H'	1.65	1.858
Simpson's D	0.67	0.76
Pooled data of 37 plots (4.65 ha)		
Number of species	99	—
Fisher's alpha	29.2	—
Shannon-Wiener H'	2.33	2.97
Simpson's D	0.79	0.89

Table 2 Results of multiple regression analysis for the Axis 1 score obtained from DCA

Coeff. Determination r^2	0.206
Corrected r^2	0.113
N. observation	37
p	0.089 (not significant)

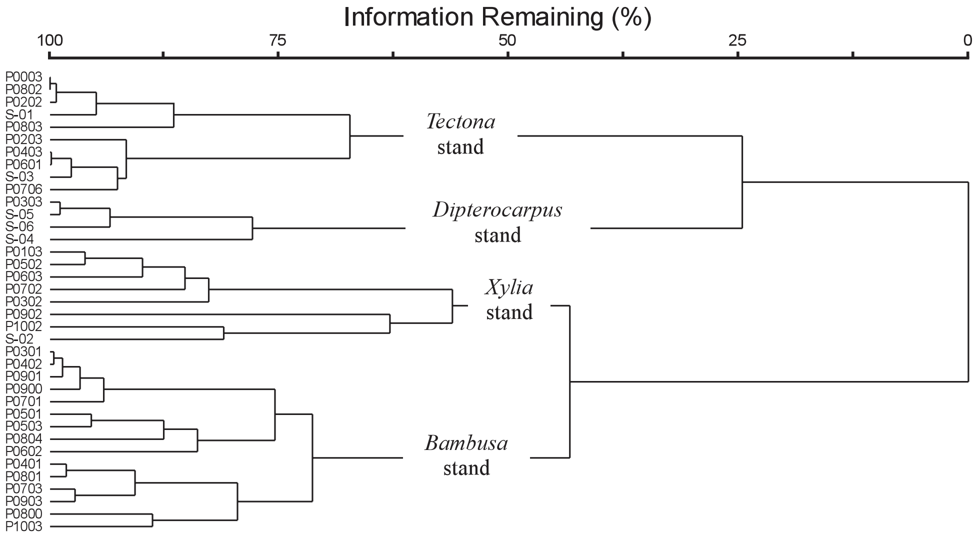

Fig. 2 Dendrogram obtained by cluster analysis using Ward's methods and relative Euclidean distance based on the relative basal area data. The clusters were identified by species name of the indicator species of each cluster.

species composition among the 37 plots.

Cluster analysis and indicator species analysis yielded four stands types, each characterized by the occurrence and/or dominance of *Tectona grandis, Dipterocarpus alatus, X. xylocarpa*, and *Bambusa polymorpha* (Figs. 2 and 3).

Among the four stand types, the *B. polymorpha* and *X. xylocarpa* types are bamboo-dominant (Fig. 3). After overexploitation of teak in Thailand, stands tend to become mostly bamboo thicket; the bamboo-dominant stands at our research site might have been the result of past overexploitation. The fact that most of these two stand types were located alongside the main extraction road also suggests the possibility of past over-exploitation of these plots.

It was quite difficult to predict the variation in species composition from a static environment, such as microtopography. The natural teak-bearing forest seemed to be a nonequilibrium community, in which human disturbances play an important role in the structure of the community.

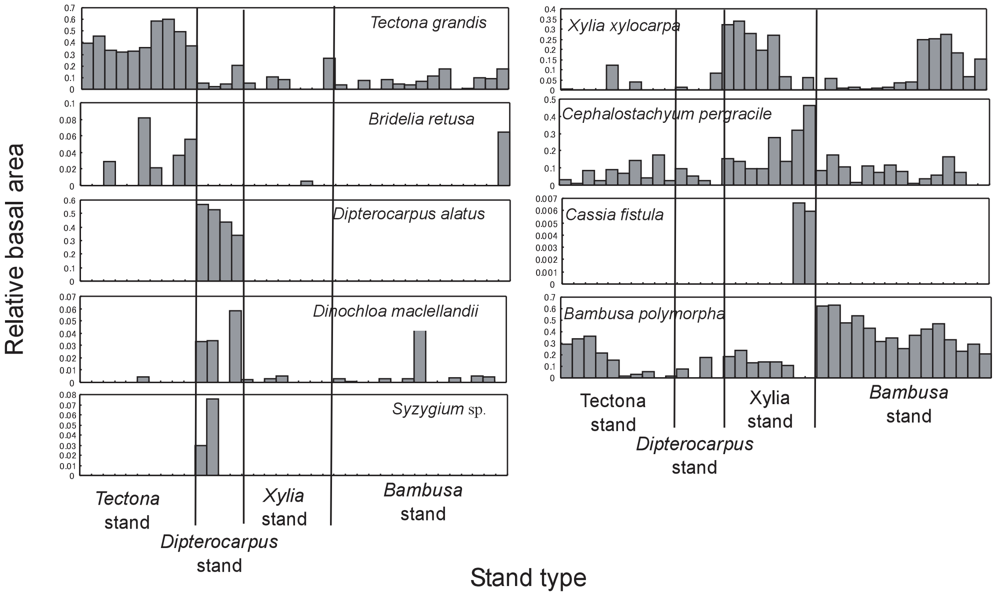

Fig. 3 Distribution pattern of indicator species among four stand types obtained from the cluster analysis. Thirty-seven stands are arranged in the order of plots in Fig. 2.

3. *Extraction of Canopy Trees*

Felling operations were conducted only in 10 of the 37 plots studied, and 10.7% of the basal area was removed by the logging (Table 3). Extracted species recorded were *T. grandis, X. xylocarpa, Terminalia tomentosa*, and *D. alatus* (Table 3). The amount of extracted teak was 0.76 m^2 ha^{-1}, less than that of *D. alatus* at an extraction rate of 1.22 m^2 ha^{-1}. Thus, the amount of extracted trees seemed to be quite small. However, extracted teaks accounted for 15% of the total basal area of teaks growing before extraction in 2001. The percentage for *X. xylocarpa, T. tomentosa*, and *D. alatus* were 7, 30, and 44%, respectively.

The extracted BA in the 2001 operation ranged from 6.9 to 51.0% in logged stands (Fig. 4). The highest %-BA-extracted was recorded in *D. alatus* stands (38.7–51.0%). In contrast, %-BA-extracted from *T. grandis* stands and *X. xylocarpa* stands were smaller (6.9–36.5%). Thus, the impact of harvesting was minimal, except in the case in *D. alatus*

Table 3 Trees extracted by the 2001 logging operation. Data from 37 circular plots

Species	Extraction (m^2 ha^{-1})	%	% Relative to Species Total BA before Extraction in 2001
Tectona grandis	0.76	33	15
Xylia xylocarpa	0.17	8	7
Terminalia tomentosa	0.15	6	30
Dipterocarpus alatus	1.22	53	44
Total	2.30	100	11

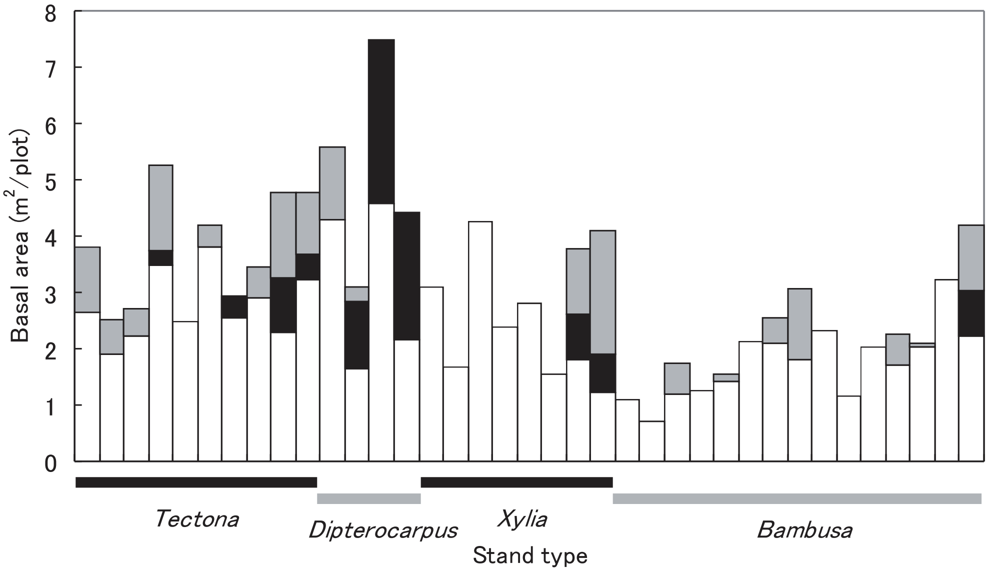

Fig. 4　Basal area composition of living trees (open bars), trees extracted by logging in 2001 (solid bars), and trees extracted by logging before 2001 (shaded bars).

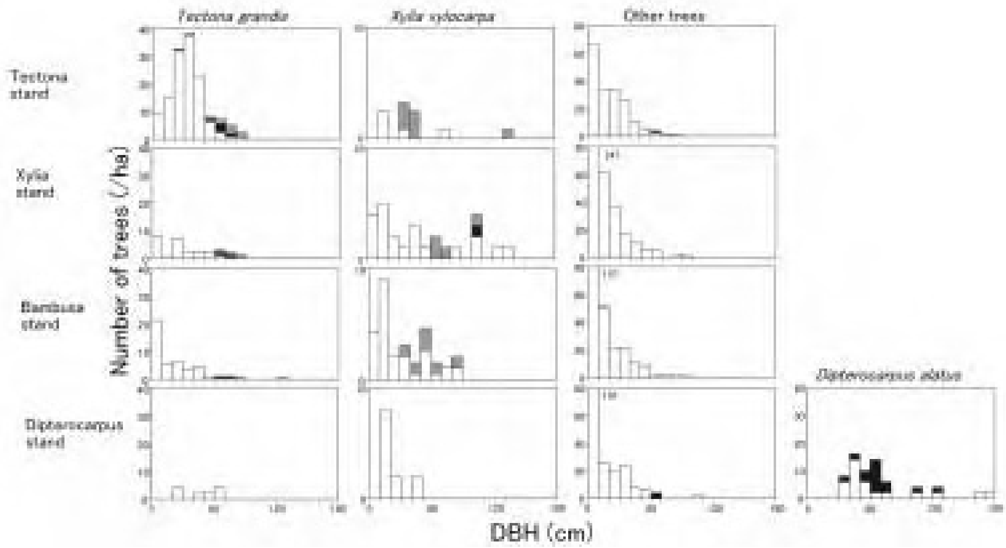

Fig. 5　Diameter structure of remaining trees (open bars), trees extracted in 2001 logging operations (solid bars), and trees extracted before 2001 (shaded bars). Note that the scale of the *y*-axis differs among species.

stands.

The DBH frequency distribution for living trees and logged trees are shown in the diagram in Fig. 5. In the diagram, understory trees with a DBH less than 10 cm are added.

Extracted trees in 2001 and other older stumps are shown separately in the diagram. Most of the extracted trees were over 60 cm DBH, but one *T. grandis* and several *D. alatus* were smaller than 60 cm DBH. Old stumps of *X. xylocarpa* were abundant and smaller trees over 20 cm DBH of this species were also extracted. Due to decay of stumps, the DBH tends to be underestimated for these old stumps, but the size distribution clearly indicates that smaller trees were also extracted before 2001. As non-teak trees are not strictly regulated by the MSS, such *X. xylocarpa* trees might have been harvested for road maintenance work or local use.

The size structure of living trees of *X. xylocarpa* that survived the 2001 logging showed an L-shaped distribution. However, the size structure of *D. alatus* was modal and lacked trees smaller than 30 cm DBH. The recovery of the population from the logging impact will be constrained by a lack or limitation to recruitment from smaller size classes. The size distribution of teak also showed a modal distribution in *T. grandis*-type stands. In the other three stand types, the amount of trees over 20 cm DBH was quite low. Thus, the recruitment of teak also seemed to be constrained by the limited number of pole-size trees.

4. *Effects of Logging and Bamboo Dieback on Saplings*

The average density of saplings was 4,814 ha^{-1} and 57 tree species were recorded. The most common and abundant species were *T. grandis* (100% frequency and 427 ha^{-1} density), *X. xylocarpa* (100% and 356 ha^{-1}), and *Milletia brandisiana* (92%, 533 ha^{-1}). Pioneer species, *Bombax insigne* and *Eriolaena candollei*, were also abundant (Table 4).

Table 4 Sapling density (ha^{-1}) of the main tree species. See footnote on the abbreviation of species names.

Stand Type	Plot Name	Species								Total
		Tectgr	Xylixy	Antive	Bombin	Erioca	Millbr	Dalbcu	Dalbov	
Tectona	08–02	350	64	159	1178	255	0	191	64	4236
	S–01	478	159	64	223	350	1720	159	1115	5955
	02–03	96	350	478	96	159	2484	510	64	5892
	06–01	828	637	159	96	64	64	96	637	3567
	S–03	1656	732	223	255	0	32	191	159	6592
Xylia	10–02	96	924	191	287	287	127	127	255	4108
	S–02	382	318	318	159	2197	32	0	0	6274
Bambusa	09–00	414	159	96	32	318	541	64	0	7611
	08–04	223	414	573	64	159	892	32	32	3376
	04–01	191	287	32	0	64	191	382	127	3376
	08–00	223	64	0	159	510	64	64	0	3535
	10–03	191	159	414	96	32	255	0	159	3248
Frequency (%)		100	100	92	92	92	92	83	75	—
Mean N (ha^{-1})		427	356	226	220	366	533	151	218	4814

Tectgr, *Tectona grandis*; Xylixy, *Xylia xylocarpa*; Antive, *Antidesma velutinum*; Bombin, *Bombax insigne*; Erioca, *Eriolaena candollei*; Millbr, *Milletia brandisiana*; Dalbcu, *Dalbergia cultrate*; Dalbov, *Dalbergia ovata*.

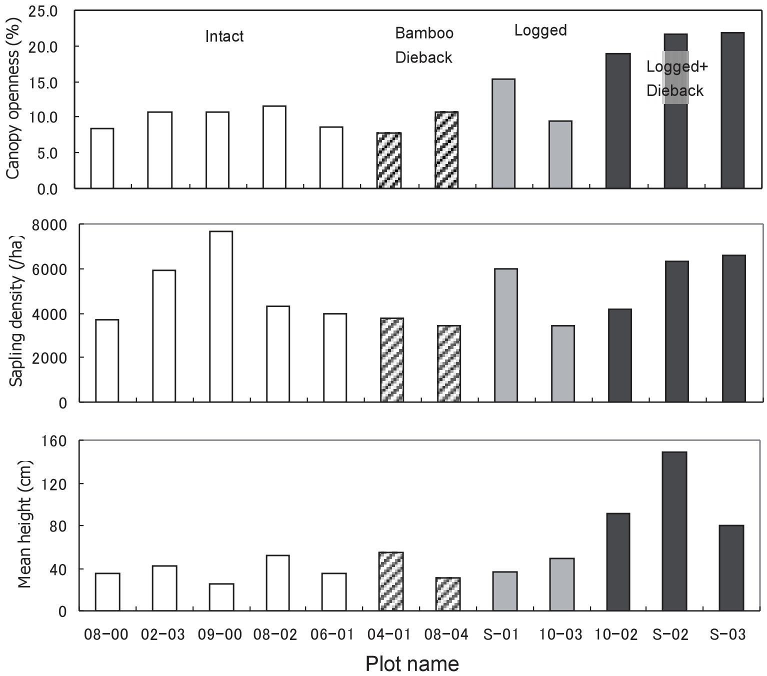

Fig. 6 Canopy openness of 12 plots (top diagram). The plots that had experienced both logging and bamboo flowering had significantly higher canopy openness than the other plots ($p < 0.05$, Mann-Whitney test). Sapling density showed no significant difference between treatments (middle diagram), while the mean height of saplings was significantly higher in the plots that had experienced both logging and bamboo flowering (bottom diagram : $p < 0.05$, Mann-Whitney test).

The canopy openness values of logged-over stands with bamboo dieback (19–22%) were significantly higher than the other stands (8–15%; Fig. 6). However, we could not detect any significant effect of logging or bamboo flowering alone. The sapling density was almost constant irrespective of logging or bamboo flowering (Fig. 6). The size structure of saplings obviously changed from an L-shaped distribution to a modal distribution when logging and bamboo flowering were combined (Fig. 7). Consequently, the mean sapling height increased from around 40 cm to over 80 cm (Fig. 6). This indicates that when the extraction of upper canopy trees and dieback of bamboo are combined, the light conditions at the forest floor change drastically and saplings are released from shading. The released saplings can probably enter the pole-size class and thus avoid the risk of dieback caused by repeated ground fires in the dry season.

Logging of trees and mass flowering of bamboos are the most positive influences on the recruitment of trees. However, bamboo seedlings form a dense ground cover and can be a formidable competitor for tree saplings. The bamboo seedling height and

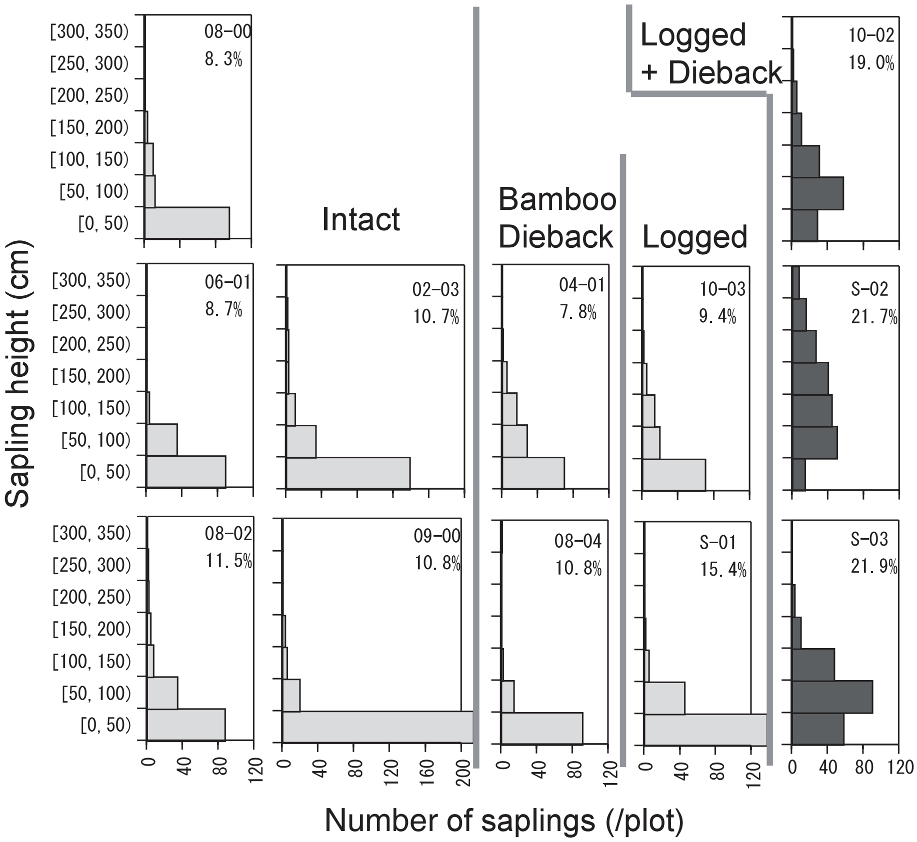

Fig. 7 Size structure of saplings in the 12 study plots. Percentage values indicate canopy openness in each plot. Only the logged plot with bamboo flowering was remarkably different from the intact plots.

tree sapling height were compared for non-logged sites and logged sites (Fig. 8). In non-logged sites, the 6-month-old seedlings of bamboo were around 25 cm in height, and 53–56% of tree seedlings were taller than the bamboo seedlings. In the logged sites, both bamboo seedling height and tree sapling height were larger than those in the non-logged sites. However, more than 84% of tree saplings were taller than the bamboo seedlings at these sites. Although tree saplings in logged sites seemed to have a large advantage, this is the situation in the first growing season after bamboo seed germination, and future consequences of the competition between trees and bamboos must be monitored.

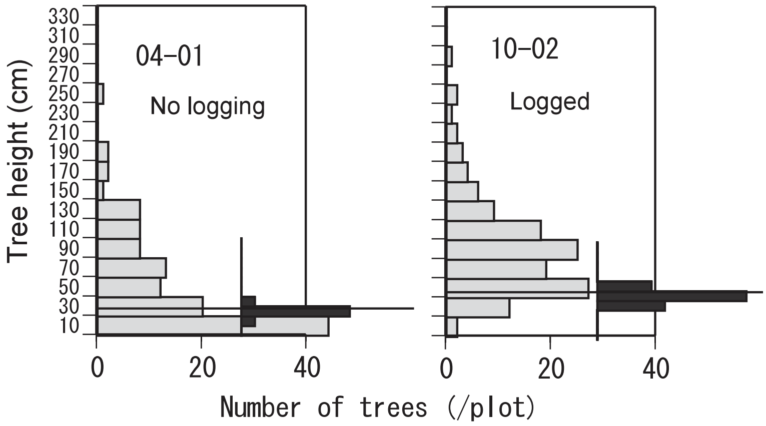

Fig. 8 Height distribution of tree saplings (shaded bars) and bamboo seedlings (filled bars). The bamboo seedling heights were measured at 20 points in the plots. Left diagram is for the plot without logging and the right diagram is for plots subjected to logging operations.

IV Conclusions

The selective logging in our studied forest compartments is well managed for teak and follows the logging codes. However, logging of *D. alatus* resulted in more than 50% removal of the BA and resulted in a huge disturbance to the site. In humid tropical forests, such as lowland dipterocarp forests, massive stand damage caused by selective logging is common, and "the minimum diameter cutting limit approach" has been criticized by Sist *et al.* [2003]. Some regulation of the harvestable amount from a stand might be necessary in teak-bearing forest.

The localized occurrence of teak and bamboo dominance in non-teak stand types possibly indicate that teak is declining in this forest. Although teak trees with a DBH of 20 to 40 cm are abundant in the compartments, the pole-size trees up to 20 cm DBH are scarce, even in teak-dominant stands. This strongly suggests that the recruitment of pole-size trees from the sapling layer is restricted in this forest. The teak sapling density and size structure were almost constant among the intact, logged, and bamboo dieback stands. However, when logging and bamboo dieback were combined, the light conditions on forest floor was improved dramatically. In such stands, the size structure of saplings clearly indicates that saplings are released from shading suppression. Thus, the simultaneous occurrence of logging and bamboo dieback can stimulate teak and other tree species regeneration, but logging or bamboo dieback alone cannot stimulate tree regeneration.

As the middle-size trees in the 20–40-cm size class are still abundant in teak-dominant stands, the harvestable size teak can be increased until the next felling cycle. Restricted recruitment from the sapling layer might be critical for the sustainability of teak-bearing forests in the future, even if the current logging system is rigorously applied to the forest. An improvement in logging methods to incorporate the control of bamboo shading is strongly recommended.

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