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Species Composition and Stand Structure of Natural Forest, Timber-harvested Forest and Degraded Forest in the Bago Yoma Region of Myanmar

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Abstract: Tree species diversity is an important aspect of forest ecosystem stability. Tree species inventories at defined sites and in minimum diameter classes give a reliable indicator of the diversity level as well as the structural stability level of a study site. This study was conducted to investigate the species composition and the stand structure of the natural forest, timber-harvested forest (logged-over forest) and degraded forest of the Oak-twin Township in the Bago Yoma Region of Myanmar. Natural forest showed the highest family and species richness in all the investigated forests. At the family level, *Verbenaceae* occupied the highest importance value index (IVI) in all the forest stands while teak (*Tectona grandis* Linn. f.) occupied the highest IVI at the species level. However, the small diameter classes of *T. grandis* and other commercial species were less than those of big diameter classes in all the investigated forests. This abnormal pattern of diameter distribution could be a problem for the sustainable production of commercial timber species in the near future.

Key words **:** *horizontal and vertical stand structure, sustainable forest management, teak, tree species diversity, tropical moist and dry deciduous forest*

Introduction

Floristic inventory is a necessary prerequisite for much fundamental research in tropical community ecology, such as modeling patterns of species diversity or understanding species distribution (Phillips *et al.*, 2003). Nowadays, tropical forests and trees are becoming interesting subjects because of its species diversity (Condit *et al.*, 1996). Tree species diversity contributes to the forest ecosystem stability (Rennolls and Laumonier, 2000). Thus, monitoring tree species composition and stand structure is of crucial importance for the tree species conservation and sustainable forest management (SFM).

Myanmar is best known as the natural home to teak (*Tectona grandis* Linn. f.), which is regarded worldwide as one of the most valuable premier woods. Myanmar Selection System (MSS) has been the principal forest management system applied in managing natural forests since 1856. However, the proportion of quality teak logs and other commercial hard woods has been decreasing continuously. Commercial growing stock has been reduced from 1,392 million m^3 in 1990 to 738 million m^3 in 2000 and 488 million m^3 in 2005, respectively (FAO, 2005).

Quantitative floristic sampling provides the necessary context for planning and long-term biodiversity conservation (Phillips *et al.*, 2003). Tree species inventories at defined sites and in minimum diameter classes give a reliable indicator of the diversity level and structural stability level of a study site (Wattenberg and Breckle, 1995). Likewise, the characterization of tree species and forest stand conditions can be useful in the planning of operations, which aim to conserve biodiversity (Belbin, 1995). Only a few studies have characterized the tree species composition and stand structure of forests in Myanmar (Kyaw, 2003). Thus, the main objective of this study was to analyze the species composition and stand structure of different forest stands in order to support the country's sustainable forest management.

Materials and Methods

1. Study Area

This study was conducted in Oak-twin Township of the Toungoo District in the Bago Yoma Region. It is situated between the latitude 18° 8" to 19° 20" N and lon-

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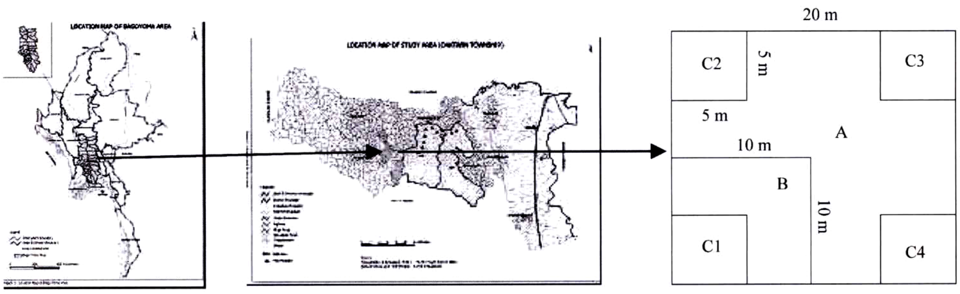


Figure 1. Location of the study area and layout of sample plot.

Table 1. Equations for the stand structure and species composition analysis.

Sr. no.	Equations	Remarks
1.	$\hat{S} = s\left(\frac{n-1}{n}\right)^k$	Where is the Jackknife estimate of species richness, s is the observed total number of species in "n" sample plots, *n* is the total number of plots sampled, and k is the number of unique species (Heltshe and Forrester, 1983).
2.	$D = \sum_{i=1}^{s}\left(\frac{n_i(n_i-1)}{(N(N-1))}\right)$	Where *D* is the Simpson's index of diversity, n_i is the number of individuals of species "i" in the sample, *s* is the number of species in the sample Σn_i, *N* is the total number of individuals in the sample (Simpson, 1949).
3.	$H' = \sum_{i=1}^{s}(Pi)(lnPi)$	Where *H'* is the Shannon-Wiener function, *S* is the number of species, *Pi* is the proportion of total sample belonging to "ith" species, and *ln* is the theoretical maximum value of diversity ($\log_2$) (Magurran, 1988).
4.	$E(\%) = 100\ (H'/lnH_{max})$	Where *E* is the Shannon's Evenness, *H'* is the Shannon-Wiener function, H_{max} is the *ln (S)*- the theoretical maximum value of diversity by a given number of total species (S) found in the sample (Krebs, 1989).
5.	$K_s = \frac{2c}{a+b} \times 100$	Where *Ks* is the coefficient of similarity, *a* is the number of species in one stand, *b* is the number of species in another stand, and *c* is the number of species common to both stands (Sörenson, 1948 cited by Lamprecht, 1989).
6.	$K_G = \frac{2G_c}{G_a+G_b} \times 100$	Where K_G is the coefficient of similarity, G_a is the total basal area of the species in one stand, G_b is total basal area of the species in another stand, and G_c is the sum of smaller values of basal area of each common species in both stands (Weidelt, 2000)
7.	$ISJ = \frac{c}{a+b+c}$	Where, *a* is the total number of species in one stand, *b* is the total number of species in another stand, and *c* is the number of species/genera/family occurring in both stands (Krebs, 1989).
8.	IVI (%) = (R.A + R.F+ R.B.A)/3	Where *RA* is the relative abundance, *RF* is the relative frequency, and *RD* is the relative dominance (Curtis and McIntosh, 1951).
9.	$V = b0 + b1\ D + b2\ D^2 + b3\ D^3 + \ldots bn\ D^n$	Where, *V* is the tree volume overbark, *D* is the tree diameter in centimeter (cm), and *b0, b1, b2 ... bn* are the estimated parameters. (Leech *et al.*, 1990)

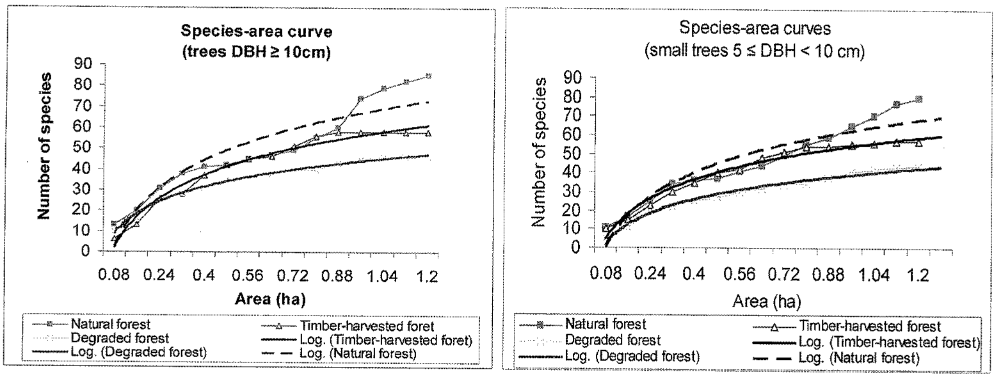
gitude 95° 50" to 96° 45" E (Figure 1). The mean temperature for a decade (1997-2006) is 28.5°C ± 2.25°C and the mean annual rainfall is 1993±338.74 mm. Tropical deciduous forests (moist and dry deciduous forests), which cover 65.56 percent, are the major forest types in the study area.

Forest inventory was carried out in the natural forest (Compartments 13, 14 and 205), timber-harvested forest (logged-over forest) (Compartments 9, 10 and 218) and degraded forest (Unclassified forest number 16) (Figure 1). Each compartment has an area of about 300 ha. In this study, all the investigated forests were managed under the selection system with the felling cycle of 30 years. The selective cutting was carried out in the natural forest in 1990 and timber-harvested forest in 2006. In this study, degraded forest is also a timber-harvested forest but it was seriously affected by the human activities including shifting cultivation, fuel wood collection and charcoal making after timber harvesting.

2. Forest Inventory for the Vegetation Analysis

In order to collect the vegetation data, 30 square plots with an area of 400 m^2 (20 m × 20 m) each were laid out systematically in each area (i.e. 3.6 ha in total), and it was referred to as A.

Height and diameter at breast height of all trees (DBH ≥5 cm) were measured in each plot. Within each plot, a sub-plot measuring 100 m^2 (10 m × 10 m) was established for the measurement of sapling (H > 130 cm, DBH < 5 cm) and it was referred to as B. Each plot was



(a) (b)

Figure 2. Species-area curves for all trees (DBH≥10 cm) (a) and for small trees (5≤DBH <10 cm) (b).

Table 2. Tree species diversity of the investigated forest stands

Investigated stands	Species richness* (Jackknife estimator)	Shannon-Wiener function (H')	Simpson's diversity index (1-D)	Shannon evenness (j') (%)
Natural forest	85.29±18.16	3.36	0.89	75.53
Timber-harvested forest	58.64±14.26	3.49	0.95	85.96
Degraded forest	45.84±5.50	3.50	0.96	92.01

*95% confidence limit

also sub-divided into four equal sub-plots measuring 25 m^2 (5 m × 5 m) to enumerate the seedling, and it was referred to as C1, C2, C3 and C4. Equations used for the stand structure and species composition analysis are shown in Table 1.

3. Soil Sampling and analysis

In order to examine the properties of soil in the investigated forests, three sample points were selected randomly in each forest stand. Then soil samples were collected in every 10 cm depth on each point (i. e. 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm and 40-50 cm) using a soil collector. Thus, a total of 45 soil samples were collected for analysis. Physical and chemical properties were tested in the Soil Laboratories of Forest Research Institute (FRI) and in the Department of Agriculture Research (DAR) in Yezin, Myanmar.

4. Statistical analysis

The mean value of forest stand parameters and soil properties were analyzed using MS Excel 2000 and SAS 9.1 for Windows (SAS Institute Inc., USA). Duncan's multiple range test (DMRT) was used for examining the difference of the soil properties among the forests.

Results

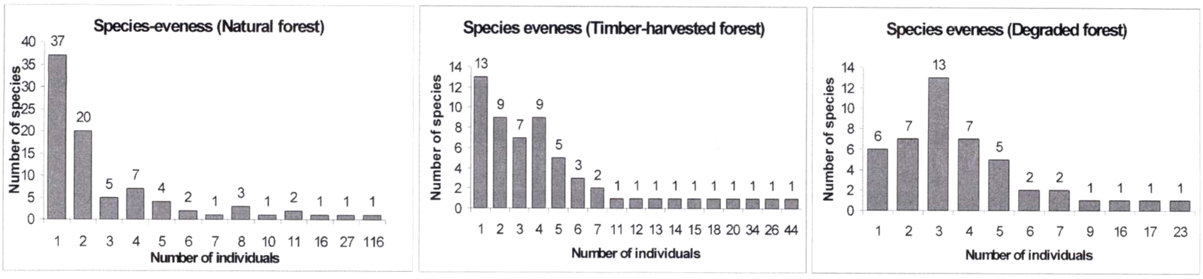
1. Tree species diversity and composition

The numbers of families observed in the natural forest, timber-harvested forest and degraded forest were 79 (± 19.13)/ha, 87 (± 8.76)/ha and 68 (± 15.41)/ha, respectively. Based on logarithmic function, the distributions of species for all surveyed areas are shown in Figures 2a and b. Natural forest showed the highest number of species per unit area in all the investigated forests (Table 2). However, it was observed that the species diversity indices and evenness of degraded forest were higher than these of timber-harvested forest and natural forest (Table 2).

In this study, the numbers of species represented by few individuals were larger than species represented by many individuals (Figures 3a-c). In natural forest, 44 percent (37 species) of total species had only one individual in total tree population whereas 22 percent (13 species) and 13 percent (6 species) in the timber-harvested forest and degraded forest, respectively. It showed that the proportion of species composition of the natural forest was less even than timber-harvested forest and degraded forest. These species can be recognized as the rare species of the forests. *T. grandis* was the only species that had the largest number of individuals such as 116 (31 percent of total individuals), 44 (13 percent of total individuals) and 23 (11 percent of total individuals) in the natural forest, timber-harvested forest, and degraded forest, respectively (Figures 3a-c).

2. Coefficients of similarity of the forests

Coefficients of similarity of species composition



(a) (b) (c)

Figure 3. Status of species evenness in the natural forest (a), timber-harvested forest (b), and degraded forest (c).

Table 3. Coefficients of similarity among the investigated forest stands.

Forest stands	Sörensen's index (%) (based on species)	Jaccard index (%) (based on species)	Weidelt index (%) (based on BA)
Natural forest vs. timber-harvested forest	64.34	66.12	28.42
Natural forest vs. degraded forest	61.10	53.10	41.12
Timber-harvested forest vs. degraded forest	86.54	79.59	44.65

Table 4. Importance value index of the 10 most important species in the investigated forest stands (DBH$\leq$10 cm) (based on 1 ha).

Natural forest		Timber-harvested forest		Degraded forest	
Species	IVI (%)	Species	IVI (%)	Species	IVI (%)
Tectona grandis	23.88	*Tectona grandis*	10.95	*Tectona grandis*	9.20
Xylia xylocarpa	8.17	*Xylia xylocarpa*	9.06	*Xylia xylocarpa*	7.99
Mitragyna rotundifolia	3.99	*Mitragyna rotundifolia*	7.32	*Mitragyna rotundifolia*	6.45
Homalium tomentosum Benth.	3.51	*Protium serratum.*	5.33	*Protium serratum*	4.97
Eriolaena candollei	3.28	*Lagertroemia villosa*	5.05	*Bridelia retusa*	3.80
Protium serratum	2.73	*Emblica officinalis*	4.81	*Erythrina stricta*	3.56
Dalbergia fusca	2.12	*Homalium tomentosum*	4.04	*Emblica officinalis*	3.42
Nauclea sessilifolia	2.09	*Terminalia chebula.*	3.43	*Markhamia stipulata*	3.35
Millettia brandisiana	2.02	*Schleichera oleosa*	2.90	*Terminalia chebula*	3.02
Stereospermum colais	2.01	*Croton roxburghianus*	2.59	*Spondias pinnata*	3.00

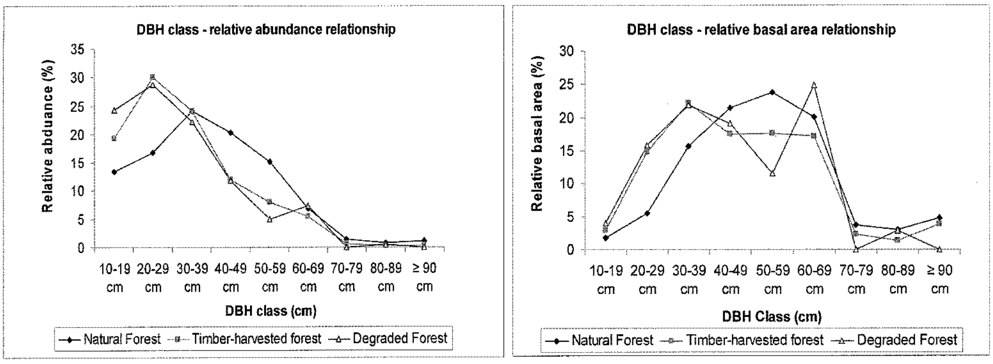
(Sörensen's and Jaccard's indices) between timber-harvested forest and degraded forest showed higher values as shown in Table 3. The species composition of these two forest stands was much similar compared with that of a natural forest. It was found out that 46 species were common between the natural forest and timber-harvested forest, 40 species between the natural forest and degraded forest and 45 species between the timber-harvested forest and degraded forest. However, Weidelt's modified index which was based on basal area of the common species was less than 45 percent among the forests (Table 3). It clearly indicated the structural differences of the forests.

3. Importance value index (IVI) of the forests

At the family level, *Verbenaceae* occupied the highest IVI in the natural forest (25.21 percent), timber-harvested forest (12.88 percent) and degraded forest (11.66 percent). At the species level, *T. grandis* occupied the highest IVI for all trees DBH$\geq$10 cm (Table 4) and for small trees (5 cm$\leq$DBH<10 cm) in all the investigated forests. Within small trees group, *T. grandis* occupied 9.07 percent of the total IVI in the natural forest, 12.39 percent in the timber-harvested forest and 13.07 percent in the degraded forest. Based on the IVI values of the two most abundant species, the investigated forest stands may be recognized as *Tectona grandis* - *Xylia xylocarpa* association type. According to the IVI, *T. grandis* can be regarded as the most important species (indicator species) in the study area and it was followed by Pyinkado (*Xylia xylocarpa*), Binga (*Mitragyna rotundifolia*) and Thadi (*Protium serratum*). It was also found out that most of the abundant species in all stands were high in frequency value. These species could be regarded as the tree species with a regular horizontal distribution (Lamprecht, 1989).

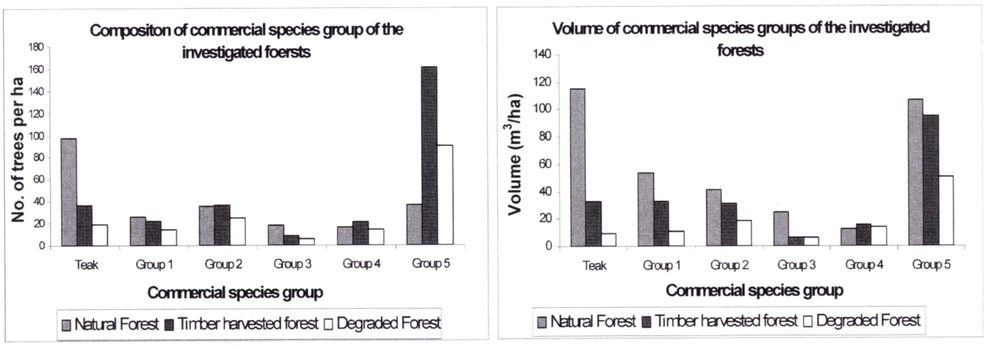
4. Stand structure of the forests

1) Horizontal stand structure



(a) (b)

Figure 4. Relationship of DBH classes with the relative abundance (a) and relative basal area (b) in the investigated forest stands.



(a) (b)

Note: Group 1 species: *Xylia xylocarpa, Pterocarpus macrocarpus, Hopea odorata, Shorea oblongifolia, Pentaceme siamensis, Dalbergia oliveri.*

Group 2 species: *Mitragyna rotundifolia, Adina cordifolia, Dipterocarpus spp, Michelia champaca, Albizzia procera, Protium serrata, Millettia pendula, Cedrela toona, Gmelina arborea, Dalbergia cultrata, Chukrasia tubularis.*

Group 3 species: *Amoora wallichii, Terminalia chebula, Lagerstroemia speciosa, Terminalia tomentosa, Artocarpus caloneura, Magifera caloneura, Anogeissus acuminate.*

Group 4 species: *Tetrameles nudiflora, Salmalia insignis, Spondias pinnata, Anthocephalus cadamba, Dubanga grandiflora, Lennea grandis,* other softwoods.

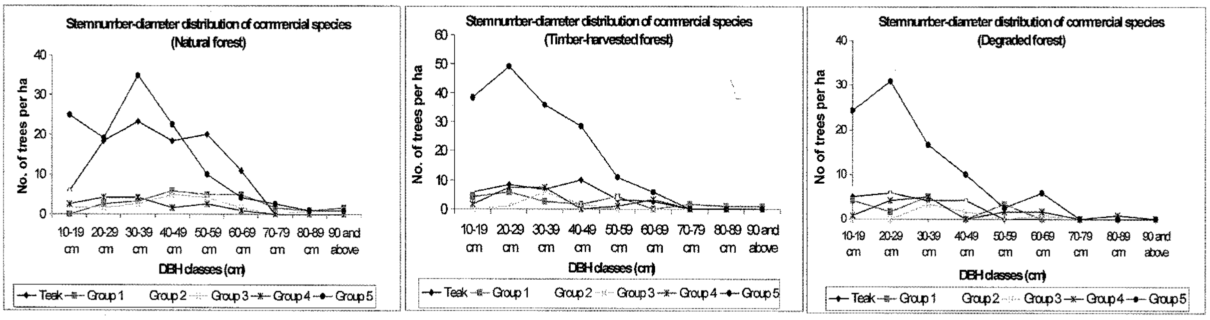
Group 5 species: *Hymenodictyon excelsum, Lagerstroemia tomentosa, Homalium tomentosum, Holoptelea integrifolia, Grewia tiliaefolia*, other hardwoods.

Figure 5. Abundance (a) and volume of the commercial timber species (b) in the investigated forest stands.

Mean tree density (DBH≥10 cm) (n/ha) of the natural forest, timber-harvested forest, and degraded forest amounted to 312 (±20.75), 293 (±109.99) and 168 (±32.62), respectively. The standing volumes were 352.61 m^3 (±72.84 m^3)/ha, 212.65 m^3 (±67.22 m^3)/ha and 109.68 m^3 (±24.05 m^3)/ha in the natural forest, timber-harvested forest, and degraded forest, respectively. The differences in mean volumes of the stands were highly significant ($p<0.001$). Natural regeneration was found satisfactory in the natural forest (sapling 2,240 (±610)/ha and seedling 2597 (±804)/ha) and timber-harvested forest (Sapling 1,583 (±374)/ha and seedling 1670 (±295)/ha). However, it is necessary to restore the degraded forest artificially because of insufficient amount of natural regeneration (sapling 830 (±187)/ha and seedling 1236 (±210)/ha). Figures 4a and b show the relationship of the DBH classes with relative abundance and relative basal area.

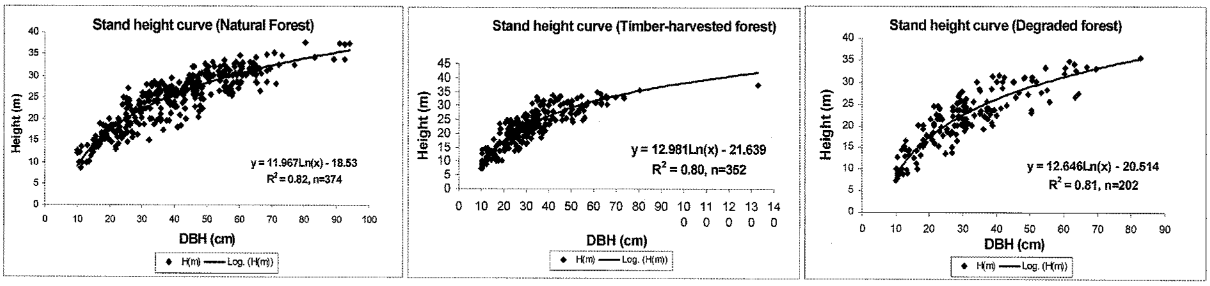
In all forest stands, few numbers of trees in the lowest diameter class (10-19 cm) were observed than the second lowest class (20-29 cm) (Figures 4a and b). Apart from the lowest diameter class (10-19 cm), the diameter distribution of the trees followed the inverse J-shape pattern (Figure 4a). The diameter distribution of the investigated forests followed the normal pattern of natural forest that the medium diameter classes such as 50-59 cm, 30-39 cm and 60-69 occupied the largest basal area per ha in the natural forest, timber-harvested forest and degraded forest, respectively (Figure 4b).

Except in the natural forest, the composition and volume of teak and other commercial timber species in the timber-harvested forest and degraded forest were more or less the same (Figures 5a and b). *T. grandis* contributed about 115 m^3 (± 64.25 m^3)/ha, 32 m^3 (± 19.15 m^3)/ha, and 14 (± 9.56 m^3)/ha in the natural forest, timber-harvested forest, and



(a) (b) (c)

Figure 6. Stem number-diameter distribution of commercial timber species in the natural forest (a), timber-harvested forest (b), and degraded forest (c).



(a) (b) (c)

Figure 7. Stand height curves of the natural forest (a), timber-harvested forest (b), and degraded forest (c).

Table 5. Vertical structure of the investigated forest stands

Vertical storey	Natural forest		Timber-harvested forest		Degraded forest	
	Trees (n/ha)	Species (n/ha)	Trees (n/ha)	Species (n/ha)	Trees (n/ha)	Species (n/ha)
Upper storey	180	49	96	25	63	23
Middle storey	122	44	153	38	83	29
Lower storey	10	7	37	14	23	10

degraded forest, respectively.

It was found out that the stem number-diameter distribution of *T. grandis* and other commercial species was very irregular in the investigated forests. Except group 5 tree species, which are the economically most unattractive, the number of smaller diameter classes of *T. grandis* and all commercial timber species (groups 1 to 4) was less than that of big diameter classes (Figures 6a-c). The pattern is similar in timber-harvested forest and degraded forest.

2) Vertical stand structure

Logarithmic function fitted suitable regressions for all height curves (Figures 7a-c). A comparison of height curves for all species reflects the dominant position of natural forest with a maximum height of about 40 m. Trees in timber-harvested forest and degraded forest reached only heights of 30 m and 35 m, respectively.

Based on the IUFRO classification (Leibundgut 1958 cited by Kyaw, 2003), the vertical structure of the investigated stands is presented in Table 5. Tree species richness and stem density decreased with the decreasing height of the forest storey in the natural forest. All the investigated forests showed that the young stage trees as well as the number of species in the lower storey were less than the middle and upper storeys. It also indicated that the productivity of forests could decline in next felling cycle as well as in the future.

5. Soil Properties of the forests

Mean values for soil properties were statistically tested. The differences in mean values of C/N ratios (carbon/nitrogen) between the investigated stands were not statistically significant (F=1.99, p=0.15). Differences between the mean values of moisture content, pH value, available phosphorus (P) and magnesium (Mg^{2+}) contents were highly significant among the stands ($p<0.001$). Natural forest showed the highest mean values among the investigated stands. The mean contents of organic carbon (OC), total nitrogen (N^{+}) and extractable nutrients such as

Table 6. Soil chemical and physical properties of the investigated forest stands

Soil properties	Soil depth (cm)	Natural forest	Timber-harvested forest	Degraded forest
Total N (%)	0-10	0.13 (0.01)	0.12 (0.04)	0.08 (0.01)
	40-50	0.08 (0.00)	0.08 (0.01)	0.07 (0.02)
Available P (%)	0-10	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	40-50	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
K^+ (%)	0-10	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
	40-50	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
Na^+ (%)	0-10	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)
	40-50	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)
Ca^{2+} (%)	0-10	0.13 (0.11)	0.06 (0.02)	0.06 (0.03)
	40-50	0.05 (0.00)	0.05 (0.02)	0.07 (0.02)
Mg^{2+} (%)	0-10	0.08 (0.00)	0.03 (0.01)	0.03 (0.01)
	40-50	0.07 (0.02)	0.03 (0.01)	0.04 (0.01)
OC (%)	0-10	1.21 (0.30)	1.25 (0.16)	0.88 (0.10)
	40-50	0.98 (0.01)	0.32 (0.11)	0.41 (0.15)
C:N ratio	0-10	10.77 (3.12)	9.66 (2.41)	11.57 (2.99)
	40-50	3.83 (1.36)	13.00 (0.19)	5.99 (2.02)
pH	0-10	6.3 (0.1)	5.2 (0.1)	5.2 (0.1)
	40-50	6.6 (0.1)	5.5 (0.1)	5.5 (0.1)
MC (%)	0-10	11.66 (0.70)	11.57 (1.21)	6.49 (0.12)
	40-50	13.83 (1.14)	10.50 (3.16)	9.22 (0.78)
BD (g/cm^3)	0-10	1.29 (0.07)	1.27 (0.10)	1.30 (0.06)
	40-50	1.31 (0.06)	1.27 (0.10)	1.31 (0.03)

Note: Standard deviations are in the parentheses.

potassium (K^+), sodium (Na^+) and calcium (Ca^{2+}) were not statistically different among the investigated stands. The soil texture of the top soil (0-10 cm) in the natural fores was sandy clay loam while sandy loam in the timber-harvested forest and degraded forest. Mean values of soil properties in 0-10 cm and 40-50 cm depths are shown in Table 6.

Discussion

A sample plot is considered representative when an enlargement of the sample area by 10 percent results in a species number increase less than 10 percent (Lamprecht, 1989). The species-area curves for all trees showed that sampling was adequate in all plots to provide representative estimates of species diversity in the study area (Figures 2a and b). This study indicated higher species richness of natural forest (71 species per ha). Zin (2000) reported that the species richness of natural forest in this study area (Oak-twin Township) was 80 species per ha whereas Kyaw (2003) showed 30 species per ha in the forests of Toungoo Township, which is adjacent to this area.

In this study, Shannon diversity indices of forests showed the highest value of 3.4 to 3.6 (Table 2) as compared with the previous studies, which had 2.7 and 2.8 (Zin, 2000; Kyaw, 2003). Simpson's diversity indices were approximately the same between this study and the previous ones. Higher diversity indices and species evenness were observed in the degraded forest as compared with the natural forest and timber-harvested forest. This reflects the monotypic characteristic of natural forest that *T. grandis* alone occupied 23.88 percent of total IVI. This result followed the previous studies 29.7 percent and 28.0 percent (Zin, 2000; Kyaw, 2003). This might be because of the forest management system (i.e. MSS) that favored *T. grandis* and few commercial timber species very much.

Although the diameter distribution of the investigated forests had exhibited a normal pattern of forests, that of *T. grandis* and other commercial species showed abnormal pattern. It means the numbers of trees in small diameter classes of *T. grandis* and other commercial species were less than those of big diameter classes in all forests although the natural regenerations were abundant. Vertical stand structure also supported these findings that the young stage trees as well as the number of species in the lower storey were less than the middle and upper storeys. This result followed the observations of the previous studies (Keh, 1993; Gyi and Tint, 1998; Zin, 2000; Kyaw, 2003). Repeated logging in the accessible areas contributed to the declined number of commercial growing stocks and the abnormal stand structure. Other possible causes might be the repeated several annual forest fire, delayed felling cycles, felling damages, and fuelwood crisis. Since the young stage trees of these species for succession were missing, the sustainable production of *T. grandis* and other commercial timber species could be a problem in the near future. On the other hand, the yields of *T. grandis* and other commercial timber will drop in the following felling cycle.

Except soil acidity, available phosphorus (P) and magnesium (Mg^{2+}), other soil properties were not significantly different among the investigated forests (Table 6). But further researches are still needed to monitor the changes of soil properties in relation to the tree species composition, stand structure and disturbances.

Conclusions

This study analyzed the tree species composition and stand structure of the natural forest, timber-harvested forest and degraded forest. In addition, the stand diameter distributions of commercial species were investigated in order to support the country's sustainable forest management. This study indicated the abnormal distributions of the stand diameter classes of *T. grandis* and other commercial tree species. Tree population needs to be maintained in a desirable stand structure with higher number of small trees and sloping down as the size increases. We urgently need to treat the forests with great care as mismanagement may lead to irretrievable consequences. Thus, we suggested that the current silvicultural practices adopted in the natural forest should be reviewed to restock *T. grandis* including other commercial timber species properly.

Acknowledgements

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