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Effects of Selective Logging on Species Diversity, Composition, Stand Structure and Natural Regeneration in Old Growth Forest and Logged Forests

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သစ်မထုတ်ရသေးသောတောနှင့်ထုတ်ပြီးတောများ၏ သစ်မျိုးစုံကြွယ်ဝမှု ၊ အပင်များ ပေါက်ရောက်မှု ၊ ပင်ထောင်နှင့်မျိုးဆက်ပင်များအပေါ် ရွေးချယ်ခုတ်လှတ်ခြင်းစနစ်၏ အကျိုးသက်ရောက်မှုအားလေ့လာခြင်း

ဒေါ်ရတနာဆွေ၊ တောအုပ်ကြီး
သစ်တောဦးစီးဌာန

စာတမ်းအကျဉ်းချုပ်

သစ်ထုတ်ခြင်းသည် သဘာဝတောအတွင်းရှိ အရေးပါသောသစ်မျိုးများကို ခုတ်လှဲခြင်းနှင့် တောကို သဘာဝအတိုင်းမျိုးဆက်နိုင်ရန်အတွက် ဆောင်ရွက်သောလုပ်ငန်းတစ်ခုဖြစ်ပါသည်။ ဤစာတမ်း၏ ရည်ရွယ်ချက်မှာ သစ်မထုတ်ရသေးသောတောနှင့် သစ်ထုတ်ပြီး (၅)နှစ်နှင့် သစ်ထုတ်ပြီး(၁၀)နှစ်တော များ၏ သစ်မျိုးများ ပါဝင်ပေါက်ရောက်မှု၊ ပင်ထောင်များ၏တည်ဆောက်ပုံနှင့် မျိုးဆက်ပင်များ၏ အခြေ အနေကိုလေ့လာရန်ဖြစ်ပါသည်။ ဤသုတေသနကို ကယားပြည်နယ်၊ ရှားတောမြို့နယ်ရှိ အရှေ့သံလွင် (၁)ကြိုးပြင်ကာကွယ်တောတွင် သစ်မထုတ်ရသေးသောတော၊ သစ်ထုတ်ပြီး (၅)နှစ်နှင့် သစ်ထုတ်ပြီး (၁၀)နှစ်တောများ၏ သစ်မျိုးများပေါများမှု၊ ပါဝင်ပေါက်ရောက်မှု၊ ပင်ထောင်များ၏ အခြေအနေနှင့် မျိုးဆက်ပင်များကို နှိုင်းယှဉ်လေ့လာခဲ့ပါသည်။ တစ်ကေလျှင် ၂၅မီတာပတ်လည် နမူနာကွက် (၁၆)ကွက် ကောက်ယူပြီး စုစုပေါင်းအကွက် (၄၈)ကွက် (၃ ဟတ်တာ) ကောက်ယူခဲ့ ပါသည်။ ထိုနမူနာကွက်များတွင် အပင်ကြီး၊အပင်လတ်နှင့် အပင်ငယ်(မျိုးဆက်ပင်)များကို သစ်ပင်အမျိုးအစားခွဲခြင်း၊ လုံးပတ်တိုင်း တာခြင်းနှင့် အမြင့်တိုင်းတာခြင်းတို့ပြုလုပ်ခဲ့ပါသည်။ သစ်ထုတ်ပြီးသည့်တောများသည် သစ်မထုတ်ရ သေးသောတောထက် သစ်ပင်မျိုးစိတ်များ ပေါများစွာ တွေ့ရှိရပါသည်။ ထို့အပြင် သစ်ပင်ပါဝင်ပေါက် ရောက်မှုများလည်း ကွာခြားမှုရှိကြောင်းတွေ့ရှိရပြီး မျိုးဆက်ပင်များ၏ အရေအတွက်မှာလည်း သစ်ထုတ်ပြီး (၅)နှစ်တွင် အများဆုံးတွေ့ရှိရပါသည်။ ဤသုတေသနသည် ရွေးချယ်ခုတ်လှဲခြင်းစနစ်၏ သဘာဝတောအတွင်းရှိ သစ်မျိုးများအပေါ် အကျိုးသက်ရောက်မှုကို လေ့လာသိရှိနိုင်ပြီး ရေရှည်တည်တံ့သော သစ်တောစီမံအုပ်ချုပ်မှုကို အထောက်အပံ့ဖြစ်စေရန် ရည်ရွယ်ပါသည်။

Effects of Selective Logging on Species Diversity, Composition, Stand Structure and Natural Regeneration in Old Growth Forest and Logged Forests

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Abstract

Selective logging is the practice of harvesting the most important timber species in natural forests while allowing the remaining forest to regenerate naturally over time. The aim of this study is to determine how far the logged forest changes in species diversity, regeneration and soil properties from old growth forest. This study was conducted in compartment 28 (5 years post logged forest, L5), compartment 27 (10 years post logged forest, L10) and old growth forest (OGF) in No (1) Eastern Than Lwin Protected Public Forest, Shartaw Township, Kayah State. This study compared the species diversity, composition, stand structure and natural regeneration of 5 years and 10 years following selection logging with old growth forest. 16 plots of 25 m × 25 m are randomly set up in each study site and total 48 plots (3ha) for three study sites. Diameter at breast height and height of all trees (DBH ≥ 5cm, height ≥ 1.3 m), saplings (DBH < 5 cm, height ≥ 1.3 m) and seedlings (height between 0.3 m and 1.3 m) were measured and identified. Logged forests had higher diversity indices such as species richness, Simpson index, Shannon-Wiener index and Shannon evenness values than old growth forest. Tree species composition was also different between logged and old growth forest. Teak (*Tectona grandis*) had the highest IVI value and dominant in OGF while In (*Dipterocarpus tuberculatus*) and Than-de (*Stereospermum personatum*) were dominant in L5 and L10 respectively. The stand structure of all study sites showed reversed J-shaped pattern. There was significant difference ($p < 0.05$) in natural regeneration density between logged and old growth forest. L5 had the highest natural regeneration density (852 trees ha^{-1}) followed by L10 (345 trees ha^{-1}) and OGF (326 trees ha^{-1}). These results indicate that selective logging had considerable effects on vegetation and these effects should be considered to implement the sustainable forest management.

Key words: Diversity, Natural regeneration, Selective logging, Species composition, Stand structure

Effects of Selective Logging on Species Diversity, Composition, Stand Structure and Natural Regeneration in Old Growth Forest and Logged Forests

1. Introduction

Selective logging is a predominant timber harvesting practice and an important contributor to the economies of most tropical countries (Asner et al., 2009; Poudyal et al, 2018). It involves periodic removal of valuable timber trees of a specified minimum felling diameter. The number of trees to be harvested differs from one country to another and at different harvesting cycles (Poudyal et al., 2018). Taxonomically, selective logging can shift the composition and relative abundance of species (Baraloto et al, 2012), including a reduction in species richness (Clark and Covey, 2012).

The effects of selective logging include the direct effect of tree felling and associated damage to the residual stand where a large proportion of the remaining vegetation is killed or damaged. The removal of a significant number of mature trees reduces potential seed sources for the subsequent regeneration. Moreover, commercial logging is commonly blamed for the major causes of primary rainforest destruction in Southeast Asia and Africa. Importantly, loggings facilitate or trigger the direct conversion of forests to other land use such as pasture and agriculture.

The extent and severity of harvesting impacts depend on a number of factors, such as inherent soil properties, topography, the type of operation (i.e. whether the forest was selectively logged or it was clear felled, ground-based or cable-logged), the type of machinery used, the frequency of machine passes and the forest conservation practices being employed (Servadio, 2010; Sowa and Kulak, 2008).

Selective logging may change the original species composition of trees via the removal of large trees and the subsequent recruitment of early successional tree species. However, the impacts of selective logging on tree biodiversity are still controversial. Putz et al, (2012) showed that trees species richness remains unchanged just after selective logging, while Gibson et al, (2011) showed that selective logging decreased plant biodiversity.

Natural regeneration is critical for the colonization and establishment of native tree species, as well as the recovery of forests after disturbances. Understanding the dynamics of natural regeneration following selective logging is crucial for sustainable forest management (Wagner et al., 2018) since the recovery and maintenance of desired native species composition are supposed to be enhanced by the current selective logging system.

In Myanmar, natural forests are still the country's primary source of production of timber and non-wood forest products. Selective logging is the most popular and widely employed approach for commercial timber production in natural forests of South-East Asia (Okuda et al., 2003). The systematic management of the natural forests in Myanmar was initiated since 1856, recording a long history of about 150 years. The Myanmar Selection System (MSS), formerly known as the Burma Selection System is an exploitation-cum-cultural system with the main features being to carefully protect the immature stock and assist it to attain maturity (Dah, 1999).

Myanmar Selection System involves adoption of felling cycles of 30 years, prescription of exploitable trees, girdling or marking of exploitable trees, selection marking of other non-teak hardwoods, thinning of congested teak stands, removal of other trees interfering with the growth of both young and old teak, enumeration of future yield trees down to fixed sizes, leaving high quality teak tree as mother tree (seed tree) and monitoring forests for fixing Annual Allowable Cut (AAC) for teak and hardwoods.

In MSS, the forest area is divided into 30 blocks of equal yield capacity. Each year, selective logging is carried out in one of these blocks and the whole forest is, therefore, worked over the felling cycle of 30 years. Under this system, when felling becomes due, all marketable trees that have attained a fixed exploitable girth limits are selected for cutting. For teak, the girth limit varies with the type and status of the forests. In good (moist) teak forests, the girth limit at breast height (1.3 m) is 73 cm DBH and in poor (dry) teak forests 63 cm DBH (Dah, 2004). The girth limit for other hardwoods varies with the species, but mostly 58-78 cm. Unhealthy trees which have not attained these exploitable sizes, but are marketable, are also selected for cutting if they are unlikely to survive during the subsequent felling cycle. If seed-bearers are scarce, a few high quality stems of and above exploitable size may be retained as seed trees.

The ultimate goal of forest management is to achieve sustainability. For the sustainable management of forest, it is important to understand the forest structure and regeneration of the forest. Detailed information of forest structure and floristic composition is needed in order to delineate guidelines for forest management and conservation, to understand stand dynamics, and to assess their potential for maintenance of tree species diversity. However, the effects of selective logging on the structure, dynamics and recovery of forests remain uncertain (Bonnell et al., 2011). This uncertainty calls for a thorough understanding of the effects of selective logging on forest regeneration, both in terms of structure and composition.

2. Objectives

The main objective of the study is to determine how far the logged forest changes in species diversity, composition, stand structure and natural regeneration from old growth forest. To fulfill the main objective the following specific objectives were set:

The specific objectives are:

i. To investigate tree diversity, species composition and stand structure in logged and old growth forests

ii. To analyze the natural regeneration in logged and old growth forests

3. Materials and Methods

3.1 Description of the Study Area

Kayah State is situated in eastern part of Myanmar and it is bounded on the north by Shan State, on the east by Thailand and on the south and west by Kayin State. Total land area of the state is about 4,529.61 square miles (11731.64 square kilometers). It lies approximately between 18° 30' and 19° 55' north latitude and between 94° 40' and 97° 93' east longitude. The state is blessed with a topographical mix of flat plains and mountainous areas; Kayah State is a woody and mountainous region. Indigenous trees of Kayah State include teak, pyinkado, pine, hard woods, and varieties of bamboo, medicinal plants and flowers.

The study area is situated in No.1 Eastern Than Lwin Protected Public Forest, Shartaw Township, Loikaw District in Kayah State. It is located at approximately the latitude 18° 30' to 19° 55' N and longitude 94° 40' to 97° 93' E. Three study sites were selected in Compartment 28; 5 years post logged forest (L5) and Compartment 27; 10 years post logged forest (L10), old growth forest (OGF). Timber extraction was conducted in 2013-2014 fiscal-year in L5 and 2008-2009 fiscal-year in L10. (Myanmar Timber Enterprise, Kayah Extraction)

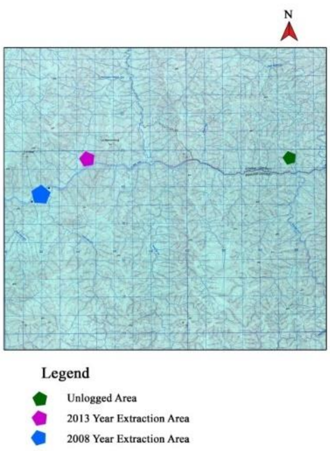


Figure 1. Map of the study area

Source: Kayah State, Forest Department

The forests in the study area belong to moist upper mixed deciduous forest. Teak (*Tectona grandis*) and other commercially important species such as Pyinkado (*Xylia xylocarpa*), Gyo (*Schleichera oleosa*), In (*Dipertrocarpus tuberculatus*), Thitya (*Shorea obtuse*), Ingyin (*Shorea siamensis*), Than-de (*Stereospermum personatum*) and Padauk (*Pterocarpus macrocarpus*) are mainly grown in association with Waphu (*D. membranaceus*) and Tinwa (*Cephalostachyum pergracile*).

3.2 Data Collection

Vegetation assessment was conducted in Compartment 28 (5 years post logged forest) Compartment 27 (10 years post logged forest) and old growth forest. By using simple random sampling design, sample plots were set in old growth forest, 5 years post logged and 10 years post logged forests. In each study site, 16 plots of 25 m × 25 m were laid out and total 48 plots (3 ha) for three sites. Data were collected during February and March 2019. In each plot, trees ≥ 5 cm DBH and ≥ 1.3 m in height are investigated, identified the species name and measured their height and DBH. Tree (DBH ≥ 5 cm and Height ≥ 1.3 m), Seedling (Height 0.3 m-1.3 m) and sapling (DBH < 5 cm and Height ≥ 1.3 m) were also enumerated, identified and measured their height and DBH.

Trees are identified to the species level during the field work with the assistance of local Forest Department, villagers and field staff working in Myanma Timber Enterprise, and then further checked with “A Checklist of the Trees, Shrubs, Herbs and Climbers of Myanmar” (Kress et al., 2003).

4. Results

4.1 Tree Species Diversity and Composition

Species-area relationship serves as a useful tool for exploring the patterns of biological diversity. Species-area relations can provide evidence for community structure and have been used as an expression of heterogeneity (Batllori et al., 2009). The slope of the species-area curve depends on the rate at which new species are encountered. The species-area curve is the best maker in assessing plant habitat diversity in a survey area. It can be used to determine sample size by plotting number of species against number of sample units. The minimum representative area should be regarded that expansion of sample area by 10% found in a species number increase less than 10% (Cain and de Oliveria, 1956). Lamprecht, 1989 suggested that the species area curves with stems (DBH ≥ 10 cm) are adequate to assess the minimum survey area. However, for the analysis of stand structure and dynamics processes, smaller trees including young trees are also needed to be surveyed. Therefore, species area curves were drawn to show a representative sample of species composition. In this study, species area-curves were drawn based on trees which had attained ≥ 1.3 m in height and ≥ 5 cm in DBH with a total area of one hectare per type.

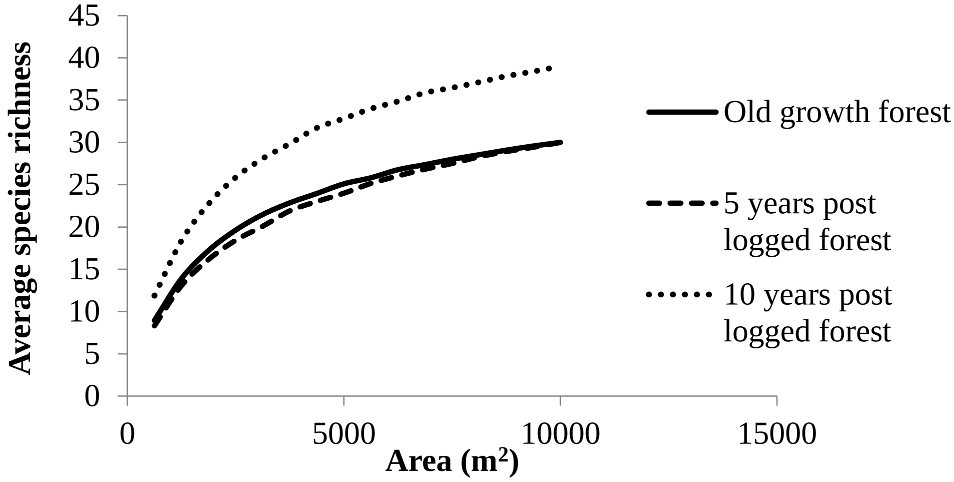


Figure 2. Species-area curves for OGF, L5 and L10

Figure 2. shows species area-curve for three study sites, in which 10 years post logged forest (L10) has the highest number of species than the other two sites. However, old growth forest (OGF) and 5 years post logged forest (L5) have similar average number of species but lower than L10. The number of species increases continuously until 4000 m^2 (OGF and L5) and 6000 m^2 (L10). In L5, the number of species noticeably raised until the area of 10,000 m^2. OGF has 30 species, L5 has 33 species and 39 species are found in L10. Based on the result, the species area-curves for all study sites indicated the representative area and it can be said that sampling area is enough for vegetation analysis.

4.1.2 Species Diversity

Table 1. Diversity Indices (Simpson, Shannon-Wiener and Evenness) for the Investigated Stands (all trees with DBH ≥ 5 cm)

Study site	**Species (n)**	**Diversity indices**		
		Simpson (D)	**Shannon-Wiener (H')**	**Evenness (J')**
OGF	30	0.81	2.26	0.67
L5	33	0.91	2.73	0.75
L10	39	0.94	3.02	0.82

OGF= Old growth forest, L5= 5 years post logged forest, L10= 10 years post logged forest

L10 has the highest tree species richness (39 species ha^{-1}), L5 has (33 species ha^{-1}) and OGF has the lowest species richness (30 species ha^{-1}). The result shows that L10 is the most complex in terms of species diversity. L10 has the highest Simpson value 0.94, Shannon-Wiener value 3.02, Shannon evenness value 0.82. OGF has the lowest Simpson value 0.81, Shannon-Wiener index value 2.26 and Evenness value 0.67 while L5 has Simpson value 0.91, Shannon value 2.73 and Evenness value 0.75. L10 has the highest diversity indices value compared with OGF and L5 (Table 1).

Table 2. Statistical Analysis of Diversity Indices for OGF, L5 and L10

Study site	Species richness	Simpson index	Shannon-Wiener index	Evenness
OGF vs L5	ns	ns	ns	ns
OGF vs L10	ns	*	ns	*
L5 vs L10	*	**	*	**

* ($p < 0.05$)   ** ($p < 0.001$)   ns (no significant different)

According to ANOVA, there are significant differences in diversity indices between old growth forest and logged forests ($p < 0.05$). Tukey test showed that there is significant difference in diversity indices between OGF and L10. However, there is no significant difference in diversity indices between OGF and L5 (Table 2).

4.1.3 Species Composition

Knowledge of species composition and diversity of tree species is of utmost importance not only to understand the structure of a forest community but also for planning and implementation of conservation strategy of the community (Malaik et al, 2014). Forests and their resilience were measured by analyzing tree species composition and species abundance. In order to compare species, the importance value index (IVI) developed by Curtis and McIntosh , (1951) was applied.

Important value index (IVI) is used as a tool to accurately indicate and identify the important species in a community. Important value index is the sum of relative abundance, relative dominance and relative frequency. IVI can be mathematically expressed as follow:

IVI = relative abundance+ relative dominance+ relative frequency

Where,

Relative abundance = $\frac{\text{Number of individuals per species}}{\text{Total number of individuals}} \times 100$

$$\text{Relative dominance} = \frac{\text{The sum of the individual stem basal area per species}}{\text{Total measured stem basal area}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Percentage of species occurrence in all subplots}}{\text{Total of the absolute frequency}} \times 100$$

Table 3. Most Important Tree Species (IVI) of OGF (all stems with DBH ≥ 5 cm)

Species	**Relative**			**IVI (%)**
	Abundance (%)	**Dominance (%)**	**Frequency (%)**	
Tectona grandis	30.53	39.54	10.56	80.63
Xylia xylocarpa	12.61	12.22	9.86	34.69
Schleichera oleosa	10.64	2.45	9.15	22.25
Homalium tomentosum	4.20	7.45	5.63	17.29
Shorea siamensis	3.92	8.86	2.82	15.60
Sterculia angustifolia	3.92	2.74	5.63	12.29
Spondias pinnata	3.08	4.10	4.93	12.11
Melanorrhoea usitata	3.36	2.96	5.63	11.96
Pterocarpus macrocarpus	2.52	2.99	4.93	10.44
Lagerstroemia tomentosa	3.64	1.17	4.93	9.74
Bischofia javanica	2.80	2.42	3.52	8.74
Terminalia chebula	2.52	3.34	2.82	8.68
Michelia champaca	3.08	2.05	3.52	8.66
Stereospermum personatum	2.24	1.54	3.52	7.30
Terminalia tomentosa	1.68	2.14	2.82	6.63
Other species	9.24	4.04	19.72	33.00
Total	100.00	100.00	100.00	300.00

In old growth forest, there are 19 families, 357 individuals belonged to 30 species. In OGF, the most dominant species is Teak (*Tectona grandis*) with 39.54% relative dominance and relative frequency of 10.56% has the highest IVI value of 80.63% (Table 3). Therefore, it can be said that the forest is a single species dominated stand. The next two dominant species are Pyinkado

(*Xylia xylocarpa*) and Gyo (*Schleichera oleosa*) represented IVI value of 34.69% and 22.25%. The lowest IVI value is found in Thanut (*Cordia dichotoma*) having 1.03% of total IVI. The species that have low IVI values are Thitya (*Shorea obtusa*), Thit-sein (*Terminalia bellerica*) and Thapan-pin (*Ficus chittagonga*).

Table 4. Most Important Tree Species (IVI) of L5 (all stems with DBH ≥ 5 cm)

Species	**Relative**			**IVI (%)**
	Abundance (%)	**Dominance (%)**	**Frequency (%)**	
Dipterocarpus tuberculatus	23.93	29.64	7.52	61.09
Shorea obtusa	23.08	25.05	7.52	55.65
Shorea siamensis	13.89	20.40	9.02	43.31
Stereospermum personatum	5.98	4.28	9.02	19.29
Melanorrhoea usitata	4.70	4.50	7.52	16.72
Vitex canescens	6.84	1.26	6.77	14.86
Pterocarpus macrocarpus	2.99	1.84	6.77	11.60
Terminalia chebula	3.21	0.83	6.02	10.05
Podocarpus neriifolius	2.14	2.26	3.01	7.40
Homalium tomentosum	1.50	2.81	3.01	7.31
Sterculia angustifolia	1.50	0.26	4.51	6.27
Schleichera oleosa	1.28	0.65	3.76	5.69
Xylia xylocarpa	1.07	1.35	3.01	5.42
Terminalia tomentosa	0.85	1.65	2.26	4.76
Antidesma bunius	0.85	0.45	2.26	3.56
Other species	6.20	2.78	18.05	27.02
Total	100.00	100.00	100.00	300.00

There are 472 stems, 33 species belonging to 23 families in L5. In (*Dipterocarpus tuberculatus*) with the highest number of relative dominance is the most dominant species having the highest IVI value of 61.09%. In (*Dipterocarpus tuberculatus*), Thitya (*Shorea obtusa*) and Ingyin (*Shorea siamensis*) are the most ecologically important species with the largest IVI values. The lowest IVI value of 0.01% is found in Chinyok (*Garuga pinnatta*).

Table 5. Important Tree Species (IVI) of L10 (all stems with DBH ≥ 5 cm)

Species	Relative			IVI (%)
	Abundance (%)	Dominance (%)	Frequency (%)	
Stereospermum personatum	15.53	12.37	8.42	36.32
Pterocarpus macrocarpus	8.24	10.72	6.32	25.27
Schleichera oleosa	8.08	7.44	6.84	22.36
Xylia xylocarpa	5.86	4.44	6.32	16.62
Shorea siamensis	2.85	10.72	2.63	16.20
Michelia champaca	7.13	3.79	4.74	15.66
Terminalia chebula	5.07	3.84	5.26	14.17
Melanorrhoea usitata	5.86	3.59	3.16	12.61
Dipterocarpus tuberculatus	4.44	6.76	1.05	12.25
Anogeissus accuminate	3.33	4.51	3.16	11.00
Dalbergia fusca	3.65	3.48	3.68	10.81
Tectona grandis	2.54	4.56	3.16	10.26
Bauhinia sulphurea	2.38	2.96	4.21	9.55
Homalium tomentosum	2.54	3.21	2.63	8.38
Grewia tiliifolia	2.54	2.27	3.16	7.97
Other species	19.97	15.35	35.26	70.58
Total	100.00	100.00	100.00	300.00

L10 possesses a total of 631 individuals, which belonged to 39 species and 22 families. In L10, Tha-de (*Stereospermum personatum*) and Padauk (*Pterocarpus macrocarpus*) are the most ecologically significant species based on their IVI values. Tha-de (*Stereospermum personatum*) has a higher dominance (12.37%) and an important value of 36.32%. Thapan-pin (*Ficus chittagonga*), Thanut (*Cordia dichotoma*) and Okshit (*Aegle marmelos*) show the lower IVI value of 0.91%, 0.86% and 0.8% respectively. Binga (*Mitragyna rotundifolia*) has the lowest IVI value of 0.73%.

4.2 Forest Structure

4.2.1 Horizontal Stand Structure by Diameter Class Distribution

Understanding of forest structure is a prerequisite to describe various ecological processes and also to model the functioning and dynamics of forests. Assessment of forest community composition and structure is very helpful in understanding the status of tree population, regeneration, and diversity for conservation purposes (Mishra et al., 2013). Stand structure involves vertical (e.g. number of tree layers) and horizontal features (e.g. spatial pattern of trees). Both horizontal and vertical structure of the forest is essential for management planning to achieve the sustainable production of timber and ecosystem stability. The horizontal structure of a forest can be measured by diameter class distribution of tree species individually or as a community.

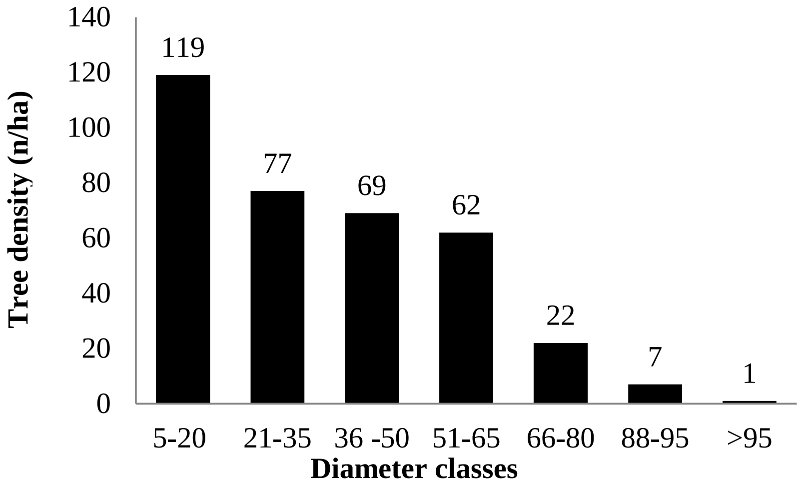


Figure 3. Diameter class distribution of old growth forest

In old growth forest, the highest tree density (119 trees ha^{-1}) is occurred in the smallest diameter class (5-20 cm). The intermediate diameter classes are characterized by tree densities of 69, 62, 22, 7 and 1 in 36-50 cm, 51-65 cm, 66-80 cm, 81-95 cm and ≥ 95 cm, respectively. This may be due to the fact that OGF has enough young stage trees to substitute for old trees.

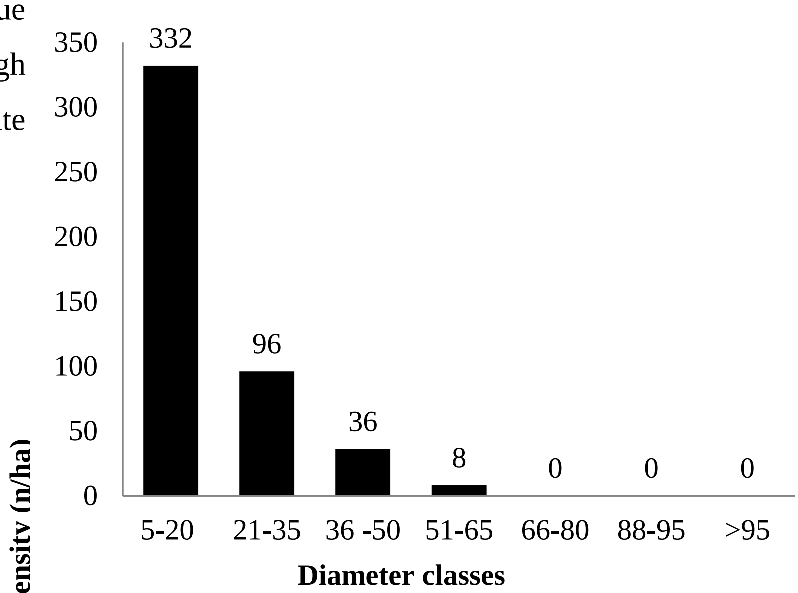


Figure 4. Diameter class distribution of 5 years post logged forest

In L5, the largest number of trees 332 stems is occurred in the smallest diameter class (Figure 4). In the middle diameter classes, tree densities gradually decrease from 96 stems (21-35 cm) to 8 stems (51-65 cm). The horizontal stand structure of trees showed a reverse J-shaped distribution with decreasing density and with increase in girth.

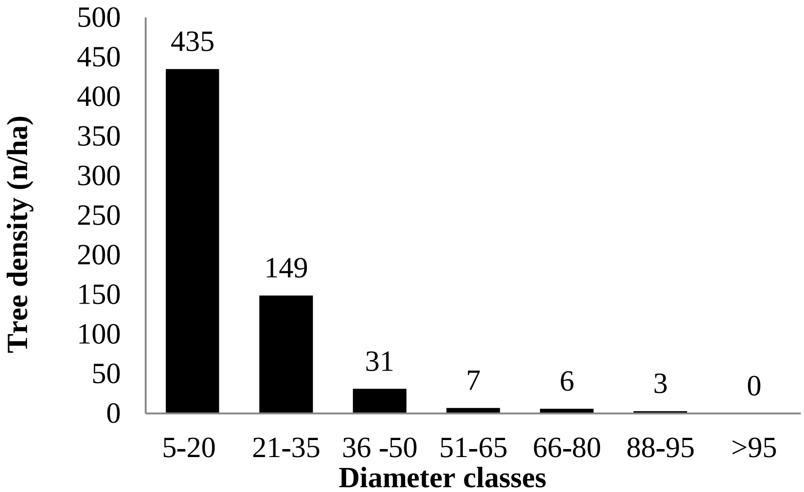


Figure 5. Diameter class distribution of 10 years post logged forest

In L10, the smallest diameter class (5-20 cm) presented 435 stems (Figure 7). The tree densities gradually decrease from 149 (21-35 cm) to 3 stems (88-95 cm).

4.2.2 Vertical Stand Structure

Vertical stand structure displays as the bottom-to-top configuration of above-ground vegetation into layers between the ground and canopy. Stand vertical structure is widely used in analyzing a forest community and forest management. IUFRO classification scheme is used to distinguish the vertical structure of the investigated stands by the following categories (Lamprecht, 1989).

Upper storey (US) = tree height > 2/3 of the top height

Middle storey (MS) = 2/3 of the top height < tree height > 1/3 of the top height

Lower storey (LS) = tree height < 1/3 of top height

Table 6. Distribution of Tree Species, Tree Abundance and Basal Area Classified by Canopy Layers in OGF (all stems with DBH ≥ 5 cm)

Storey	Tree height (m)	Tree species		Tree abundance		Basal area	
		No.	%	No.	%	m^2 ha^{-1}	%
Upper	> 28.53 m	8	26.67	65	18.21	17.82	37.80
Middle	> 14.27 m < 28.53 m	24	80.00	175	49.02	26.09	55.35
Lower	< 14.27 m	25	83.33	117	32.77	3.23	6.85
Total		30		357	100.00	47.13	100.00

The vertical stratification of OGF can be classified into three storeys by using IUFRO classification. OGF has the tallest tree, Teak (*Tectona grandis*) with the height of 42.8 m. As shown in Table 6, the upper storey consists of minimum number of tree species and abundance. A total of 8 species, Teak (*Tectona grandis*), Myauk-chaw (*Homalium tomentosum*), Padauk (*Pterocarpus macrocarpus*), Panga (*Terminalia chebula*), Pyinkado (*Xylia xylocarpa*), Gwe (*Spondias pinnata*), Ingyin (*Shorea siamensis*) and Tha-de (*Stereospermum personatum*) with a total of 65 individuals occur in the upper storey. The middle storey represents the highest number of tree abundance and basal area. About 24 species and 175 individuals belong to the middle storey and all these stems contribute to 55.35% of total basal area. The lower storey consists of 117 stems of 25 species.

Table 7. Distribution of Tree Species, Tree Abundance and Basal Area Classified by Canopy Layers in L5 (all stems with DBH ≥ 5 cm)

Storey	Tree height (m)	Tree species		Tree abundance		Basal area	
		No.	%	No.	%	m^2ha^{-1}	%
Upper	> 20.87 m	7	23.33	37	7.84	3.39	20.53
Middle	> 10.43 m < 20.87 m	22	73.33	204	43.22	10.05	60.88
Lower	< 10.43 m	26	86.67	231	48.94	3.07	18.59
Total		33		472	100.00	16.51	100.00

In L5, Thitya (*Shorea obtusa*) is the highest tree with the height of 31.3 m (Table 7). A total of 7 species, Thitya (*Shorea obtuse*), Thitsi (*Melanorrhorea usitata*), Ingyin (*Shorea* *siamensis*), In (*Dipterocarpus tuberculatus*), Kyet-yo (*Vitex canescens*), Tauk-kyan (*Terminalia tomentosa*) *and* Myauk-chaw (*Homalium tomentosa*), with a total of 37 individuals occur in upper storey. The middle storey represents 22 species and 204 individuals with the highest basal area. The lower storey consists of 26 species and 231 individuals representing the highest tree species and abundance.

Table 8. Distribution of Tree Species, Tree Abundance and Basal Area Classified by Canopy Layers in L10 (all stems with DBH ≥ 5 cm)

Storey	**Tree height (m)**	**Tree Species**		**Tree abundance**		**Basal area**	
		No.	**%**	**No.**	**%**	**m^2 ha^{-1}**	**%**
Upper	> 26.33m	15	38.46	29	4.60	4.25	17.66
Middle	> 12.37m < 26.33m	33	84.62	328	51.98	16.63	69.12
Lower	< 12.37m	33	84.62	274	43.42	3.18	13.22
Total		39		631	100.00	24.06	100.00

In L10, the maximum number of species, tree abundance and basal area are found in middle storey (Table 8). More than 60% of total basal area (16.63 m^2 ha^{-1}) is recorded in the middle storey. The highest tree is Tauk-kyan (*Terminalia tomentosa*) with the height of 39.5 m. The upper storey consists of minimum number of species and tree abundance. The lower storey consists of 274 stems of 33 species.

4.3 Natural Regeneration

Regeneration is a key process for the existence of species in a community under varied environmental conditions. In forest management, the study of regeneration not only depicts the current status but also hints about the possible changes in forest composition in the future (Malik and Bhatt, 2016). The abundance of natural regeneration is shown in Table 9. Natural regeneration (seedlings and saplings) density is 326 trees ha^{-1} in OGF, whereas 852 trees ha^{-1} in L5 and 345 trees ha^{-1} in L10. The higher abundance of seedlings and saplings are found in L5 compared with others. This may be due to selective logging which creates gaps and more growing space for recruitment and growth of seedlings and saplings and leading to significantly higher density of natural regeneration. In all study sites, the number of seedlings density is lower than that of saplings.

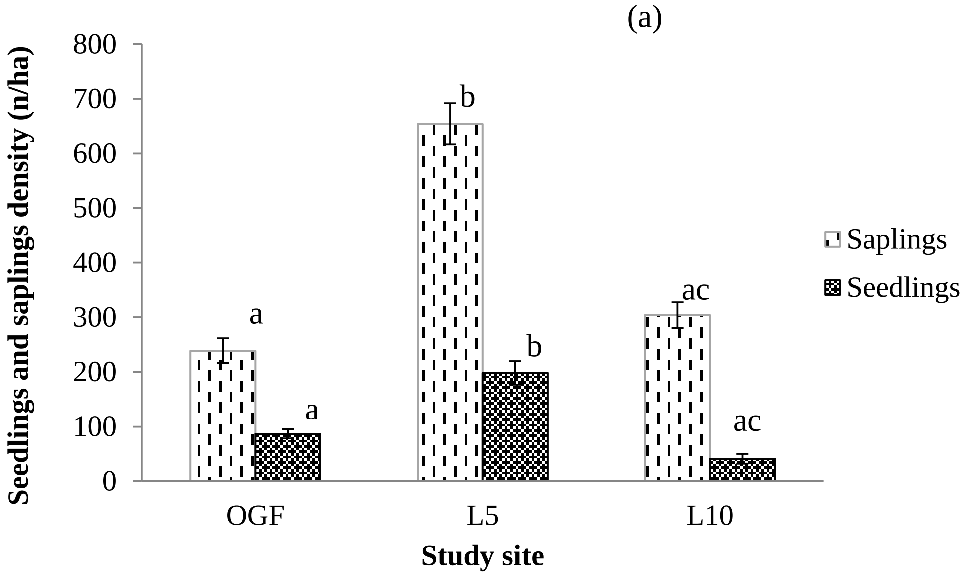
Table 9. Abundance of Natural Regeneration in Study Site

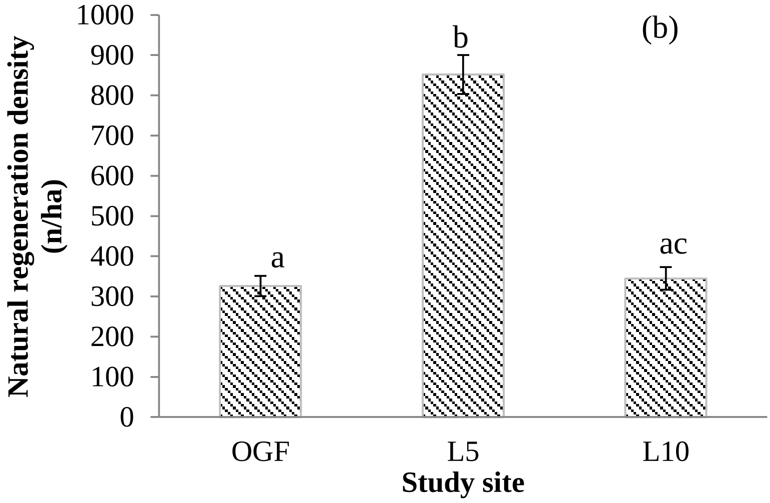
Study site	Abundance

	Seedlings		Saplings	
	n ha^{-1}	SD	n ha^{-1}	SD
Old growth forest	87	± 4.23	239	± 11.28
5 years post logged forest	198	± 10.76	654	± 18.85
10 years post logged forest	41	± 4.49	304	± 11.69

Seedlings were classified as woody stems with the total height ≥ 0.3 m and < 1.3 m

Saplings were classified as woody stems with the total height ≥ 1.3 m and DBH < 5 cm





Note: Different letters indicate significant difference among the forests according to Tukey tests at 5% level of probability. Open bar indicates the standard error.

Figure 6. (a) Seedlings and saplings density and (b) natural regeneration density of three study sites

5.Discussion

5.1 Species diversity and composition

Tree species diversity is an important aspect of forest ecosystem diversity and is also fundamental to tropical forest biodiversity (Evariste et al., 2010). Species diversity was significantly influenced by forest structure and species composition (Huang et al., 2003) and high species diversity is often connected to more complex vertical structure. Diversity indices were calculated for OGF, L5 and L10. Logged forests have higher diversity indices compared with OGF. L10 has highest diversity indices followed by L5. OGF has the lowest diversity indices. This finding was agreement with the finding of Cannon, (1988) that high tree species richness in logged forest in West Kalimantan. One way analysis of variance (ANOVA) is used to analyze the significant differences in diversity indices between logged and old growth forests. According to ANOVA test, there are significant differences in diversity indices between old growth forest and logged forests. Post hoc, Tukey test showed that there is significant difference in Simpson index, Shannon-Wiener index, Shannon evenness and species richness values between OGF and L10. However, there is no significant difference in diversity indices between OGF and L5. L10 has the highest Simpson index, Shannon-Wiener index, Shannon evenness and Species richness compared with OGF and L5. According to the result, logged forests had higher species diversity than old growth forest.

Selective logging causes canopy gap formation which can profoundly influence species regeneration as well as the structure, dynamics, and composition of tropical secondary and old-growth forests (Brokaw and Busing, 2000). In OGF, teak (*Tectona grandis*) is the most dominant species with highest IVI. In L5, In (*Diperocarpus tuberculatus*) has the highest IVI and occupy the most dominant species. Than-de (*Stereospermum personatum*) is the most dominant species with the highest IVI in L10. Environmental changes resulting from selective logging must also modify the dynamics of the forest (Pinard, 2005), especially through increased growth of individuals, because more light reaches the lower strata of the forest (Duah-Gyamfi et al., 2014). Species composition is likely to differ in logged forests from primary forest due to a combination of random chance arrival of pioneers and alteration microclimatic conditions which influences recruitment, germination and establishment (Whitemore, 1984).

5.2 Horizontal Stand Structure

In this study, diameter class distribution of OGF, L5 and L10 follow a reverse J -shaped pattern. The reverse J -shape of forests' diameter class distribution indicates a stable species composition and a sustainable distribution in forest management. This illustrates the fact that these forests have enough young stage trees to substitute to the old trees. It is one of the most important factors for the sustainable harvesting of timber. Logged forests have higher tree density in lowest diameter class and few large trees in higher diameter class compared with old growth forest. Tree density (332 trees ha^{-1}) of the smaller diameter class (5-20 cm) in L5 is lower than L10 (435 trees ha^{-1}). In L5 and L10, larger diameter classes have lower or no stems occurred. Densities of trees with DBH > 66 cm in logged forests are much lower than that in old growth forest and this may be as a result of extracting large stems of commercially valuable tree species.

In Myanmar, the minimum DBH of trees to be harvested under MSS is 63 cm for the production of sustained yield. In this study, OGF exhibited the highest basal area coverage (47.13 m^2 ha^{-1}) since the number of larger diameter trees in OGF was higher than that of other two sites.

5.3 Vertical Stand Structure

According to the result of forest canopy stratification, the upper storey consists of minimum number of species, tree abundance and basal area. The middle layer of OGF and L10 has found the highest species composition, abundance and basal area compared with L5. The distribution of stock density and basal area in the three layers varied among the study sites. In OGF and L10, the highest tree density is found in the middle layer and lowest in the lower layer. The middle storey of OGF has the highest basal area compared with L5 and L10. Moreover, OGF has the highest basal area (47.14 m^2 ha^{-1}) followed by L10 (24.06 m^2 ha^{-1}) and L5 (16.51 m^2 ha^{-1}).

5.4 Natural Regeneration

The regeneration density of OGF, L5 and L10 are 326, 852 and 345 (n ha^{-1}). According to ANOVA test, there are significant differences in regeneration density among old growth forest and logged forests. Both sapling and seedling densities (n ha^{-1}) are significantly different among the sites (sapling: $p < 0.001$; seedling: $p < 0.05$). Tukey test shows that natural regeneration densities of OGF and L5 were significantly different ($p < 0.05$). There is also significant difference in natural regeneration densities between L5 and L10 ($p < 0.05$). In this study, L5 has the highest natural regeneration density because of selective logging which creates more gaps and more growing spaces for recruitment and growth of seedlings and saplings and leading to significantly higher density of natural regeneration. Although logging disturbance can encourage recruitment and growth of seedlings through gap formation, it is likely that such disturbance only has temporary impacts on seedling density as has been suggested in studies by Duah-Gyamfiet al., (2014) which found that numbers of seedlings were initially increased by logging disturbance. The density of regeneration in L10 (345 trees ha^{-1}) is lower than L5 (852 trees ha^{-1}). According to Kermode (1964), competing vegetation at ground level can result in tree regeneration failure. In moist deciduous forest, the undergrowth is very variable and if the canopy has been opened, the undergrowth become very dense and effectively prevents regeneration of trees. In Myanmar, natural tree regeneration is hampered by the heavy undergrowth of bamboo (Tewari, 1992). According to Saung, (2021) the basal area of bamboo culms had a direct negative association with the number of regenerated trees. Therefore, the lower regeneration density in L10 may be due to the heavy undergrowth of bamboo.

6. Conclusion

The main objective of the study is to determine how far the logged forest changes in species diversity, composition, stand structure and natural regeneration from old growth forest.

Species diversity indices such as Species richness, Simpson index, Shannon-Wiener index and Shannon Evenness values are calculated. Among the study sites, OGF has the lowest diversity indices value while L10 has the highest diversity indices. Species composition is different between logged and old growth forest. In OGF, Teak (*Tectona grandis*) 80.6% of total IVI value is the most dominant species occupying the highest IVI. In (*Dipterocarpus tuberculatus*) (61.1% of total IVI) and Than-de (*Stereospermum personatum*) (36.3% of total IVI) are the most dominant species occupying the highest IVI in L5 and L10 respectively. In natural tropical forest, one of the main steering mechanisms of natural regeneration is the gaps and are usually an important consequence for the forest dynamics and their magnitude can determine the level of changes in the floristic composition. The differences of tree composition among the sites may be due to the types of timber extracted during harvesting differed and influenced the damage of the residual forest during logging.

The horizontal stand structure of trees shows a reverse J-shaped distribution with decreasing density and with increase in girth. This pattern indicates that stands are developing and regeneration is occurring in the forest indicating a high potential for species substitution when mature trees in the dominant species die. Logged forests have higher tree density in lowest diameter class and few large trees in higher diameter classes compared with OGF. This is due to the removal of larger diameter class trees during selective logging. The horizontal stand structure of OGF shows favorable results by means of well stocked and diameter-frequency distribution compared with L5 and L10.

Natural regeneration densities of both logged and old growth forests are analyzed. According to the ANOVA test, there are significant differences in natural regeneration density between logged and old growth forest. L5 has the highest natural regeneration density comparison with OGF and L10. There is no significant difference in natural regeneration density between OGF and L10.

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