Government of the Union of Myanmar

Ministry of Forestry

Forest Department

Restoration of degraded forest ecosystems with special emphasis on stand structure analysis and enrichment planting techniques

Min Zaw Oo,

Dr. Myint Oo, Aung Win Tun, Kyaw Lwin, Than Soe Oo, and Thant Shin

Silviculture and Management Sub-division

Forest Research Institute

May, 2006

Acknowledgements

The authors would like to express sincere and profound thanks to the "ASEAN-Korea Environmental Cooperation Unit (AKECU)" for financial support to implement this research. Heartily thanks are due to Project Coordinator U Htun Paw Oo (Director, FRI), members of Restoration Research Team, and all of the field staff of Forest Management & Silviculture Sub-division of FRI for their contribution and invaluable assistance throughout the research project. Thanks are also extended to the staff of Yedashe Township Forest Office for their willing help that made the data collection in Coupe XIII in the Township smooth and convenient.

စာတမ်းအကျဉ်းချုပ်

ဤသုတေသနသည် အာဆီယံ-ကိုရီးယားပတ်ဝန်းကျင်ဆိုင်ရာ ပူးပေါင်းဆောင်ရွက်ရေး စီမံကိန်းအရ အဆင့်အတန်းနိမ့်ကျနေသောတောများကို ပြန်လည်ပြုစုပျိုးထောင်ခြင်းအတွက် ဆောင်ရွက်ခဲ့သော စီမံကိန်းလုပ်ငန်းများအနက် တစ်ခုဖြစ်ပါသည်။ အဆင့်အတန်းနိမ့်ကျနေသော တောများကို ပြန်လည်ပြုစုပျိုးထောင်ခြင်းအတွက်၊အထူးသဖြင့် သဘာဝတောတန်ဘိုးမြှင့် စိုက်ပျိုးနည်းနှင့်ပတ်သက်၍ အသုံးဝင်သော သတင်းအချက်အလက်များ ရရှိရန်ရည်ရွယ်ပါသည်။ ဤစာတမ်းတွင် သဘာဝတော၏အပင်ဖွဲ့စည်းပုံ၊ မျိုးဆက်မှုတို့ကို စာရင်းကောက်ယူခြင်းနှင့် အတန်းလိုက်တန်ဘိုးမြှင့် စိုက်ပျိုးနည်းစမ်းသပ်ခြင်းဟူI အပိုင်း (၂) ပိုင်းကို တင်ပြထား ပါသည်။ ပျဉ်းမနား နှင့် ရေတာရှည် မြို့နယ်များရှိ အဆင့်အတန်းနိမ့်ကျနေသော တောများမှ ကောက်ယူခဲ့သောကိန်းဂဏန်းများကို တွက်ချက်လေ့လာဆန်းစစ်ခြင်း ရလဒ်များအရ၊ လက်ရှိ တောများသည် ထုတ်လုပ်နိုင်မှုစွမ်းအား သိသာစွာကျဆင်းနေကြောင်း တွေ့ရသော်လည်း သင့်တင့်သော သစ်မျိုးပါဝင်ဖွဲ့စည်းမှု ရှိနေသေးကြောင်း တွေ့ရပါသည်။ အရေးကြီးသော သစ်မျိုး အပင်ကြီးများကို ထိန်းသိမ်းခြင်းဖြင့်လည်းကောင်း၊ သဘာဝတော တန်ဘိုးမြှင့်စိုက်ခင်းများ တည်ထောင်ပေးခြင်း ဖြင့်လည်းကောင်း ပြန်လည်ကောင်းမွန်လာနိုင်သည်ဟု သုံးသပ်ရပါသည်။ ပျဉ်းမနားမြို့နယ်တွင် အတန်းလိုက်ဖြည့်စွက်စိုက်ပျိုးနည်း စမ်းသပ်ကွက်တစ်ခု တည်ထောင်ခဲ့ပြီး အလင်းဖွင့်ပေးမှု (၃)မျိုးတွင် ကျွန်းနှင့်ပိတောက်တို့၏ ရှင်သန်ကြီးထွားမှု အခြေအနေကို လေ့လာခဲ့ပါသည်။တစ်နှစ်အကြာရလဒ်များအရပိတောက်သည်ကျွန်းထက် ကြီးထွားနှုန်းပိုမို ကောင်းမွန်ပြီး၊ သစ်မျိုးနှစ်မျိုးလုံးသည် အလင်းပိုမိုဖွင့်ပေးပိုင်ပါက ကြီးထွားနှုန်း ပိုမိုကောင်းမွန်စေကြောင်းတွေ့ရပါသည်။ သို့ရာတွင် ဤသုတေသနလုပ်ငန်းတို့၏ သဘာဝအရ နှစ်စဉ်တိုင်းတာမှတ်တမ်းတင်ထားပြီး၊ အချိန် ကာလကြာမြင့်မှသာ သစ်မျိုးသင့်တော်မှုနှင့် အလင်းဖွင့်ပေးမှု အသင့်တော်ဆုံးအခြေအနေတို့ကို ဆုံးဖြတ်ပေးနိုင်မည် ဖြစ်ပါသည်။

Abstract

This research is a part of the ASEAN-Korea Environmental Cooperation Project (AKECOP) entitled "Restoration of Degraded Forest Ecosystems in Southeast Asian Tropical Regions". The study aims to provide relevant information, especially of enrichment planting, and to suggest appropriate measures for the restoration of degraded forest ecosystems. In this paper, two major components of the Project, namely, assessment of stand characteristics and regeneration, and enrichment planting experiment are focused. Following the assessment of stand characteristics and regeneration, an enrichment planting experiment was established in the Bago Yoma area of Myanmar. Survival and height growth of two commercial species (*Tectona grandis* Linn.f. and *Pterocarpus macrocarpus* Kurz.) under three different light opening intensities were investigated in the experiment. Results of stand surveys indicate a considerable degree of floristic heterogeneity in the degraded stands under investigation, in spite of a lack of large-sized trees and low regeneration potential of economically valuable species. Appropriate restoration measures combined with enrichment planting, in this regard, may improve economic value of the stands. According to first year results of enrichment planting experiment, *Padauk* shows a better height growth than that of teak, and both species show better growth performance in treatments with increased light opening intensities. To make a valid evaluation, however, survival and growth assessments in the successive years are required.

Contents

1. Introduction

Some 850 million hectares of land in the tropics is estimated as of degraded primary forests or secondary forests, of which 270 million hectares are located in Asia (ITTO, 2002). Widespread degradation of tropical forests raised a global concern and restoration of the degraded and/ or deforested areas in the tropics has become a priority to ensure the sustainable management for production and to secure environmental services. Apart from focusing on preserving or conserving existing primary forests, equal emphasis needs to be given to restoring degraded forest land to increase its productivity. Through the enhanced goods and services flourished by the restoration of degraded forest ecosystems, demand for wood and non-wood forest products should be fulfilled to some extent, and the pressure on the remaining primary forests of the region could be mitigated.

A basic management principle of forest restoration is to make use of the natural dynamics already existing in a degraded stand. The simplest restoration measure is “protection and natural recovery” (Sabogal, 2005) which is only appropriate for slightly degraded primary stands. To accelerate the natural restoration process in the stands which have been extensively degraded, two basic types of silviculural treatments, viz., improvement and enrichment can be employed. Choice of suitable intervention depends primarily on the structural characteristics and regeneration potential of the degraded stand. An important task in the initial stage of restoration process is, therefore, the assessment of stand characteristics and existing natural regeneration. The essential preconditions for the success of the improvement of the stand are the existence of sufficient regeneration of desirable species and more or less even distribution of these species over the entire area. Provided that these prerequisites are satisfied, improving pre-existing natural regeneration and tending of advanced growth will be appropriate.

If the number of economically valuable trees in the initial stand is not sufficient, or there is a complete lack of such trees, then enrichment may be a better option than improvement (Lamprecht, 1989). Emphasis has long been placed on enrichment planting, because the probability of success with inducing natural regeneration is doubtful (Dawkins and Philip, 1998). In order to improve economic as well as ecological value of a degraded forest, one of the simplest and most effective methods is enrichment planting. Out of possible types of planting, line planting and gap planting are the two most common forms of enrichment practiced today. Enrichment by irregularly spaced groups, however, had been abandoned because of difficulties in control and retracing the groups for tending operations (Weidelt, 1976).

Like many other tropical countries, Myanmar is also facing with degradation of forested lands due to various causes. Forest cover of the country has been decreasing by 0.27% annually and about 15% of the total land area is categorized as degraded or open forests (Anon., 2003). With the awareness of this problem, the Forest Department (FD) of Myanmar is now focusing on the restoration and rehabilitation of degraded forests through possible remedial measures including reforestation and afforestation of depleted forests, and improvement and enrichment operations in natural forests. Moreover, FD has recently launched the rehabilitation project in Bago Yoma Region covering 5.1 million ha of land area. Therefore, reliable information on silvicultural characteristics of these degraded forests, classification of type and level of degradation, and restoration strategies are now valuable to devise effective restoration campaign.

Recognizing the need of research information, a restoration research activity was included in the ASEAN-Korea Environmental Cooperation Project (AKECOP) entitled "Restoration of Degraded Forest Ecosystems in Southeast Asian Tropical Regions". One of the key activities of the Project is the regional research programme that aims at developing and implementing technologies for restoration, agroforestry, and biodiversity. Myanmar joined the Project's regional research programme in 2003 and this restoration research was one of two research activities carried out simultaneously in different study areas by two research teams from Forest Research Institute (FRI).

2. Objectives

Primary objective of this research is to provide relevant information and appropriate measures for the restoration of degraded forest ecosystems through enrichment planting techniques. Specifically this study aims:

- to provide the stand structure and stand dynamics information for a better understanding of the complex degraded forest ecosystems;
- to test the growth performance of *Tectona grandis* and *Pterocarpus macrocarpus* for the restoration of degraded forests by enrichment planting techniques;
- to compare the three different light opening intensities in enrichment planting; and
- to provide some useful information for the enrichment planting programs of Forest Department of Myanmar.

3. Study Area

This research was conducted in two study sites of the Bago Yoma area; Compartment No. 18 of Ngalaik Reserved Forest, Pyinmana Township (Study Site 1) and Coupe XIII of Yedashe Township (Study Site 2), as shown in Figure 1. The forests of both study sites are formally categorized as "Moist and Dry Upper Mixed Deciduous Forests (MUMD and DUMD)" and the soil and climatic conditions are favorable for the good growth of teak. Both areas have a tropical monsoon climate with a rainy season and a pronounced dry season (Figure 2).

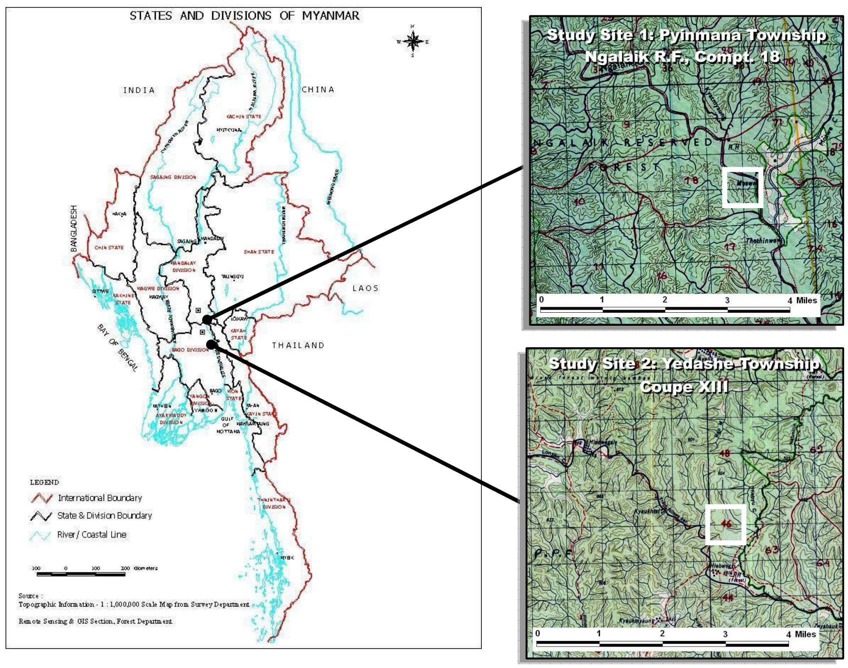

Figure 1. Location map of two study sites

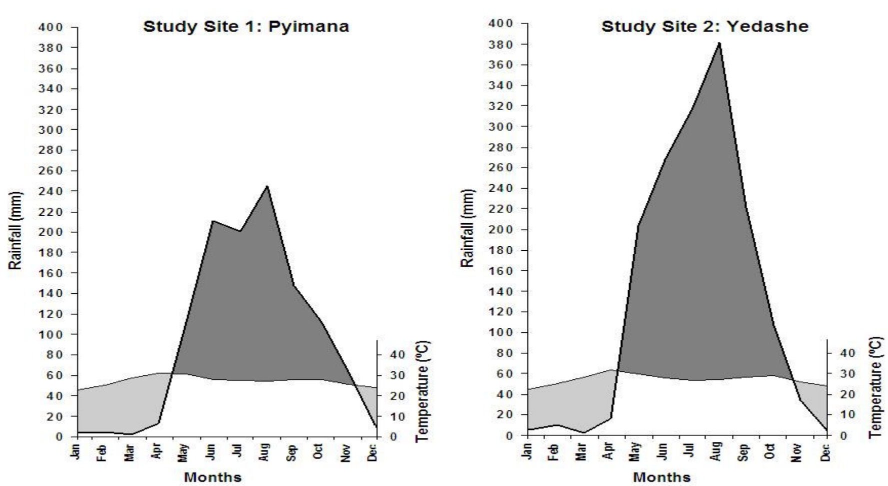

Figure 2. Mean monthly rainfall and temperature of study sites

Study site 1 is situated near the Moeswe Research Station of FRI and the geographical location of the area is 19º 56' N and 95º 56' E. This area receives a mean annual rainfall of 1329 mm and has an average daily temperature of 27º C (Figure 2). The soil of the study area is classified as Xanthic Ferralsols (yellow brown forest soils). Soil texture ranges from silt loam to clay loam. The area possesses the soil pH around 6 (Tewari, 1992). The area is now under the pressure of degradation process due to excessive cutting and shifting cultivation, being interspersed with occasional patches of forest fallow and bare land.

Study site 2 is located in the Coupe XIII of Yadashe township (geographically 19º 20' N and 96º 05' E). Mean annual rainfall of the study site is 1570 mm and average daily temperature is 27º C (Figure 2). The major type of the soil is also Xanthic Ferralsol, soil texture ranging from silt loam to clay loam. The soil pH is around 6. The area is undulating, and low areas and valleys are predominantly occupied by the paddy fields. Natural vegetation occurred in mosaics, sometimes bamboo forests were dominant.

4. Materials and Methods

4.1 Stand structure and dynamics study

4.1.1 Assessment of stand characteristics and regeneration

The stand characteristics and regenerations of the forest ecosystems in two study areas were assessed through systematic sampling surveys in December, 2003 for study site 1 and in December, 2004 for study site 2. 25 squared plots each having an area of 400 m^2 (20m x 20m) were laid out over each area depending upon the topography of the study sites (Figure. 3). Each sample plot was divided into four equal sub-plots, viz. A1, A2, A3 and A4 (Figure. 3). Each sub-compartment covered an area of 100 m^2 (10m x 10m). At the corners of each sub plot, 4 sub-compartments B1, B2, B3and B4 were built up, each comprising an area of 25 m^2 (5m x 5m). Therefore, the sampling area was composed of 100 sub-plots of A and 100 sub-compartments of B.

In each sub-plot A, all trees with a diameter at breast height, DBH ≥ 5 cm were recorded their species name, and measured the total height and DBH. The saplings with DBH < 5 cm and total height > 130 cm were enumerated and their species names were recorded. For the assessment of regeneration potential of teak, seedlings, root-suckers and stool coppices with a height ≥ 30 cm and < 130 cm were enumerated in all sub-plots. Un-established teak seedlings with a height < 30 cm were also counted. In each sub-compartment B, regeneration counting for all tree species was carried out in such a way that the seedlings (height ≥ 30 cm and < 130 cm) and the un-established seedlings (height < 30 cm) were enumerated.

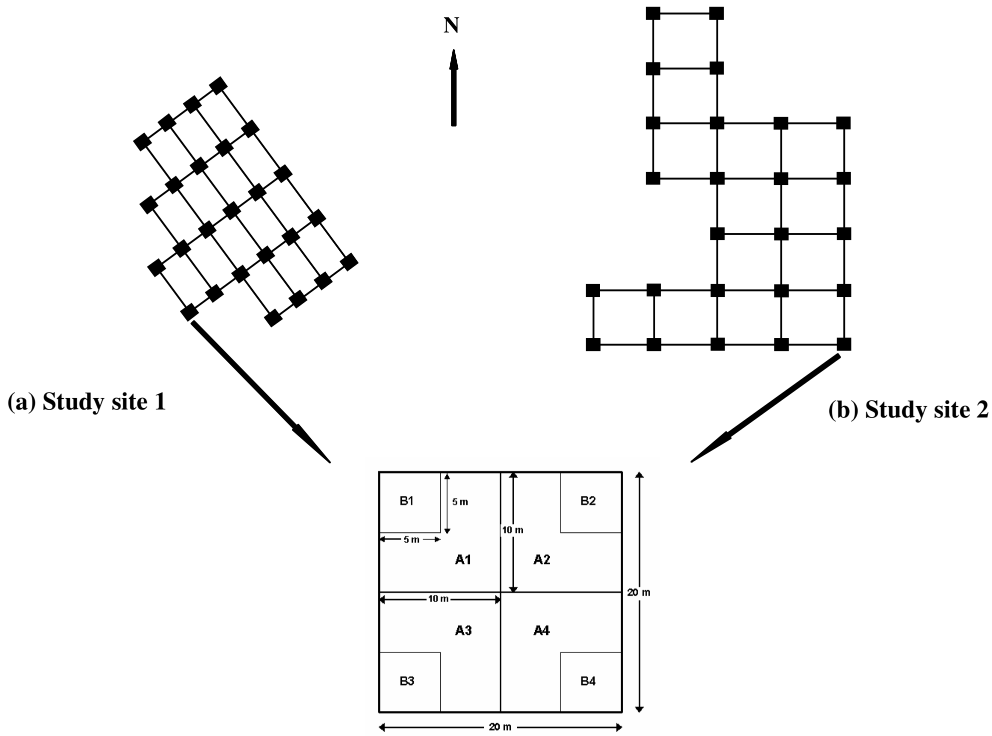

Figure 3. Distribution and lay out of the sample plots for stand structure assessment

4.1.2 Analysis of collected data

The collected data were analyzed to describe the structural characteristics of investigated forest ecosystems. Well-known Shannon index of diversity (H'), Shannon's Evenness (E) and Simpson's index (D) were used to compare the species diversity of the study areas with other typical forest stands. These indices are based on the proportional abundance of species rather than looking at the full species abundance distribution. The Shannon index emphasizes on the uncommon (rare) species whereas the Simpson's index is referred to as dominance measure since it is weighted towards the abundances of commonest species (Magurran, 1988). Simpson index is usually expressed as 1-D or 1/D because diversity decreases with the increase of D value. The indices were computed using the following formulae:

$$\text{Shannon Index } H' = - \sum_{i=1} p_i \ln p_i$$

where $p_i = n_i / N$;

n_i = number of the species I; and

N = total number of individuals.

Shannon Evenness $\quad E = \left[\frac{H'}{\ln S}\right] * 100$

where S = total number of species observed.

Simpson Index $\quad D = \sum\left[\frac{n\,(n\ -1)}{N(N-1)}\right]$

where n_i = the number of individuals in the i^{th} species; and

N = the total number of individuals.

The horizontal stand structures of both study sites were evaluated through the parameters such as species distribution, basal area and number of the individuals observed. Abundance, Frequency, Dominance and Important Value Index (IVI) were derived from collected data set. The absolute abundance is the number of individuals per species. The relative abundance is a percentage of each species to the total individuals. Frequency is the occurrence of a given species in a sub-plot. Absolute frequency is expressed as a percentage. The relative frequency of a species is calculated as a percentage of the total absolute frequency of all species. The sum of the basal area in m^2 is referred to as the absolute dominance of a species. Relative dominance is the percentage of a given species of the total stem basal area. The IVI is defined as the sum of relative abundance, relative frequency and relative dominance. In this study, IVI developed by Curtis and McIntosh (1951) was calculated for each species to compare the ecological significance of that species in each investigated stand. The vertical stand structure of each area was described by distribution of individuals and species in different height classes.

4.2 Enrichment planting experiment

Experimental plots for line planting techniques were set in Compartment No. 18 of Ngalaik Reserved Forest, Pyinmana Township. In this experiment two major factors are considered: treatments of different light opening intensities along the planting lines, and suitable species for planting. The growth responses of two commercially important tree species (*Tectona grandis* Linn.f. and *Pterocarpus macrocarpus* Kurz.) to three different light opening intensities along the planting lines were tested. Both species are commonly flourishing in moist deciduous forests of Myanmar. Foury (1956) suggested that species used in enrichment planting should be light demanders with the capability of fast height growth in juvenile stage. Teak (*Tectona grandis* Linn.f.) is a strong light demander, and Padauk (*Pterocarpus macrocarpus* Kurz.) is also a light demanding species that grows well on the ridges (Troup, 1921). Apart from commercial importance and light demanding nature, these two species also possess some important silvicultural characteristics suitable for enrichment planting including rapid height growth, regular flowering and fruiting, and a potential for high volume production.

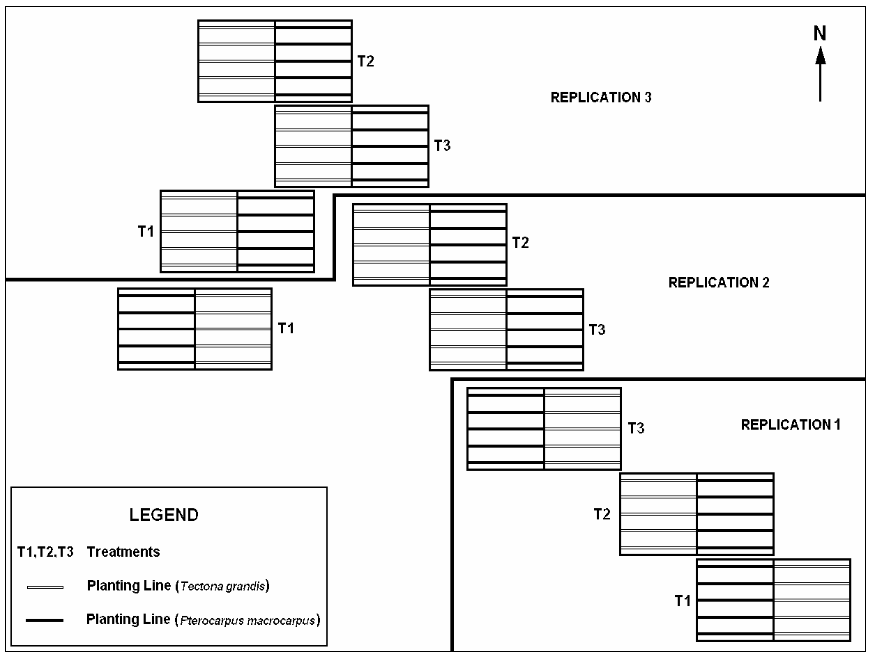

Figure 4. Lay out of the experimental plots on the ground

The experimental design was a split plot design with three replicates. Each replicate consisted of three main plots to which three different light opening intensities as treatments were assigned. Each main plot was then divided into two sub-plots, in which two tested species were incorporated (Figure. 4). There were altogether 18 sub-plots, each plot covering 1 hectare (100m x 100m). In each sub-plot, 5 parallel lines were laid out in east-west direction at 20 m intervals from axis to axis. Planting spacing along each planting line was 5 m. Three light opening intensities tested were as follows:

- Treatment 1 (T1): Planting lines with a width of 2 m were cleared (Figure. 5a).
- Treatment 2 (T2): Planting lines with a width of 2 m were cleared and trees ≥10 cm DBH except commercially important species were felled on both sides of the planting line up to the distance of 2.5 m from the axis (Figure. 5b).
- Treatment 3 (T3): Planting lines with a width of 5 m were cleared (Figure. 5c).

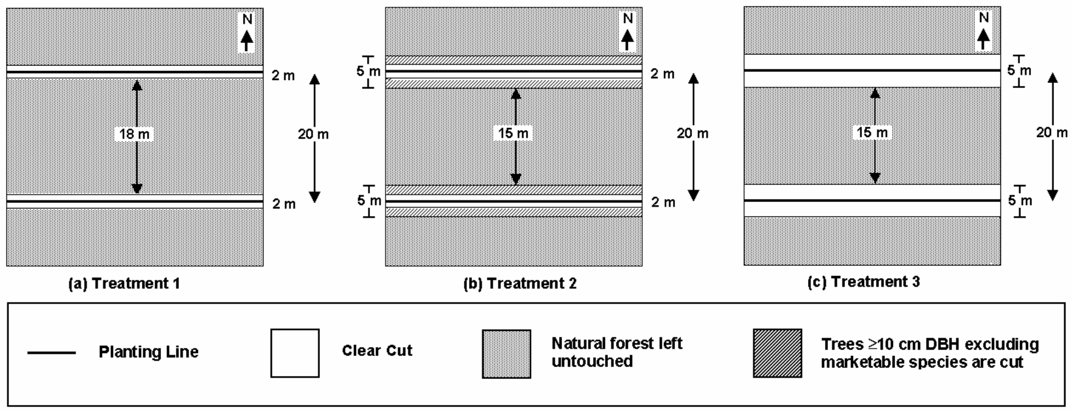

Figure 5. Three light opening treatments tested in the research

Nursery works were done in Moeswe research station starting from December 2003. Site preparations such as laying out the plots, line clearing and staking were done during February and May 2004. A total of 1800 seedlings were out-planted during June and July 2004. At the time of planting, the seedlings were six-month old and the average height was 20 cm. During the rainy season of 2004, two weeding operations and clearing along the planting lines have been accomplished. To increase light availability for the planted trees removal of overtopping shade and branches was also carried out.

Survival counting and assessment of tree height for the first year was conducted in December 2004, six months after planting. The assessment was repeated at the end of dry period of the year (in June 2005) when the planted seedlings were eleven-months old. Topographic indicators such as aspect, slope steepness in percent and slope position were recorded for each planted seedling. Both two data sets obtained (December 2004 and June 2005) were used for statistical analysis. Analysis of variance (ANOVA) was carried out and the least significant difference (LSD) test was also calculated to compare the differences of the assessed parameters among the light treatments and between the tested species.

5. Results and discussion

5.1 Stand structure and dynamics

5.1.1 Overall stand parameters

The stand parameters of both study areas clearly indicated that the investigated forest stands were being degraded in terms of productivity. In this study, some parameters of the study sites were compared with those of a typical mixed deciduous forest in order to determine the type of degradation. The number of trees and species per hectare in both study areas showed higher values than the typical stand, however basal area, average DBH and average stand height were much lower. Despite the number of trees was relatively high, about half of the individuals in each study area were accumulated within the range of DBH 5 to 10 cm (Table. 1).

Table 1: Comparison of stand parameters between a typical mixed deciduous stand (Lwin, 2001) and the investigated stands

(a) Minimum DBH assessed: 5 cm

Parameters	Study site 1	Study site 2	Typical stand
Number of trees/ha	442	624	381
Number of species/ha	56	60	44
Ratio of individuals per species	1 : 8	1 : 10	1 : 9
Basal area (m^2/ha)	10.7	12.2	33.4
Average DBH (cm)	14.1	13.4	28.7
Average stand height (m)	9.7	12.1	18.9

(b) Minimum DBH assessed: 10 cm

Parameters	Study site 1	Study site 2	Typical stand
Number of trees/ha	229 (52%)	335 (54%)	336 (88%)
Number of species/ha	45	52	40
Ratio of individuals per species	1 : 5	1 : 6	1 : 8
Basal area (m^2/ha)	9.9	10.9	33.3
Average DBH (cm)	21.0	18.9	31.7
Average stand height (m)	12.4	15.5	20.4

5.1.2 Diversity indices and species distribution

The calculated diversity indices consistently showed that the investigated stands were more heterogeneous and more even in terms of the abundances of the species (Table 2). Frequency diagram also revealed that the species were evenly distributed throughout the area (Figure. 6). It could be considered that, the investigated stands were more open than the typical stand due to the scarcity of the upper canopy trees and there were some niches for newly established natural regenerations of more species.

Table 2. Comparison of diversity indices

Index	Study site 1	Study site 2	Typical stand
Shannon index (H')	3.37	3.09	2.74
Shannon evenness (E)	0.84	0.76	0.72
Simpson Index	0.05	0.11	0.14
1/D	20	9.09	7.14
1-D	0.95	0.89	0.86

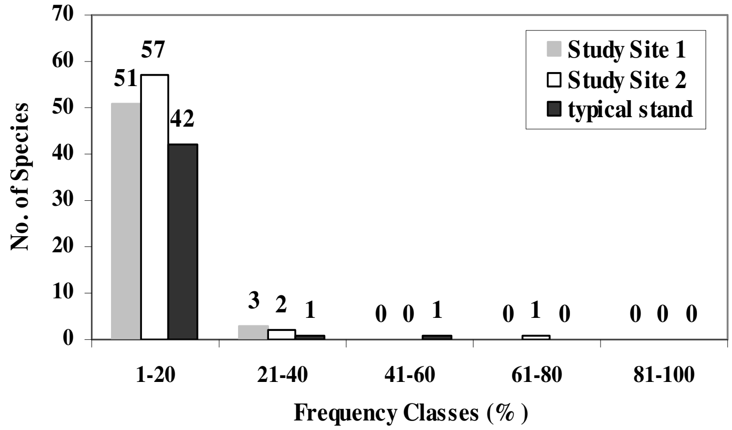

Figure 6. Frequency diagrams of the investigated stands (DBH ≥ 5cm)

5.1.3 Important value index (IVI) as an indicator for stand structure

Dominance, abundance, frequency and IVI for all species having a DBH ≥ 5 cm are reported in Appendix I. In study site1, *Chukrasia tabularis* (Yinma), *Bridelia retusa* (Seikchi) and *Tectona grandis* (Teak) possessed the highest IVI values, while Teak, *Mitragyna rotundifolia* (Binga) and *Xylia dolarbriformis* (Pyinkado) in study site 2 (Table 3). Three economically important species (Teak, Padauk and Pyinkado) were among the species with highest IVI values in both study sites and could be regarded as the characteristic species of the areas. Yinma, an important hardwood timber species, seemed dominated species in study site 1 but IVI values of other species were within the same range 28 to 10 (Appendix I A). Therefore it could be suggested that 10 species with highest IVI values were more or less equally dominated in the area of study site 1.

Table 3: Species with highest IVI values (DBH≥5 cm)

Rank	Study site 1	Study site 2
1	*Chukrasia tabularis* A. Juss.	***Tectona grandis* Linn. f.**
2	*Bridelia retusa* (L.) A. Juss	*Mitragyna rotundifolia* (Roxb.) Kuntze
3	***Tectona grandis* Linn.f.**	***Xylia dolarbriformis* Benth.**
4	*Bombax insigne* Wall.	*Holarrhena antidysenterica* Wall.
5	*Cratoxylon neriifolium* Kurz.	*Anogeissus accuminata* Wall.
6	***Pterocarus macrocarpus* Kurz.**	***Pterocarus macrocarpus* Kurz.**
7	*Schleichera oleosa* (Lour.) Oken	*Celtis cinnamomea* Lindl.
8	*Kydia calycina* Roxb.	*Cratoxylon neriifolium* Kurz.
9	***Xylia dolarbriformis* Benth**.	*Terminalia chebula* Retz.
10	*Markhamia stipulata* (Wall.) Seem.	*Protium serratum* Engl.

In study site 2, however, Teak with the highest IVI value of 85.9 apparently out-competed the other species (Appendix I B). According to field observations during data collection, teak trees were competing for light, resulting excessive height growth than the diameter. In consequence, the Teak trees were subjective to damages by wind and the majority was not good in crown shape.

5.1.4 Diameter distribution as an indicator for stand dynamics

Lack of large-sized trees, i.e. lack of seed trees, was apparent when the distribution of individuals by DBH classes (Figure. 7) was examined. In both study areas, most of the individuals accumulated in small diameter classes and the number of individuals decreased dramatically from lower to higher diameter classes. Distribution of individuals in smaller DBH classes, however, was observed that the dynamic process of the stands followed a normal trend when all tree species were considered. The scarcity of the seed trees was more obvious for all commercially important species (Teak, Padauk and Pyinkado) in both sites (Figure 8). The number of individuals for each species in study site 1 indicated very low tree density even in the lower diameter class than in the study site 2.

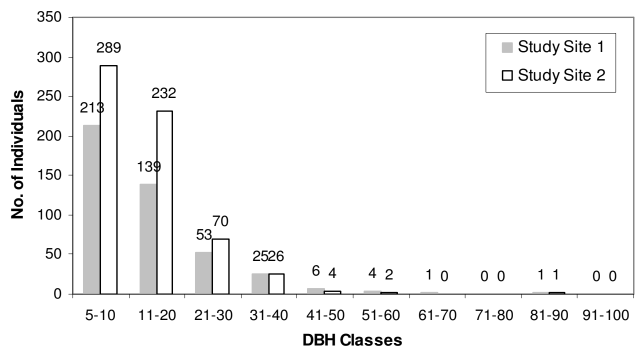

Figure 7. Distribution of individuals by DBH classes (all species)

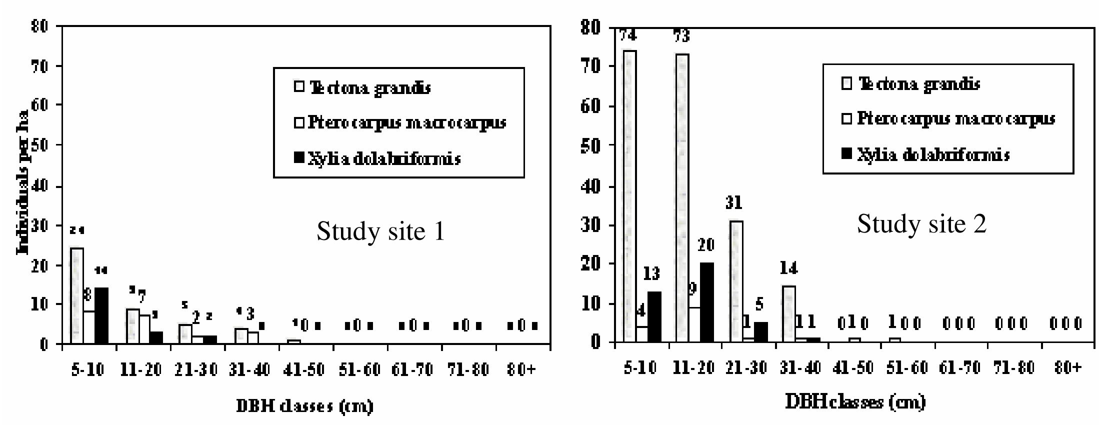

Figure 8. Distribution of individuals by DBH classes (three important species)

5.1.5 Natural regeneration

Density of sapling (DBH < 5 cm and height > 130 cm) for all species in the study site 1 and 2 was found to be 707 and 606 per ha respectively. In this study, the saplings and seedlings were categorized by analyzing their abundance and frequency, and Table 4 shows top ten species as ranked by the relative abundance plus relative frequency. Teak and Pyinkado were still among the ten most abundant species; however Padauk in sapling stage showed fewer numbers of saplings. Dominance and frequency for natural regeneration (saplings) are reported in Appendix II.

Table 4: Most abundant species at the sapling stage (DBH < 5 cm and height 130 cm), ranked by relative abundance plus relative frequency

Rank	Study site 1	Study site 2
1	*Chukrasia tabularis* A. Juss.	*Mitragyna rotundifolia* (Roxb.) Kuntze
2	***Tectona grandis*** **Linn.f.**	*Bridelia retusa* (L.) A. Juss
3	*Antidesma diandrum* Roth.	*Holarrhena antidysenterica* Wall.
4	*Bridelia retusa* (L.) A. Juss	***Tectona grandis*** **Linn. f.**
5	***Xylia dolarbriformis*** **Benth.**	*Cratoxylon neriifolium* Kurz.
6	*Dalbergia collettii* Prain	*Schleichera oleosa* (Lour.) Oken
7	*Holarrhena antidysenterica* Wall.	*Sapindus saponaria* L.
8	*Heterophragma sulfureum* Kurz	***Xylia dolarbriformis*** **Benth.**
9	*Schleichera oleosa* (Lour.) Oken	*Vitex canescens* Kurz
10	*Bombax insigne* Wall.	*Celtis cinnamomea* Lindl.

Despite of being large amount of seedling (height < 130 cm) density in both study sites (923 and 684 per 0.25 ha for the study site 1 and 2 respectively), 3 economically valuable species appeared relatively low regeneration. Table 5 shows ten most abundant species at seedling stage. Only a few of top 10 species with highest regeneration density were economically valuable, indicating very poor regeneration potential. Natural regeneration of Teak is poorer in the study site 1 than in site 2. Padauk and Pyinkado also showed lower density of regeneration in seedling stage. Dominance and frequency for natural regeneration (seedlings) are reported in Appendix III.

In considering suitable species for enrichment planting, light requirements and growing characteristics of that species, especially at initial stage, are of prime importance. Natural regeneration of the species under influencing environmental factors can give an insight into silvicultural features of the species. Of two species included in the research, present situation of existing degraded stands still provides favourable conditions for successful natural regeneration of teak. Well-established seedlings are occasionally observed where overhead light is sufficiently available. Low quantity in seedling density in the study site 1 is probably caused by insufficient number of sound seed trees, rather than failures in natural regeneration. The regeneration of *Pterocarpus macrocarpus* is scarce in both study sites, which could be a consequence of the lack of mature seed trees combined with site preferences of the species. It usually seeks the upper and drier portion of the hill slopes (Troup, 1921). Two restoration strategies, viz., improvement and enrichment, are not necessarily mutually exclusive. Depending on the condition of existing stand a combination may also be practiced.

Table 5: Most abundant tree species at seedling stage (height <130 cm), ranked by relative abundance plus relative frequency

Rank	Study site 1	Study site 2
1	*Holarrhena antidysenterica* Wall.	*Holarrhena antidysenterica* Wall.
2	*Markhamia stipulata* (Wall.) Seem.	*Cratoxylon neriifolium* Kurz.
3	*Chukrasia tabularis* A. Juss.	*Grewia tiliifolia* Vahl
4	*Dalbergia collettii* Prain	*Antidesma diandrum* Roth.
5	*Antidesma diandrum* Roth.	*Premna latifolia* Roxb.
6	*Cratoxylon neriifolium* Kurz.	*Albizia odoratissima* (L. f.) Benth.
7	*Pterospermum semisagittatum* Buch.-Ham.	***Tectona grandis* Linn. f.**
8	*Grewia tiliifolia* Vahl	*Celtis cinnamomea* Lindl.
9	*Protium serratum* Engl.	*Derris robusta* Benth.
10	*Premna latifolia* Roxb.	*Anogeissus acuminata* Wall.

5.2 Enrichment planting experiment

5.2.1 Mean survival of the planted seedlings

The data of the first assessment in December 2004 (before the dry season) indicate relatively high survival of both species. Average survival rates for teak and Padauk (*Pterocarpus macrocarpus*) are 87% and 91% respectively. Overall survival in June 2005 (after the dry season), however, has considerably decreased to 77% for teak and 85% for Padauk. In Table 6, the overall survival before and after the dry season are compared for each treatment. As the light conditions were, despites of clearing, not always satisfactory along the planting line, strong light demander like teak and Padauk failed to survive where the line passes through the valleys or it falls under the intense shade of neighboring vegetation. Apart from the availability of light and moisture during the growing season, drought, particularly in the dry season, may be an important limiting factor for the survival of planted trees.

Table 6: Survival of planted trees before and after the dry season

Treatment	December 2004		June 2005	
	Teak	Padauk	Teak	Padauk
1	85 %	92 %	74 %	83 %
2	85 %	92 %	77 %	87 %
3	92 %	90 %	79 %	84 %

Results from statistical analysis of June 2005 data set for mean survival are shown in Appendix IV A. There were no significant differences among the treatments (main plot factor) and between two tested species (subplot factor). The mean survival rates consistently showed no significant difference by interaction of species and light treatment, by species and by treatment alone (Figure 9a and 9b).

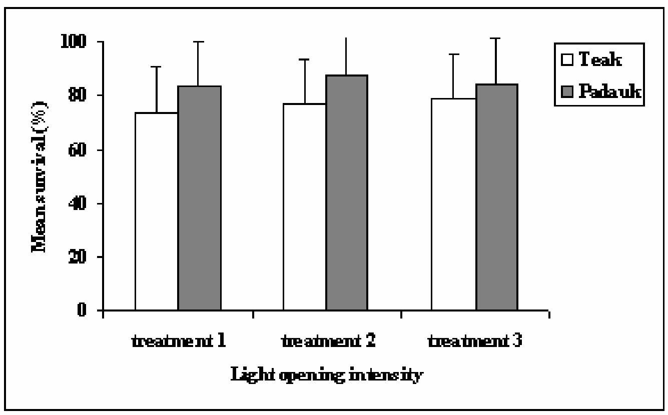

Figure 9 (a). Comparison of mean survival percent by species vs. light treatment interaction (vertical lines indicating the LSD)

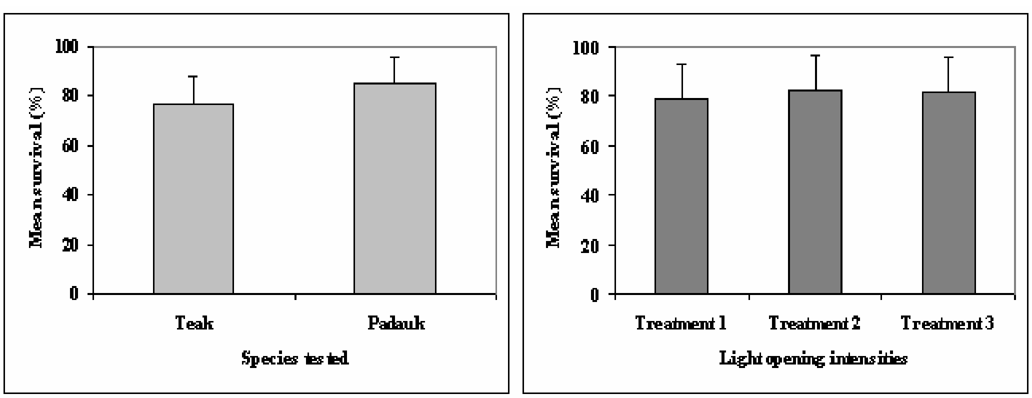

Figure 9 (b). Comparison of mean survival percent by species (left) and light treatment in line enrichment planting (right) (vertical lines indicating the LSD)

5.2.2 Mean height of the planted seedlings

Due to the relatively low rainfall and rainy days during the growing season of the year (June to October 2004), planted trees reached average height of 27 cm for teak and 37 cm for Padauk six months after planting. Eleven months after planting, average height has increased to 30 cm and 48 cm for teak and Padauk respectively. In comparison with planted trees under normal plantation conditions, the height growth of planted seedlings in this experiment is notably lower. Average growth of teak trees planted in the same location was reported as 33 cm eight months after planting (Maung et al., 2002). According to a study conducted in the same area, mean height of planted Padauk trees was 89 cm seven months after planting (Doo, 1981). In Table 7 the height growth before and after the dry season are compared for each treatment.

Table 7: Height growth of planted trees before and after the dry season

Treatment	December 2004		June 2005	
	Teak	Padauk	Teak	Padauk
1	26 cm	33 cm	28 cm	39 cm
2	28 cm	42 cm	31 cm	57 cm
3	27 cm	37 cm	30 cm	48 cm

Significant height growth responses of the planted seedlings to interaction of species and light treatment, to species and to treatment alone were observed in this study (Appendix IV B). The interaction of the species and light treatment influenced significantly to the height growth of the planted seedlings (F pr = 0.040). Similarly the height growth of the planted seedlings was highly significant to species and light treatment alone. Comparison of mean heights in response to interaction of species and light treatment, to species and to treatment alone were shown in Figure 10. Padauk seedlings showed the best height growth in Treatment 2 (medium light opening intensity). Compared to Teak seedlings, Padauk performed better in all light treatments. However, both species were poor in low light opening intensities.

The poor height growth of Teak in line enrichment planting has also reported by Lwin (2003) because it had a strong light demanding characteristics and could not tolerate to shade conditions. The weeds in the line enrichment plantings were also competitive to Teak seedlings and it was suggested that more weeding operations should be practiced in line enrichment planting.

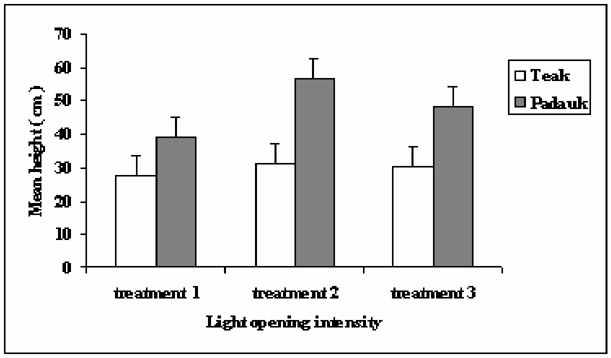

Figure 10 (a). Comparison of mean height by species vs. light treatment interaction (vertical lines indicating the LSD)

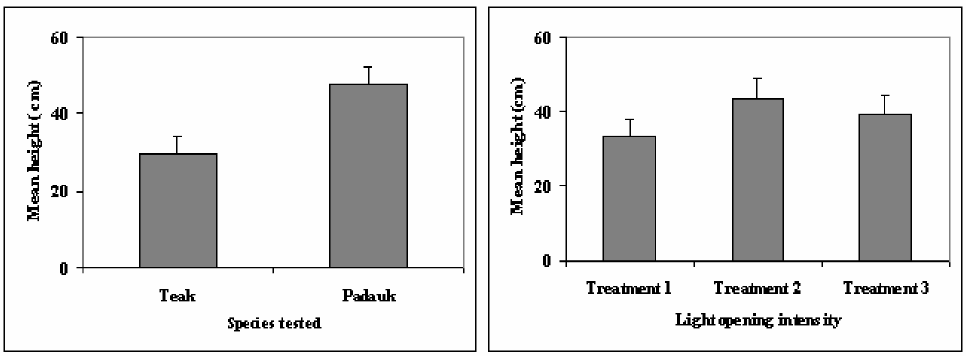

Figure 10 (b). Comparison of mean height by species (left) and light treatment in line enrichment planting (right) (vertical lines indicating the LSD)

5.2.3 Influence of topographic features on planted seedlings

Significant influence of aspect was not detected (data not shown here). Although soil erosion may have caused low soil fertility and thus site productivity at very steep slopes, slope steepness also showed no significant differences both in survival and height growth. Survival of planted seedlings in the "valley" was significantly lower than those of other classes. The reason for very low survival of planted seedlings at valleys was strong run-off water in rainy season rather than the influence of site position.

5.2.4 Further research requirements

To adopt more appropriate restoration strategy and to devise more effective measures, additional research information is still required. Followings are some aspects that should also be taken into account:

Biodiversity of degraded stands – Although the diversity indices used in this study offer quick estimates of species diversity in terms of both richness and evenness, they are wholly unsuitable for measuring biodiversity (Pielou, 1994). To assess real ecological value of the degraded stands, appropriate biodiversity measures giving more weight to primary species should be introduced.

Spatial distribution of trees and regeneration – Frequency provides a rough description of spatial distribution. It alone is not adequate to assess more exact spatial positions of seed trees and advanced growth distributed over the entire area.

Silvicultural features of potential species for enrichment planting – Information on important features such as inherent maximum growth, light requirements, and tolerance to drought and shade at juvenile stage are still lacking or incomplete.

Quantification of light intensities – Accurate methods and instruments are necessary to measure light intensity under normal crown cover in a degraded stand and light availability of different canopy opening treatments.

Costs – Cost of enrichment planting is not included in present study since total costs can only be calculated when the planted trees have been completely established several years after planting. High costs of tending operations such as weeding and removal of overtopping branches can be justified by the maintenance of existing biodiversity, which is difficult to be valued in monetary terms.

6. Conclusion

It is observed that the investigated stands were severely degrading in terms of productivity, but not in the species diversity. The scarcity of the seed bearers for three economically important species (Teak, Padauk, and Pyinkado) is a critical problem for their natural regenerations. Improvement operations alone cannot recover this situation and therefore adding the regeneration stock by planting is essential. Conserving and practicing tending operations to the established saplings can also enhance the degraded stands. It can be concluded that the present situation of the degraded stands still provides favorable conditions for successful restoration with proper remedial measures.

For the whole enrichment planting experiment, Treatment 2 (medium light opening intensity) showed the best height growth for both species. For Teak, Treatment 2 and 3 offered a better height growth than that of Treatment 1. For Padauk, Treatment 2 significantly showed the best performance among three treatments. Padauk showed better height growth than Teak in all treatments. Notwithstanding, it is premature to suggest that the growth performance of Padauk is better than Teak or to draw a conclusion that the specific treatment is the most appropriate or any of two species is better suited for the enrichment planting. Continuous evaluation and follow-up tending operations are still needed to verify the species suitability and appropriate light opening intensity.

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Appendix I: Abundance, dominance, frequency and IVI for all tree species found in the study sites (based on the individuals having a DBH ≥ 5 cm)

A. Study site 1, Ngalaik Reserved Forest, Compartment No. 18, Pyinmana Township

			Total			Relative		
Sr.	**Species**	**Abun. N/Ha**	**Dom. m^2/Ha**	**Freq. %**	**Abun. %**	**Dom. %**	**Freq. %**	**IVI**
1	*Chukrasia tabularis*	53	0.67	33	11.99	6.28	9.76	28.0
2	*Bridelia retusa*	35	1.20	27	7.92	11.18	7.99	27.1
3	*Tectona grandis*	43	1.03	25	9.73	9.56	7.40	26.7
4	*Salmalia insignis*	19	1.20	19	4.30	11.19	5.62	21.1
5	*Cratoxylum neriifolium*	23	0.57	17	5.20	5.34	5.03	15.6
6	*Pterocarpus macrocarpus*	20	0.47	16	4.52	4.35	4.73	13.6
7	*Schleichera trijuga*	14	0.67	11	3.17	6.21	3.25	12.6
8	*Kydia calycina*	20	0.29	13	4.52	2.73	3.85	11.1
9	*Xylia dolabriformis*	19	0.21	16	4.30	1.98	4.73	11.0
10	*Markhamia stipulata*	20	0.21	13	4.52	1.98	3.85	10.4
11	*Dalbergia ovata*	18	0.19	14	4.07	1.75	4.14	10.0
12	*Haplophragma adenophyllum*	13	0.29	11	2.94	2.67	3.25	8.9
13	*Streopermum grandiflorum*	9	0.34	9	2.04	3.14	2.66	7.8
14	*Pongamia pinnata*	11	0.27	8	2.49	2.53	2.37	7.4
15	*Holarrhena antidyscenterica*	9	0.18	5	2.04	1.65	1.48	5.2
16	*Grewia hirsuta*	8	0.12	7	1.81	1.10	2.07	5.0
17	*Garuga pinnata*	7	0.16	6	1.58	1.44	1.78	4.8
18	*Premna latifolia*	4	0.27	4	0.90	2.53	1.18	4.6
19	*Pterospermum semisagittatum*	7	0.19	4	1.58	1.77	1.18	4.5
20	*Lannea grandis*	7	0.08	7	1.58	0.71	2.07	4.4
21	*Celtis cinnamomea*	4	0.24	4	0.90	2.19	1.18	4.3
22	*Miliusa roxburghiana*	7	0.08	5	1.58	0.75	1.48	3.8
23	*Mitragyna rotundifolia*	7	0.06	5	1.58	0.57	1.48	3.6
24	*Vitex pubescens*	5	0.11	5	1.13	1.02	1.48	3.6
25	*Semecarpus anacardium*	5	0.11	5	1.13	1.00	1.48	3.6
26	*Cordia fragrantissima*	4	0.16	4	0.90	1.49	1.18	3.6
27	*Largerstroemia tomentosa*	2	0.27	2	0.45	2.52	0.59	3.6
28	*Anogeissus accuminata*	1	0.31	1	0.23	2.86	0.30	3.4
29	*Largerstroemia villosa*	3	0.18	3	0.68	1.70	0.89	3.3

30	*Oroxylum indicum*	5	0.02	4	1.13	0.22	1.18	2.5
31	*Dalbergia fusca*	4	0.04	3	0.90	0.35	0.89	2.1
32	*Holoptelea integrifolia*	3	0.06	3	0.68	0.53	0.89	2.1
33	*Dalbergia cultrata*	4	0.06	2	0.90	0.52	0.59	2.0
34	*Spondias pinnata*	2	0.06	2	0.45	0.58	0.59	1.6
35	*Mallotus phillippenesis*	2	0.05	2	0.45	0.49	0.59	1.5
36	*Sapindus mukorossi*	2	0.05	2	0.45	0.48	0.59	1.5
37	*Ailanthus triphysa*	1	0.11	1	0.23	0.99	0.30	1.5
38	*Terminalia pyrifolia*	2	0.02	2	0.45	0.20	0.59	1.2
39	*Miliusa velutina*	2	0.01	2	0.45	0.12	0.59	1.2
40	*Antidesma diandram*	2	0.01	2	0.45	0.05	0.59	1.1
41	*Aegle marmelos*	2	0.01	1	0.45	0.10	0.3	0.8
42	*Streblus Asier*	2	0.01	1	0.45	0.06	0.3	0.8
43	*Pouteria tomentosa*	1	0.01	1	0.23	0.28	0.3	0.8
44	*Wrightia tomentosum*	1	0.01	1	0.23	0.22	0.3	0.7
45	*Erblica officinalis*	1	0.01	1	0.23	0.12	0.3	0.6
46	*Zanthoxylum budrunga*	1	0.01	1	0.23	0.11	0.3	0.6
47	*Hesperethusa caenulata*	1	0.01	1	0.23	0.09	0.3	0.6
48	*Erythropsis colorata*	1	0.01	1	0.23	0.08	0.3	0.6
49	*Picus hispida*	1	0.01	1	0.23	0.06	0.3	0.6
50	*Rinorea racemosa*	1	0.01	1	0.23	0.06	0.3	0.6
51	*Hymennodictyon excelsum*	1	0.01	1	0.23	0.05	0.3	0.6
52	*Dillenia parviflora*	1	0.00	1	0.23	0.02	0.3	0.5
53	*Careya arborea*	1	0.00	1	0.23	0.02	0.3	0.5
54	*Tetrameles nudiflora*	1	0.00	1	0.23	0.02	0.3	0.5
	Total	**442**	**10.74**	**-**	**100**	**100**	**100**	**300**

Appendix I: Abundance, dominance, frequency and IVI for all tree species found in the study sites (based on the individuals having a DBH ≥ 5 cm)

B. Study site 2, Coupe XIII of Yedashe Township

Sr.	Species	Total			Relative			IVI
		Abun. N/Ha	Dom. m^2/Ha	Freq. %	Abun. %	Dom. %	Freq. %	
1	*Tectona grandis*	183	4.50	63	30.93	36.79	18.21	85.93
2	*Mitragyna rotundifolia*	46	0.49	32	7.37	4.04	9.25	20.66
3	*Xylia dolabriformis*	39	0.75	17	6.25	6.16	4.91	17.32
4	*Holarrhena antidyscenterica*	33	0.31	21	5.29	2.56	6.07	13.91
5	*Anogeissus accuminata*	14	1.14	8	2.24	9.33	2.31	13.88
6	*Pterocarpus macrocarpus*	16	0.47	10	2.56	3.84	2.89	9.29
7	*Celtis cinnamomea*	15	0.33	10	2.4	2.70	2.89	7.99
8	*Cratoxylum neriifolium*	13	0.27	9	2.08	2.23	2.60	6.91
9	*Terminalia chebula*	14	0.21	10	2.24	1.75	2.89	6.88
10	*Protium serratum*	12	0.31	7	0.92	2.57	2.02	6.51
11	*Schleichera trijuga*	14	0.12	11	2.24	0.95	3.18	6.37
12	*Stereopermum personatum*	13	0.17	7	2.08	1.36	2.02	5.47
13	*Miliusa velutina*	10	0.04	10	1.60	0.36	2.89	4.86
14	*Largerstroemia tomentosa*	15	0.15	4	2.40	1.22	1.16	4.78
15	*Bridelia retusa*	9	0.18	6	1.44	1.45	1.73	4.62
16	*Homalium tomentosum*	10	0.08	8	1.60	0.65	2.31	4.56
17	*Sapindus mukorossi*	12	0.06	7	1.92	0.49	2.02	4.44
18	*Grewia hirsute*	7	0.13	7	1.12	1.03	2.02	4.18
19	*Salmalia malabarica*	5	0.20	5	0.80	1.66	1.45	3.91
20	*Spondias pinnata*	7	0.17	4	1.12	1.43	1.16	3.71
21	*Streospermum graniflorum*	7	0.10	6	1.12	0.81	1.73	3.66
22	*Derris robusta*	9	0.09	5	1.44	0.72	1.45	3.61
23	*Gardenia erythroclada*	10	0.04	5	1.60	0.34	1.45	3.39
24	*Salmalia insignis*	6	0.17	3	0.96	1.42	0.87	3.25
25	*Streblus asper*	5	0.12	3	0.80	0.94	0.87	2.61
26	*Bauhinia malabarica*	5	0.08	4	0.80	0.64	1.16	2.59
27	*Cordia dichotoma*	4	0.08	4	0.64	0.68	1.16	2.47
28	*Dalbergia ovata*	6	0.07	3	0.96	0.55	0.87	2.38
29	*Dipterocarpus baudii*	1	0.23	1	0.16	1.85	0.29	2.29

30	*Kydia calycina*	5	0.03	4	0.80	0.23	1.16	2.19
31	*Lannea grandis*	2	0.15	2	0.32	1.23	0.58	2.12
32	*Largerstroemia villosa*	4	0.02	4	0.64	0.20	1.16	2.00
33	*Microcos paniculata*	4	0.06	3	0.64	0.46	0.87	1.97
34	*Largerstroemia speciosa*	2	0.12	2	0.32	0.95	0.58	1.85
35	*Neonauclea excelsa*	3	0.02	3	0.48	0.14	0.87	1.49
36	*Garuga pinnata*	2	0.07	2	0.32	0.58	0.58	1.48
37	*Diospyros martabanica*	3	0.01	3	0.48	0.08	0.87	1.42
38	*Pterospermum semisagittatum*	3	0.04	2	0.48	0.32	0.58	1.38
39	*Antidesma diandram*	4	0.02	2	0.64	0.15	0.58	1.37
40	*Eugenia spp.*	3	0.04	2	0.48	0.29	0.58	1.35
41	*Vitex pubescens*	3	0.03	2	0.48	0.27	0.58	1.33
42	*Haplophragma adenophyllum*	2	0.04	2	0.32	0.30	0.58	1.19
43	*Alstonia scholaris*	4	0.03	1	0.64	0.26	0.29	1.19
44	*Albizzia marmelos*	1	0.09	1	0.16	0.73	0.29	1.18
45	*Terminalia bellerica*	1	0.09	1	0.16	0.73	0.29	1.18
46	*Albizzia procera*	2	0.03	2	0.32	0.25	0.58	1.15
47	*Pentace griffithii*	2	0.02	2	0.32	0.20	0.58	1.10
48	*Erblica officinalis*	4	0.02	1	0.64	0.15	0.29	1.08
49	*Mitragyna parviflora*	2	0.02	2	0.32	0.16	0.58	1.06
50	*Oroxylum indicum*	3	0.03	1	0.48	0.26	0.29	1.03
51	*Cassia fistula*	2	0.01	2	0.32	0.07	0.58	0.97
52	*Wrightia tomentosum*	2	0.01	2	0.32	0.06	0.58	0.96
53	*Eriolaena candollei*	2	0.04	1	0.32	0.31	0.29	0.92
54	*Macaranga denticulate*	2	0.02	1	0.32	0.17	0.29	0.78
55	Unidentifiable	1	0.03	1	0.16	0.29	0.29	0.74
56	*Manglietia insignis*	1	0.03	1	0.16	0.28	0.29	0.73
57	*Hymennodictyon excelsum*	2	0.01	1	0.32	0.06	0.29	0.67
58	*Ficus cunia*	1	0.02	1	0.16	0.15	0.29	0.60
59	*Adina cordifolia*	1	0.02	1	0.16	0.14	0.29	0.59
60	*Dalbergia fusea*	1	0.00	1	0.16	0.03	0.29	0.48
	Total	**624**	**12.2**	**-**	**100**	**100**	**100**	**300**

Appendix II: Relative abundance + relative frequency for natural regeneration (saplings) found in the study sites (based on the individuals having > 130 cm height and < 5 cm DBH)

A. Study site 1, Ngalaik Reserved Forest, Compartment No. 18, Pyinmana Township

Sr.	Species	Total		Relative		Relative (Abun. + Freq.)
		Abun. N/Ha	Freq. %	Abun. %	Freq. %	
1	*Chukrasia tabularis*	70	33	9.9	7.1	17.0
2	*Tectona grandis*	65	36	9.2	7.7	16.9
3	*Antidesma diandram*	47	27	6.6	5.8	12.4
4	*Bridelia retusa*	37	28	5.2	6.0	11.2
5	*Xylia dolabriformis*	37	22	5.2	4.7	9.9
6	*Dalbergia ovata*	36	21	5.1	4.5	9.6
7	*Wrightia tomentosum*	31	20	4.4	4.3	8.7
8	*Haplophragma adenophyllum*	27	22	3.8	4.7	8.5
9	*Schleichera trijuga*	32	18	4.5	3.9	8.4
10	*Salmalia insignis*	30	19	4.2	4.1	8.3
11	*Markhamia stipulata*	23	18	3.3	3.9	7.1
12	*Kydia calycina*	24	16	3.4	3.4	6.8
13	*Cratoxylum neriifolium*	24	15	3.4	3.2	6.6
14	*Mitragyna rotundifolia*	18	11	2.5	2.4	4.9
15	*Oroxylum indicum*	17	11	2.4	2.4	4.8
16	*Grewia hirsuta*	13	12	1.8	2.6	4.4
17	*Vitex pubescens*	12	11	1.7	2.4	4.1
18	*Lannea grandis*	12	9	1.7	1.9	3.6
19	*Pterocarpus macrocarpus*	9	9	1.3	1.9	3.2
20	*Protium serratum*	9	9	1.3	1.9	3.2
21	*Dalbergia cultrata*	10	8	1.4	1.7	3.1
22	*Streopermum grandiflorum*	9	8	1.3	1.7	3.0
23	*Largerstroemia villosa*	12	5	1.7	1.1	2.8
24	*Pterospermum semisagittatum*	8	7	1.1	1.5	2.6
25	*Celtis cinnamomea*	12	3	1.7	0.6	2.3
26	*Dalbergia fusca*	7	6	1.0	1.3	2.3
27	*Hymennodictyon excelsum*	7	5	1.0	1.1	2.1
28	*Pongamia pinnata*	5	5	0.7	1.1	1.8

29	*Rinorea racemosa*	5	5	0.7	1.1	1.8
30	*Anogeissus accuminata*	7	3	1.0	0.6	1.6
31	*Miliusa roxburghiana*	5	4	0.7	0.9	1.6
32	*Croton roxburghianus*	4	4	0.6	0.9	1.4
33	*Garuga pinnata*	4	3	0.6	0.6	1.2
34	*Miliusa velutina*	4	3	0.6	0.6	1.2
35	*Terminalia bellerica*	4	3	0.6	0.6	1.2
36	*Premna latifolia*	3	3	0.4	0.6	1.1
37	*Vitex peduncularis*	3	3	0.4	0.6	1.1
38	*Cassia fistula*	3	2	0.4	0.4	0.9
39	*Terminalia pyrifolia*	2	2	0.3	0.4	0.7
40	*Cordia fragrantissima*	2	2	0.3	0.4	0.7
41	*Adenanthera pavonina*	2	2	0.3	0.4	0.7
42	*Stereopermum personatum*	2	1	0.3	0.2	0.5
43	*Aegle marmelos*	2	1	0.3	0.2	0.5
44	*Eriolaena candollei*	1	1	0.1	0.2	0.4
45	*Adina cordifolia*	1	1	0.1	0.2	0.4
46	*Picus hispida*	1	1	0.1	0.2	0.4
47	*Picus pomifera*	1	1	0.1	0.2	0.4
48	*Wrightia tomentosum*	1	1	0.1	0.2	0.4
49	*Sapindus mukorossi*	1	1	0.1	0.2	0.4
50	*Zanthoxylum budrunga*	1	1	0.1	0.2	0.4
51	*Homalium tomentosum*	1	1	0.1	0.2	0.4
52	*Streblus Asier*	1	1	0.1	0.2	0.4
53	*Holoptelea integrifolia*	1	1	0.1	0.2	0.4
54	*Mallotus phillippenesis*	1	1	0.1	0.2	0.4
55	*Erblica officinalis*	1	1	0.1	0.2	0.4
	Total	**707**	**467**	**100**	**100**	**200**

Appendix II: Relative abundance + relative frequency for natural regeneration (saplings) found in the study sites (based on the individuals having > 130 cm height and < 5 cm DBH)

B. Study site 2, Coupe XIII of Yedashe Township

Sr.	Species	Total		Relative		Relative (Abun. + Freq.)
		Abun. N/Ha	Freq. %	Abun. %	Freq. %	
1	*Cratoxylum neriifolium*	172	48	18.1	9.4	27.5
2	*Holarrhena antidyscenterica*	102	37	10.7	7.2	18.0
3	*Grewia hirsuta*	74	35	7.8	6.8	14.6
4	*Xylia dolabriformis*	42	37	4.4	5.3	9.7
5	*Antidesma diandrum*	38	27	4.0	5.3	9.3
6	*Vitex pubescens*	32	26	3.4	5.1	8.4
7	*Celtis cinnamomea*	36	21	3.8	4.1	7.9
8	*Mitragyna rotundifolia*	35	19	3.7	3.7	7.4
9	*Tectona grandis*	25	17	2.6	3.3	6.0
10	*Psychotria calocarpa*	36	11	3.8	2.1	5.9
11	*Schleichera trijuga*	23	18	2.4	3.5	5.9
12	*Protium serratum*	24	17	2.5	3.3	5.8
13	*Terminalia chebula*	22	17	2.3	3.3	5.6
14	*Gardenia erythroclada*	24	15	2.5	2.9	5.5
15	*Premna latifolia*	26	13	2.7	2.5	5.3
16	*Haplophragma adenophyllum*	19	13	2.0	2.5	4.5
17	*Deris robusta*	17	13	1.8	2.5	4.3
18	*Sapindus mukorossi*	24	9	2.5	1.8	4.3
19	*Annogeissus accuminata*	20	10	2.1	2.0	4.1
20	*Largerstroemia villosa*	15	11	1.6	2.1	3.7
21	*Bridelia retusa*	12	7	1.3	1.4	2.6
22	*Mytragyna pavifolia*	10	8	1.1	1.6	2.6
23	*Erblica officinalis*	10	8	1.1	1.6	2.6
24	*Kydia calycina*	11	7	1.2	1.4	2.5
25	*Pterocarpus macrocarpus*	10	7	1.1	1.4	2.4
26	Unidentified	9	4	0.9	0.8	1.7
27	*Diospyros martabanica*	7	5	0.7	1.0	1.7
28	*Oroxylum indicum*	7	4	0.7	0.8	1.5

29	*Homalium tomentosum*	5	5	0.5	1.0	1.5
30	*Albizzia odoratassiama*	6	4	0.6	0.8	1.4
31	*Mallotus cochinchinensis*	5	4	0.5	0.8	1.3
32	*Pterospermum semisagittatum*	4	4	0.4	0.8	1.2
33	*MIliusa velutina*	4	4	0.4	0.8	1.2
34	*Albezzia procera*	5	3	0.5	0.6	1.1
35	*Spondias pinnata*	3	3	0.3	0.6	0.9
36	*Stereospermum personatum*	3	3	0.3	0.6	0.9
37	*Largerstroemia tomentosa*	3	3	0.3	0.6	0.9
38	*Cordia dichotoma*	3	3	0.3	0.6	0.9
39	*Croton rodburghianus*	3	2	0.3	0.4	0.7
40	*Streblus asper*	2	2	0.2	0.4	0.6
41	*Macaranga denticulata*	2	2	0.2	0.4	0.6
42	*Dillenia pentagyna*	2	2	0.2	0.4	0.6
43	*Clausena excavata*	3	1	0.3	0.2	0.5
44	*Mallotus phillippenesis*	2	1	0.2	0.2	0.4
45	*Dalbergia fusea*	2	1	0.2	0.2	0.4
46	*Diospyros ehretioides*	1	1	0.1	0.2	0.3
47	*Garuga pinnata*	1	1	0.1	0.2	0.3
48	*Salmalia insignis*	1	1	0.1	0.2	0.3
49	*Vitex glabrata*	1	1	0.1	0.2	0.3
50	*Buchanania lanzan*	1	1	0.1	0.2	0.3
51	*Microcos paniculata*	1	1	0.1	0.2	0.3
52	*Lrgerstroemia speciosa*	1	1	0.1	0.2	0.3
53	*Streopermum grandiflorum*	1	1	0.1	0.2	0.3
54	*Dalbergia lanceolaria*	1	1	0.1	0.2	0.3
55	*Gmelina arborea*	1	1	0.1	0.2	0.3
56	*Dichroa febrifuga*	1	1	0.1	0.2	0.3
	Total	**950**	**512**	**100**	**100**	**200**

Appendix III: Relative abundance + relative frequency for natural regeneration (seedlings) found in the study sites (based on the individuals having < 30 cm height)

A. Study site 1, Ngalaik Reserved Forest, Compartment No. 18, Pyinmana Township

Sr.	Species	Total		Relative		Relative (Abun. + Freq.)
		Abun. N/Ha	Freq. %	Abun. %	Freq. %	
1	*Holarrhena antidyscenterica*	129	38	14.0	8.1	22.0
2	*Markhamia stipulata*	86	42	9.3	8.9	18.2
3	*Chukrasia tabularis*	76	42	8.2	8.9	17.1
4	*Dalbergia ovata*	88	29	9.5	6.1	15.7
5	*Antidesma diandram*	46	29	5.0	6.1	11.1
6	*Cratoxylum neriifolium*	63	18	6.8	3.8	10.6
7	*Pterospermum semisagittatum*	43	24	4.7	5.1	9.7
8	*Grewia hirsuta*	42	17	4.6	3.6	8.2
9	*Protium serratum*	32	22	3.5	4.7	8.1
10	*Premna latifolia*	34	18	3.7	3.8	7.5
11	*Haplophragma adenophyllum*	33	14	3.6	3.0	6.5
12	*Dalbergia cultrata*	24	17	2.6	3.6	6.2
13	*Hymennodictyon excelsum*	25	13	2.7	2.8	5.5
14	*Bridelia retusa*	19	15	2.1	3.2	5.2
15	*Schleichrea trijuga*	20	12	2.2	2.5	4.7
16	*Xylia dolarbriformis*	17	11	1.8	2.3	4.2
17	Vitex pubescens	15	11	1.6	2.3	4.0
18	*Aegle mamelos*	18	7	2.0	1.5	3.4
19	Tectona grandis	13	9	1.4	1.9	3.3
20	*Kydia calycina*	10	6	1.1	1.3	2.4
21	*Oroxylum indicum*	10	6	1.1	1.3	2.4
22	*Mallotus phillippenesis*	8	6	0.9	1.3	2.1
23	*Anogeissus accuminata*	7	6	0.8	1.3	2.0
24	*Mitragyna rotundifolia*	6	5	0.7	1.1	1.7
25	*Sapindus mukorossi*	5	5	0.5	1.1	1.6
26	*Maliusa roxburghiana*	5	4	0.5	0.8	1.4
27	*Salmalia insignis*	4	4	0.4	0.8	1.3
28	*Wrightia tomentosum*	4	4	0.4	0.8	1.3

29	*Lagerstroemia tomentosa*	3	3	0.3	0.6	1.0
30	*Streopermum grandiflorum*	3	3	0.3	0.6	1.0
31	*Pongamia pinnata*	3	3	0.3	0.6	1.0
32	*Terminalia bellerica*	3	3	0.3	0.6	1.0
33	*Rinorea recemosa*	3	3	0.3	0.6	1.0
34	*Terminalia pyrifolia*	3	2	0.3	0.4	0.7
35	*Miliusa velutina*	2	2	0.2	0.4	0.6
36	*Croton roxburghianus*	2	2	0.2	0.4	0.6
37	*Dalbergia fusea*	2	2	0.2	0.4	0.6
38	*Largerstroemia villosa*	2	2	0.2	0.4	0.6
39	*Celtis cinnamomea*	3	1	0.3	0.2	0.5
40	*Diospyros ehretioides*	1	1	0.1	0.2	0.3
41	*Garuga pinnata*	1	1	0.1	0.2	0.3
42	*Stereospermum personatum*	1	1	0.1	0.2	0.3
43	*Ptercarpus macrocarpus*	1	1	0.1	0.2	0.3
44	*Bauhinia recemosa*	1	1	0.1	0.2	0.3
45	*Vitex pedunculais*	1	1	0.1	0.2	0.3
46	*Holoptelea integrifolia*	1	1	0.1	0.2	0.3
47	*Cordia fragrantissima*	1	1	0.1	0.2	0.3
48	*Hesperethusa caenulata*	1	1	0.1	0.2	0.3
49	*Pouteria tomentosa*	1	1	0.1	0.2	0.3
50	*Erythropsis colorata*	1	1	0.1	0.2	0.3
51	*Emblica officinalis*	1	1	0.1	0.2	0.3
	Total	**923**	**472**	**100**	**100**	**200**

Appendix III: Relative abundance + relative frequency for natural regeneration (seedlings) found in the study sites (based on the individuals having < 30 cm height)

B. Study site 2, Coupe XIII of Yedashe Township

Sr.	Species	Total		Relative		Relative (Abun. + Freq.)
		Abun. N/Ha	Freq. %	Abun. %	Freq. %	
1	*Holarrhena antidyscenterica*	140	41	20.5	11.6	32.1
2	*Cratoxylum neriifolium*	69	30	10.1	8.5	18.6
3	*Grewia hirsuta*	57	29	8.3	8.2	16.6
4	*Antidesma diandram*	34	22	5.0	6.3	11.2
5	*Premma latifolia*	33	16	4.8	4.5	9.4
6	*Albizzia odoratissiama*	31	17	4.5	4.8	9.4
7	*Tectona grandis*	27	19	3.9	5.4	9.3
8	*Celtis cinnamomea*	28	14	4.1	4.0	8.1
9	*Derris robusta*	22	16	3.2	4.5	7.8
10	*Anogeissus accuminata*	31	10	4.5	2.8	7.4
11	*Gardenia erythroclada*	16	12	2.3	3.4	5.7
12	*Protium serratum*	17	11	2.5	3.1	5.6
13	*Xylia dolarbriformis*	14	12	2.0	3.4	5.5
14	*Mallotus phillippenesis*	17	7	2.5	2.0	4.5
15	*Vitex pubescens*	13	8	1.9	2.3	4.2
16	*Sapindus mukorossi*	16	6	2.3	1.7	4.0
17	*Mitragyna rotundifolia*	10	9	1.5	2.6	4.0
18	*Pterocarpus macrocarpus*	11	7	1.6	2.0	3.6
19	*Terminalia chebula*	11	6	1.6	1.7	3.3
20	*Psychotria calocarpa*	9	6	1.3	1.7	3.0
21	*Erblica officinalis*	9	6	1.3	1.7	3.0
22	*Mitragyna parvifolia*	8	5	1.2	1.4	2.6
23	*Lagerstroemia tomentosa*	7	5	1.0	1.4	2.4
24	*Dalbergia lanceolaria*	9	2	1.3	0.6	1.9
25	*Stereospermum personatum*	6	3	0.9	0.9	1.7
26	*Diospyros martabanica*	4	4	0.6	1.1	1.7
27	*Oroxylum indicum*	4	3	0.6	0.9	1.4
28	*Homalium tomentosum*	4	3	0.6	0.9	1.4

29	*Bridelia retusa*	3	3	0.4	0.9	1.3
30	*Albizzia procera*	3	3	0.4	0.9	1.3
31	*Pterospermum semisagittatum*	3	2	0.4	0.6	1.0
32	*Schleichera trijuga*	2	2	0.3	0.6	0.9
33	*Haplophragma adenophyllum*	2	2	0.3	0.6	0.9
34	*Croton roxburghianus*	2	2	0.3	0.6	0.9
35	*Largerstroemia villosa*	2	2	0.3	0.6	0.9
36	*Kydia calycina*	3	1	0.4	0.3	0.7
37	*Pentace griffithii*	2	1	0.3	0.3	0.6
38	*Bauhinia malabarica*	1	1	0.1	0.3	0.4
39	*Macaranga denticulata*	1	1	0.1	0.3	0.4
40	*Mallotus cochinchinensis*	1	1	0.1	0.3	0.4
41	*Cordia dichotoma*	1	1	0.1	0.3	0.4
42	*Pentace bumanica*	1	1	0.1	0.3	0.4
	Total	**684**	**352**	**100**	**100**	**200**

Appendix IV: Results from statistical analysis

A. Analysis of variance for mean survival in line planting experiment

Analysis of variance

Variate : Survival

Source of variation	d.f.	s.s	m.s.	v.r.	F pr.
Repl stratum	2	70.78	35.39	0.46	
Repl. Main stratum					
Main	2	45.39	22.7	0.30	0.758
Residual	4	304.85	76.21	0.86	
Repl. Main. Sub stratum					
Sub	1	310.09	310.09	3.50	0.111
Main. Sub	2	19.36	9.68	0.11	0.898
Residual	6	531.67	88.61		
Total	17	1282.15			

Least significant differences of means (5% level)

	Main	Sub	Main. Sub
l. s. d	13.99	10.86	16.55

Standard errors and coefficients of variation

Stratum	d.f.	s.e.	cv %
Repl	2	2.43	3.0
Repl. Main	4	6.17	7.6
Repl. Main. Sub	6	9.41	11.6

Appendix IV: Results from statistical analysis

B. Analysis of variance for mean height in line planting experiment

Analysis of variance

Variate : Height

Source of variation	d.f.	s.s	m.s.	v.r.	F pr.
Repl stratum	2	205.31	102.66	11.04	
Repl. Main stratum					
Main	2	340.75	170.38	18.33	**0.010**
Residual	4	37.19	9.30	0.69	
Repl. Main. Sub stratum					
Sub	1	1493.68	1493.68	110.80	**< .001**
Main. Sub	2	155.29	77.65	5.76	**0.040**
Residual	6	80.89	13.48		
Total	17	2313.11			

Least significant differences of means (5% level)

	Main	Sub	Main. Sub
l. s. d	4.888	4.235	6.140

Standard errors and coefficients of variation

Stratum	d.f.	s.e.	cv %
Repl	2	4.136	10.7
Repl. Main	4	2.156	5.6
Repl. Main. Sub	6	3.672	9.5