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Silvicultural assessment of enrichment planting with commercial tree species after selective logging

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The integrity of forest stands in logging concessions depends on the logging method. Selective logging is the most commonly used method in the tropics, disturbing a considerable proportion of soil and canopy cover creating distinct sites for plant establishment. The objective of this study was to evaluate the silvicultural requirements in terms of light and moisture of seedlings of some commercial tree species used for enrichment planting. This study was carried out in two Forest Management Units in the East Region and a shade house at the University of Buea campus in the South West Region of Cameroon. 15 of the 20 most exploited species were selected for the assessment of their seedling functional performance. Nineteen log yards with their corresponding skid trails were selected randomly for enrichment planting. Monthly height measurements of the seedlings were recorded for 34 months. The shade house experiment had an unbalanced factorial experiment incorporating light and moisture. The growth rate in height was significantly higher in log yards (3.8 cm/month) and least under the forest canopy (1.2 cm/month). The growth rate in height was highest under high light and high moisture in *Pterocarpus soyauxii* (13.3 cm/month) and least under low light and high moisture in *Entandrophragma cylindricum* (0.7 cm/month). Mortality was highest under the forest canopy (11.1%) and least in the skid trails (0%). The results indicated that plant species should be planted according to their light and moisture requirements during enrichment planting at the seedling stage and for a sustainable forest management.

Key words: Enrichment planting, log yards, skid trails, shade house, under forest canopy.

INTRODUCTION

Tropical forests are very diverse in terms of composition, structure and functioning and serve as habitat for heterogeneous animal and plant species (Rhett., 2019). They control the climate, provide hydrological services,

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controls erosion in the area where it is located and provides many timber and non-timber products, that are indispensable to man's livelihood (Dkamela et al., 2009; Blanco and Yueh-Hsin, 2012; Megevand et al., 2013). Forests are thus very essential for life on earth and therefore deserve wise use and conservation for the benefit of rural people in particular who are directly dependent on the forest and for the benefit of humanity in general (Biswas, 1993). However, there has been increasing awareness and concern about the rapid rate of deforestation and forest degradation in developing countries caused by anthropogenic activities like logging, shifting cultivation and urban development.

The integrity of forest stands in logging concessions depends on the method applied in logging. Selective logging is one of the most common forms of forest use in the tropics and in Cameroon in particular with only six logged species accounting for 75% of total timber volume (Ruiz Pérez et al., 2005). This over dependence on some particular species will eventually lead to the extinction of these species in the forest ecosystem altering the natural regeneration of the forest ecosystem dynamics making the ecological and biological complexity of the forest to be profoundly disrupted (Panayotou and Ashton, 1992). This depletion of logged species is of growing concern making some of these species to be listed on the International Union for Conservation of Nature (IUCN) red list (Bourland et al., 2012).

Putz et al. (2012) emphasized in their meta-analysis that although 85-100% of species of mammals, birds, invertebrates, and plants remain after selective logging, the timber volumes decline by about 65% after the first harvest if the same species are again harvested (Deckker and de Graaf, 2003). Thus though logging concessions could be used as a conservation intervention to protect forests (Gaveau, 2014), the timber volume and biodiversity may decline after selective logging To conserve the biodiversity of the forest after selective logging, an enrichment of the forest with exploited species is of outmost importance.

Present forest composition may be largely due to natural selection operating in the past but we can expect major changes to occur in the edaphically extreme sites and those already with limited resources after logging thus hindering regeneration of these species. The main constraint in tropical forests over plant growth and regeneration is the low light intensity at the canopy understory allowing only about 2-3% of the Photosynthetically Active Radiation (PAR) to reach the understorey (Gastellu-Etchegorry et al., 1999). In selectively logged tropical forest, the creation of skid trails and log yards can disturb a considerable proportion of soil and canopy cover during timber harvesting creating distinct sites for plant establishment. Forest recovery in these sites may be substantially retarded due to substrate compaction by heavy machinery use and lack of onsite plant propagules after topsoil disturbance creating a more heterogeneous structure with patches of felling gaps, skid trails, and log yards (Fimbel et al., 2001; Putz et al., 2001). Large openings are subject to invasion by understory shrubs, lianas and herbs that can be an obstacle to tree regeneration by competing with the seedlings of slow growing economically important tree species (Mokake et al., 2018). The logged forest might therefore gradually be replaced by relatively species-poor forests dominated by pioneer species and over time by more diverse mixtures of later successional species, and ultimately the climax forest will re-establish (Chazdon, 2014); thereby affecting its biodiversity.

One approach to recover the original forest is simply to protect these forests and allow nature to take its course; but results from the natural regeneration assessments indicate competition of the seedlings of timber species with the dense undergrowth of lianas, strubs and herbs for nutrients, moisture and light (Vieira and Scariot, 2008; Mokake et al., 2018). Silvicultural interventions including planting of high-value species are therefore necessary to overcome the relative depletion of commercial tree species, to compensate for the slow growth rate, and to ensure a future commercial timber value of the forest (ITTO, 2002) thereby reestablishing or conserving the timber biodiversity of forest stands. Through these interventions, it may be possible to enhance the rate of recovery and, moreover, deliberately manipulate forest composition to meet particular management objectives (Lamb, 2011).

Enrichment planting is a method of silvicultural management process of supplementing natural regeneration with seedlings of commercial and indigenous species (Martinez-Garza and Howe, 2003; Paquette et al., 2006a). Unfortunately, baseline information about ecological processes and the specific growth requirements of many of the commercial species that are available for planting is still very limited (Thomas and Chuyong, 2006; Paquette et al., 2006b). Also many enrichment planting trials in Africa were based on a few or single species (e.g., *Khaya spp*., *Tarrietia utilis*, Dupuy and Koua, 1993) sometimes planted on huge areas (e.g., *Aucoumea klaineana* in Gabon, Brunck et al., 1990). During enrichment planting, species mixtures are desirable for both improving biodiversity and the range of goods and services as well as limiting pest-induced damages (Piotto et al., 2004; Potvin and Gotelli, 2008). Different kinds of mixtures exist ranging from simple mixtures consisting of two or more species planted in single-species blocks or rows (Stanturf et al., 2014). Such mixtures are useful on sites with distinct gradients in environmental factors such as drainage or light. However, it is necessary that these species be planted in specific sites according to their growth requirements (Stanturf et al., 2014). Avon et al. (2013) indicated that, openings created along skid trails can lead to competition

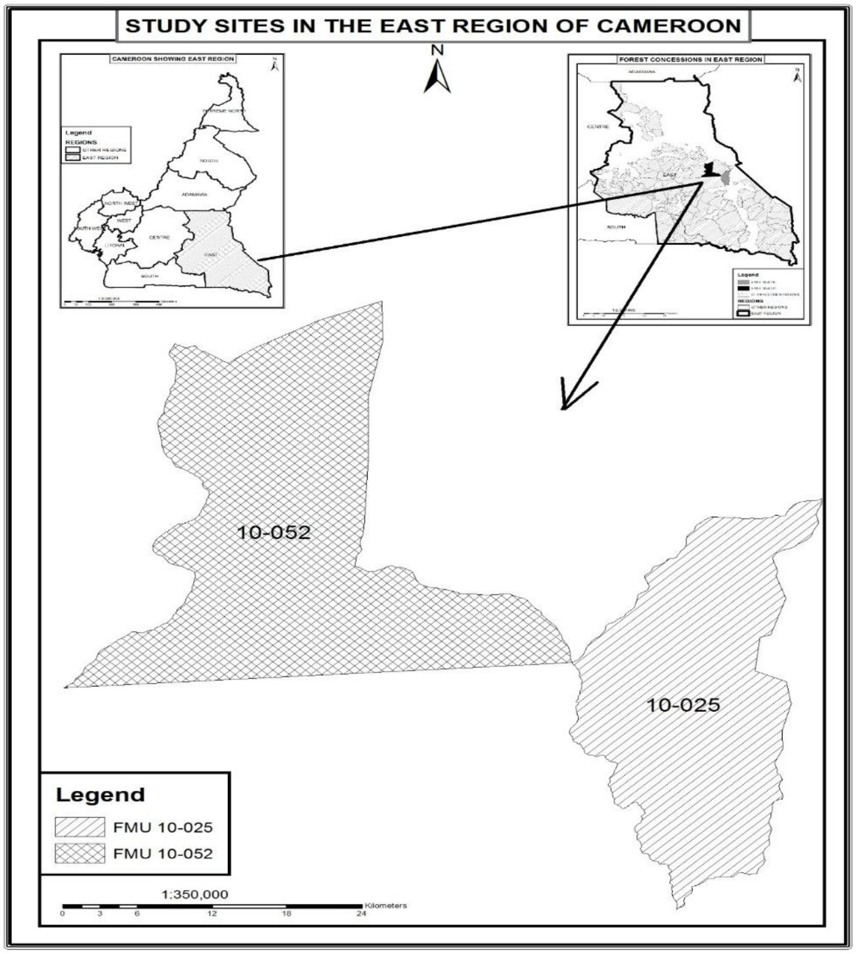

Figure 1. Study site (Localization of FMUs 10-025, and 10-052 logging concessions in the East Region of Cameroon).

sequences between shade-tolerant and shade-intolerant species which in turn affect natural regeneration. Therefore care needs to be taken on the type of species planted on the different sites created during logging. However, there is little data on site tolerance and growth of timber species used for enrichment planting after selective logging in Africa (Dupuy and Mille, 1993; Piotto, 2008; Doucet et al., 2016). Most enrichment plantings carried out are not reported and are not species and site specific to edaphically extreme sites created by logging. Therefore knowledge of the growth requirements of the seedlings of commercial species are necessary if they have to be incorporated into any enrichment planting scheme. The objective of this study was to evaluate the silvicultural requirements in terms of light and moisture of seedlings of some commercial tree species using functional traits to predict species performance under uncontrolled environment of different stand conditions (e.g., log yards, skid trail and under forest canopy) and a controlled environment in a shade house experiment.

MATERIALS AND METHODS

Study sites

An enrichment planting was established in two Forest Management Units (FMU) (FMUs 10-052 and 10-025) in the East Region of Cameroon (Figure 1) while the shade house experiment was carried out at the University of Buea main campus in the South West Region of Cameroon (Figure 2). The East Region occupies the Southeastern portion of the Republic of Cameroon. It lies between latitude 3°08 to 3°21 North and longitude 14°31 to14°52 East. It is bordered to the East by the Central African Republic, to the South by the Republic of Congo, to the North by the Adamawa Region, and to the West by the Centre and South Regions. It has an area of 109,011 km² with its soil predominantly ferrallitic, rich with iron and red in colour. The East Region has a wet equatorial climate with high temperatures (24°C on average) and a lack of

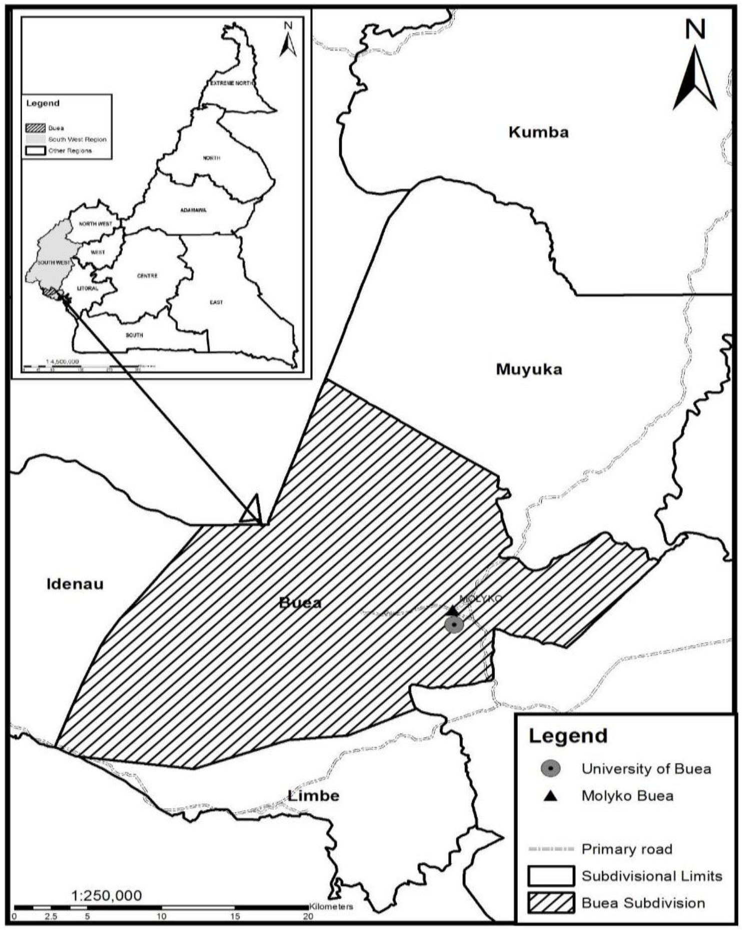

Figure 2. Location of the shade house experiment in the South West Region of Cameroon.

traditional seasons. Instead, there is a long dry season from December to May, a light wet season from May to June, a short dry season from July to October, and a heavy wet season from October to November (Fitzpatrick, 2002). Relative humidity and cloud cover are relatively high, and annual mean precipitation 1500-2000 mm except in the extreme eastern and northern portions, where it is slightly less. Relative humidity is highest in the month of June and lasts till the month of December (Fitzpatrick, 2002).

On the other hand, the shade house experiment was carried out in the South West Region of Cameroon at the University of Buea main campus located in the Fako Division (Figure 2) and in the coastal belt of the Gulf of Guinea (Cronin et al., 2014). Buea is located at Longitude 4° 09' North to Latitude 9° 14' East, having a distance of approximately 823 km from the East region where the seedlings were harvested (Google Maps) and a humid tropical climate with a rainfall not greater than 50 mm over a 5 months span (Oates et al., 2004). The climate is strongly seasonal, with one pronounced dry season between December and February and a long wet season from march to November (Newbery et al., 2006). The site has a precipitation of 100 mm each month which peaks in August (Cronin et al., 2014). The mean annual temperature is about 25^0C (Oates et al., 2004). The relative humidity of the area is between 75 and 85 % throughout the year on the South Western side of Mount Cameroon due to the coastal influence and the incidence of mist and orographic cloud formation (Cronin et al., 2014). The soils are mainly volcanic which are relatively fertile (CDC, 1997). The Mount Cameroon region lies within the tropical rainforest of West Africa. According to the different agro ecological zones in Cameroon, the South West and East Region both belong to the tropical rain forest. However, the South West Region has a monomodal rainy season while the East Region has a bimodal rainy season. This is the more reason why the shade house experiment could conveniently be carried out in the South West Region.

Selection of commercial species used in controlled and uncontrolled environments

15 of the 20 most exploited species in Cameroon were selected based on the seeds and seedlings found on the forest floor for the assessment of their seedling functional performance in both natural forest stands (uncontrolled environment) and shade house (controlled environment) (Table 1).The Fabaceae had 4 species, Sterculiaceae had 3 species, and Meliaceae had 2 species; while the Sapotaceae, Combretaceae, Lecythidaceae, Irvingiaceae, Ochnaceae and Moraceae were represented by a species each (Figures 1 and 2).

Table 1. Commercial tree species and number of their seedlings used in controlled and uncontrolled environments.

Econimically important tree species	Family	Common name	LYs	STs	UFC	SH	Total
Triplochyton scleroxylon K.Schum.	Sterculiaceae	Ayous	174	25	24	0	223
Mansonia altissima (A.Chev.) A. Chev.	Sterculiaceae	Bete	55	13	24	12	104
Aningeria altissima (A. Chev.) Aubrév. and Pellegr.	Sapotaceae	Aningre	82	19	24	9	134
Terminalia superba Engl. and Diels.	Combretaceae	Frake	13	4	24	28	69
Entandrophragma cylindricum (Sprague) Sprague.	Meliaceae	Sapelli	76	20	24	19	139
Erythrophleum sauveolens A.Chev.	Fabaceae	Tali	47	15	24	16	102
Petersianthus macrocarpus (P.Beauv.) Liben.	Lecythidaceae	Abale	0	0	0	3	3
Klainedoxa gabonensis Pierre.	Irvingiaceae	Eveuss	0	0	8	0	9
Pterocarpus soyauxii Taub.	Fabaceae	Padouk rouge	93	15	24	9	141
Afzelia africana Sm. ex Pers.	Fabaceae	Doussie	3	3	0	0	6
Cylicodiscus gabonensis Harms	Fabaceae	Okan	6	0	0	0	6
Entandrophragma excelsum (Dawe and Sprague) Sprague	Meliaceae	Tiama	1	0	0	0	1
Lophira alata Tiegh. ex Keay	Ochnaceae	Azobe	0	0	0	7	7
Milicia excelsa (Welw.) C.C. Berg	Moraceae	Iroko	0	2	0	0	2
Eribroma oblongum Mast.	Sterculiaceae	Eyong	0	0	24	0	24
TOTAL			550	116	200	103	969

LYs = log yards, STs = skid trails and UFC = under forest canopy, and SH= shade house.

Raising of seedlings for enrichment planting and shade house experiments

All the seedlings and seeds for this study was collected from the forest of the East Region. Seedlings for the enrichment planting were collected from the nursery of the National Forestry Development Agency (ANAFOR) located in the FMU 10052 (Plate 1). For the shade house experiment, wildings of *Lophira alata, Pterocarpus soyauxii, Entandrophragma cylindricum,* and *Petersianthus macrocarpus* were collected from the forest floor in the East Region of Cameroon. The seedlings were of that year's seed rain as cotyledonous scares were still very visible. These were wrapped in a mixture of top soil and sand and watered every two hours. Upon getting to the shade house, they were immediately transplanted in to black polythene bags (18 x 17 x 15 cm) filled with top soil. The seedlings of *Erythrophleum sauveolens, Klainedoxa gabonensis*, *Mansonia altissima* and *Terminalia superba* were raised from the seeds of these species collected from the forest of the East Region of Cameroon.

Seeds having a thick seed coat were pre-treated before sowing into the germinator. These included the seeds of *Erythrophleum sauveolens*, which were treated in 10% of concentrated Sulphuric acid for 10-15 minand *Klainedoxa gabonensis* which were soaked in water for three days. The seeds were planted at 1cm depth in a germinator of 1 m × 50 cm and watered daily with the use of an 11 L watering can, in order to maintain the moisture of the soil (Plate 2). The germinator was sheltered at 2 m height with 70% shade cloth spread wide overhead to block direct sunlight. New germinants were censured at 2 days intervals for 30 days as hypocotyls emerged above the soil surface. However some species had no seedlings that germinated, maybe due to the fact the transportation conditions were not favorable enough for the specific species. The germinated seedlings were then transplanted into 18 x 17x 15 cm black polythene bags filled with top soil.

Enrichment planting of seedlings under different stand conditions in the East Region of Cameroon

Each FMU (10-052 and 10-025) has an average of 50-60 small log yards with an average area of 1,050m^2 with many skid trails. Nineteen log yards (LYs) with their corresponding skid trails (STs) were selected randomly for enrichment planting with seedlings of the selected timber species. Seedlings of 10 of the 15 selected species for the study were used for the enrichment planting (Table 1). The

Plate 1. Seedlings in the ANAFOR nursery before transplanting in the log yards and skid trails in the East region of Cameroon. a: *Entandrophragma cylindricum* seeds in the germinator, b: *Pterocarpus soyauxii* seedlings in the germinator, c: pretransplanted *Pterocarpus soyauxii* seedlings from the germinator, d: *Entandrophragma cylindricum* seedlings, e: *Triplochyton scleroxylon* seedlings, f: partial view of nursery site.

leaves of the seedlings were prunned and planted using the line method with a spacing of 5 × 5 m in log yards, skid trails and under the forest canopy. These seedlings were tagged in order to differentiate them from already established and germinating seedlings on the forest floor. A total of 666 seedlings were planted in 19 Log yards (Lys=550) with their corresponding skid trails (STs=116) and 200 under the forest canopy (Table 1). Monthly height measurements of the seedlings were recorded using a metric tape over a period of 34 months (March 2012-December 2014).

Shade house experiment in the South West Region of Cameroon

The shade house was constructed with a Tildnet netting material (Tildnet, UK). A Photosyntheically Active Radaition (PAR) quantum sensor (Skye, USA) was used to measure the amount of light intensity available for the plants. An amount of 65% of sunlight was available to the plants. The three light levels were obtained by varying the layers of the netting material as follows:

(i) High: no netting of approximately 100% Photosyntheically Active Radaition (PAR);
(ii) Medium: single layer of Tildnet netting of approximately 65% PAR;
(iii) Low: double layers of Tildnet netting approximately 20% of PAR.

The moisture levels were as described by Hall et al. (2003);
(i) High: watering with 200 ml of water twice a week
(ii) Low: watering with 200 ml of water once a week.

The seedlings of 8 of the 15 selected exploited species were used for the shade house experiment (Table 1). The unbalanced factorial experiment incorporated two factors: light with three levels (high, medium and low) and moisture with two levels (high and low) giving a six treatment combinations (Table 2). The layout was in three blocks with three replicates. Rain was prevented from adding to the moisture level by placing a transparent plastic sheet atleast one meter above the seedlings. A total of 103 seedlings were used for the shade house experiment and monthly height measurements were recorded over a duration of six months from June 2014 - December 2014.

Data analyses

Growth rates in height of seedlings were determined as described by Hunt (1982);

(i) Absolute growth rates of seedlings

$$\text{Absolute growth rate} = \frac{\text{Log (H2)} - \text{Log (H1)}}{\text{t2} - \text{t1}}$$

Plate 2. Germinating seedlings of some commercial timber species in the germinator for the shade house experiment. a=*Mansonia altissima*, B= seedlings of *Mansonia altissima*, C=germinating seeds of *Alstonia boonei*, D= seedlings of *Alstonia boonei*, E=germinating seeds of *Erythrophleum sauveolens*, F=seedling of *Erythrophleum sauveolens.*

Table 2. Treatments following combinations of the factorial levels for light and moisture in the shade house experiment.

Moisture	Light		
	High	**Medium**	**Low**
High	HLHM	MLHM	LLHM
Low	HLLM	MLLM	LLLM

HLHM= High Light and High moisture, HLLM= High Light and Low moisture MLHM=Medium Light and High moisture, MLLM= Medium Light and Low moisture LLHM=Low Light and High moisture LLLM= Low Light and Low moisture.

(ii) Relative growth rates of seedlings

$$\text{Relative growth rate} = \frac{\text{Log }((H2)-(H1))}{t2-t1} \times 100$$

Mortality was determined following the approach of Hall and Bawa (1993);

(i) Mortality rates of seedlings

$$\text{Mortality} = \left(\text{In}\left(\frac{N0}{No-Di}\right)\right)/t1$$

Where No =total number of individuals and Di =number of death recorded.

A 2×3 factorial analysis was carried out for the shade house experiment to evaluate main effects and interactions of light and moisture. Means were determined for each species and the Kruskal

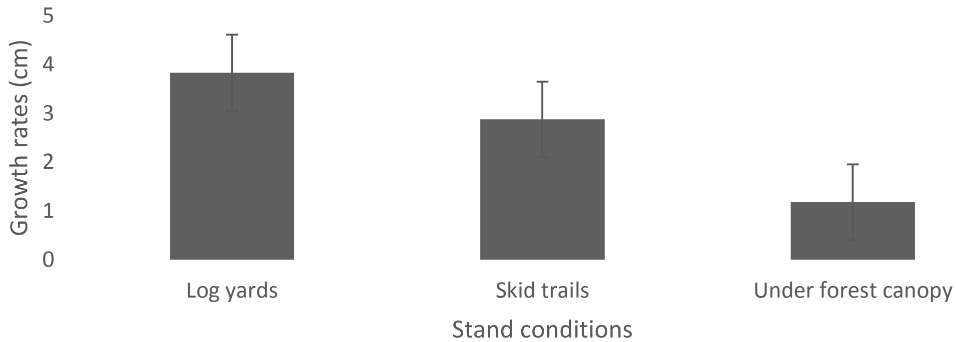

Figure 3. Growth rates in height in log yards, skid trails and under forest canopy in the East Region of Cameroon.

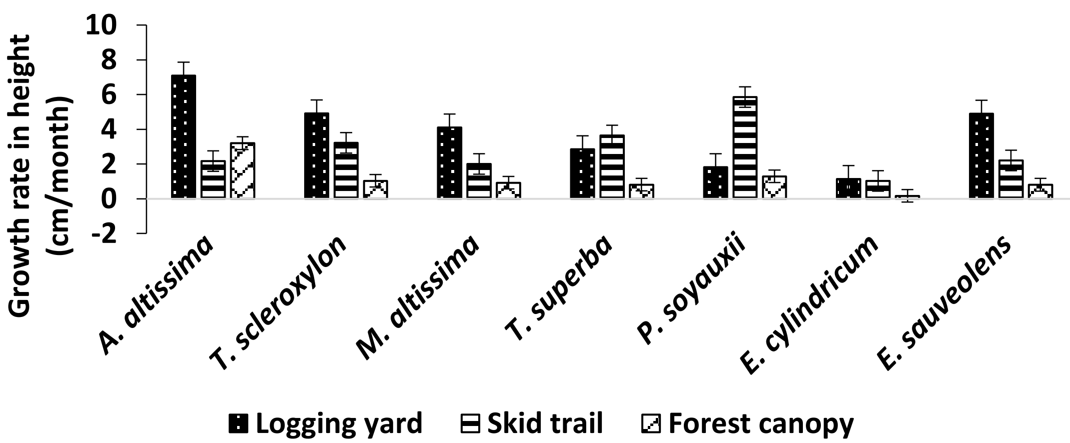

Figure 4. Species growth rate in height across sites. Growth rates in height (cm/month) of seedlings of species in log yards, skid trails and under forest canopy in the East Region of Cameroon.

Wallis and ANOVA tests were used to determine a significance difference between means for the enrichment planting and shade house experiments, respectively. All analyses were done using MINITAB version 17 (MINITAB 2010) and Excel 2013 (Microsoft Corporation 2013) with statistical significance fixed at P < 0.05.

RESULTS

Growth rates in height of seedlings in different treatments/experiment sites

Growth rates in height of seedlings were significantly different (p=0.01) between forest stand conditions with the log yards having the highest (3.8 cm/month) and the least under the forest canopy (1.2 cm/month) (Figure 3). Growth rates in height were also significantly different between species across the stand conditions (p=0.01) with the highest found in *Aningeria altissima* (7.1 cm/month) in the log yards while the least was in *Entandrophragma cylindricum* (0.2 cm/month) under the forest canopy (Figure 4). This is further confirmed by the growth rates in height of each species between the various stands found in Table 3.

Similarly in the shade house, absolute growth in height (cm/month) was significantly different between treatments and species (p=0.01). This was highest in *Pterocarpus soyauxii* (13.3 cm/month) under high light and high moisture condition while *E. cylindricum* had the least absolute growth rate (0.7 cm/month) under low light and high moisture condition. The relative growth in height on the other hand was highest in *A. altissima* (100 cm/month) under medium light and high moisture condition and least in *E. cylindricum* (1.9 cm/month) under low light and high moisture condition (Table 4) indicating that a combined effect of light and moisture has a significant effect on the growth rate in height of the species.

Apparently, *Terminalia superba* and *E. cylindricum*

Table 3. Growth rates in height (cm/month) of seedlings of selected species transplanted in log yards, skid trails and under forest canopy in some logging concessions in the East Region of Cameroon.

Species	Growth rates in height of seedlings (cm/month)		
	Log yards	Skid trails	Under forest canopy
Aningeria altissima	**7.1**	2.2	**3.2**
Triplochyton scleroxylon	4.9	3.2	1.0
Mansonia altissima	4.1	2.0	0.9
Afzelia africana	6.8	4.9	-
Terminalia superba	2.8	3.6	0.8
Pterocarpus soyauxii	1.8	**5.9**	1.3
Entandrophragma cylindricum	**1.1**	**1.0**	**0.2**
Erythrophleum sauveolens	4.9	2.2	0.8
Baillonella toxisperma	2.2	-	-
Cylicodensis gabunensis	4.0	-	-
Entandrophragma excelsum	4.6	-	-
Milicia excelsa	-	5.8	-
Klainedoxa gabonensis	-	-	0.4
Eribroma oblongum	-	-	2.6

-= absent.

Table 4. Absolute and relative growth rate in height (cm/month) of seedlings of selected species across treatments in some logging concessions in the East Region of Cameroon.

Species	Treatments											
	LLLM		LLHM		MLLM		MLHM		HLLM		HLHM	
	A*	R#	A	R	A	R	A	R	A	R	A	R
Petersianthus macrocarpus	1.6	6.4	-	-	5.8	11.7	-	22.1	9.4	34.4	-	-
Mansonia altissima	8.1	32.4	10.7	29.8	10.3	20.9	10.1	15.5	-	-	7.5	23.4
Terminalia superba	2.3	9.0	3.3	5.5	8.3	16.8	7.1	22.6	5.2	19.2	4.9	15.4
Lophira alata	6.8	27.2	5.9	16.5	8.5	17.2	10.4	24.5	-	-	-	-
Pterocarpus soyauxii	1.1	4.5	2.7	7.6	6.7	13.6	11.2	6.8	-	-	**13.3**	41.7
Entandrophragma cylindricum	1.4	5.6	**0.7**	**1.9**	3.4	6.8	3.1	4.2	3.8	13.9	3.2	10.0
Erythrophleum sauveolens	3.7	15	4.1	11.3	4.8	9.7	1.9	-	5.5	20.1	-	-
Klainedoxa gabonensis	-	-	6.7	18.6	-	-	-	4.4	-	-	-	-
Aningeria altissima	-	-	1.9	5.3	1.6	2.2	2.0	**100**	3.4	12.4	3.0	9.5

-=absent, A*= absolute growth rate, and R#= relative growth rate.

found in all treatments in the shade house had a linear increment in mean height with time in all treatments from the medium and high light conditions (Figure 5a and b, respectively). A confirmation that light was the main determining factor of growth.

Species seedling mortality

Mortality was not significantly different between species in the different stand conditions and between stand conditions (p =0.1). Mortality was generally very low for all the seedlings planted with no death recorded along the skid trails (0 %). Mortality was recorded for just 4 species; *Terminalia superba*, and *Baillonella toxisperma* (9.1%) in log yards, and *E. cylindricum* and *Eribroma oblongum* (11.1%) under the forest canopy. Thus mortality was highest under the forest canopy and least in the skid trails.

Similarly, mortality was not significantly different between treatments (p=0.4) and species under controlled conditions (p=0.5). Most species had a zero mortality. However the highest mortality occurred in *T. superba* (11.1%) under low light and high moisture condition and

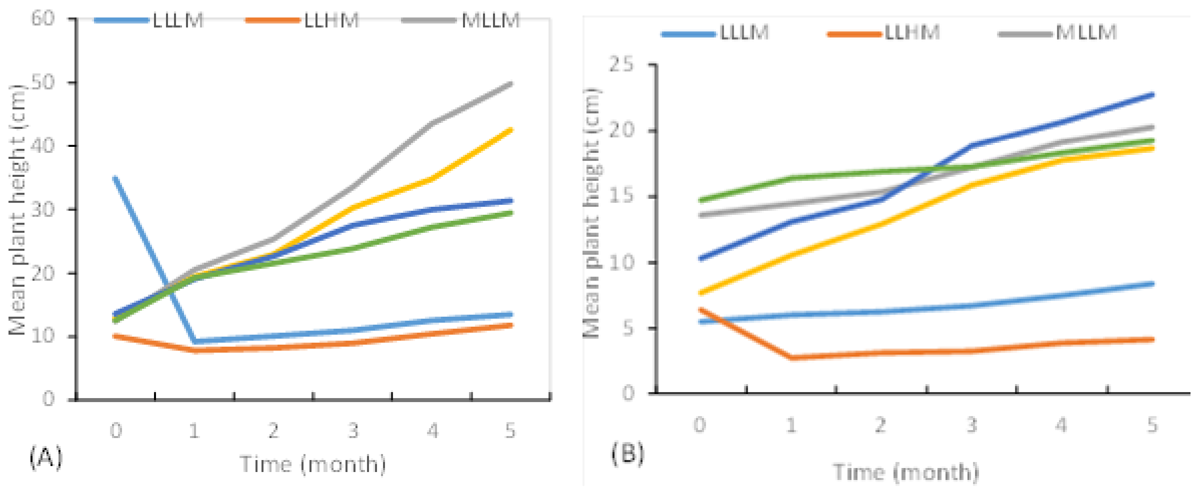

Figure 5. Mean height for different treatments over time for *Terminalia superba* (a) and *Entandrophragma cylindricum* (b) in the shade house.

Table 5. Relative mortality rate (%) between treatments and species of seedlings of selected species across treatments in the Shade house experiment in the South west Region of Cameroon.

Species	**Treatments**					
	LLLM	**LLHM**	**MLLM**	**MLHM**	**HLLM**	**HLHM**
Petersianthus macrocarpus	0	-	0	-	0	-
Mansonia altissima	0	0	0	0		0
Terminalia superba	5.6	11.1	0	0	0	0
Lophira alata	0	0	0	0	-	-
Pterocarpus soyauxii	5.6	0	0	-	-	0
Entandrophragma cylindricum	0	5.6	0	0	0	0
Erythrophleum sauveolens	0	0	0	0	0	-
Aningeria altissima	-	0	4.3	0	0	0

-=absent.

Table 6. Factorial analysis of the main effects and interactions of light and moisture on selected seedling growth rate under controlled conditions in the South West region of Cameroon.

Species	**Source of variation**	**Mean**	**F-value**	**P-value**
	Light	5.3	63.69	**0.001**
Growth rate	Moisture	0.3	3.18	0.125
	Light and Moisture	0.6	7.34	**0.024**

least in *Aningeria altissima* (4.3%) under medium light and low moisture condition with no deaths recorded under medium light and high moisture (conditions similar to skid trails) (Table 5). A factorial analysis indicated that light and a combined effect of light and moisture, had significant effects on the growth rates in height of these species in the shade house as shown in Table 6.

Specifically, the research findings revealed that light had a significant influence on all species for growth rate in height except for *A. altissima* (p = 0.9) and

Table 7. Factorial analysis of the interactions for growth rate in height between light and moisture.

Species	Source of variation	Growth rate in height		
		Mean	**F-value**	**P-value**
Mansonia altissima	Light	44.99	43.76	0.001
	Moisture	21.8	21.16	**0.004**
	Light*moisture	17.4	16.95	0.003
Terminalia superba	Light	20.6	34.18	0.001
	Moisture	0.18	0.30	0.605
	Light*moisture	1.01	1.67	**0.266**
Lophira alata	Light	54.2	499.59	0.001
	Moisture	1.44	13.34	**0.011**
	Light*moisture	24.2	223.23	0.001
Pterocarpus soyauxii	Light	27.17	23.05	0.002
	Moisture	63.63	53.99	**0.001**
	Light*moisture	59.07	50.12	0.001
Entandrophragma cylindricum	Light	7.61	14.17	0.005
	Moisture	0.99	1.86	0.22
	Light*moisture	0.07	0.13	**0.879**
Erythrophleum sauveolens	Light	0.7	0.71	**0.529**
	Moisture	12.08	11.80	**0.014**
	Light*moisture	9.3	9.11	0.015
Aningeria altissima	Light	3.8	0.12	**0.889**
	Moisture	23.5	0.00	0.99
	Light*moisture	3.8	0.30	**0.750**

Erythrophleum sauveolens (p=0.5). Moisture on the other hand had an insignificant influence on the growth rate for all species except *Mansonia altissima* (p=0.01), *Lophira alata* (p=0.01), *Pterocarpus soyauxii* (p=0.01) and *E. sauveolens* (p=0.01). Finally a combined effect of light and moisture had a significant influence on the growth rate in height of *M. altissima*, *L. alata, P. soyauxii, Entandrophragma cylindricum* and *E. sauveolens* (Table 7). Taking into consideration the growth rates and factorial analysis, the growth requirements of these species at the seedling stage can be proposed; with the treatment of low light low moisture not having any species (Table 8).

DISCUSSION

Climatic factors like light, temperature, moisture, and nutrients affects the growth and developmemt of plant species (Yang and Tian, 2004). In the tropical regions, different climatic conditions may have developed under the canopies of great rain forest trees (Forseth, 2010). Because of this, plants are adapted to different types of light and moisture levels adapting easily to their environment. Changes in the light intensity, quality and duration and moisture content are therefore important features of tropical forests. These changes are related to openings in the forest canopy caused by selective logging, branch and tree fall (Girona et al., 2017). Various intensities of light and moisture content affect plant growth, reproduction, primary production and thus indirectly the structure of the forest. Tree growth is thus affected by many factors, such as silvicultural treatment, competition from neighbouring trees, and microclimate (Girona et al., 2017). Separating the effect of these factors can be difficult thus the main objective of this study; to determine the growth requirements of some commercial timber species used for enrichment planting. The main impact of these results would therefore relate to the canopy structure and light penetration, with secondary

Table 8. Shade tolerance of commercial species under controlled and uncontrolled environments in the study site of Cameroon.

Treatments	Species	Shade/Light tolerance	Implications
Low light low moisture		Shade tolerant species	Under forest canopy
Low light high moisture	*Klainedoxa gabonensis, Mansonia altissima*		
Medium light low moisture	*Terminalia superba*	Mid tolerant species	Skid trails
Medium light high moisture	*Lophira alata, Aningeria altissima*		
High light low moisture	*Petersianthus macrocarpus, Entandrophragma cylindricum, Erythrophleum sauveolens, Aningeria altissima*	Shade tolerant species but light demander at a certain level of seedling species development	Log yards
High light high moisture	*Pterocarpus soyauxii*		

effects on temperature and moisture content of vegetation and soils (Kammesheidt, 2002) as light limitation in tropical forests takes many years to re-establish in log yards following forest canopy opening.

The results of this study indicated a significantly higher growth rate in height of commercial species in log yards and least under forest canopy; as well as a higher absolute growth rate in height under high light and low moisture and least in low light and high moisture. This might be due to the light availability caused by the opening of the forest canopy after selective logging. Similar results were obtained by Sist and Nguyen-The' (2002), Brenes et al. (2004) and Ne Win et al. (2012). In Bolivia, Fredericksen and Mostacedo (2000) found the greatest growth rates of tree regeneration on areas with the greatest amount of light transmittance, including log yards and log roads.

The growth and development of plants are affected by environmental factors (Yang and Tian, 2004) which would have effects on plant morphology, especially blade size, texture, thickness and plant morphology (Huang et al., 2009). Among the various environmental factors, light is one of the most important variables affecting photosynthesis as well as plant growth and development (Smith, 2000). Plants require light not only as an energy source but also as a clue to adjust their development to environmental conditions which might be the log yards, skid trails or under forest canopy. During photosynthesis, absorbed energy is transferred to the photosynthetic apparatus, which is comprised of Photosystem I (PSI), Photosystem II (PSII), electron transport carriers (cytochrome b6f (cytb6f), plastoquinone (PQ), plastocyanin (PC)), and ATP synthase. Both quality quantity and duration of incident light can have drastic impacts on photosynthetic activity and photosystem adaption to changing light quality (Belkov et al., 2019) which eventually has an effect on the growth rate.

The greater canopy openness and soil disturbance in log yards favours tree regeneration in log yards than in skid trails (Denslow, 1995; Dickinson and Whigham, 1999). This high degree of light scavenging and likely light limitation found in skid trails and under canopy; confirms the reason why growth of these species is retarded significantly in the other sites as compared to that of the log yards. Also Skid trails (conditions similar to medium light and medium moisture) have higher ground damage as compared to log yards which are usually restored before enrichment. Asner et al. (2004) indicated higher ground damage in skid trails (7-12%) than in log yards (1%) of the total harvest area in the Eastern Amazon of Brazil. This in turn leads to soil compaction and therefore retards seed germination and thus seedling growth after enrichment in the skid trails which is not usually restored. Studies have shown that soil compaction can delay the establishment of seedlings (Pinard et al., 2000; Fredericksen and Mostacedo, 2000). However, if the soils are dry during logging, commercial tree species can regenerate abundantly on skid trails (Dickinson and Whigham, 1999; Dickinson et al., 2000). This is however not the case in this study as the soil type here is clay loam which is easily compacted by logging machines; thus soil compaction should be limited during logging. Also taking into consideration that the level of canopy openness is reduced in skid trails and almost absent under the canopy, the reduced evaporation of water easily leads to soil compaction.

Competing fast growing vegetation like weeds and lianas at ground level can result in growth failure of the slow growing exploited seedlings in skid trails (Ne Win et al., 2012). Asner et al. (2004) indicated canopy gap closure in skid trails (0.5 years post-harvest) recovered faster than the corresponding log yards (1.5 years post-harvest) from selective logging. Due to greater canopy openness and frequent use by logging trucks in the log yards, skid trails had greater competing vegetation than in log yards thus greater growth of competing vegetation in log yards. Breckage and Clark (2003) indicated similar results with seedling growth and survival higher in canopy gaps with forest types of under story removal; evident in log yards than in skid trails. Quang et al. (2020) confirmed that competition from saplings and trees that were situated outside the enriched areas emerged as a major source of competition in some plots. A significantly higher growth in skid trails than under forest canopy may be due to the reduced radiation found under the forest canopy. Similar results were obtained by Duah-Gyamfi et al. (2012) who studied the natural regeneration of timber species following selective logging in Ghana indicating that growth rates were higher in the main skid trails than in unlogged. In the skid trails, the amount of light is moderate keeping enough moisture necessary for the growth of seedlings. In this study no species died in the skid trails indicating the best growth condition for most seedlings in the forest.

Similarly in the shade house experiment, light was the main factor which had a significant influence on the growth of the seedlings of these species. These treatments mimic conditions found in the forest. Light availability in the forest depends on the level of disturbance of the forest canopy. The disturbance categories were characterized in terms of light availability, measured indirectly as canopy openness (Duah-Gyamfi et al., 2014). Log yards had the highest canopy openness, which indicates high light level than skid trails, which indicates the medium light level. Under the forest canopy, only 2-3% of PAR indicating the low light intensity.

However a combined effect of light and moisture had a significant influence on the growth of the seedlings. Most growing plants contain about 90 percent water. Also the light-responsive photosynthetic process is driven by the released electrons through the water-splitting reaction on the PSII side, followed by Nicotinamide adenine dinucleotide phosphate ($NADP^+$) reduction to NADPH, and proton flow into the lumen in order to generate Adenosine Triphosphate (ATP) (Ceccarelli et al., 2004). Generated NADPH and ATP serve as an energy source for the carbon fixation process in photosynthesis (Ceccarelli et al., 2004). This was confirmed by the relative growth rate being highest under medium light and high moisture while the least was observed under low light and high moisture. Furthermore, no deaths were recorded in the skid trails indicating that too much sunlight is not necessary for the seedlings of some of these species. Although light is necessary for the germination of seedlings, the quality quantity and duration of light will determine their survival in a particular environment.

This is in corroboration with the shade house and factorial experiments where most species had a significant growth from the medium light condition and an interaction between light and moisture had a significant growth rate. A linear increment in height over time in log yards is an indication of the presence of light process of photosynthesis after gap opening in the forest structure. This gap opening is also present in the skid trails which form a canopy faster than in the log yards leading to decrease in the growth of most species in the skid trials. This is corroborated by the fact that species like *E. cylindricum* and *T. superba* had a linear increment in all treatments from medium light; results are similar to the results obtained by Doucet et al. (2016) indicating their shade tolerance.

This is further confirmed by the highest mortality under the forest canopy than in skid trails and log yards. Chandrashekara and Ramakrishnan (1993) indicated that the higher irradiance in gaps results in better growth, regardless of the ecological category. According to Kobe (1999), the mortality of certain rainforest tree seedlings such as *Trophis racemosa*, *Castilla elastica*, *Pourouma aspera* and *C. obtusifolia* decreased with increase in light intensity (to 20% full sun). Chazdon et al. (1996), mentioned that light availability would be higher in the center of the gap (that is, in the logging yard) than in the gap edge (skid trails) or in the understorey of a forest. This therefore implies a higher mortality under forest canopy than in log yards.

The growth of these species under the different stand conditions also depends on the growth requirements of the specific species at the seedling stage. Some may be shade tolerant, mid tolerant or shade intolerant or better still shade bearers, non-pioneer or pioneer respectively (Hawthorne, 1995) or late or early-succession species. Restricted as seedlings to gaps, early successional species are light demanders (pioneer species) while late successional species grows under the forest canopy (shade bearers). Mid tolerant species are species which require gaps to develop beyond saplings. These are species that are obvious light-demanders, and typical trees of secondary forest and fallow, yet which exist as seedlings in the deepest shade of little-disturbed forest (Hawthorne, 1995; Antobre et al., 2021). Thus while some species grow in light, others persists grow under shade but do not grow appreciably in the shaded understory; accounting for the heterogeneous structure in tropical forest. The requirement of light for the germination of seeds of certain plant species prevents germination and thus not favourable for seedling establishment and growth (Fenner and Thompson, 2005). The light requirement of such seeds and seedlings acts as a mechanism that determines where and when germination takes place, and is important for survival of the plant species concerned, as it prevents stored seed reserves from being depleted. Some seeds germinate equally well in light and darkness, whilst others germinate better under only light or darkness (Chanyenga et al., 2012). Thus different plants have different light requirements for their growth and development.

The findings of this study indicates that the highest growth rate in *A. altissima* in log yards indicates that the species is a light loving early successional. This was confirmed by the shade house experiment where the species had its highest growth rate under high light and low moisture conditions. High light and low moisture are similar conditions in the log yards after gap opening.

Lemmens (2007) indicated that *A. altissima* thrives more on the driest soils in the semi-deciduous forests of tropical forests. Specifically this species had the highest growth rate in log yards and under the forest canopy this indicates the shade tolerance of this species since it can survive in both conditions. Also this is confirmed by the fact that in the shade house experiment, light did not have a significant effect on the growth of *A. altissima*. This indicates its shade tolerance at the seedling stage having fast growth under openings thus a pioneer species. The highest growth rate of *P. soyuaxii* in skid trails indicates that the species is shade intolerant and a light demander in corroboration with Khurana and Singh (2001) and Doucet et al. (2016) who indicated that *P. soyuaxii* was a non-pioneer and light demander. The species prefers moist and well drained soils with an average temperature of 23°C conditions similar to the log yards. Under the forest canopy, the soil is moist and there are situations of flooding with a temperature reduction which might impede the growth of these species. Also germination and seedling growth are rather fast in this species (Jansen, 2005). This is in corroboration with the results obtained in shade house experiment where *P. soyuaxii* had the highest growth rate in height under high light and high moisture conditions.

This is in contrast with *E. cylindricum* that had the least growth rate in skid trails and under the forest canopy. This may be due to the slow growth of this species with a growth rate of 20-40 cm/year (Kémuezé, 2008). This is an indication of its intolerance of shade and a non-pioneer light demander species (Doucet et al., 2016). Also this species is extremely sensitive to parasites (gall-forming insectsand/or shootborers) (Bosu et al., 2006; Opuni-Frimpong et al., 2008 and Doucet et al., 2016) which are usually persistent under the forest canopy and skid trails due to their high level of moisture as compared to the log yards. Such damage in fallow forests with canopy structure very similar to young plantations has also been reported by Hall (2008). The tradeoffs among survival, growth, and herbivory present a serious challenge for these species (Goodale et al., 2014). This is confirmed by the fact that in the shade house, the species had its best growth rate under high light and low moisture conditions and the fact that it did not have the least growth in log yards. Kémeuzé (2008) also indicated that seedlings of up to 2 years old require light shade but there after they should be gradually exposed to more light.

Mortality was highest in *T. superba* and *Baillonella toxisperma* in the log yards and *E. cylindricum* and *Eribroma oblongum* under the forest canopy. According to the shade house experiment, *T. superba* had the best growth rate under medium light and low moisture; confirming its shade tolerance. Kimpouni (2009) indicated that *T.superba* are often abundant along roadsides and in medium-sized forest gaps indicating they are usually found in areas of reduced light intensity. Also Doucet et al., 2016 indicated that this species is a pioneer species; thus its shade tolerance. Aslo a high mortality of species like *E. cylindricum* under the forest canopy is due to the high mortality of this species in the natural forest with less than 1% reaching 10cm diameter (Kémuezé, 2008). Doucet et al., 2016 indicated a high mortality rate of this species 690 days after enrichment planting. Taking this into consideration it is recommended that *T. superba, M. altissima* and *L. alata* should be planted in skid trails while *P. macrocarpus, E. cylindricum, Erythrophleum sauveolens, A. altissima* and *P. soyauxii* should be planted in log yards However these species might change their growth requirements after the seedling stage. Thus it is recommended that these sites be ameliorated through treatments, to minimize the effects of competition, compaction and other limitations on the regeneration and recovery of logged over forests after the seedling stage for a sustainable development.

Conclusion

The growth rate in height was higher in log yards than in skid trails and under forest canopy. This was due to the amount of light available when a gap is formed under the forest canopy. An interaction of light and moisture influenced the growth in height of these species in the forest ecosystem depending on their growth requirements. The results of this study therefore indicate that every species has a specific growth requirement; thus should be planted where appropriate during enrichment planting at the seedling stage. However some level of management is required to maintain the growth of these species for forest regeneration after logging. Thus further research should be carried out on the survival of these species after the seedling stage inorder to ensure their survival and growth while ensuring sustainable management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Antobre OO, Gyamfi AD, Asante WA, Nsor CA, Kyereh B (2021). Forest recovery on skid trails and felling gaps following post-decadal selective logging in a moist semi-deciduous forest in Ghana. Trees, Forests and People 6:100152.

Asner GP, Keller MR, Pereira JC, Zweede, Silva JNM (2004). Canopy damage and recovery after selective logging in Amazonia: field and satellite studies. Ecological Applications 14(4):280-298.

Avon C, Dumas Y, Berges L (2013). Management practices increase the impact of roads on plant communities in forests. Biological Conservation 159:24-31.

Belkov V, Garnik EY, Konstantinov YM (2019). "Mechanism of plant adaptation to changing illumination by rearrangements of their photosynthetic apparatus. Current Challenges in Plant Genetics, Genomics, Bioinformatics, and Biotechnology 24:101.

Biswas PK (1993). Forestry-Based Sustainable Development: The Social Dimensions. Indian Journal of Public Administration 39(3):473-478.

Blanco JA, Yueh-Hsin (Ed) (2012). Forest ecosystems- more than just trees. ISSN 978-953-5-0202-1.

Bosu PP, Cobbinah JR, Nichols JD, Nkrumah EE, Wagner MR (2006). Survival and growth of mixed plantations of *Milicia excelsa* and *Terminalia superba* 9 years after planting in Ghana. Forest Ecology and Management 233(2-3):352-357.

Bourland N, Kouadio YL, Fétéké F, Lejeune P, Doucet J-L (2012). Ecology and management of *Pericopsis elata* (Harms) Meeuwen (Fabaceae) populations: A review: Biotechnology Agronomy Society Environment 16:486-498.

Breckage B, Clark JS (2003). Seedling survival and growth of three forest tree species: the role of spatial heterogeneity. Ecology 84(7):1849-1861.

Brenes AR, Chazdon RL, Alvarado BV (2004). Effects of selective logging on dynamics and composition of woody seedlings in a tropical secondary forest, Kurú. Revista Forestal 1(3).

Brunck F, Grison F, Maitre HF (1990). L'Okoumé: Monographie. Montpellier: Centre Technique Forestier Tropical (CIRAD-Forêt).

Cameroon Development Coorporation (CDC) (1997). Soil surveys and land evaluations for the second development of program of program of the Cameroon Development Corporation. Ekona 7:113.

Ceccarelli EA, Arakaki AK, Cortez N, Carrillo N (2004). Functional plasticity and catalytic efficiency in plant and bacterial ferredoxin-NADP (H) reductases. Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics 1698(2):155-165.

Chandrashekara UM, Ramakrishnan PS (1993). Gap phase regeneration of tree species of differing successional status in a humid tropical forest of Kerala, India. Journal of Bioscience 18(2):279-290.

Chanyenga TF, Gelldenhuys CJ, Sileshi GW (2012). Germination response and viability of an endangered tropical conifer *Widdringtonia whytei* seeds to temperature and light. South African Journal of Botany 81:25-28.

Chazdon R (2014) Second growth: The promise of tropical forest regeneration in an age of deforestation. Chicago: The University of Chicago Press.

Chazdon RL, Pearcy RW, Lee DW, Fetcher N (1996). Photosynthetic responses of tropical forest plants to contrasting light environments. In Mulkey, S.S., Chazdon, R.L, and Smith, A.P. (Eds). Tropical Forest Plant Ecophysiology. Chapman and Hall. New York, US. pp. 5-55.

Cronin DT, Libalah MB, Bergl RA, Hearn GW (2014). Biodiversity and Conservation of Tropical Montane Ecosystems in the Gulf of Guinea, West Africa, Arctic, Antarctic, and Alpine Research 46(4):891-904.

Deckker M, de Graaf NR (2003). Pioneer and climax tree regeneration following selective logging with silviculture in Suriname. Forest Ecology and Management 172(2-3):183-190.

Denslow JS (1995). Disturbance and diversity in tropical rain forests: the density effect. Ecological Applications 5(4):962-968.

Dickinson MB, Whigham DF (1999). Regeneration of mahogany (*Swientenia macrophylla*) in the Yucatan. International Forestry Review 1:35-39.

Dickinson MB, Whigham DF, Hermann SM (2000).Tree regeneration in felling and natural tree fall disturbances in a semideciduous tropical forest in Mexico. Forest Ecology and Management 134:137-151.

Dkamela GP, Félicien KM, Kemen A, Minnemeyer S, Stolle, F (2009). Voices from the Congo Basin: Incorporating the Perspectives of Local Stakeholders for Improved REDD Design. WRI Working Paper. World Resources Institute, Washington DC.

Doucet J-L, Daïnou K, Ligot G, Ouédraogo D-Y, Bourland N, Ward SE, Tekam P, Lagoute P, Fayolle A (2016) Enrichment of Central African logged forests with high-value tree species: testing a new approach to regenerating degraded forests. International Journal of Biodiversity Science, Ecosystem Services and Management 12(1-2):83-95.

Duah-gyamfi A, Kyereh B, Adam KA, Agyeman VK, Swaine MD, Forest S (2014). Natural Regeneration Dynamics of Tree Seedlings on Skid Trails and Tree Gaps Following Selective Logging in a Tropical Moist Semi-Deciduous Forest in Ghana. Journal of Science and Technology for Forest Products 4(1):49-57.

Duah-Gyamfi A, Swaine MD, Kyere B, Agyeman VK (2012). Natural regeneration of timber species following selective logging in a tropical moist semi-deciduous forest in Ghana. IUFRO FORNESSA Congress.

Dupuy B, Koua MB (1993). Les plantations d'acajou d'Afrique. Leur sylviculture en forêt dense humide ivoirienne. *Bois and Forets des Tropiques* 236:25-42.

Dupuy B, Mille G (1993). Timber plantations in the humid tropics of Africa. FAO forestry paper 98. Rome: FAO.

Fenner M, Thompson K (2005). The Ecology of Seeds. Cambridge University Press, Cambridge.

Fimbel RA, Grajal AA, Robinson JG (2001). Logging and wildlife in the tropics. pp 667-695 in Fimbel, R.A., A. Grajal and J.G. Robinson (eds.). The cutting edge: conserving wildlife in logged tropical forest. Columbia University Press New York USA.

Fitzpatrick M (2002). Cameroon, Lonely Planet West Africa, 5th ed. China: Lonely Planet Publications Pty Ltd.

Forseth I (2010). Terrestrial Biomes. Nature Education Knowledge 3(10):11.

Fredericksen TS, Mostacedo B(2000). Regeneration of timber species following selection logging in a Bolivian tropical dry forest. Forest Ecology and Management 131(1-3):47-55.

Gastellu-Etchegorry JP, Guillevic P, Zagolski F, Demarez V, Trichon V, Deering D, Leroy M (1999). Modeling BRF and radiation regime of boreal and tropical forests. Environment 68(3):281-316.

Gaveau D (2014). How selective logging could help to protect Indonesia's forest. Forest news. A CIFOR production. Available at http://blog.cifor.org/22924/how-selective-logging-could-help-protect-indonesias-forests?fnl=en.

Girona MM, Rossi S, Lussier JM, Walsh D, Morin H (2017). Understanding tree growth responses after partial cuttings: A new approach. PLoS ONE2 12:e0172653.

Goodale UM, Berlyn GP, Gregoire TG, Tennakoon KU, Ashton MS (2014). Differences in survival and growth among tropical rain forest pioneer tree seedlings in relation to canopy openness and herbivory. *Biotropica* 46(2):183-193.

Hall JS (2008). Seed and seedling survival of African mahogany (*Entandrophragma spp*.) in the Central African Republic: implication for forest management. Forest Ecology and Management 255(2):292-299.

Hall JS, Harris DJ, Medjibe V, Ashton PMS (2003). The effects of selective logging on forest structure and tree species composition in a Central African forest: Implications for management of conservation areas. Forest Ecology and Management 183(1-3):249-264.

Hall P, Bawa K (1993). Methods to Assess the Impact of Extraction of

Non-Timber Tropical Forest Products on Plant Populations. Economic Botany 47(3):234-247.
Hawthorne WD (1995). Ecological profiles of Ghanaian forest trees. Trop. For. Pap. 29.
Huang YZ, Pan DR, Wang ZC, Ning WJ, Zhou YF (2009). Effects of different growing period on *Baphicacanthus cusia* (Nees) Bremek Medicine Constituents. Chinese Agricultural Science Bulletin 25(16):75-78.
Hunt R (1982). Plant growth curves – The Functional Approach to Plant Growth. Edward Arlnold: London P 248.
International Tropical Timber Organization (ITTO) (2002). ITTO guidelines for the restoration, management and rehabilitation of degraded and secondary tropical forests. ITTO Policy Development Series No 13, ITTO, Yokohama, Japan.
Jansen PCM (2005). *Pterocarpus soyauxii* Taub. In: Louppe, D., Oteng-Amoako, A.A. and Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. Accessed 16 February 2018.
Kammesheidt L (2002). Perspectives on secondary forest management in tropical humid lowland America. *Ambio*: A Journal of the Human Environment 31(3):243-250.
Kémeuzé VA (2008). *Entandrophragma cylindricum* (Sprague) Sprague. In: Louppe, D., Oteng-Amoako, A.A. and Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. Accessed 15 February 2018.
Khurana E, Singh JS (2001). Ecology of seed and seedling growth for conservation and restoration of tropical dry forest: a review. Journal of Environment and Conservation 28(1):39-52.
Kimpouni V (2009). *Terminalia superba* Engl. and Diels. In: Lemmens, R.H.M.J., Louppe, D. and Oteng-Amoako, A.A. (Editors). Prota 7(2): Timbers/Bois d'œuvre 2. [CD-Rom]. PROTA, Wageningen, Netherlands.
Kobe RK (1999). Light gradient partitioning among tropical tree species through differential seedling mortality and growth. Ecology 80(1):187-201.
Lamb D (2011). Regreening the Bare Hills: Tropical Forest Restoration in the Asia-Pacific Region. Series. World Forests 8:547.
Lemmens RHMJ (2007). *Pouteria altissima* (A.Chev.) Baehni. In: Louppe, D., Oteng-Amoako, A.A. and Brink, M. (Editors). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands. Consulté le 15 mars 2018.
Martinez-Garza C, Howe HF (2003). Restoring tropical diversity: beating the time tax on species loss. Journal of Applied Ecology 40(3):423-429.
Megevand C, Mosnier A, Houticq J, Sander K, Doetinchem N, Streck C (2013). Deforestation trends in the Congo Basin reconciliation economic growth and forest protection. A World Bank production. Washington D,C 179 p.
Microsoft Corporation (2013). Microsoft Excel, Available: https//office.microsoft.com.excel
Minitab 17 Statistical Software (2010). [Computer software]. State College, PA: Minitab, Inc. (www.minitab.com).
Mokake SE, Chuyong GB, Egbe AE, Ndiang Z, Njumbam B (2018). Natural regeneration of some commercial timber tree species following selective logging in a semi deciduous forest in the east region of Cameroon. Journal of Biodiversity and Environmental Sciences 12(1):22-39.
Ne win R, Suzuki R, Akeda ST (2012). Effects of selective logging on the regeneration of two commercial tree species in the Kabaung Reserved Forest, Bago Mountains, Myanmar. Journal of Tropical Forest Science 24(3):312-321.
Newbery DM, Chuyong GB, Zimmermann L (2006). Mast fruiting of large ectomycorrhizal African rain forest trees: importance of dry season intensity, and the resource-limitation hypothesis. New Phytologist 170(3):561-579.
Oates JF, Bergl RA, Linder JM (2004). Africa's Gulf of Guinea Forests: Biodiversity Patterns and Conservation Priorities. Advances in Applied Biodiversity Science, Volume 6. Conservation International, Washington DC.
Opuni-Frimpong E, Karnosky DF, Storer AJ, Cobbinah JR (2008). Silvicultural systems for plantation mahogany in Africa: Influences of canopy shade on tree growth and pest damage. Forest Ecology and Management 255(2):328-333.
Panayotou T, Ashton PS (1992). Not by Timber Alone: Economics and Ecology for Sustaining Tropical Forests. Island Press, Washington, D.C.
Paquette A, Bouchard A, Cogliastro A (2006a). Successful under-planting of red oak and black cherry in early-successional deciduous shelterwoods of North America. Annals of Forest Science 63(8):823-831.
Paquette A, Bouchard A, Cogliastro A (2006b). Survival and growth of under-planted trees: a meta-analysis between four biomes. Ecological Applications 16(4):1575-1589.
Pinard MA, Barker MG, Tay J (2000). Soil disturbance and post-logging forest recovery on bulldozer paths in Sabah, Malaysia. Forest Ecology and Management 130(1-3):213-225.
Piotto D (2008). A meta-analysis comparing tree growth in monocultures and mixed plantations. Forest Ecology and Management 255(3-4):781-786.
Piotto D, Vıquez E, Montagnini F, Kanninen M (2004). Pure and mixed forest plantations with native species of the dry tropics of Costa Rica: a comparison of growth and productivity. Forest Ecology and Management 190(2-3):359-372.
Potvin C, Gotelli NJ (2008). Biodiversity enhances individual performance but does not affect survivorship in tropical trees. Ecology Letter 11:217-223.
Putz FE, Zuidema PA, Synnot T, Peña- Claros M, Pinard MA, Sheil D, Vanclay JK, Sist P, Gourlet-Fleury S, Griscom B, Palmer J, Zagt R (2012). Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conservation Letter 5(4):296-303.
Putz, FE, Sirot LK, Pinard MA (2001). Tropical forest management and wildlife. Silvicultural: effects on forest structure, fruit production, and locomotion on arboreal animals pp. 11-34 In: Fimbel, R.A., A. Grajal and J.G Robinson (eds.). The cutting edge: conserving wildlife in logged tropical forest. Columbia University Press New York.
Quang MP, Baynes J, Herbohn J, Grahame Applegate G, Keys M (2020). The Long-Term Survival and Growth of Enrichment Plantings in Logged Tropical Rainforest in North Queensland, Australia. Forests 11(4):386. doi:10.3390/f11040386.
Rhett B (2019). Rainforest diversity: origins and implications. Available at https://rainforests.mongabay.com/03-diversity-of-rainforests.html.
Ruiz-Perez MD, Ezzine de Blas R, Nasi JA, Sayer M, Sassen C, Angoué N, Gami O, Ndoye G, Ngono JC, Nguinguiri D, Nzala B, Toirambe, Yalibanda Y (2005). Logging in the Congo Basin: a multi-country characterization of timber companies. Forest Ecology and Management 214(1-3):221-236.
Sist P, Nguyen-The´ N (2002). Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan (1990–1996). Forest Ecology and Management 165(1-3):85-103.
Smith H (2000). Phytochromes and light signal perception by plants—an emerging synthesis. Nature 407(6804):585-591.
Stanturf JA, Palik BJ, Dumroese RK (2014). Contemporary forest restoration: A review emphasizing function. Forest Ecology and Management 331:292-323.
Thomas DW, Chuyong, GB (2006). The establishment of long-term forest monitoring plots in South East, Cameroon for timber certification in the Jengi Project Area, Cameroon by CTFS and WWF in collaboration with Groupe Decalvenaere Timber Company. Report to CARPE. P 38.
Vieira DLM, Scariot A (2008). Environmental Variables and Tree Population Structures in Deciduous Forests of Central Brazil with Different Levels of Logging. Brazilian Archives of Biology and Technology 51(2):419-431.
Yang JX, Tian YX (2004). Medicinal Plant Cultivation. Version. Beijing, China: China Agriculture Press.