


# Long-Term Effects and Carbon Stock of Exploitable Plant Species after Enrichment Planting in the East Region of Cameroon

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## Abstract

An increase in the human population causes deforestation, affecting tropical forests' sustainability. Enrichment planting is the restoration of over-exploited and secondary forests in order to increase the total tree volume and economic value of forests. The purpose of this article was to present the results of enrichment plantings of exploitable species in the East Region of Cameroon. This study was carried out in Log yards (LYs), Skid trails (STs), and under forest canopy in some forest concessions. The seedlings of 15 most exploitable species in Cameroon were selected and planted in 30 enriched plots. A transect of 4 × 50 m<sup>2</sup> was established using a line spacing of 5 × 5 m. The height and diameter of each exploitable seedling species were measured 1.5 and 10 years after enrichment planting. A total of 1288 individuals of 15 species belonging to 8 families were recorded. The most important species was *Erythrophleum sauveolens* (183.1) that regenerated naturally in the LYs. The most important families were the Fabaceae and Malvaceae. A year and ten years after enrichment planting, growth was highest in the LYs as compared to the STs. Generally, annual mortality was highest in STs, while annual survival was highest in LYs. This may be due to the availability of light after canopy destruction. However, biomass was highest under the forest canopy in the first year, the same for both LYs and STs in the 5<sup>th</sup> year, and highest in the LYs in the 10<sup>th</sup> year. Carbon stock, though low, increased over time, with a Carbon stock of 0.004 t/ha ten years after enrichment planting. The species *Triplochiton scleroxylon* had the highest Carbon stock due to silvicultural management of its plots,

emphasizing the necessity of site-species matching before enrichment planting and post-planting silvicultural management for effective forest restoration.

## Keywords

Disturbance, Gabs, Log Yards, Light, Skid Trails, Sequestration

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## 1. Introduction

Tropical forests have been under threat due to an increase in human population dynamics in the tropics in general and in Africa in particular. This increase in human population causes deforestation for livelihood and shelter, thus affecting the tropical forest's sustainability. Also, a large and growing percentage of the Congo Basin is under concession to logging and mining companies, which increases the rate of deforestation. Since the 1950s, most of these forests have been granted to private logging companies and have been impacted by selective logging [1] [2]. Due to mismanagement and the conversion of large tracts of West African forests to agricultural production and exploitation, Central African forests are experiencing increased harvesting pressures, and this is particularly true for the few timber species targeted by selective logging [3]. In spite of the logging regulatory framework and limited extraction put in place by most Central African countries, the sustainable supply of key timber species in Central Africa remains a serious issue.

Tropical Africa has 21% of the secondary forests that developed after timber extraction [4]. However, the forests of the Congo Basin have had relatively low annual deforestation rates of less than 0.76 percent between 2000 and 2005, in contrast to deforestation rates in the same period of 2.56 percent in tropical South America and 2.90 percent in tropical Asia [5]. Particularly, [6] in 1968 indicated that Cameroon had a forest area of 57,008 million ha, representing 62.84% of the undisturbed forest. In 2008, [7] indicated that the forest types cover 22,523,732 ha of land cover in Cameroon. In 2015, [8] indicated that Cameroon has around 18.8 million hectares of forest land, which constitutes about 40% of the total land area. Forest land cover in Cameroon has thus declined in the last 47 years with a loss of around 0.5% - 1% forest cover per year [8]. Putz [9] emphasized that although 85% - 100% of species of mammals, birds, invertebrates, and plants remain after selective logging, timber volumes decline by about 65% after the first harvest if the same species are again harvested. That is why many of the exploitable species are now listed in the International Union for Conservation of Nature's (IUCN) Red List, e.g., [10]. Post-logging silvicultural treatments, including planting of high-value species, would need to be applied in order to reestablish and/or conserve the timber biodiversity of forest stands.

Enrichment planting, which is the introduction of valuable species to degraded

forests without the elimination of already existing valuable individuals [11], is a technique for the restoration of over-exploited and secondary forests, which increases the total tree volume and the economic value of forests [12] [13]. Enrichment of natural forests after logging may be appropriate in areas where natural regeneration is insufficient or soil characteristics are not conducive to other uses [12]. Although many authors have suggested enrichment planting in forest fragments as a conservation strategy [14]-[16], few studies have tested specific techniques like determining which species is good for which disturbance site according to its growth requirements. Also, forest managers face two major issues: i) the insufficient regeneration of pioneer species that make up most of the harvest because of the natural decline of their populations with increasing stand age, and ii) the difficulty of recovering the timber stock 20 - 30 years after logging (*i.e.*, after a complete cutting cycle). Plant species used for enrichment planting need to be planted in forest gaps where the light and the moisture content are appropriate for their growth. However, knowledge on the light and moisture requirements of the seedlings of these species, or on the specific ecological needs at early or more advanced stages of development, is scarce. There is insufficient knowledge concerning species selection and site matching [17] [18]. There has been little evidence on which to base the selection of species and the way that species are combined as the forest moves from pioneer light-demanding species to non-pioneer species. This is because there is little data on site tolerance and growth in Africa, as emphasized in the meta-analysis of [19], as the light and moisture situation of the log yards and skid trails are different [20]. The skid trails have a low light and high moisture content as compared to the log yards with a high light and low moisture content, and under the forest canopy with a low light intensity and the highest moisture content.

Understanding the dynamics of tree populations for each commercial species is crucial for creating effective and sustainable management plans. Tropical forest tree species each have their own unique patterns of recruitment, growth, and mortality. Vital environmental parameters like light and moisture change depending on the type of forest and its successional stage. Additionally, factors like topography, soil, the specific species, an individual tree's history, competition with other trees species, and its physical development all play a significant role as interactions among pre-established vegetation and newly-planted seedlings can range from facilitation, through amelioration of harsh growing conditions and increased nutrient availability, to suppression through competition for above- and below-ground resources [21] [22]. While the partially shaded conditions of an enrichment planting setting can improve seedling survival of later-succession species when compared with full-sun conditions [23], these same shaded conditions may inhibit the growth of more heliotropic desired species [24] [25]. Mokake [20] indicated that each plant species needs to be planted either in the skid trail and/or log yard, depending on their light and moisture requirements. Nguyen [26] found that over time, shade-intolerant species became less important and native shade-tolerant

species increased in importance, with at least part of this change being driven by anthropogenic influences such as harvesting of fast-growing exotic species. Thus, further research needs to be carried out to demonstrate the growth requirements in the various gaps in the forest after selective logging.

With the presence of climate change, it is becoming necessary to determine the effect of disturbance on the restoration of tropical forests. Though most African timber species are widespread light-demanding species [27] [28] that require high light environments at the seedling stage for survival and growth [29], as temperatures are rising, this might affect the growth of certain species, thus reducing the biodiversity of the forests after exploitation. Also, although biomass can recover quickly after logging [30], regaining exploitable wood volume (Carbon stock) is much slower [31]. Logging creates canopy gaps that may be invaded by vines and pioneer species; thereby increasing the proportion of non-commercial tree species to the detriment of high-value species [32] [33]. This therefore changes the composition of the forest and thus renders the forest unexploitable after the 30-year rotation cycle. In a long-term study at the FMU 10025 and 10052 in the East Region of Cameroon and M'Baïki in the Central African Republic, the number of exploitable species decreased 21 and 24 years after logging, respectively [30] [34]. This will lead to a decrease in the carbon stock content in the long run and thus have a negative effect on climate change, presenting an urgent need to develop silvicultural techniques like enrichment planting to improve the growth of timber species that have been removed through selective logging in the next exploitation cycle.

Enrichment techniques through the regeneration of light-demanding timber species [35] [36] have been tested in several tropical contexts with promising results for forest restoration while promoting timber resource sustainability [13] [37]-[41]. Planting timber species in logging gaps or restoring degraded forest areas are effective techniques that have the potential to maintain ecosystem diversity and resilience while protecting sensitive species of high commercial value [42]. Due to the improvement of the forest composition after exploitation, the timber stock may recover. The recovery process may even be faster with enrichment planting, taking into consideration that though natural regeneration may recover more than half but not all the carbon stock removed during selective logging, as it may take a longer period to do so [30].

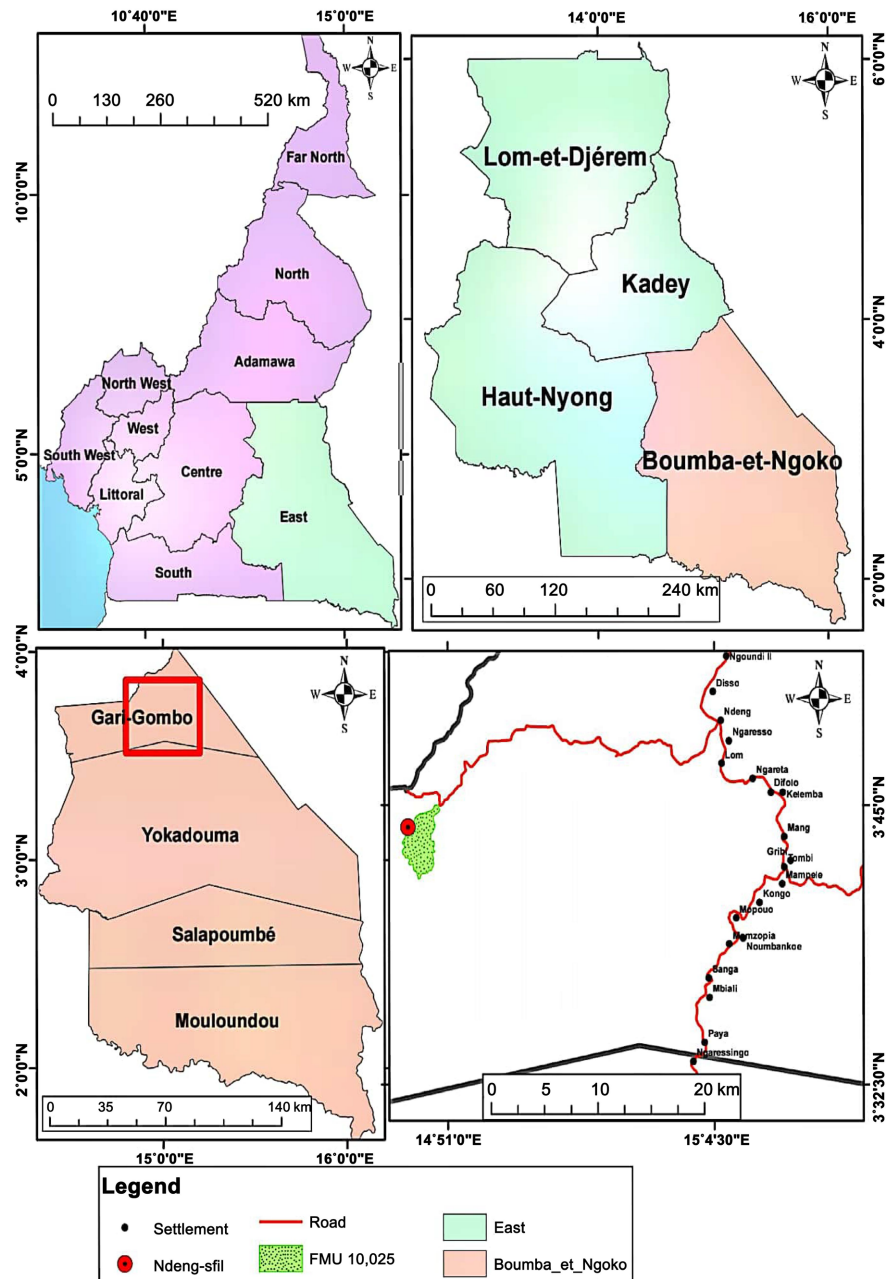
The success of enrichment planting as a silvicultural technique can be measured by survival and growth in terms of tree diameter and stand height. Hence, long-term information is required to indicate whether the enrichment plantings are likely to provide a sufficient stocking of merchantable trees within an expected harvesting cycle, and whether the diameter and height development of these trees has not been suppressed by competition. This is because logging gaps are difficult to monitor long-term, and the good performance in the early stage of a tree's life may be reduced by competition in later stages [43]. The purpose of this article was to present results of enrichment plantings in exploited forests using exploitable

species in the East Region of Cameroon, as it improves the forest composition in terms of both quantity and quality of commercially important species, and determine the suitability of species for forest enrichment so as to allow harvests from short and medium cutting cycles (15 - 40 years). Specifically in this study, we analyzed the growth and Carbon stock of timber species years after enrichment planting at the different gaps created during timber exploitation versus under the forest canopy, given that the different species have different environmental requirements. In order to achieve this, the following research questions were asked: What is the difference in the diversity of exploitable species at the different sites created by selective logging? What is the difference in the growth of the different timber species after selective logging? What is the carbon stock change brought by enrichment planting after selective logging?

## 2. Materials and Methods

### 2.1. Study Site

An enrichment planting was carried out in the Forest Management Units (FMU) 10-025 in the East Region of Cameroon (**Figure 1**). This study was carried out at the Société Forestière Industrielle de la Lokoundje (SFIL, Ndeng) in its FMU10-025 belonging to the Groupe Decolvenaere (GDC) timber company located at the Boumba and Ngoko Division of the East Region to establish baseline conditions of the forest. 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 to 14°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 km<sup>2</sup> with its soil predominantly ferrallitic (rich with iron and reddish in colour). The East Region has a wet equatorial climate with high temperatures (24°C on average) and a lack of 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 [44]. Relative humidity and cloud cover are relatively high, and annual mean precipitation is 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 [20]. The forest flora is dominated by commercially valuable timber species, *Triplochiton scleroxylon* (Ayous), and is heavily targeted for exploitation. Some other important economic plant resources present in the forest include: *Entandrophragma cylindricum*, *Terminalia superba*, *Entandrophragma utile*, *Erythrophleum suaveolens*, *Eribroma oblonga*, *Guarea cedrata*, *Pterocarpus soyauxii*, and *Enantia chlorantha* [45]. The presence of forest savannah transition zones makes the flora unique, with both savannah and forest species coexisting as the forest transitions into savannah, which supports plant species unique to this habitat type [44].



**Figure 1.** Study site of enrichment planting in the East Region of Cameroon.

## 2.2. Site Establishment and Demarcation

This study was carried out in the forest gaps created after selective logging (Log yards (LYs), Skid trails (STs), and Under forest canopy (UFC) in FMU 10025 in the East Region of Cameroon. The seedlings of 15 from the 20 most exploitable species [46] in Cameroon were selected based on their use as high-value timber and/or non-timber forest products (fruits, edible caterpillars, medicine, etc.) and their availability in the nursery and natural environment after selective logging (Table 1). Many of them are considered threatened by the IUCN (<http://iucnredlist.org/>). Information was gathered on qualitative traits (deciduousness and regeneration guild)

from [27] [47]. The FMU 10025 had an average of 34 LYs covering an average area of 864 km<sup>2</sup> with their corresponding STs. However, not all LYs do have corresponding STs; 10 LYs with their corresponding STs of ages 1 year after logging and 20 LYs and their corresponding STs of ages 5 and 10 years after enrichment planting were randomly selected for analyses. All plots had been enriched with exploitable species, and some plots of *Triplochiton scleroxylon* received management treatment of yearly weeding. A transect of 4 × 50 m<sup>2</sup> was established along the length of the LYs and STs. The seedlings of the exploitable species were planted during enrichment planting using a line spacing of 5 × 5 m in the LYs and STs after selective logging; stated here as “planted”. However, after logging, some seedlings germinated from the soil seed banks in the LYs and STs, which are natural recruits from the seed bank within plots; considered here as “non-planted”. Under the forest canopy, seedlings that had germinated naturally were considered as seedlings in control areas. Three plots of 4 × 50 m<sup>2</sup> under the forest canopy (UFC) were established to determine the growth of exploitable species under the forest canopy; considered here as “under the forest canopy”.

### 2.3. Site Enumeration

The 20 LYs and their corresponding STs that were enriched 5 and 10 years ago were measured in 2011 to obtain baseline data on the effects of enrichment planting after selective logging on exploitable species [20] and later in 2021 to determine the dynamics of the seedlings of exploitable species after selective logging. Each seedling had a metal number tag attached to it. The 10 LYs and their corresponding STs, enriched 1 year ago, were measured only in 2020 to determine the immediate effect of enrichment planting after selective logging, and a new number tag was attached to them. Under the forest canopy, only the seedlings in the understory were considered. The height, collar diameter, and diameter at breast height (DBH) for each exploitable seedling species were measured in the LYs, STs, and under the forest canopy using a metric tape, a veneer calliper, and a diameter tape, respectively. Collar diameter measurements were taken for all seedlings less than 6 cm with a veneer caliper, while stems greater than 6 cm were measured at 1.3 m with diameter tapes for larger diameters. Each stem was measured to the nearest millimeter. All specimens of the species were identified by a botanist in the field. Unidentified species were taken to the Limbe Botanic Garden Herbarium for proper identification using the Angiosperm Phylogeny Group II [48] classification. Soil samples of depths 0 - 10 cm, 10 - 20 cm, and 20 - 30 cm were collected from all the sites, and later, analysis of soil chemical properties was conducted at the University of Dschang’s soil laboratory.

### 2.4. Data Analyses

#### 2.4.1. Determination of the Species Composition Following Enrichment Planting

The species composition was determined by the abundance and species richness, which was used to determine the most important species and family at the level of the seedlings. The abundance of the species was determined as the total number

of individuals of all the different species present in each plot [49]. Species richness (S) was the total number of species present in the population considered in a given ecosystem [50]. It is mainly expressed by the total number of species observed per unit area. The important Value Index (IVI) corresponds to the most important species according to [51]. It is calculated using the formula:

$$IVI = SRDe + SRDo + SRF \quad (1)$$

where SRDe = Species Relative Density, which is

$$SRDe = \frac{\text{number of individuals of that species}}{\text{total number of individuals}} \times 100$$

SRDo = Species Relative Dominance, which is

$$SRDo = \frac{\text{Basal area of that species}}{\text{total basal area}} \times 100$$

SRF = Species Relative Frequency, which is

$$RF = \frac{\text{number of quadrats with that species}}{\text{total number of quadrats}} \times 100$$

The Family Importance Value (FIV) corresponds to the most important family [52]. It is calculated by the formula:

$$FRDe + FRF + FRDo \quad (2)$$

where FRDe = Family Relative Density, which is

$$FRDe = \frac{\text{Number of individuals of that family}}{\text{total number of families}} \times 100$$

FRDo = Family Relative Dominance, which is

$$FRDo = \frac{\text{Basal area of that family}}{\text{total basal area}} \times 100$$

FRF = Family Relative Frequency, which is

$$FRF = \frac{\text{Number of quadrats with that family}}{\text{total number of quadrats}} \times 100$$

#### 2.4.2. Determination of the Growth of Exploitable Species after Enrichment Planting

The absolute and relative growth rate in height and diameter of the different tree species under the different site conditions of LYs, STs, and forest canopy was determined. The absolute growth rates in diameter and height of seedlings were determined as described by [53];

$$\text{Absolute growth rate} = \frac{\log(H_2) - \log(H_1)}{t_1 - t_2} \quad (3)$$

The relative growth rate was determined as:

$$\text{Relative growth rate} = \frac{\log(H_2) - \log(H_1)}{t_1 - t_2} \times 100 \quad (4)$$

where  $H_2$  and  $t_2$  are the final diameter or height and time (2020), while  $H_1$  and

time (2011) are the initial diameter or height.

The rate of mortality was calculated by the formula:

$$\text{Mortality} = \frac{N_0 - N_t}{N_0 \times \Delta_t} \times 100 \quad (5)$$

The rate of survival was calculated by the formula:

$$\text{Survival} = \frac{N_t}{N_0} \times 100 \quad (6)$$

The rate of recruitment was calculated by:

$$\text{Recruitment} = \frac{N_t - N_0}{N_0} \times 100 \quad (7)$$

where  $N_0$  = number of individuals at  $t_0$ ;  $N_t$ : number of individuals at  $t_n$ ;  $\Delta_t = t_n - t_0$ : the time between  $t_0$  and  $t_n$  or time difference.

### 2.4.3. Determination of the Biomass and Carbon Stock after Enrichment Planting

The above-ground biomass (AGB) was determined through the equation of [54]:

$$\text{AGB} = 0.0673 \times (\rho D^2 H)^{0.976} \quad (8)$$

where AGB is the above-ground biomass (kg);  $D$  is the diameter of the tree (cm);  $H$  is the height of the tree (m);  $\rho$  is the specific density of the tree ( $\text{g}\cdot\text{cm}^{-3}$ ). The specific density used for each species was from the Global Wood Density Database [55].

The Carbon stock of the different sites was determined by multiplying the above-ground biomass by 0.47 [56] while the amount of  $\text{CO}_2$  sequestered was determined by multiplying the total biomass by 3.67 [57] [58]. The chemical properties of the soil analyzed included the pH value, organic C, total N, C/N ratio, P, K, Mn, cation exchange capacity (CEC), and organic matter. A mixture of soil and water extract with a composition of 1:5 was used to measure soil acidity. Walkley-Black method was used to determine C organic content, Kjeldahl method to determine N total, Bray I method to measure P, extraction method to analyze exchangeable base cations ( $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$ ) with ammonium acetate and acidic cations ( $\text{Al}^{3+}$ ,  $\text{H}^+$ ) with sodium chloride, and Morgan method to determine K, and Mn [59]-[62].

## 2.5. Statistical Analyses

The data collected were arranged in Microsoft Excel 2013 and exported to other packages for statistical analysis and graphics. Sorting out was carried out through the package of dplyr of tidyverse of the R software. Tables were done with the help of the R software (R Studio) version 4.2.1. through the ggplot2 and ggpubr packages. The test of Shapiro-Wilk was used to test for normality, the test of Levene's statistics [63] to test for homogeneity and ANOVA to compare the diameter, height, biomass and carbon stock through the R (R studio) version 4.2.1. In each

site, the values for the aboveground biomass and the corresponding carbon stock in standing trees of all the sampling plots were reported as mean ( $\pm$  standard error). The probability threshold was set at a 5% level of significance.

### 3. Results

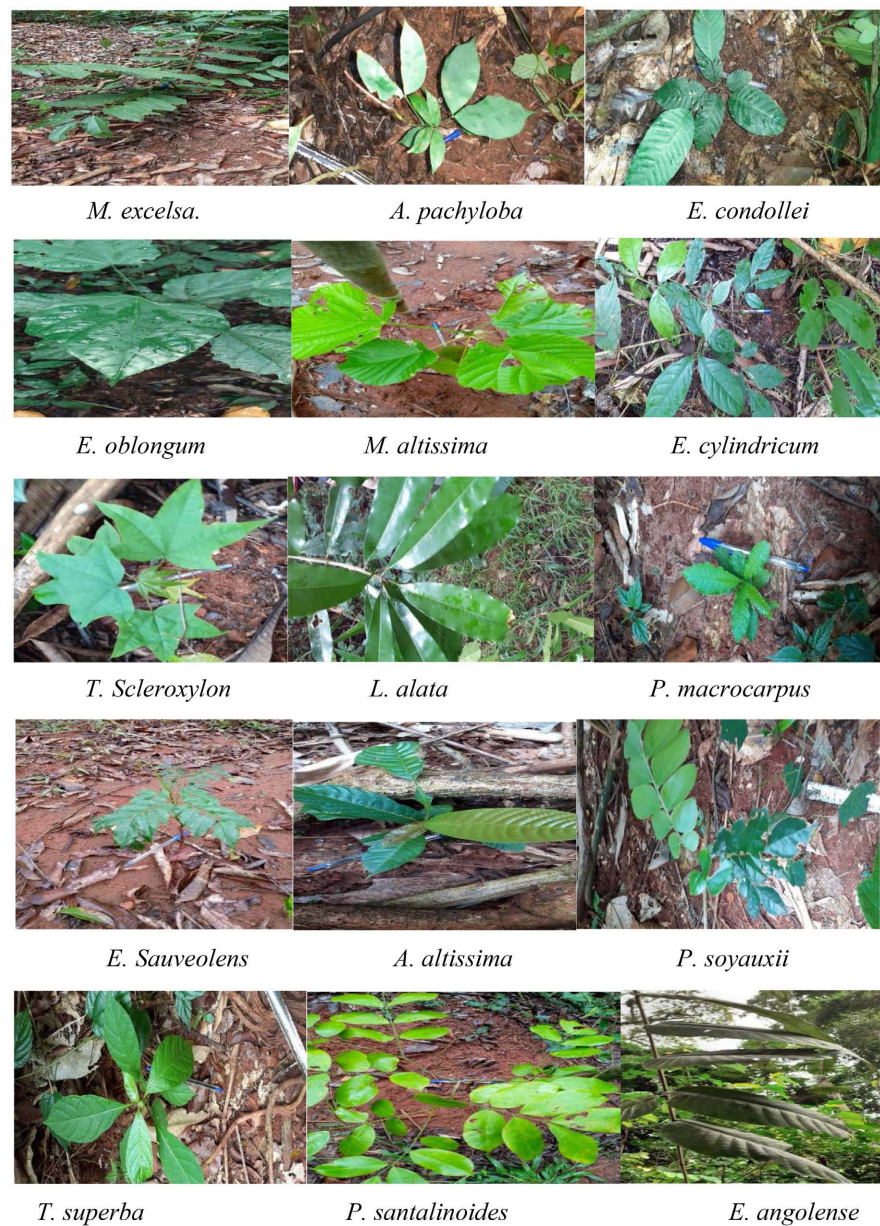
#### 3.1. Stand Composition following Enrichment Planting in the East Region of Cameroon

A total of 1288 individuals of 15 species (**Figure 2**) belonging to 8 families were recorded in the Log yards (LYs), Skid trails (STs), and Under Forest Canopy (UFC) (**Table 1**). Generally, *Erythrophleum suaveolens* had the highest number of individuals (229 individuals). Specifically, the LYs had the highest number of individuals (999 individuals), while the least was found in the STs (186 individuals). *Erythrophleum suaveolens* in the LYs had the highest number of individuals (204 individuals). In the STs, *Pterocarpus santalinoides* had the highest number of individuals (27 individuals), and under the forest canopy, *Afzelia pachyloba* had the highest number of individuals with 122 individuals (**Table 1**).

**Table 1.** Exploited species after enrichment planting in different stand conditions in the East Region of Cameroon.

Scientific Name	Family	Common Name	LYs	STs	UFC	Total	IUCN Status <sup>1</sup>	Guild <sup>2</sup>
<i>Afzelia pachyloba</i> Harms	Fabaceae	Doussie	67	6	<b>122</b>	195	VU	NPLD
<i>Aningeria altissima</i> (A. Chev.) Aubrev. and Pellegr.	Sapotaceae	Aningre	72	-	-	72		NPLD
<i>Entandrophragma angolense</i> (Welw.) C.DC.	Meliaceae	Tiama	50	3	-	53	VU	NPLD
<i>Entandrophragma cylindricum</i> (Sprague) Sprague	Meliaceae	Sapelli	27	2	-	29	VU	NPLD
<i>Erythrophleum suaveolens</i> A.Chev	Fabaceae	Tali	<b>204</b>	13	12	<b>229</b>	NA	P
<i>Mansonia altissima</i> (A.Chev.) A. Chev	Malvaceae	Bete	181	5	4	190	NA	De
<i>Petersianthus macrocarpus</i> (P.Beauv.) Liben	Lecithydaceae	Abale	16	5	19	40	LC	
<i>Pterocarpus santalinoides</i> L'Her. ex DC.	Fabaceae	Padouk	157	<b>27</b>	17	201	LC	ST
<i>Pterocarpus soyauxii</i> Taub	Fabaceae	Padouk rouge	21	6	-	27	NA	De
<i>Terminalia superba</i> Engl. and Diels	Combretaceae	Frake	146	17	-	163	NA	De
<i>Lophira alata</i> Tieg ex Keay	Ochnaceae	Azobe	5	-	-	5	VU	P
<i>Triplochiton scleroxylon</i> K. Schum	Malvaceae	Ayous	63	2	-	65	LC	De
<i>Eribroma oblongum</i> Mast. Pierre ex A. Chev	Malvaceae	Eyong	-	-	1	1		NPLD
<i>Milicia excelsa</i> (Welw) C.C.Berg	Moraceae	Iroko	9	1	-	10	NT	De
<i>Entandrophragma condollei</i> Harms	Meliaceae	Kossipo	-	-	11	11	VU	NPLD
<b>Total</b>			<b>999</b>	<b>103</b>	<b>186</b>	<b>1288</b>		

**Note:** LY = Lys; SK = STs; UFC = Under Forest Canopy. <sup>1</sup>IUCN Status: CR = Critically Endangered; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered. <sup>2</sup>Guild: De = Deciduousness; Ev = Evergreen; P = Pioneer; NPLD = Nonpioneer Light Demanding; ST = Shade Tolerance.



**Figure 2.** Seedlings of exploited timber species in the East Region of Cameroon.

### 3.1.1. The Most Important Species (IVI) following Enrichment Planting in the East Region of Cameroon

The most important species in the LYs was *Erythrophleum sauveolens* (183.1) that regenerated naturally after enrichment planting. Specifically, the most important species in the LYs that regenerated naturally after five years of enrichment planting was *Terminalia superba* (144.8), and 10 years after was *Mansonia altissima* (119.2). While the most important species planted in the LYs after enrichment planting was *Entandrophragma angolense* (53.8) after a year, *Pterocarpus santalinoides* (76.5) after 5 years, and *Triplochiton scleroxylon* (127.5) after 10 years of enrichment planting. Generally in the STs, the most important species was *Triplochiton scleroxylon* (163.91) after 5 years of enrichment planting. Specifically,

the most important species that regenerated naturally after one year was *Aningeria altissima* (73.21), none after 5 years and *Mansonia altissima* (141.5) after 10 years. On the other hand after enrichment planting, *Pterocarpus santalinoides* (81.58) was the most important a year after, *Triplochiton scleroxylon* (163.91) after 5 years and none survived after 10 years of enrichment planting in the STs. Finally under the forest canopy, *Azelia pachyloba* (134.6) was the most important species that regenerated naturally (**Table 2**).

**Table 2.** The most important species (IVI) after natural regeneration and enrichment plant in the East Region of Cameroon.

LYs											
1 year after				5 years after				10 years after			
Natal		Planted		Natural		Planted		Natural		Planted	
Species	IVI	Species	IVI	Species	IVI	Species	IVI	Species	IVI	Species	IVI
<i>E. suaveolens</i>	183.1	<i>E. angolense</i>	53.8	<i>T. superba</i>	144.8	<i>P. santalinoides</i>	76.5	<i>M. altissima</i>	119.2	<i>T. scleroxylon</i>	127.5
<i>T. superba</i>	45.6	<i>P. santalinoides</i>	49.5	<i>P. santalinoides</i>	43.7	<i>T. scleroxylon</i>	61.9	<i>T. superba</i>	67.7	<i>P. santalinoides</i>	46.4
<i>P. santalinoides</i>	20.1	<i>M. altissima</i>	47.8	<i>M. altissima</i>	41.5	<i>E. angolense</i>	40.5	<i>P. santalinoides</i>	57.4	<i>A. altissima</i>	42.5
<i>A. altissima</i>	17.5	<i>E. suaveolens</i>	45.4	<i>A. pachyloba</i>	30.0	<i>E. suaveolens</i>	30.3	<i>E. suaveolens</i>	23.2	<i>E. suaveolens</i>	35.3
<i>A. pachyloba</i>	9.2	<i>A. pachyloba</i>	38.4	<i>P. macrocarpus</i>	19.6	<i>T. superba</i>	27.7	<i>M. excelsa</i>	12.4	<i>M. altissima</i>	23.9
<i>E. cylindricum</i>	8.2	<i>T. superba</i>	31.6	<i>E. angolense</i>	7.3	<i>A. pachyloba</i>	24.2	<i>T. scleroxylon</i>	7.4	<i>E. cylindricum</i>	10.4
<i>P. soyauxii</i>	6.2	<i>P. soyauxii</i>	21.9	<i>E. cylindricum</i>	3.9	<i>L. alata</i>	12.8	<i>A. altissima</i>	5.1	<i>T. superba</i>	8.0
<i>M. altissima</i>	5.9	<i>A. altissima</i>	6.0	<i>E. suaveolens</i>	3.9	<i>E. cylindricum</i>	11.6	<i>P. macrocarpus</i>	3.7	<i>A. pachyloba</i>	4.8
<i>P. macrocarpus</i>	4.2	<i>T. scleroxylon</i>	2.9	<i>M. excelsa</i>	3.8	<i>M. altissima</i>	11.0	<i>A. pachyloba</i>	2.5	<i>M. excelsa</i>	1.2
		<i>E. cylindricum</i>	2.8	<i>A. altissima</i>	1.6	<i>M. excelsa</i>	3.6	<i>E. cylindricum</i>	1.5		
STs											
<i>A. altissima</i>	73.21	<i>P. santalinoides</i>	81.58			<i>T. scleroxylon</i>	163.91	<i>M. altissima</i>	141.5		
<i>P. santalinoides</i>	67.63	<i>M. altissima</i>	70.84			<i>T. superba</i>	51.14	<i>P. santalinoides</i>	104.6		
<i>T. superba</i>	42.43	<i>E. angolense</i>	59.99			<i>P. santalinoides</i>	42.50	<i>E. cylindricum</i>	30.4		
<i>P. macrocarpus</i>	37.67	<i>P. soyauxii</i>	41.34			<i>E. suaveolens</i>	42.46	<i>E. suaveolens</i>	23.5		
<i>E. suaveolens</i>	33.39	<i>E. suaveolens</i>	25.55								
<i>P. soyauxii</i>	19.46	<i>A. pachyloba</i>	20.70								
<i>M. excelsa</i>	11.75										
<i>A. pachyloba</i>	10.93										
<i>E. cylindricum</i>	3.52										
Canopy											
<i>A. pachyloba</i>	134.6										
<i>P. macrocarpus</i>	101.4										
<i>P. santalinoides</i>	28.5										
<i>E. suaveolens</i>	13.1										
<i>E. cylindricum</i>	10.4										
<i>E. candollei</i>	5.5										
<i>M. altissima</i>	5.1										
<i>F. oblongum</i>	1.5										

### 3.1.2. The Most Important Family (FIV) following Enrichment Planting in the East Region of Cameroon

Generally, the most important family was the Fabaceae (199.61) in the LYs that regenerated naturally a year after enrichment planting. 5 and 10 years after enrichment planting, the most important families were Combretaceae (125.18) and Malvaceae (91.89) that regenerated naturally respectively. After enrichment planting, the most important species was Fabaceae a year (149.64) and 5 years (108.30) after, and Malvaceae, 10 years after (135.98). Generally, in the STs, the most important family was the Fabaceae (181.29) a year after enrichment planting. Specifically, the most important family 5 years after enrichment planting was Malvaceae (148.91). The most important family that regenerated naturally was Fabaceae (131.41) a year later, nothing 5 years after and Malvaceae (116.49) 10 years after. Under the forest canopy the most important family was the Fabaceae that regenerated naturally (115.62) (Table 3).

**Table 3.** The most important family (FIV) after natural regeneration and enrichment plant in the East Region of Cameroon.

LYss											
1 year after				5 years after				10 years after			
Natural		Planted		Natural		Planted		Natural		Planted	
Family	FIV	Family	FIV	Family	FIV	Family	FIV	Family	FIV	Family	FIV
Fabaceae	199.61	Fabaceae	149.64	Combretaceae	125.18	Fabaceae	108.30	Malvaceae	91.89	Malvaceae	135.98
Combretaceae	36.54	Meliaceae	58.30	Fabaceae	73.17	Malvaceae	75.93	Fabaceae	87.87	Fabaceae	84.52
Sapotaceae	21.30	Malvaceae	51.27	Malvaceae	31.46	Meliaceae	55.15	Combretaceae	71.28	Sapotaceae	34.78
Malvaceae	14.50	Combretaceae	27.97	Meliaceae	27.19	Combretaceae	30.50	Moraceae	18.39	Meliaceae	17.42
Meliaceae	14.36	Sapotaceae	12.81	Lecithydaceae	20.04	Ochnaceae	18.30	Sapotaceae	11.06	Combretaceae	15.57
Lecithydaceae	13.69			Moraceae	12.15	Moraceae	11.81	Lecithydaceae	10.30	Moraceae	11.74
				Sapotaceae	10.81			Meliaceae	9.21		
STs											
Fabaceae	131.41	Fabaceae	181.29			Malvaceae	148.91	Malvaceae	116.49		
Sapotaceae	57.93	Malvaceae	60.24			Fabaceae	94.95	Fabaceae	138.12		
Lecythidaceae	41.84	Meliaceae	58.48			Combretaceae	56.14	Meliaceae	45.39		
Combretaceae	34.10										
Moraceae	21.47										
Meliaceae	13.25										
Canopy											
Fabaceae	115.62										
Lecithydaceae	98.23										
Malvaceae	25.68										
Meliaceae	31.23										

### 3.2. Growth of Exploitable Species following Enrichment Planting in the East Region of Cameroon

The growth of species was determined by the average diameter and height of the exploitable species used for enrichment planting. Generally, there was a significant difference ( $p \geq 0.05$ ) in the average diameter across sites and species with the LYs ( $7.33 \text{ kg/ha} \pm 5.4 \text{ kg/ha}$ ) having the highest diameter a year after enrichment planting. Specifically under the forest canopy, *Petersianthus macrocarpus* had the highest diameter ( $14.85 \text{ mm/ha} \pm 18.1 \text{ mm/ha}$ ), while in the LYs and STs, the species *Entandrophragma angolense* had the highest diameter of  $14.16 \text{ mm/ha} \pm 6.3 \text{ mm/ha}$  and  $12.23 \text{ mm/ha} \pm 1.8 \text{ mm/ha}$  respectively. Thus, *Entandrophragma angolense* had the highest average diameter of  $14.03 \pm 6.2$  across the different sites after a year of enrichment planting (Table 4). Similarly, there was a significant difference ( $p \geq 0.05$ ) in the average height across sites and species. Generally, the average height was highest in LYs ( $38.98 \text{ cm/ha} \pm 27.8 \text{ cm/ha}$ ). Specifically, the species *Mansonia altissima* had the highest average height under the forest canopy ( $38 \text{ cm/ha} \pm 17.4 \text{ cm/ha}$ ), LYs ( $55.72 \text{ cm/ha} \pm 26.1 \text{ cm/ha}$ ) and STs ( $46.67 \text{ cm/ha} \pm 17 \text{ cm/ha}$ ); making it the species with the highest average height across sites ( $53.21 \text{ cm/ha} \pm 25.4 \text{ cm/ha}$ ) (Table 4).

**Table 4.** Average diameter and height after a year of enrichment planting in the East Region of Cameroon.

Species/Site	Diameter (mm)				Height (cm)			
	Canopy	LYs	STs	Average	Canopy	LYs	STs	Average
<i>A. pachyloba</i>	$1.23 \pm 1.5$	$8.99 \pm 3.7$	$4.28 \pm 1.2$	$2.82 \pm 3.7$	$11 \pm 17.3$	$49.29 \pm 18.8$	$36.5 \pm 19.3$	$19.11 \pm 23.4$
<i>A. altissima</i>		$4.95 \pm 3.3$	$3.73 \pm 2.3$	$4.31 \pm 2.9$		$21.29 \pm 17$	$26.53 \pm 12.9$	$24.06 \pm 15.2$
<i>E. angolense</i>		<b><math>14.16 \pm 6.3</math></b>	<b><math>12.23 \pm 1.8</math></b>	<b><math>14.03 \pm 6.2</math></b>		$40.19 \pm 10.3$	$55 \pm 5$	$41.21 \pm 10.7$
<i>E. candollei</i>	$1.66 \pm 1.1$			$1.66 \pm 1.1$	$6.2 \pm 3.6$			$6.2 \pm 3.6$
<i>E. cylindricum</i>	$7.47 \pm 5.4$	$2.93 \pm 2.9$	$3.65$	$4.57 \pm 4.4$	$70.17 \pm 55.1$	$16.8 \pm 14.3$	$40$	$37 \pm 42.7$
<i>E. oblongum</i>	$7.5$			$7.5$	$100$			$100$
<i>E. suaveolens</i>	$1.08 \pm 0.6$	$5.35 \pm 4.2$	$3.67 \pm 2.1$	$4.95 \pm 4.1$	$8.83 \pm 9.1$	$29.77 \pm 20.1$	$28.64 \pm 15.8$	$28.25 \pm 20$
<i>M. altissima</i>	$4.4 \pm 2.4$	$10.77 \pm 4.3$	$8.35 \pm 0.7$	$9.93 \pm 4.4$	<b><math>38 \pm 17.4</math></b>	<b><math>55.72 \pm 26.1</math></b>	<b><math>46.67 \pm 17</math></b>	<b><math>53.21 \pm 25.4</math></b>
<i>M. excelsa</i>			$12.65$	$12.65$			$110$	$110$
<i>P. macrocarpus</i>	<b><math>14.85 \pm 18.1</math></b>	$11$	$7.14 \pm 5.8$	$13.16 \pm 16.3$	$117.89 \pm 108.1$	$30$	$30 \pm 25.3$	$96.8 \pm 102$
<i>P. santalinoides</i>	$5.08 \pm 7.7$	$10.82 \pm 6.8$	$5.2 \pm 4.9$	$8.22 \pm 7.2$	$41.67 \pm 61.1$	$63.5 \pm 41.3$	$30.76 \pm 25.9$	$50.87 \pm 45.7$
<i>P. soyauxii</i>		$7.04 \pm 4.1$	$5.98 \pm 5.5$	$6.81 \pm 4.5$		$38.05 \pm 25.5$	$30.17 \pm 22.8$	$36.3 \pm 25.1$
<i>T. superba</i>		$5.57 \pm 4$	$2.04 \pm 0.6$	$4.87 \pm 3.8$		$40.63 \pm 32.1$	$12.86 \pm 3.6$	$35.07 \pm 30.8$
<i>T. scleroxylon</i>		$9.15 \pm 0.7$		$9.15 \pm 0.7$		$50 \pm 10$		$50 \pm 10$
Average	$3.23 \pm 7.7$	<b><math>7.33 \pm 5.4</math></b>	$4.61 \pm 4$	$5.82 \pm 6.3$	$27.09 \pm 54.4$	<b><math>38.98 \pm 27.8</math></b>	$28.9 \pm 21.7$	$34.32 \pm 37.3$
Pr(>F)	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000

**Note:** Figures in bold are the highest.

Five years after enrichment planting, there was a significant difference ( $p \geq 0.05$ )

in the growth of the exploitable species across the different sites. The STs had the highest average diameter (58.76 mm/ha  $\pm$  31.7 mm/ha) and height (440 cm/ha  $\pm$  220.5 cm/ha). Specifically, in LYs and STs, the species *Triplochiton scleroxylon* had the highest average diameter of 94.08 mm/ha  $\pm$  22.6 mm/ha and 104.65 mm/ha  $\pm$  12.4 mm/ha respectively. Making the species *Triplochiton scleroxylon* have the highest diameter across all sites (95.49 mm/ha  $\pm$  21.8 mm/ha) (**Table 5**). The average height on the other hand was highest in LYs in the species *Entandrophragma angolense* (389.41 cm/ha  $\pm$  106.4 cm/ha) and in STs in the species *Triplochiton scleroxylon* (750 cm/ha  $\pm$  50 cm/ha). Making *Triplochiton scleroxylon* have the highest average height across the different sites (590 cm/ha  $\pm$  141.7 cm/ha) (**Table 5**).

**Table 5.** Average diameter and height after five years of enrichment planting in the East Region of Cameroon.

Species/Site	Diametre (mm)			Height (cm)		
	LYs	STs	Average	LYs	STs	Average
<i>A. pachyloba</i>	13.21 $\pm$ 14.1		3.49 $\pm$ 7.9	143.45 $\pm$ 96.9		35.87 $\pm$ 69
<i>A. altissima</i>	2.7		2.7	80		80
<i>E. angolense</i>	47.75 $\pm$ 26.4		47.75 $\pm$ 26.4	<b>389.41 <math>\pm</math> 106.4</b>		389.41 $\pm$ 106.4
<i>E. candollei</i>			1.66 $\pm$ 1.1			6.2 $\pm$ 3.6
<i>E. cylindricum</i>	32.03 $\pm$ 15.7		20.69 $\pm$ 17.2	267.14 $\pm$ 99.4		176.23 $\pm$ 127.9
<i>E. oblongum</i>			7.5			100
<i>E. suaveolens</i>	22.91 $\pm$ 12	25.5	14.27 $\pm$ 14.1	277.65 $\pm$ 104.6	230	168.53 $\pm$ 152.7
<i>L. alata</i>	40.44 $\pm$ 27.9		40.44 $\pm$ 27.9	359.2 $\pm$ 137.2		359.2 $\pm$ 137.2
<i>M. altissima</i>	6.94 $\pm$ 3.3	0.157	6.65 $\pm$ 3.3	99.36 $\pm$ 75.4		92.35 $\pm$ 73.8
<i>M. excelsa</i>	9.83 $\pm$ 4.3		9.83 $\pm$ 4.3	170 $\pm$ 82.2		170 $\pm$ 82.2
<i>P. macrocarpus</i>	5.05 $\pm$ 1		11.06 $\pm$ 14.9	67.5 $\pm$ 29.8		98.39 $\pm$ 90
<i>P. santalinooides</i>	26.14 $\pm$ 21.7	25.7	21.26 $\pm$ 21.2	282.32 $\pm$ 143.4	250	226.93 $\pm$ 162.6
<i>T. superba</i>	34.22 $\pm$ 33.7	50.27 $\pm$ 6	35.23 $\pm$ 32.9	254.67 $\pm$ 175	366.67 $\pm$ 124.7	261.67 $\pm$ 174.4
<i>T. scleroxylon</i>	<b>94.08 <math>\pm</math> 22.6</b>	<b>104.65 <math>\pm</math> 12.4</b>	<b>95.49 <math>\pm</math> 21.8</b>	565.38 $\pm$ 135	<b>750 <math>\pm</math> 50</b>	<b>590 <math>\pm</math> 141.7</b>
Average	27.66 $\pm$ 29.4	<b>58.76 <math>\pm</math> 31.7</b>	17.6 $\pm$ 26.3	246.57 $\pm$ 172.3	<b>440 <math>\pm</math> 220.5</b>	154.78 $\pm$ 177.4
Pr(>F)	0.000	0.02	0.000	0.000	0.10	0.000

**Note:** Figures in bold are the highest.

Ten years after enrichment planting, there was a significant difference ( $p \geq 0.05$ ) in the growth of the exploitable species across sites. The LYs had the highest average diameter (35.94 mm/ha  $\pm$  41.5 mm/ha) and height (257.39 mm/ha  $\pm$  229.7 mm/ha) respectively. Specifically, in the LYs, the species *Triplochiton scleroxylon* had the highest average diameter (102.76 mm/ha  $\pm$  55.4mm/ha), while in the STs, the species *Pterocarpus santalinooides* had the highest average diameter (17.73 mm/ha  $\pm$  11.1 mm/ha). For the average height, in the LYs, the highest was found in the species *Triplochiton scleroxylon* (595.3 cm/ha  $\pm$  270.4 cm/ha) while in the STs, the highest was in the species *Pterocarpus santalinooides* (200 cm/ha  $\pm$  29.4

cm/ha). This made the species *Triplochiton scleroxylon* the species with the highest average diameter (102.76 mm/ha  $\pm$  55.4 mm/ha) and height (595.3 cm/ha  $\pm$  270.4 cm/ha) 10 years after enrichment planting (Table 6).

**Table 6.** Average diameter and height after ten years of enrichment planting in the East Region of Cameroon.

Species/Site	Diametre (mm)			Height (cm)		
	LYs	STs	Average	LYs	STs	Average
<i>A. pachyloba</i>	10.36 $\pm$ 7.8	11 $\pm$ 1	1.76 $\pm$ 3.1	135 $\pm$ 59.7	120	17.74 $\pm$ 35.3
<i>A. altissima</i>	28.19 $\pm$ 21.5		28.19 $\pm$ 21.5	223.96 $\pm$ 98.8		223.96 $\pm$ 98.8
<i>E. candollei</i>			1.66 $\pm$ 1.1			6.2 $\pm$ 3.6
<i>E. cylindricum</i>	47.35 $\pm$ 17.9	17.5	29.41 $\pm$ 23.6	385 $\pm$ 133	180	245.4 $\pm$ 183.4
<i>E. oblongum</i>			7.5			100
<i>E. suaveolens</i>	35.3 $\pm$ 23.2	10.2	26.41 $\pm$ 24.8	277.36 $\pm$ 166	200	210.02 $\pm$ 183
<i>M. altissima</i>	10.13 $\pm$ 13	15.13 $\pm$ 4	10.15 $\pm$ 12.7	86.54 $\pm$ 77.8	166 $\pm$ 80.4	88.19 $\pm$ 78.8
<i>M. excelsa</i>	28 $\pm$ 28.2		28 $\pm$ 28.2	314 $\pm$ 207.1		314 $\pm$ 207.1
<i>P. macrocarpus</i>	7.2 $\pm$ 3.1		13.81 $\pm$ 17	72.33 $\pm$ 39.1		111.68 $\pm$ 102.7
<i>P. santalinoides</i>	42.52 $\pm$ 25.2	<b>17.73 <math>\pm</math> 11.1</b>	32.47 $\pm$ 27.2	331.18 $\pm$ 155.8	<b>200 <math>\pm</math> 29.4</b>	256.66 $\pm$ 182.6
<i>T. superba</i>	27.83 $\pm$ 28.1		27.83 $\pm$ 28.1	233.67 $\pm$ 167.9		233.67 $\pm$ 167.9
<i>T. scleroxylon</i>	<b>102.76 <math>\pm</math> 55.4</b>		<b>102.76 <math>\pm</math> 55.4</b>	<b>595.3 <math>\pm</math> 270.4</b>		<b>595.3 <math>\pm</math> 270.4</b>
Average	<b>35.94 <math>\pm</math> 41.5</b>	14.88 $\pm$ 6.7	24.14 $\pm$ 36.8	<b>257.39 <math>\pm</math> 229.7</b>	170.83 $\pm$ 60.3	175.69 $\pm$ 215.1
Pr(>F)	0.000	1.0	0.000	0.000	1.0	0.000

**Note:** Figures in bold are the highest.

In this study, though more individuals died in the LYs than in the STs, the annual mortality was highest in the STs, 5 and 10 years after enrichment planting. Also in both sites, the number of individuals who died decreased with time. Contrarily, the survival rate was highest in the LYs, 5 and 10 years after enrichment planting (Table 7).

**Table 7.** Annual mortality and survival rate of disturbed sites after enrichment planting in the East Region of Cameroon.

Sites	Time (Years)			Annual Mortality Rate (%)		Annual Survival Rate (%)	
	1	5	10	1 - 5 years	1 - 10 years	1 - 5 years	1 - 10 years
Log yards	385	237	339	9.6	1.3	61.6	88.1
Skid trails	83	7	12	22.9	9.5	8.4	14.5

In the LYs mortality was highest in the species *Aningeria altissima* (23.5%), 5 years after enrichment planting. Ten years after enrichment planting, mortality was highest in *Entandrophragma angolense* (11.1%) and *Pterocarpus soyauxii* (11.1%). Total survival was least in *Pterocarpus soyauxii* (0.0%) and *Entandrophragma angolense* (0.0%), 5 and 10 years respectively. Five and ten years after enrichment planting,

recruitment was highest in *Petersianthus macrocarpus* (1100%) and *Triplochiton scleroxylon* (2400%) respectively (Table 8).

**Table 8.** Species annual mortality rate, total survival and recruitment of exploitable species after enrichment planting in the East Region of Cameroon.

Sites	Species	Time (Years)			Annual Mortality (%)		Total Survival Rate (%)		Recrutement Total (%)	
		1	5	10	1 - 5 years	5 - 10 years	1 - 5 years	5 - 10 years	1 - 5 years	5 - 10 years
LYs	<i>Afzelia pachyloba</i>	31	29	6	1.6	9.0	93.5	19.4		
	<i>Aningeria altissima</i>	17	1	36	<b>23.5</b>		5.9			112
	<i>Entandrophragma angolense</i>	27	17		9.3	<b>11.1</b>	63	0		
	<i>Entandrophragma cylindricum</i>	10	7	8	7.5	2.2	70	80		
	<i>Erythrophleum suaveolens</i>	150	17	36	22.2	8.4	11.3	24		
	<i>Lophira alata</i>		5							100
	<i>Mansonia altissima</i>	32	31	114	0.8		96.9	100		256
	<i>Milicia excelsa</i>		4	5						100 100
	<i>Petersianthus macrocarpus</i>	1	12	3			100	100	<b>1100</b>	200
	<i>Pterocarpus santalinoides</i>	38	56	51			100	100	47	34
	<i>Pterocarpus soyauxii</i>	21			25	<b>11.1</b>	0	0		
	<i>Terminalia superba</i>	56	45	30	4.9	5.2	80.4	53.6		
<i>Triplochiton scleroxylon</i>	2	13	50			100	100	550	<b>2400</b>	
STs	<i>Afzelia pachyloba</i>	4		2	25	<b>5.6</b>	0	50		
	<i>Aningeria altissima</i>	19			25	11.1	0	0		
	<i>Entandrophragma angolense</i>	2			25	11.1	0	0		
	<i>Entandrophragma cylindricum</i>	1		1	25	0	0	<b>100</b>		
	<i>Erythrophleum suaveolens</i>	11	1	1	22.7	10.1	9.1	9.1		
	<i>Mansonia altissima</i>	3		5	25		0	<b>100</b>		67
	<i>Milicia excelsa</i>	1			25	11.1	0	0		
	<i>Petersianthus macrocarpus</i>	5			25	11.1	0	0		
	<i>Pterocarpus santalinoides</i>	17	1	3	23.5	9.2	5.9	17.6		
	<i>Pterocarpus soyauxii</i>	6			25	11.1	0	0		
	<i>Terminalia superba</i>	14	3		<b>19.6</b>	11.1	<b>21.4</b>	0		
	<i>Triplochiton scleroxylon</i>		2							100

**Note:** Figures in bold are the highest or lowest.

In the STs, mortality was least in the species *Terminalia superba* (19.6%) with the a highest total survival of 21.4%, 5 years after enrichment planting. Ten years after, the species *Afzelia pachyloba* had the least mortality but the highest total survival was found in the species *Mansonia altissima* and *Entandrophragma cy-*

*lindricum* (100%). Recruitment was highest in *Triplochiton scleroxylon* (100%) and *Mansonia altissima* (67%), 5 and 10 years respectively (Table 8).

### 3.3. Biomass and Carbon Stock Dynamics after Enrichment Planting in the East Region of Cameroon

There was a significant difference across sites ( $p \geq 0.05$ ) for the mean biomass a year after enrichment planting as the forest canopy had the highest mean biomass (1.163 kg/ha) while the STs had the least biomass (0.014 kg/ha). *Petersianthus macrocarpus* had the highest biomass (10.325 kg/ha) under the forest canopy, *Mansonia altissima* (0.059 kg/ha) in the LYs, and *Milicia excelsa* (0.114 kg/ha) in the STs a year after enrichment planting. However, there was no significant difference for all the species across the sites except for *Terminalia superba* which was significantly different between the LYs and the STs (Table 7). Five years after the biomass was the same for both LYs and STs (3.552 kg/ha), with *Triplochiton scleroxylon* having the highest biomass in both LYs and STs (18.214 and 27.002 kg/ha respectively). Only the species *Azelia pachyloba* and *Erythrophleum suaveolens* had a significant difference in their biomass across the different sites. Ten years after enrichment planting, the LYs had a higher biomass (7.604 kg/ha) than

**Table 9.** Biomass dynamics across the different sites after enrichment planting in the East Region of Cameroon.

Years	1 Year				5 Years			10 Years		
	Sites/Species	Canopy	LY	ST	Pr(>F) <sup>2</sup>	LY	ST	Pr(>F) <sup>2</sup>	LY	ST
<i>A. pachyloba</i>	0.024	0.042	0.007	0.893	0.731		<b>4.81e-07***</b>	0.248	0.115	0.087
<i>A. altissima</i>		0.009	0.004	0.184	0.004					
<i>E. angolense</i>		0.057	0.044	0.807	6.469			2.293		
<i>E. candollei</i>	0.003									
<i>E. cylindricum</i>	0.656	0.005	0.004	0.066	2.433		0.135	6.443	0.348	0.056
<i>E. oblongum</i>	0.428									
<i>E. suaveolens</i>	0.003	0.025	0.009	0.385	2.039	1.372	<b>0.0212*</b>	6.528	0.2	0.059
<i>M. altissima</i>	0.084	<b>0.059</b>	0.021	0.628	9.95			0.515	0.302	0.967
<i>M. excelsa</i>			<b>0.114</b>		0.053		0.474	5.264		
<i>P. macrocarpus</i>	<b>10.325</b>	0.026	0.03	0.548	0.164			0.042		0.434
<i>P. santalinoides</i>	0.728	0.092	0.019	0.051	0.014		0.115	6.293	<b>0.553</b>	0.152
<i>P. soyauxii</i>		0.028	0.033	0.814	2.679	0.928	0.379			
<i>T. superba</i>		0.018	0.00	<b>0.017*</b>	4.887	4.823	0.99	3.701		
<i>T. scleroxylon</i>		0.016			<b>18.214</b>	<b>27.002</b>	0.244	<b>33.805</b>		
Biomass (kg·ha <sup>-1</sup> )	<b>1.163</b>	0.036	0.014	1.21e-14***	<b>3.552</b>	<b>3.552</b>	<2e-16***	<b>7.604</b>	0.329	0.000
Biomass (t·ha <sup>-1</sup> )	0.001	0.00	0.00		0.004	0.004		0.008	0.00	
Pr(>F) <sup>2</sup>	0.000	0.000	0.009		0.000	0.000		0.000	0.847	

**Note:** Figures in bold are the highest. ANOVA: Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1.

the STs. In the LYs, the highest was in the species *Triplochiton scleroxylon* (33.805 kg/ha). While in the STs, the highest was in *Pterocarpus santalinoides* (0.553 kg/ha). No species had a significant difference in their biomass across sites 10 years after enrichment planting (**Table 9**).

There was a significant difference ( $p \geq 0.05$ ) across sites and species for the amount of carbon stocked and sequestered. A year after enrichment planting, the forest canopy had the highest carbon stock and sequestration (0.546 kg/ha and 2005 CO<sub>2</sub><sup>-e</sup>/ha respectively). Specifically under the forest canopy, the species *Pterocarpus macrocarpus* had the highest carbon stock and sequestration (4.853 kg/ha and 17,809 CO<sub>2</sub><sup>-e</sup>/ha). In the LYs, the highest carbon stock and sequestration was recorded in *Mansonia altissima* (0.028 kg/ha and 0.101 CO<sub>2</sub><sup>-e</sup>/ha).

In the STs, the highest Carbon stock and sequestration was recorded in *Milicia excelsa* (0.054kg/ha and 0.197 CO<sub>2</sub><sup>-e</sup>/ha) (**Table 8**). Five and ten years after enrichment planting, the highest Carbon stock and sequestration was recorded in the LYs. *Triplochiton scleroxylon* had the highest Carbon stock and sequestration (8.6 kg/ha and 31.4 kg/ha respectively) in the LYs 5 years and 10 years after (15.9 kg/ha and 58.31 CO<sub>2</sub><sup>-e</sup>/ha). In the STs however 10 years after enrichment planting, the species *Pterocarpus santalinoides* stored the most carbon and sequestration (**Table 10**).

**Table 10.** Carbon stock and sequestration across the different sites after enrichment planting in the East Region of Cameroon.

Years	1 Year				5 Years				10 Years					
	Canopy		LY		ST		LY		ST		LY		ST	
	Carbon	Co <sub>2</sub>	Carbon	Co <sub>2</sub>	Carbon	Co <sub>2</sub>	Carbon	Co <sub>2</sub>	Carbon	Co <sub>2</sub>	Carbon	Co <sub>2</sub>	Carbon	Co <sub>2</sub>
<i>A. pachyloba</i>	0.011	0.041	0.02	0.073	0.003	0.012	0.344	1.261			0.116	0.43	0.054	0.20
<i>A. altissima</i>			0.004	0.015	0.002	0.006	0.002	0.007			1.078	3.96		
<i>E. angolense</i>			0.027	0.099	0.021	0.076	3.04	11.158						
<i>E. candollei</i>	0.001	0.005												
<i>E. cylindricum</i>	0.309	1.132	0.002	0.008	0.002	0.006	1.144	4.197			3.028	11.11	0.164	0.0563
<i>E. oblongum</i>	0.201	0.738												
<i>E. suaveolens</i>	0.001	0.005	0.012	0.043	0.004	0.015	0.958	3.517	0.645	2.366	3.068	11.26	0.094	0.0589
<i>M. altissima</i>	0.039	0.144	<b>0.028</b>	<b>0.101</b>	0.01	0.036	4.676	17.162			0.242	0.89	0.142	0.967
<i>M. excelsa</i>					<b>0.054</b>	<b>0.197</b>	0.025	0.091			2.474	9.08		
<i>P. macrocarpus</i>	<b>4.853</b>	<b>17.809</b>	0.012	0.045	0.014	0.052	0.077	0.282			0.02	0.072		0.434
<i>P. santalinoides</i>	0.342	1.256	0.043	0.159	0.009	0.033	0.007	0.024			2.958	10.85	<b>0.26</b>	<b>0.152</b>
<i>P. soyauxii</i>			0.013	0.049	0.015	0.057	1.259	4.621	0.436	1.601				
<i>T. superba</i>			0.009	0.032	0	0.001	2.297	8.43	2.267	8.319	1.74	6.38		
<i>T. scleroxylon</i>			0.007	0.027			<b>8.6</b>	<b>31.4</b>	<b>12.7</b>	<b>46.6</b>	<b>15.9</b>	<b>58.31</b>		
Biomass (kg·ha <sup>-1</sup> )	<b>0.546</b>	<b>2.005</b>	0.017	0.062	0.006	0.024	1.669	6.127	4.752	17.439	3.574	13.12	0.155	
Biomass (t·ha <sup>-1</sup> )	0.001	0.002	0.000	0.000	0.00	0.00	<b>0.002</b>	<b>0.006</b>	0.00	0.02	<b>0.004</b>	<b>0.013</b>	0.00	
Pr(>F) <sup>2</sup>	0.000	0.000	0.000		0.008	0.012	0.000	0.000	0.0894	0.0894	0.000	0.000	0.847	0.000

**Note:** Figures in bold are the highest.

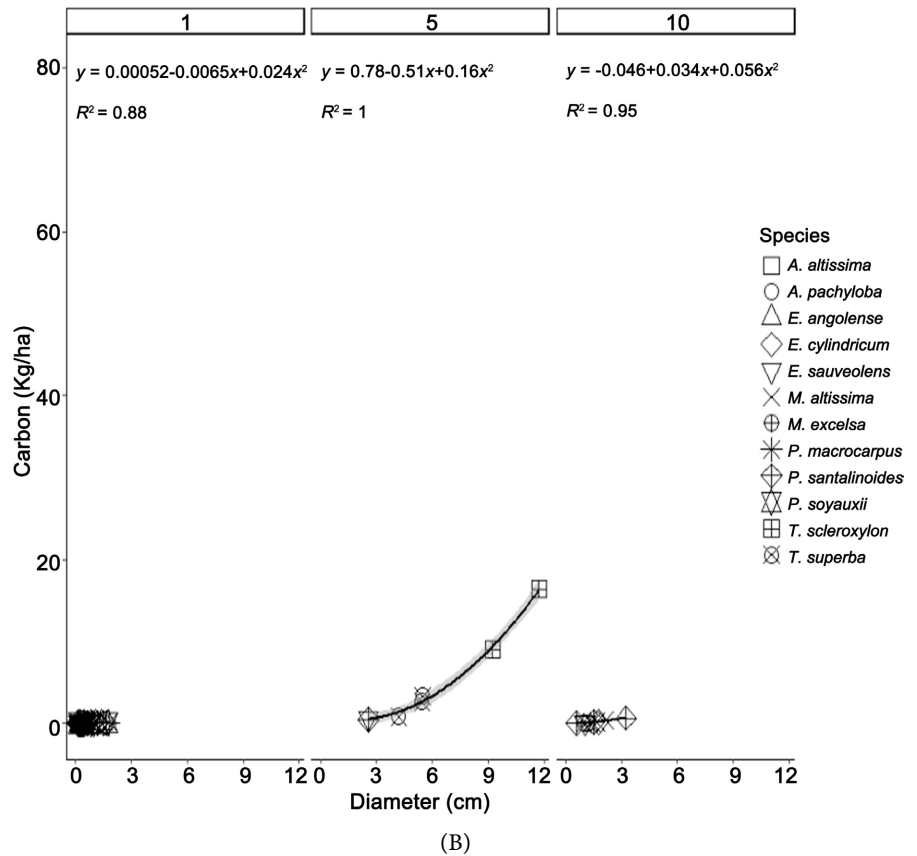
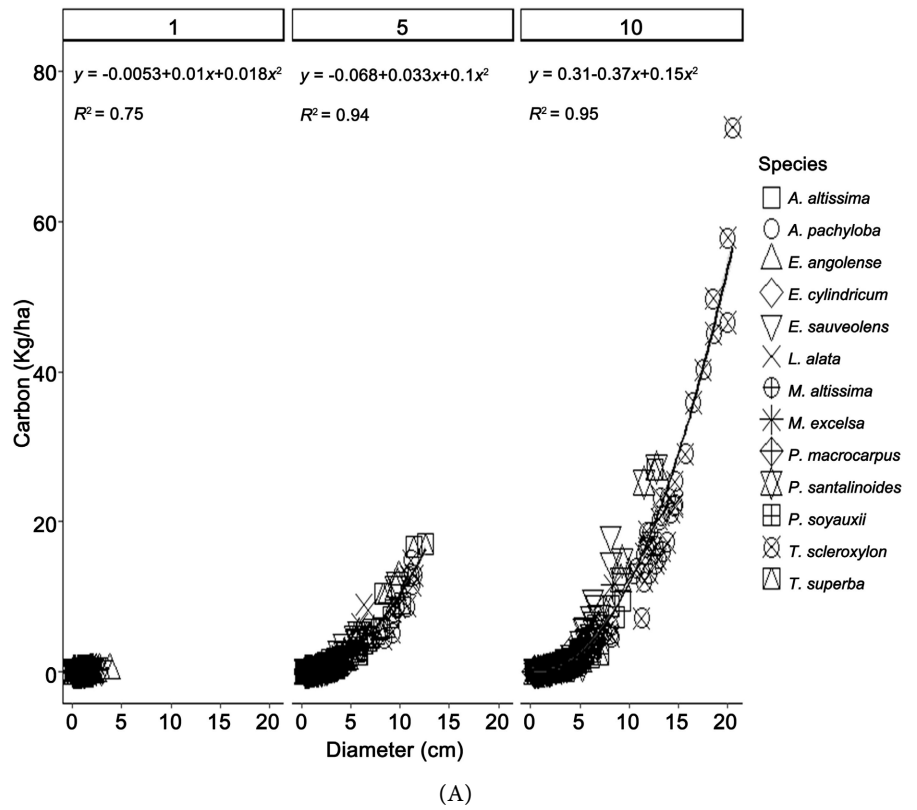
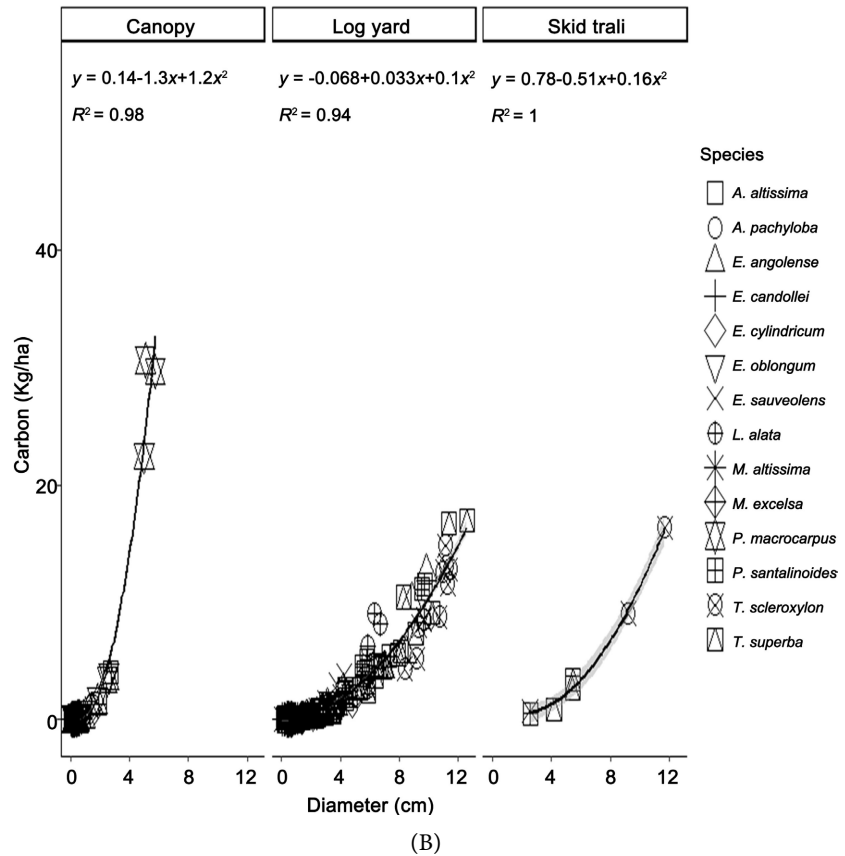
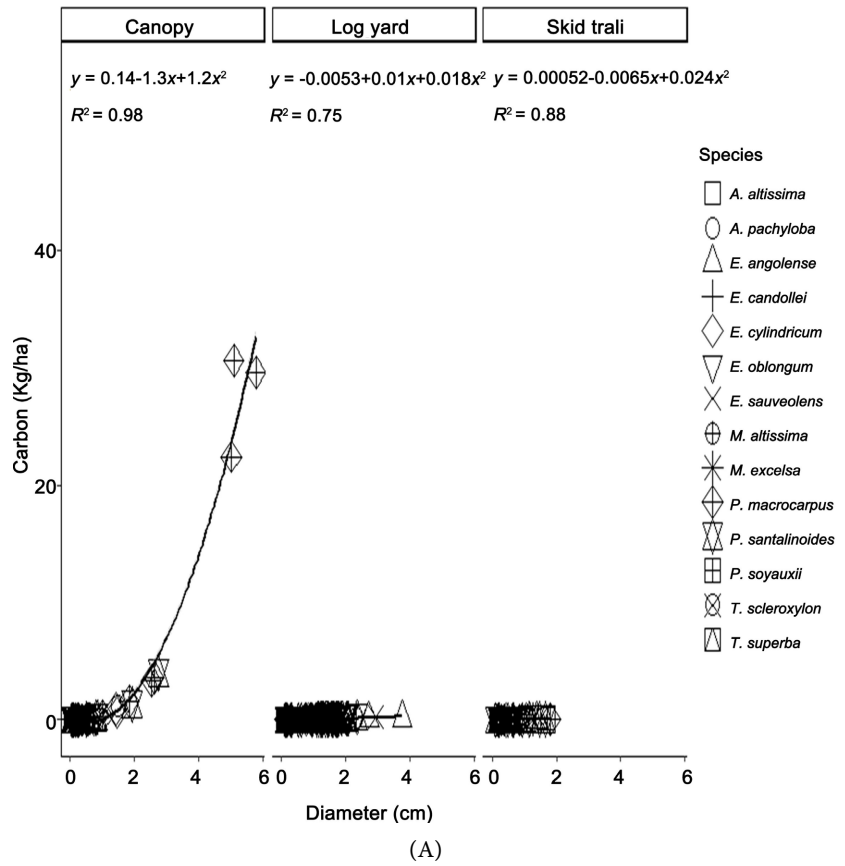
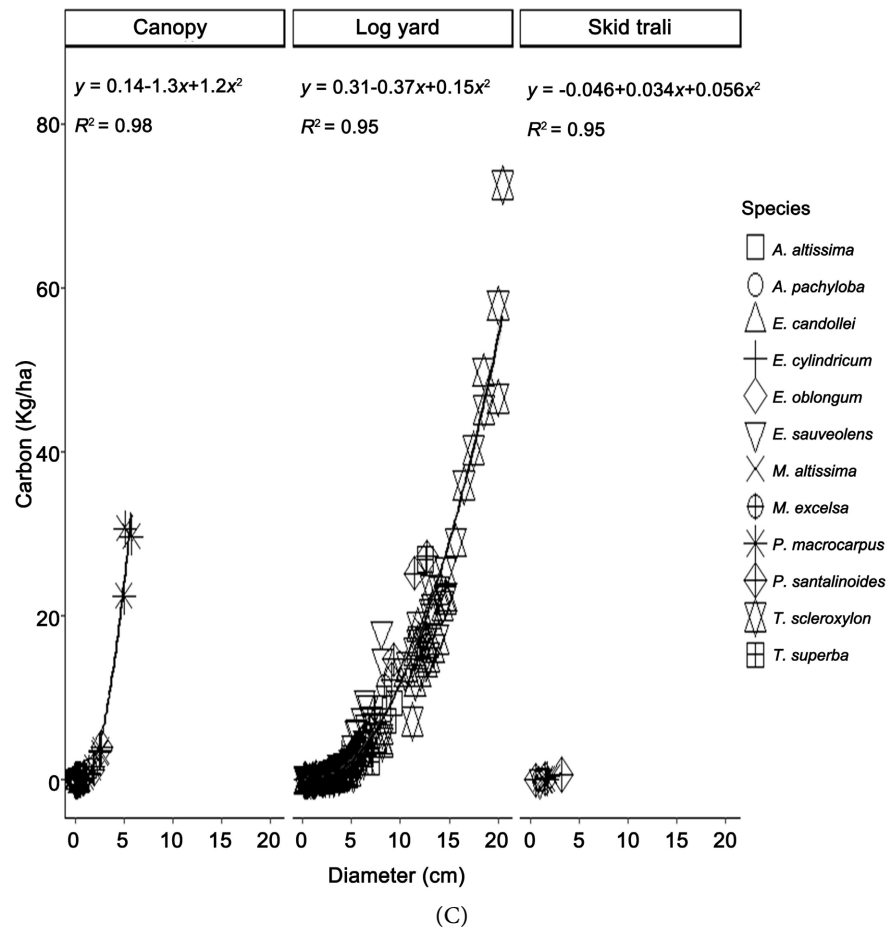


Figure 3. Variation of carbon stock and diameter over time in the LYs (A) and STs (B).





**Figure 4.** Variation of carbon stock and diameter a year (A) 5 years (B) and 10 years (C) after enrichment planting.

The variation of the Carbon stock and diameter over time per site indicates that, Carbon stock and diameter increased over time in all the sites. In the LYs, it increased from the first year to the 10<sup>th</sup> year. However, in the STs, there was an increase from the first year to the 5<sup>th</sup> year and as time increased, the carbon stock and diameter decreased in the 10<sup>th</sup> year (Figure 3).

A year after enrichment planting, growth was only evident under the forest canopy (Figure 4(A)). As time increased, growth became evident in all three sites without a major change under the forest canopy (Linear relationship) (Figure 4(B)). Ten years after enrichment planting, the diameter and Carbon stock were maintained under the forest canopy, increased in the LYs and almost nothing in the STs (Figure 4(C)).

### 3.4. Soil Characteristics after Enrichment Planting

Soil chemical properties under the forest canopy was not significantly different ( $p < 0.05$ ) from that of the disturbed sites (Log yards and skid trails) except for Potassium, pH (water), pH(KCL) and Cation exchange capacity (CEC) that were significantly different ( $p < 0.05$ ). Generally there was an increase in most of the soil prop-

erties after selective logging except for Exchanged acidity, Phosphorus and Magnesium. In term of soil properties, the enriched sites had a lower average pH value than that under the canopy, suggesting that the soil in the enriched sites were still more acidic. In addition, the enriched sites had higher values of C organic, C/N ratio, Organic matter, Potassium, Calcium and CEC than those in under the forest canopy, implying that soil fertility in the reclaimed sites was not yet equal as in the forest canopy. The mineral contents showed varying conditions between the forest canopy and the reclamation sites. Both the forest canopy and the reclaimed sites contained a high amount of potassium, with the highest potassium content found at the enriched site. The cation exchange capacity (CEC) was categorized as high in the enriched sites. This value indicates that the available cations for plants are high in enriched sites. Based on the soil properties overall, the enriched sites had good soil conditions although these conditions were not far below that of the forest canopy (Table 11).

**Table 11.** Soil properties after enrichment planting in the East Region of Cameroon.

SOIL Property	Under Forest Canopy (UFC)			Disturbed Sites			Mean		
	0 - 10 cm	10 - 20 cm	20 - 30 cm	0 - 10 cm	10 - 20 cm	20 - 30 cm	UFC	Disturbed Sites	Pr(>F) <sup>2</sup>
pH (water)	5.05	4.4	4.6	6.2	6.5	6.4	4.5 ± 0.3	6.4 ± 0.2	<b>0.001</b>
pH (KCL)	4.1	3.5	3.6	5.4	5.8	5.4	3.7 ± 0.3	5.5 ± 0.2	<b>0.001</b>
Exchanged Acidity	12.9	13.4	14.4	4.1	4.1	4.0	13.6 ± 0.8	4.1 ± 0.1	<b>0.000</b>
Organic Carbon (%)	3.6	3.5	3.4	5.4	3.9	3.1	3.5 ± 0.1	4.1 ± 1.2	0.402
Organic Matter (%)	6.2	6.07	5.8	9.4	6.8	5.3	6.0 ± 0.2	7.2 ± 2.1	0.396
Nitrogen (%)	0.2	0.2	0.2	0.3	0.1	0.1	0.2 ± 3.4	0.2 ± 0.1	0.643
Phosphorous (Kg)	7.1	6.2	5.6	5.9	2.8	3.6	6.3 ± 0.8	4.1 ± 1.6	0.100
Sodium (Kg)	0.1	0.1	0.1	0.1	0.1	0.1	0.1 ± 0.01	0.1 ± 0	0.837
Potassium (Kg)	0.3	0.3	0.5	0.7	0.7	0.7	0.4 ± 0.1	0.7 ± 1.4	<b>0.001</b>
Calcium (Kg)	1.8	4.2	2.8	5.6	4.3	2.5	2.9 ± 1.2	4.1 ± 1.6	0.351
Magnesium (Kg)	2.7	1.5	4.3	4.7	1.6	0.4	2.8 ± 1.4	2.2 ± 2.2	0.713
C/N Ratio (%)	16.1	19.7	23.1	20.7	40.6	23.4	19.6 ± 3.5	28.2 ± 10.8	0.26
CEC (Kg)	10.8	10.8	10.8	22.2	23.2	22.7	10.8 ± 2.2	22.7 ± 0.5	<b>0.000</b>

**Note:** Figures in bold are significantly different.

## 4. Discussion

### 4.1. Stand Composition after Enrichment Planting in the East Region of Cameroon

#### The Most Important Species and Family after Enrichment Planting in the East Region of Cameroon

The stand composition in this study was determined by the abundance and the species richness which was highest in the LYs than in the STs. This may be due to

the large space that is usually created for LYs. Log yards are usually large areas created to store wood that has been harvested from nearby forests and pulled through STs. This requires clearing of a large surface area as compared to the STs where much damage is not done to the surrounding vegetation. Thus due to more space of LYs, more seedlings are required for planting. Seedlings used for the enrichment planting were based on their availability in the nursery and forest floor. The species *Erythrophleum sauveolens* was the most available due to its fast germination rate of maximum 3 weeks after sowing or exposure to sunlight [64]. The Important Value Index (IVI) indicates the relative ecological significance of a tree species in a stand. The most important species in this study *Erythrophleum sauveolens* that regenerated naturally, is a species that occurs in moist semi deciduous forests or gallery forests and grows best in fairly open forests [64]. That is why this species was found in the LYs. The species also belongs to the Fabaceae family with its podlike structure ready to spread far and wide at the opening of the forest canopy [65]. That may be the reason why it is the most important just a year after enrichment planting and possibly selective logging. After 5 and 10 years of enrichment planting, the most important species that regenerated naturally were *Terminalia superba* and *Mansonia altissima* respectively. The species *Terminalia superba* prefers well-drained soils and does not tolerate prolonged waterlogging, conditions similar to that of LYs and STs after a year of logging and enrichment planting [66]. The species *Mansonia altissima* was found to grow naturally in both LYs and STs 10 years after enrichment planting. Ohene-Coffie, [67] indicated that in southern Ghana seedlings of this species of up to 1m tall are most common in disturbed forest, while smaller seedlings are more common in undisturbed forest and adult trees are more common in logged or burnt forest than in undisturbed forest. This indicates its preference to be located in disturbed sites and thus considered a light demanding species at the seedling stage. This is further confirmed by the results obtained by [68] who indicated that the family of Sterculiaceae having individuals like *Mansonia altissima* was the most important family 17 years after enrichment planting. In our study these species were found 10 years after enrichment planting and should be used in LYs during enrichment planting. A year after enrichment planting, in the STs, the most important species was *Aningeria altissima* that regenerated naturally because this species inhabits areas with increased moisture usually found in riverine forest and freshwater swamp forest [69].

After enrichment planting, the most important species was *Entandrophragma angolense*, a year after in the LYs. This may be due to the fact that this species requires light for growth after the seedling stage [70]. The most important species was *Triplochiton scleroxylon* in the STs. This may be due to the fact that this species is usually found as seedlings in forest gaps because its a light demander [71] and also some plots experienced management treatment of clearing and weeding thus allowing more light in the skid trails. These results are similar to that obtained by [68] who indicated that the family of Sterculiaceae having individuals like *Triplochiton scleroxylon* as the most important family 17 years after enrich-

ment planting. *Terminalia superba* is often found in association with *Triplochiton scleroxylon* K. Schum. (Kimpouni, 2009), reason why they are found in both LYs and STs in this study.

The most important family in the early years (1 - 5 years) after enrichment planting was the Fabaceae family. The Fabaceae family is the third largest family with 740 genera and 19,400 species [65]. Our study confirmed the comparable results of [72] in a semi-tropical forest where the Moraceae, Meliaceae, Apocynaceae, Euphorbiaceae, Ebenaceae, and Fabaceae were found to be the major family species drivers in the restoration status of a tropical semi-evergreen forest of Assam, Northeast India. Ten years after the most important family was the Malvaceae in both LYs and STs, indicating the restoration of the forest towards the mid successional stages of the forests. This was confirmed by [30] who indicated that the Malvaceae family was present in both logged forests and forests logged 21 years ago. This therefore is an indication that enrichment planting actually helps in the restoration of the forests after selective logging.

## 4.2. Stand Structure after Enrichment Planting in the East Region of Cameroon

### Growth of Exploitable Species after Enrichment Planting in the East Region of Cameroon

Several measures can be used to compare growth performance: diameter, height, volume or biomass, and they all have merits. In this study, diameter increment was preferred, as diameter is the most direct, accessible and reliable measure of tree size, and because the use of increment (rather than diameter) avoids serial correlation [73] and thus better satisfies conventional statistical assumptions. In this study the diameter and height were used as a measure of the growth of the exploitable species. A year after enrichment planting, growth was highest in the LYs; however, with time, growth was highest in the STs 5 years after and returned to the LYs 10 years after logging. This is similar to the results of [20] who indicated that growth was higher in the LYs than in the STs in a similar study in the East Region of Cameroon. Tree growth is affected by many factors, such as silvicultural treatment, competition from neighbouring trees, and microclimate. Separating the effect of these factors can be difficult. Thus, the results obtained here may be due to firstly the high light availability after the canopy has been opened by selective logging to create LYs. During photosynthesis, absorbed energy from the sunlight is transferred to the photosynthetic apparatus. This energy required for photosynthesis is obtained from sunlight which is highest in the LYs than the STs and under the forest canopy and thus leads to the growth of the seedlings present. This also means an increase in the growth of other species such as weeds and lianas which have a faster growth rate than the exploitable species used for enrichment planting [74]. These undergrowth weeds and lianas are more evident in the STs than in the LYs as they hinder the growth of the exploitable species. Extensive growth of climbers, lianas and other vegetation has been shown in previous stud-

ies to hinder regeneration of trees [75]. Trimato [76] indicated that the number of understorey species and richness at two reclamation sites was more than that of saplings, suggesting that ground cover plants are more adaptable to the harsh environmental conditions in mine reclamation areas in Indonesia. Montagini [77] indicated that after 4 years of enrichment planting, the number of saplings from natural regeneration was close to or even surpassed the amount of planted seedlings. This aligns with a preliminary enrichment planting trial in Agua Salud teak plantations [78] which found that crowding explained more variation in enrichment planting growth than light alone [79]. Also, there might be competition amongst the exploitable species used for the enrichment planting, evident more in the STs which has less space and more likely to suffer from overcrowding. Vanclay [80] in the Phillipines indicated that species like *Pterocarpus indicus* exhibits strong intraspecific, but low inter-specific competition, so appears well-suited for polyculture plantings. It is thus recommended that species should thus be separated as species used for mono and polyculture systems. Montagini [77], however still recommends slow growth timber species for enrichment planting due to their multipurpose.

Secondly, the soil compaction that is experienced in the STs makes it difficult for the germination and growth of species seedlings as [81] indicated higher ground damage in STs (7% - 12%) than in LYs (1%) of the total harvest area in the Eastern Amazon of Brazil. The compaction of the soil also occurs in the LYs but this is usually restored (soil removed during clearing for the formation of the LYs is put back) before enrichment planting as opposed to the STs where this is not done. This compaction slows down the germination of most of the seeds found in the soil seed bank or better still destroys the seeds.

However, the LYs are exposed to severe sunlight quality and quantity which may not be right for seedlings growth thus improving growth in the STs (conditions similar to medium light and medium moisture) [20]. Both quality, quantity and duration of incident light can have drastic impacts on photosynthetic activity and photosystem adaption to changing light quality [82] which eventually has an effect on the growth rate. Sensitivity to light is usually different according to the seedling stage and varied also according to the species [83]. However, light is not the only factor that determines the growth of species as [79] indicated that light did not significantly affect growth ( $p > 0.05$ ) of the species *Terminalia amazonia* after enrichment planting in Panama. In the STs, the amount of light is moderate keeping enough moisture necessary for the growth of seedlings. The best growth of species between 1 - 5 years after enrichment planting in the STs is similar to the results of [20] where no species died in the STs indicating the best growth condition for most seedlings in the STs.

As time increases to 10 years, the amount of light is reduced in both LYs and STs and the LYs become best for the growth of species. The STs become too dark for the survival of these species which almost becomes like under the forest canopy. Similar results were obtained by [83] who indicated a highest mean height in

an open canopy as opposed to a dense canopy in a forest plantation in Vietnam. The decrease in the growth of the STs may be due to the growth of the remnant cohort which have also increased in height and thus formed a canopy reducing the incident light required for growth. Similar results were found by [84] who indicated that the survival of enrichment plantings declined with increasing understory vegetation over time in a tropical forest in Australia. Thus the initial level of post-logging understory vegetation did not appear to affect the immediate survival of enrichment plantings, but in the longer term (up to 10 years) survival decreased as post-logging understory vegetation and regrowth increased. This suggests that removal of understory vegetation should take place at the time of enrichment planting. That is why the STs had an increased rate of growth in the first five years but later decreased in growth. Similar results were obtained by [84] in Australia after 30 years of enrichment planting. Marshall [79] indicated that 30 months after enrichment planting, both crowding pressure and light availability explained a significant amount of variation in growth for all species combined.

A year after enrichment planting, the diameter and height were highest in the species *Entandropgrama angolense* and *Mansonia altissima* respectively. *Mansonia altissima* had a good growth rate in both the LYs and STs. This is in corroboration with the results of [20] who indicated that the growth of *Mansonia altissima* was highest in the condition of low light and high moisture and ended up recommending the species to be used in the STs during enrichment planting. *Entandropgrama angolense* is a species that grows well in forest gaps and its growth is fair under medium-sized gaps [85]; indicating why its growth was best in the LYs than in the STs. Five and ten years later the highest growth was obtained from the species *Triplochiton scleroxylon* in the ST and LYs respectively. Fotso [45] indicated that the forest of the East Region is dominated by this species. This is in corroboration with the studies of [86] who indicated that *Trplochyton scleroxylon* had the fastest growth and highest survival rate of 61.3% after 17 years of enrichment planting. This may be due to the fact that *Triplochiton scleroxylon* is a light-demanding pioneer species and thus grows very fast after disturbance as the tree is characteristic of secondary forest [71]. This was further strengthened by the fact that in this study some plots containing *Triplochiton scleroxylon* had the silvicultural management practice of weeding and clearing yearly. Weeding involves the removal of other competing vegetation of undergrowth lianas and weeds which hinder the growth of species. Schnitzer [75] indicated that extensive growth of climbers, lianas and other vegetation has been shown in previous studies to hinder regeneration of trees. Over time, the undergrowth of lianas and weeds grows faster than exploitable species which have a slower growth. Weeding thus removes or reduces the competition and hindrance of these undergrowth species for nutrients and light, thereby allowing the species to grow in the light condition created by the gaps. This is thus a limitation of this study as all other plots didn't receive the same treatment for a better comparison. This also calls for a study to determine the unexploitable species that generate naturally during enrichment planting.

In our study growth in the LYs increased over time from the 1<sup>st</sup> to the 10<sup>th</sup> year after enrichment planting (Figure 3). This may be due to the continuous availability of sunlight and enough space for the growth of each and every germinated seedling. The survival rate in the forest was sufficiently high suggesting that their seedling growth conditions in the nursery and then in the forest were appropriate. This is similar to the results of [83] who indicated a survival rate of most species used for enrichment planting three years after especially for the species *Afzelia xylocarpa* who had a survival rate of 95%. In this study, the species *Afzelia pachyloba* had the least mortality of 5.6% after 10 years of enrichment planting in the STs. Similarly, [79] indicated that growth was significant 30 months after enrichment planting in Panama. The growth of the species *Milicia excelsa* only in LYs may be due to the fact that this species is a pioneer species as this species grew from a mean diameter of 9.83 mm/ha  $\pm$  4.3 mm/ha 5 years after logging to 28.0 mm/ha  $\pm$  28.2 mm/ha 10 years after logging. The survival and growth of *Milicia excelsa* has been demonstrated to be higher in forest than in a degraded ecosystem [87]. This was the contrary in the STs where the growth was only prevalent in the first five years after enrichment planting. This may be due to the reduction of the gap created which closes the canopy on the slow growing exploitable species and the fast growth of weeds that are found in the STs. This may be due to the reason why the mortality was highest in STs and survival was highest in LYs in our study. The highest mortality in the species *Aningeria altissima* in LYs is similar to the results of Mokake [20], who indicated that *Aningeria altissima* had the highest mortality under medium light and low moisture condition.

### 4.3. Climate Change Mitigation of Enrichment Planting in the East Region of Cameroon

#### Biomass and Carbon Stock after Enrichment Planting in the East Region of Cameroon

Forest biomass serves as the main indicator for monitoring ecosystems and climate conditions [88], thus its accumulation in tropical forests resulting from reforestation and restoration activities is deemed crucial for climate change mitigation efforts [89]. On average, around 50% of living biomass in global forests is stored within the most significant 1% of living trees [90]. The amount of carbon stored and the potential emissions released from various activities such as logging, clearing, degradation, and land conversion are determined by forest biomass [91]. The process of forest degradation may lead to recovery through natural or assisted regeneration, whereas deforestation entails changes in land use that result in the permanent loss of the forest [92], making knowledge of the biomass after recovery optimal.

It is noteworthy that during the initial 1 - 5 years, the biomass and carbon stock was highest under the forest canopy due to already established seedlings as compared to the LYs and STs that are still trying to acclimatize themselves in the new environment after the nursery. The larger already established trees present under

the forest canopy in comparison to the newly established seedlings in the LYs and STs, have biomass and CO<sub>2</sub> stocked that have been found to be linked to the diameter and height of the trees [93]. Thus the species under the forest canopy had a higher diameter as compared to the LYs and STs for though the canopy had a lesser number of individuals (n = 186 individuals) compared to the LYs (n = 999 individuals), it still had the highest biomass and carbon stock which may have contributed to these results in this study. This may suggest that stem density is not a main factor in biomass and Carbon stock accumulation as other factors could have played a role, like species, site, and age. Taking into consideration that the same species were sampled in all sites at the seedling stage, this means the reason for this variation would be in the diameter and wood density clearly stated in this study. This means the amount of Carbon added by enrichment planting should be dependent on the diameter and wood density. Moreover, the LYs and STs had just been established requiring the species time to acclimatize before growth to accumulate more biomass in these sites. One other reason for the lower biomass and carbon stock in the LYs and STs area may be due to intraspecific competition between the exploitable species since the same species that are planted have the same requirements; hence, resource competition is more intense [94]. This therefore calls for site-specific and species-specific information on which species are to be planted in each forest gap.

This however changed at 5 - 10 years after enrichment planting with more biomass and Carbon stock in the LYs than under the forest canopy. This may be due to the fact that, secondary forests have high rates of biomass productivity, especially during early succession [95]. In fact, secondary forests have been found to have greater potential for Carbon sequestration, and larger Carbon pools, than even primary forests [96] [97]. Ergstrom, [98] indicated that both mean diameter of trees and trees per hectare was higher for restored plots compared to the control plots (under forest canopy) in Malaysia, as an analysis of AGC in relation to year since restoration, also show a positive increasing trend of 1.91 Mg C ha<sup>-1</sup>. These results also support previous findings from [99] which showed that degraded tropical forests that had undergone active restoration treatments recover faster (4.4 Mg C ha<sup>-1</sup>) than natural regenerating forests (2.9 Mg C ha<sup>-1</sup>). Wheeler [100] stated similar results but also concluded that initial recovery of AGC after active restoration might be slow but increases over time. Last but not the least, after enrichment planting, there is usually a rapid increase of weeds, lianas and climbers that grow fast and increase the Carbon stock of the degraded enriched forests. This may be the case with our study although the growth of the understory was not determined in the baseline dataset of 2011. This therefore calls for research studies that take into consideration not only the exploitable species but every other species in the LYs and STs.

Evaluation of the datasets showed that the naturally regenerated seedlings had more importance (IVI) in this study than those that were planted (**Table 2**). Ergstrom [98] indicated that planted seedlings in actively restored plots had a minor

impact on AGC accumulation, contributing only 1.5% ( $1.84 \text{ Mg C ha}^{-1}$ ) of the current AGC in Malaysia. Instead, it is more likely that the maintenance practices performed regularly during a 10 yearly period after planting resulted in increased AGC in already established trees [74] [101] (Schnitzer *et al.* 2000; Schwartz *et al.* 2013). This might be the case of our study where some plots enriched with *Triplochiton scleroxylon* received periodical maintenance practices and thus had the highest biomass 5 and 10 years after enrichment planting. Thus enrichment planting with silvicultural management is necessary for an optimal Carbon storage. However at the establishment of a silvicultural treatment of strip planting about half of the standing C is removed leaving roughly  $25 \text{ Mg ha}^{-1}$  in the remaining stand. Thus, the use of treatment in enrichment planting should be well taken into consideration before implementation. This study presents a picture that fit well with the hypothesis, that severely degraded forests can have difficulties to naturally regenerate especially in the STs where the compactness of the soil and the light reduction drastically reduces the germination and thus growth of species.

The highest biomass in the species *Pterocarpus santalinoides* in the STs may be due to the fact that this species is a late successional species. These species have slower initial growth, higher wood density and are a major contribution to the carbon storage in later stages of forest development [102]. In comparison, planted trees contribute an average of  $0.09 \text{ ton/carbon}$  annually the first 23 years after restoration. Although, for every year that passes, this number will continue to increase as more and more planted trees reach the threshold dbh of  $\geq 10 \text{ cm}$ . As planted trees continue to grow and reach the canopy, an even greater growth is expected. Oclarit, [103] indicated that enrichment planting with the species *Pterocarpus indicus* had a higher biomass than exotic species in the Phillipines. We therefore recommend that this species be used in the STs for enrichment planting. *Triplochiton scleroxylon*, which is an early successional species, is thus recommended for the LYs so that they can grow faster than the fast-growing weeds and form a canopy, as this species had the highest growth in the LYs in our study.

The relationship between biomass, diameter, and time indicated a linear relationship in our study, which is similar to the results of [104], who indicated a linear relationship between the diameter and stand age with biomass of a Dipterocarp species in Indonesia. Xanthopoulos [105] also indicated a linear relationship between biomass and age in an enrichment planting in Greece. Hughes [106] indicated that biomass and Carbon accumulation are positively correlated with time since abandonment. The increase in the Carbon stock and biomass may be due to the age of the forest, similar to the results we obtained in this study. The growth in vegetation age demonstrates a linear correlation with an augmented capacity of vegetation to sequester carbon, eventually reaching an equilibrium state [107].

Forests play a critical role in sequestering carbon dioxide from the atmosphere, a role that is indispensable for mitigating climate change [108]. Forest ecosystems serve as an essential tool in climate change mitigation by absorbing atmospheric

CO<sub>2</sub> and storing it within tree biomass [109]. Our study indicates a higher Carbon stock of 0.004 t/ha, 10 years after enrichment planting. Ergstrom [98] indicated similar results of a positive increasing trend of 1.91 Mg C/ha in degraded tropical forests in Sabah, Malaysia, which is high when compared to our results of 0.004 t/ha. This might be due to the non-implementation of management activities in most of the plots after enrichment planting, creating competition for nutrients with the undergrowth lianas and weeds. Wheeler [100] stated similar results but also concluded that initial recovery of AGC after active restoration might be slow but increases over time. Furthermore, [101] showed that tending naturally established seedlings with liberation, as well as enrichment planting with maintenance, resulted in higher initial growth rates and survival. This calls for further research to be carried out in forest concessions for a longer period of time, with the implementation of silvicultural activities like weeding, as this may be the reason for these differences in the amount of Carbon.

The insignificant difference in some chemical properties of the soil is similar to the results of [76], who indicated that most soil properties were not significantly different between the forest and reclaimed sites after mining in Borneo. Specifically, after enrichment planting, the soil became more acidic, similar to the results of [76] in Borneo. Forest clearing causes a drastic loss of CEC and cations [110], degrading the quality of the soils. However, in our study, the log yards were enriched with soil that was removed during forest clearing; thus increasing the CEC and fertility. Several studies have shown that soil conditions can be improved through the addition of organic matter (e.g., animal manure, crop residues, and organic waste) [111]-[113] as Organic compounds activate the microbial population in the reclaimed soil [111]. This is confirmed in our study by the greater fertility in enriched sites than under the forest canopy.

## 5. Conclusion

Accurate measurement of forest area and carbon stock is essential to comprehensively capture the emissions resulting from forest degradation and their subsequent release into the atmosphere. The growth of trees contributes to the biomass accumulation, leading to increased diameter and growth rates, which in turn augment the carbon sequestration process. The high biomass and the presence of families like the Malvaceae in this study are an indication that enrichment planting stores carbon and changes the forest to the mid successional stage years after enrichment. However, the amount of Carbon stock within 10 years of enrichment planting is low, calling for further research over a longer time span. This study has contributed to the knowledge of the site and species specificity involved in enrichment planting, recommended the study of other species present in the LYs and STs during enrichment planting, and proposed further silvicultural management activities to be implemented during enrichment planting. This is an important first step to developing silvicultural guidelines, and those guidelines are currently lacking to develop strategies for the sustainable management of Central African

forest stands and species.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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