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Natural regeneration of some commercial timber tree species following selective logging in a semi deciduous forest in the east region of Cameroon

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Abstract

A critical step in sustainable forest management is to ensure the establishment and regeneration of seedlings and sapling of exploitable tree species following logging. Since selective logging is one of the main silvicultural practices in Cameroon, a detailed understanding of regeneration following selective logging is vital. This study evaluated the natural regeneration of some commercial timber species in logged and unlogged forest types in two forest management units (FMU) in the East Region of Cameroon (FMU 10052 and 10025). Two transects of 5000 x 50m each were established in logged and unlogged forest types. Eleven commercial tree species were assessed for fruit fall, the number of seedlings established and the height increment of the established seedlings. Three of these commercial tree species fruited in both forest types. Fruit fall was significantly higher ($p \leq 0.001$)in the logged forest (492 fruits/ha)than in the unlogged forest (52 fruits/ha). Comparing species that fruited in both forest types *Klainedoxa gabonensis* recorded the highest number of fruit fall(84 fruits/ha) and least (0.24 fruits/ha) in the logged and unlogged forest types respectively. Seedling establishment was significantly higher ($p \leq 0.001$) in the unlogged forest (404 seedlings/ha) than in the logged forest (72 seedlings /ha). Seedling performance was better in the unlogged forest compared to the logged forest (low mortality rate). Due to the low seedling establishment and performance of these species in the logged forest, seed trees should be marked and protected prior and after logging as prescribed in the sustainable forest management.

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Introduction

A critical step in sustainable forestry is to ensure the establishment and regeneration of the seedlings of tree species following timber harvesting (Fredericksen and Mostacedo, 2000). Post-logging species-level recovery depends on growth and reproduction of surviving adults, juveniles, and seedling regeneration (Smith *et al.,* 1997). Tropical rainforests have high temperatures and predominantly moist environment enabling selected seed traits to achieve mainly the reproductive and dispersal function of the seed (Khurana and Singh, 2001). Native species of the forests are able to sense such environmental conditions simultaneously and confine their germination and emergence to particular periods of the year and habitat locations for successful establishment and survival (Bell *et al.,* 1993).

The cyclical perturbation due to the pronounced seasonality in the tropical forest allows natural seasonal germination and establishment with different consequences for size–age population distribution and community structure (Rincon and Huante, 1993).

According to Tiscar and Linares, (2011), natural regeneration should always be the first management option, because it will let natural selection act on trees that are well adapted to the site, preserve local genotypes and greater structural diversity of the resulting forest after selective logging (Spracklen *et al.,* 2013).

Logged forests have been recognized as an important repository for biodiversity conservation and enhancing the functionality of ecosystems (Pinard and Putz, 1996; Gaveau 2014).

A recent global study concluded that timber extraction in tropical forests has relatively benign impacts on biodiversity, because 85 percent to 100 of the flora and fauna remain in forests that have been harvested once (Deckker and de Graaf 2003; Medjibe *et al.,* 2011; Picard *et al.,* 2012).

However due to the use of heavy machinery and high creaming in large-scale selective logging, its impact could be felt in terms of biodiversity loss, extinction of commercial species and vegetation and soil damage (Asner *et al.,* 2005; Dauber *et al.,* 2005).

Selective logging increases canopy openness (Webb, 1997) through the creation of gaps (Vieira, 1995). This increases the growth of some species especially pioneer and shade intolerant species and germination of seeds stored in the soil seed bank. Canopy gap openness however increases the levels of light, and nutrients and reduces soil moisture in the forest understory (Pacala and Tilma, 1994), limiting seedling growth and survival depending on the shade tolerance of the species.

These changes in canopy openness can thus retard the regeneration of species that are present in seed, seedling and juvenile banks (Fredericksen and Mostacedo, 2000) altering the species composition in the logged forest. Selective logging also causes soil compaction (Frederiksen and Pariona, 2002; Olander *et al.,* 2005), soil disturbance and removal of top soil (Frederiksen and Mostacedo, 2000; Fredericksen and Pariona, 2002), which causes seeds to be stored or removed in the seed bank making the soil seed bank to store seeds that could produce seedlings for several years due to different periods of dormancy (Khurana and Singh, 2001).

Selective logging causes collateral damages to trees and saplings in logged stands (Jackson *et al.,* 2002). The forest understory further modifies resource heterogeneity at the seedling scale (George and Bazzaz, 1999).

The thick undergrowth of lianas, herbs and pioneer trees that usually benefit from high canopy openness, frequently prevent the regeneration of other species especially the slow growing timber species (Fredericksen and Mostacedo, 2000). Understory herbs, ferns, and shrubs thus increase in response to high light availability in canopy gaps and compete with timber tree species seedlings for moisture and nutrients.

The gap formed during logging thus affects the distribution and growth of many species, and since they can favour the regeneration of species of non-commercial value, this may change the composition of the residual forest (Johns, 1997).

Selective logging is one of the main silvicultural practices in Cameroon, and detailed understanding of the dynamics of stand structure regeneration following logging is vital for sustainable forest management. Several studies on regeneration following selective logging have received a lot of attention due to their importance in forest dynamics (Felton *et al.,* 2006; Lobo *et al.,* 2007).

Despite the importance of gab dynamics in regulating ecosystem processes following selective logging, we have little understanding of spatial and temporal characteristics of timber species after canopy openings caused by selective logging in general and in the East region in particular. Also the regeneration of timber species after logging has been evaluated at the community level on the germination, survival and growth rate of juvenile and adult stages in logging gaps (Costa and Magnusson, 2003).

Few studies have followed the demographic dynamics of timber species seedlings after logging (Guariguata and Sa´enz, 2001) which includes establishment, germination, growth and survival of seedlings and saplings. Knowledge on the fruit fall, the number of seedlings established and the height increment of some timber tree species is therefore an effort on the maintenance, augmentation, introduction and re-introduction of timber tree species populations.

This study was therefore designed to assess the natural regeneration of some timber species after selective logging in the East region of Cameroon. We hypothesize that selective logging would improve on the natural regeneration of some timber species after logging. If removal of woody vegetation results in insignificant regeneration, the amount of true seedlings needs to be maintained at a reasonable level by protecting them and/or leaving a number of seed trees after logging.

Materials and methods

Study area

This study was carried out in two logging concessions in the East region of Cameroon. The East region with an area of 109,011 km², stretches between Latitudes 3°49'59Nand longitude 14º10'0E. 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 of Cameroon (Fig. 1).

The soil is predominantly ferrallitic, rich in iron and red in colour (Fitzpatrick, 2002).

The East region has a wet equatorial climate, with a mean temperature of 24˚ C and annual rainfall range of 1500-2000mm except in the extreme East and Northern portions which have less proportion. It has a bimodal rainfall pattern with 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.

The humidity and cloud cover are relatively high and the relative humidity is highest in the month of June (Fitzpatrick, 2002). Each forest concession in Cameroon is made up of a number of Forest Management Units (FMU); which is subsequently divided into Annual Allowable Cuts (AAC) where selective logging is carried out in a specific year. This study was carried out in two FMUs mainly FMU 10052 and FMU 10025. FMU 10052 belonging to concession 1058 covers an area of 70,912 ha situated between latitudes 3°44'28,21" and 4°06'54,95" North and longitudes 14°27'24,84" and 14°48'44,84" East. FMU 10025 belonging to concession 1070 covers an area of 49,595 ha is situated at latitudes 3°55'3,30' North and longitudes 14°45'and 15°00' East (Fig. 1).

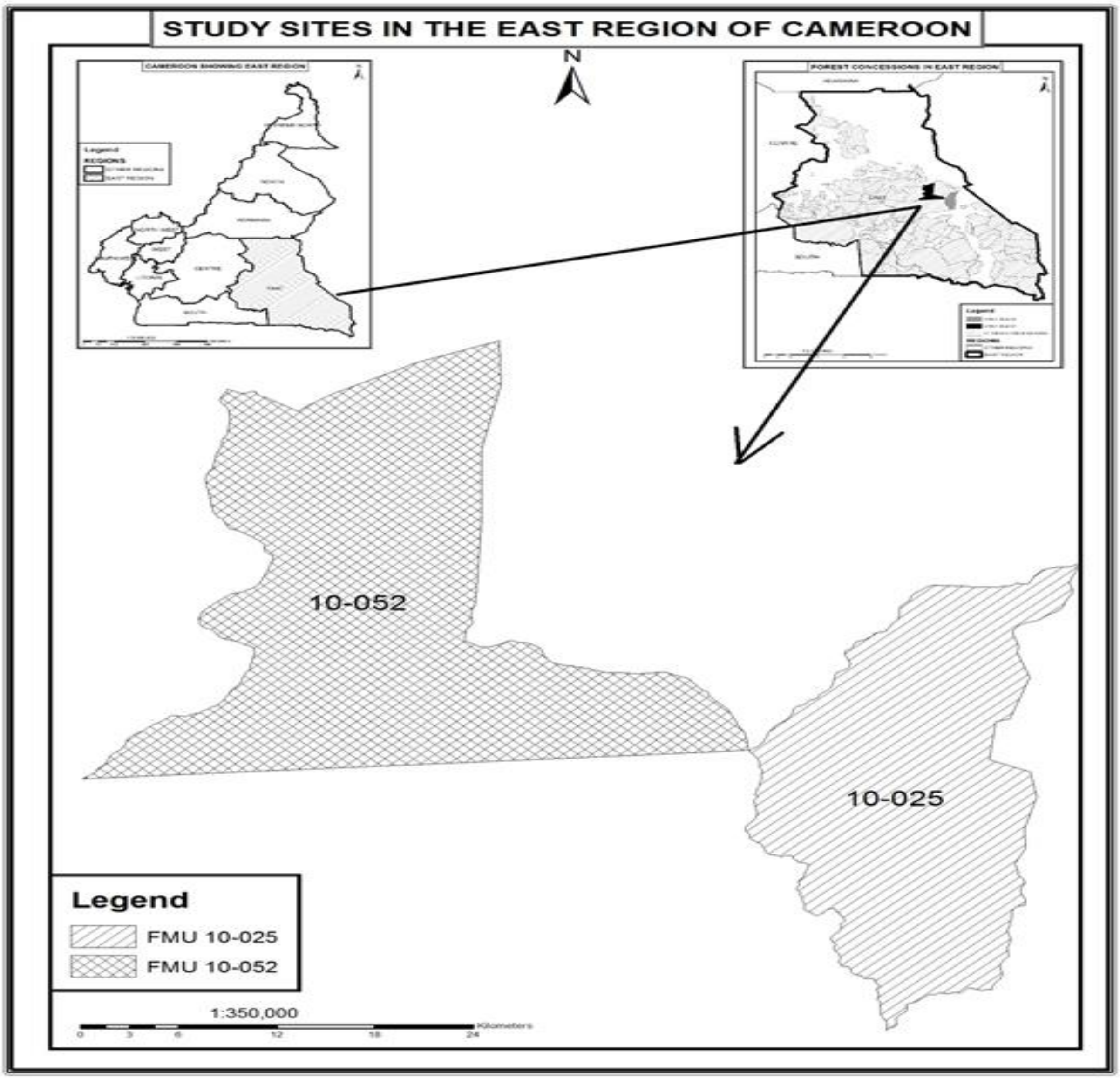

Fig. 1. Localization of the study sites.

Plot selection and establishment

Two plots traversing different Annual Allowable Cuts (AAC) with different characteristics were selected for sampling rom September 2011 to December 2014 for each FMU.Plot1:logged forest with two years' post-logging (exploited in 2010) permitted the assessment of early growth stages (FMU 10052).

Plot 2: unlogged forest (exploited in 2015 after the study period) allowed the monitoring of samples under undisturbed natural conditions (FMU 10025).

In each forest type, a transect of 5000 x 50m was established (Fig. 2a-b).

Three individuals of eleven commercial tree species exploited by the timber company were selected for monitoring at points where the nearest conspecifics were at least 200m apart (Table 1). Semi-permanent transects of 2 x 14m were laid at the four cardinal directions of each selected commercial tree species and further divided into seven 2 x 2m subplots.

The target species were assessed monthly for fruit fall (FF), seedling establishment and performance in the 2x2m quadrats from September 2011 to December 2014. All seedlings of the target species were tagged as well as subsequent recruits during the monthly assessments with different colors for different years.

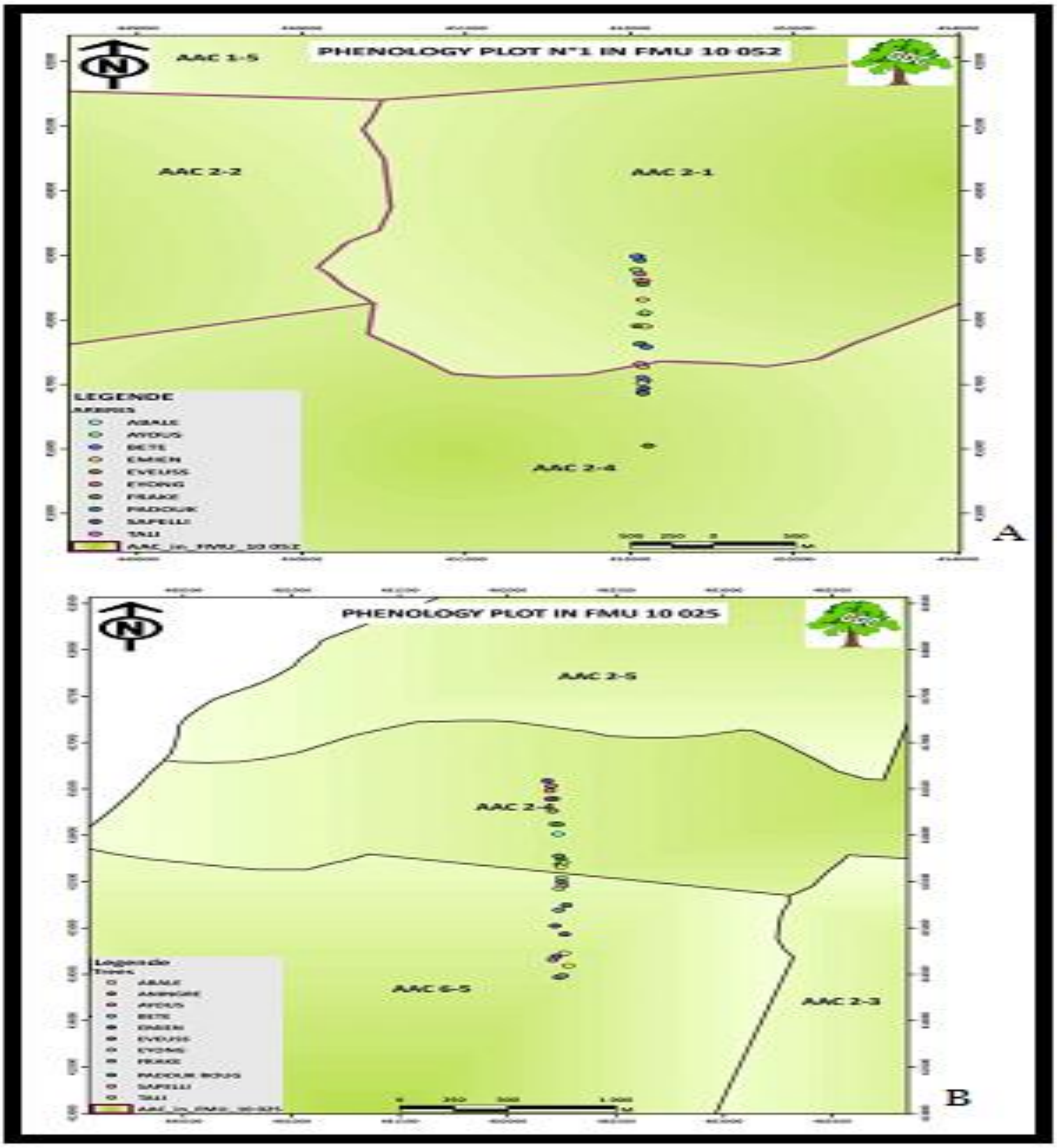

Fig. 2. Localization of individuals of the target tree species in the logged (a) and unlogged (b) forest types respectively East region of Cameroon.

Fruit fall (FF) was estimated by counting the number of whole matured fruits on the forest floor. Reproductive success (RS) was determined as described by Spigler and Chang (2008), which is the total number of seeds produced per plant determined as:

ASs X TNF ....*Equation 1*

Where ASs=Average seed set and is the average number of seeds in the fruit.

TNF= Total number of fruits produced by that species

Seedling establishment was determined by counting all new seedlings found on the forest floor. Seedling performance was evaluated based on growth and mortality. Growth rate based on monthly height measurements was determined according to Hunt, 1982:

$Ln (H_2) - Ln (H_1)/ t_2 - t_1$.................................*Equation 2*

Where t=time and H=height

Seedling mortality was determined for each species and cohort by counting the number of seedlings that died and expressed as percentages.

Data analyses

Counts of fruit fall, seedlings establishment, and seedling performance were compared for species using the Friedman Test. The non-parametric test chi square goodness of fit was used to determine a significant difference across forest types for fruit fall and seedling establishment and performance. A trend analysis was used to predict the height increment of species in logged and unlogged forest types. These analyses were done at $\alpha = 0.05$ using MINITAB Version 17 Statistical Package (Minitab Inc, USA).

Results

Fruit fall

Fruit fall (FF) was significantly higher($p \leq 0.001$) in logged forest than in the unlogged forest with the logged forest having a total of 559 fruits/ha and the unlogged having 54 fruits/ha (Table 2).

The different types of fruits from some species are found in Fig. 3. *Mansonia altissima* (A.Chev.) A. Chev., *Petersianthus macrocarpus* (P. Beauv.) Liben. and *Klainedoxa gabonensis* Pierre. were the only species that fruited in both forest types and *Klainedoxa gabonensis* recorded the highest number of fruits (84 fruits/ha) and the least (2 fruits/ha) in the logged and unlogged forests respectively.

Fruit fall (FF) was significantly different in logged forest ($p \leq 0.001$) though not different in unlogged forest ($p \geq 0.06$) across species. In the logged forest, *Terminalia superba* Engl. and Diels. had the highest total FF (351 fruits/ha) while *Petersianthus macrocarpus* had the lowest FF (15 fruits/ha). Most species did not produce fruits annually with the exception of *Mansonia altissima* (Table 2).

Table 1. Common names of some economic timber species exploited in the East region of Cameroon.

Scientific name	Family	Common name
Triplochyton scleroxylon K.Schum.	Malvaceae	Ayous
Mansonia altissima (A. Chev.) A. Chev.	Sterculiaceae	Bete
Aningeria altissima (A. Chev.) Aubrév and Pellegr.	Sapotaceae	Aningre
Terminalia superba Engl. and Diels.	Combretaceae	Frake
Eribroma oblogum Mast.	Sterculiaceae	Eyong
Entandrophragma cylindricum (Sprague) Sprague.	Meliaceae	Sapelli
Erythropleum sauveolens A.Chev.	Leguminosae	Tali
Petersianthus macrocarpus (P.Beauv.) Liben.	Lecythidaceae	Abale
Klainedoxa gabonensis Pierre.	Irvingiaceae	Eveuss
Alstonia boonei De Wild.	Apocynaceae	Emien
Pterocarpus soyauxii Taub.	Fabaceae	Padouk rouge

Similarly the reproductive success (RS) was higher in logged forest (727 seeds/ha) compared to unlogged forest (46 seeds/ha). Comparing species that fruited in both forest types, *Klainedoxa gabonensis* had higher seed set (252 seeds/ha) in logged plots. In the logged forest, seed set was highest in *Terminalia superba* (351 seeds/ha) and lowest in *Petersianthus macrocarpus* (15 seeds/ha). However in the unlogged forest, *Pterocarpus soyauxii* Taub. had the highest seed set (21 seeds/ha) while *Klainedoxa gabonensis* had the least (5 seeds/ha) (Table 2).

Seedling establishment

Relatively more seedlings were found in the unlogged forest compared to the logged forest (404.4 seedlings/ha and 72 seedlings/ha respectively) ($p \leq 0.001$). The unlogged forest had more surviving seedlings (65 seedlings/ha) than the logged forest after 40 months of observation.

For species that recorded seedlings across forest types, the seedlings of *Mansonia altissima* (10 seedlings/ha) were more abundant in the unlogged forest after 40 months of observation. *Mansonia altissima* had seedlings in both forest types, *Petersianthus macrocarpus* in the logged forest and seedlings of *Klainedoxa gabonensis* lack up in both forest types (Table 3).

The abundance of seedlings varied significantly in logged and unlogged forest types (p ≤ 0.022 and p ≤ 0.014 respectively) for the different species. In the logged forest, *Entandrophragma cylindricum* (Sprague) Sprague. (59 seedlings/ha) had the highest total number of seedlings while *Petersianthus macrocarpus* had the least (0.04 seedlings/ha).

Table 2. Fruit fall (number /ha) of selected timber species from 2011-2014 in the East region of Cameroon. Species.

	Logged							Unlogged						
	2011	2012	2013	2014	TNF	ASs	RS	2011	2012	2013	2014	TNF	ASs	RS
M. altissima	39	2	1	0.2	42	1	42	-	16	4	0.3	20	1	20
T. superba	305	46	-	-	351	1	351	-	-	-	-	-	-	-
E. sauveolens	-	-	67	-	67	1	67	-	-	-	-	-	-	-
P. macrocarpus	15	-	-	-	15	1	15	-	-	-	11	11	1	11
K. gabonensis	29	55	-	-	84	3	252	-	2	-	-	2	3	6
P. soyauxii	-	-	-	-	-	-	-	-	-	-	21	21	1	21
Totals	388	103	68	0.2	559.2		727	-	18	4	32.3	54		58

'-' = no activity.

In the unlogged forest, the highest total number of seedlings were found in *Aningeria altissima*(A. Chev.) Aubrév and Pellegr. (372 seedlings/ha) while the least was in *Triplochyton scleroxylon* (0.4 seedlings/ha). Not all species recorded seedlings annually except *Aningeria altissima* that produced seedlings from 2012-2014 (Table 3).

Table 3. Seedling establishment (seedling/ha) in logged and unlogged forest types in the East region of Cameroon.

	Logged					Unlogged				
Species	2011	2012	2013	2014	Totals	2011	2012	2013	2014	Totals
T. scleroxylon	-	-	-	-	-	-	-	-	0.4	0.4
M. altissima	-	-	2	-	2	-	8	10	10	28
A. altissima	-	-	-	-	-	-	45	272	55	372
T. superba	-	2.6	0.04	-	3	-	-	-	-	-
E. cylindricum	-	55	4	-	59	-	-	-	-	-
P. macrocarpus	0.04	-	-	-	0.04	-	-	-	-	-
P. soyauxii	3.2	5	0.2	-	8.4	-	2	2	-	4
Totals	3.2	62.6	6.2	-	72	-	55	284	65.4	404.4

Entandrophragma cylindricum did not produce fruits in any of the forest types but hadseedlings in the logged forest. *Pterocarpus soyauxii* produced fruits only in the unlogged forest but had seedlings in both forest types.

Seedling performance

Height increment

The net change in height was significantly higher in the logged forest than in the unlogged forest (p≤0.001) (123cm and 39cm respectively).

Table 4. Net change in height of seedlings in each forest types in the East region of Cameroon.

Logged				
Species	Initial Height (cm)	Final Height (cm)	Net Change	AGR (cm/yr.)
Entandrophragma cylindricum	40	65	25	0.3
Mansonia altissima	30	56	26	0.4
Terminalia superba	9	38	29	1.2
Pterocarpus soyauxii	7	75	68	1.1
Unlogged				
Species	Initial Height (cm)	Final Height (cm)	Net Change	
Pterocarpus soyauxii	28	37	9	0.2
Mansonia altissima	31	35	4	0.1
Aningeria altissima	43	68	25	0.1

“= no activity.

In the logged forest, *Pterocarpus soyauxii* had the highest (68 cm) while *Entandrophragma cylindricum* had the least (25 cm) net change in height. In the unlogged forest, *Aningeria altissima* had the highest (25 cm) while *Mansonia altissima* had the least (4 cm) net change in height (Table 4).

A trend analysis indicated a higher mean height increment of species in the unlogged forest compared to those in the logged forest. *Mansonia altissima* that produced seedlings in both forest types indicated the same pattern (Fig. 4 and 5).

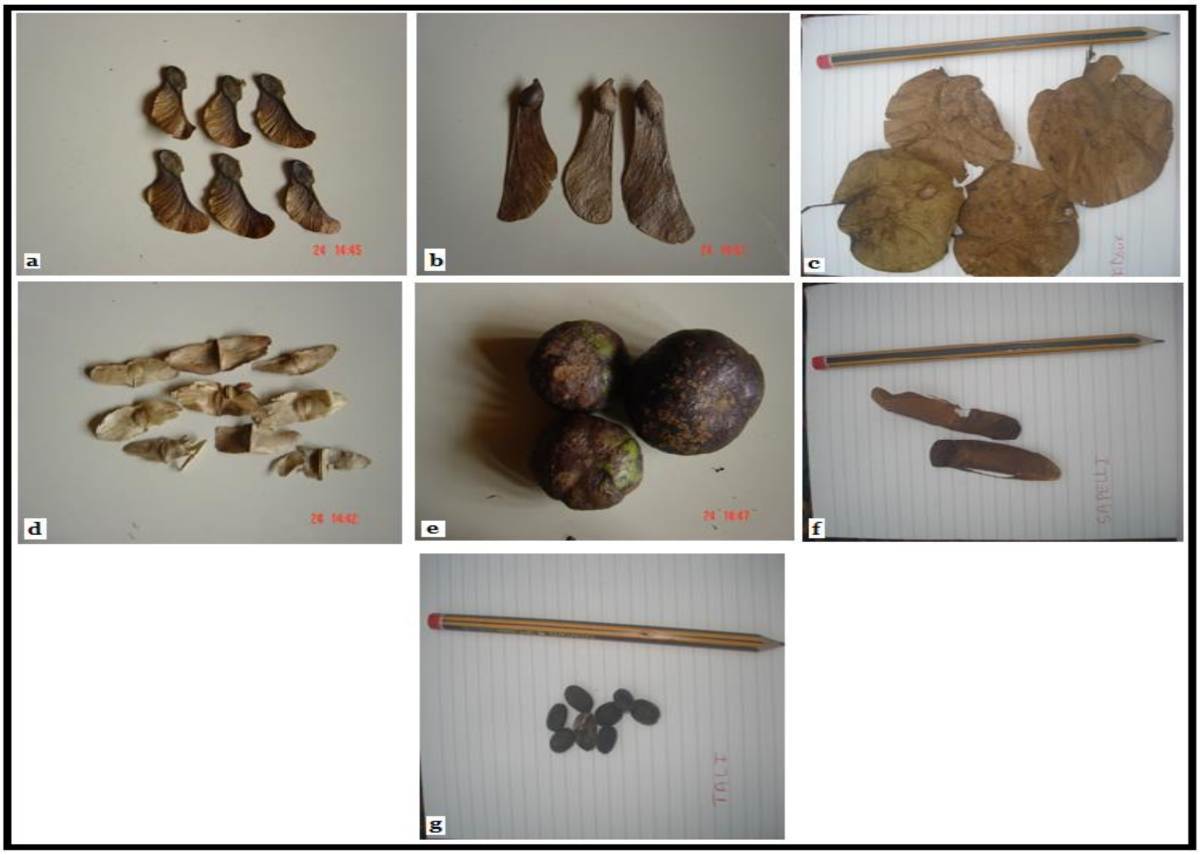

Fig. 3. Fruits of a= *Triplochyton scleroxylon*, b= *Mansonia altissima*, c= *Pterocarpus soyauxii*, d= *Terminalia superba*, e= *Klainedoxa gabonensis*, f= *Entandrophragma cylindricum*, g= *Erythropleum ivorense* found on the forest floor in East region of Cameroon.

Conversely the growth rate was higher in logged forest (0.7cm/yr.) than in unlogged forest (0.12cm/yr.). *Mansonia altissima* had a higher growth rate in the logged forest (0.4cm/yr.) than in the unlogged forest (0.1cm/yr.). In the unlogged forest, height increment was highest in *Pterocarpus soyauxii* (0.2 cm/yr.) and least in *Mansonia altissima* (0.1 cm/yr.). In the logged forest, *Terminalia superba* (1.2cm/yr.) had the highest height increment and least in *Entandrophragma cylindricum* (0.3cm/yr.) (Table 4).

Mortality

Mortality was higher in the logged forest (34 %/yr.) compared to the unlogged forest (28 %/yr.). In the logged forest, *Entandrophragma cylindricum* had the highest mortality of 50 %/yr. while *Petersianthus macrocarpus* had the least of 25 %/yr.

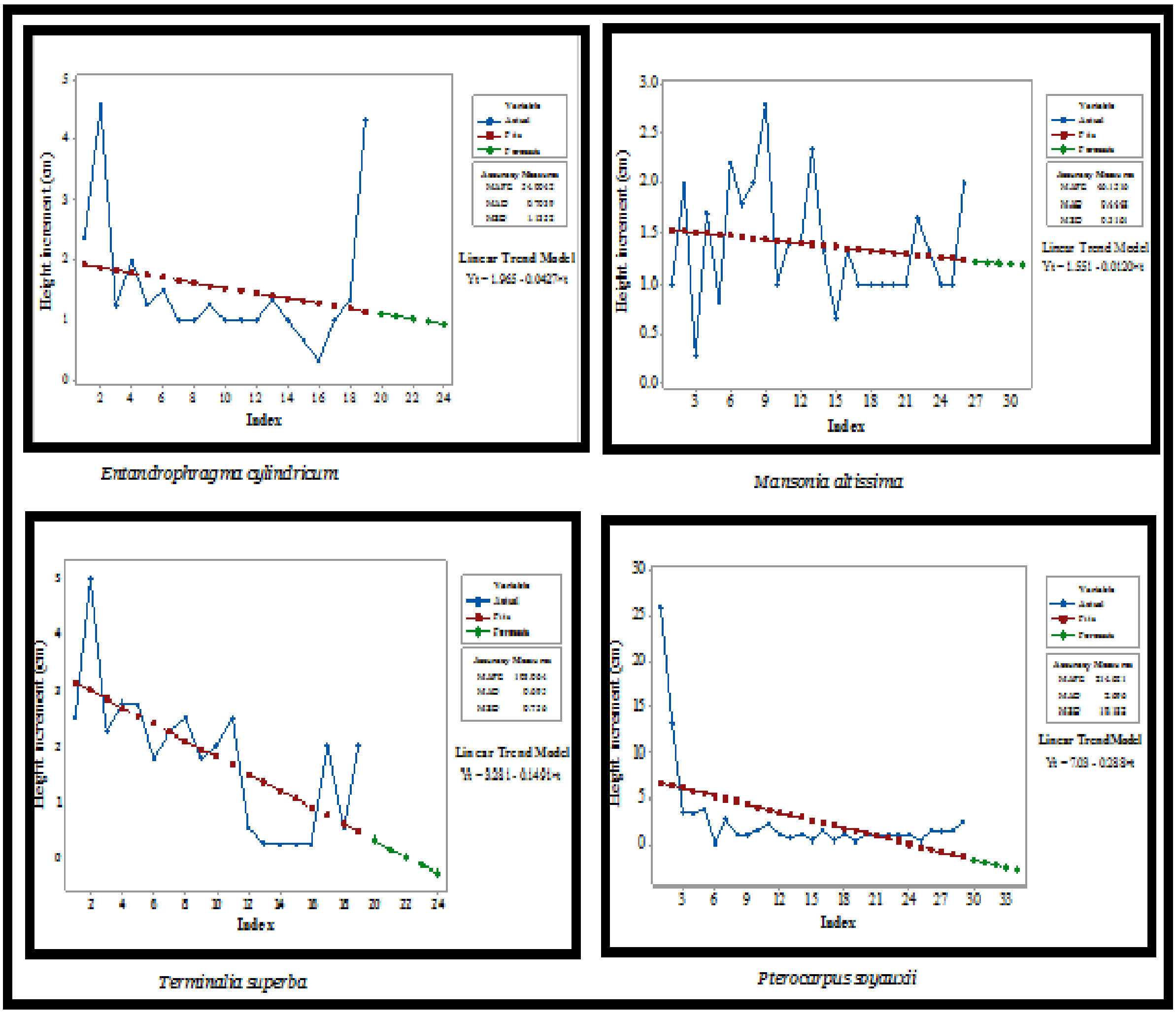

Fig. 4. Trend analysis of species in the logged forest in the East region of Cameroon.

In the unlogged forest, mortality was highest in *Mansonia altissima* (37 %/yr.) and least in *Aningeria altissima* (22 %/yr.) (Fig. 6a and b). *Mansonia altissima*; the only species that had seedlings in both forest types, lost more seedlings in the logged than the unlogged forest (35%/yr. and 37%/yr. respectively). Taking into consideration the different cohorts, in the logged forest, mortality was highest in the third cohort (2014) whereas in the unlogged forest, mortality was highest in the first cohort (2012).

Over time, mortality was highest in 2014 in both forest types (Fig. 7a and b).

Discussion

Forest recovery after anthropogenic activities, such as logging, depends on the severity of the disturbance. Changes in light and shade levels of the understory are due to openings in the forest canopy which may be due to branch fall, tree fall, or selective logging (Chazdon *et al.,* 1996). Logging does not necessarily mimic natural disturbances and these effects need to be examined in order to determine changes brought about by natural or anthropogenic causes.

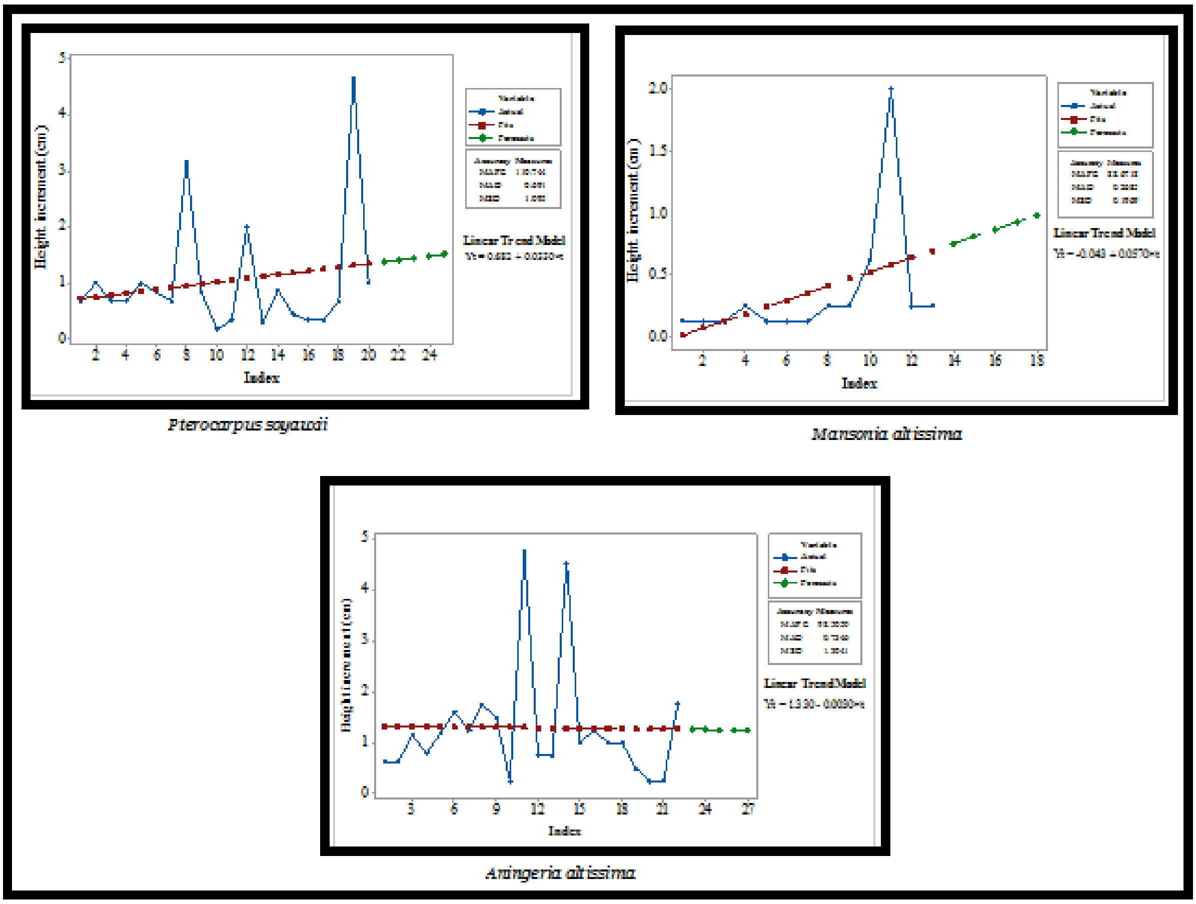

Fig. 5. Trend analysis of species in the unlogged forest in the East region of Cameroon.

Fruit fall

A higher fruit fall in the logged forest might be due to the presence of large individual trees including seed trees left after logging which have reached the fruiting size/age. This is similar to results obtained by Grogan and Galva˜o, (2006) who reported that fruit production in *Swietennia macrophylla* depended on a few individuals of the largest diameter categories. Species like *Klainedoxa gabonensis* are usually left standing during logging due to the hardness of the wood thus increasing fruit production (Oteng-Amoako, 2012); reason why it produced the highest number of fruits across forest types.If the Minimum Cutting Diameter (MCD) in each AAC is respected, there is the possibility of still finding tree species that are producing seeds. This is an indication of a sustainable management of the forest. This also corroborates the results obtained by Guariguata and Sa´enz, (2001) who studied the mast-fruiting year of *Quercus costarricensis*, indicating that fruit production within logged treatments was higher than in adjacent unlogged treatments. Also increase in the light intensity in the logged forest due to canopy openness (Webb, 1997) causes increased growth in forest tree species (Fredericksen and Mostacedo, 2000). The unlogged forest on the other had large individuals as well but most of the species might not be fruiting during the study period taking into consideration that forest species usually go through a long periods without fruiting. Fruit production in

Swietennia macrophylla depended on a few individuals of the largest diameter categoriesin certain years (Grogan and Galva˜o, (2006). After logging, the remaining flowers which were exposed, promote pollination and thus fruit production.

However in the unlogged forest, the canopy layer decreases the visibility of these flowers to pollinators and subsequently reduction in the production of fruits. A high fruit fall of *Terminalia superba* in the logged forest might be due to the small fruit size and wind dispersed nature of the species.

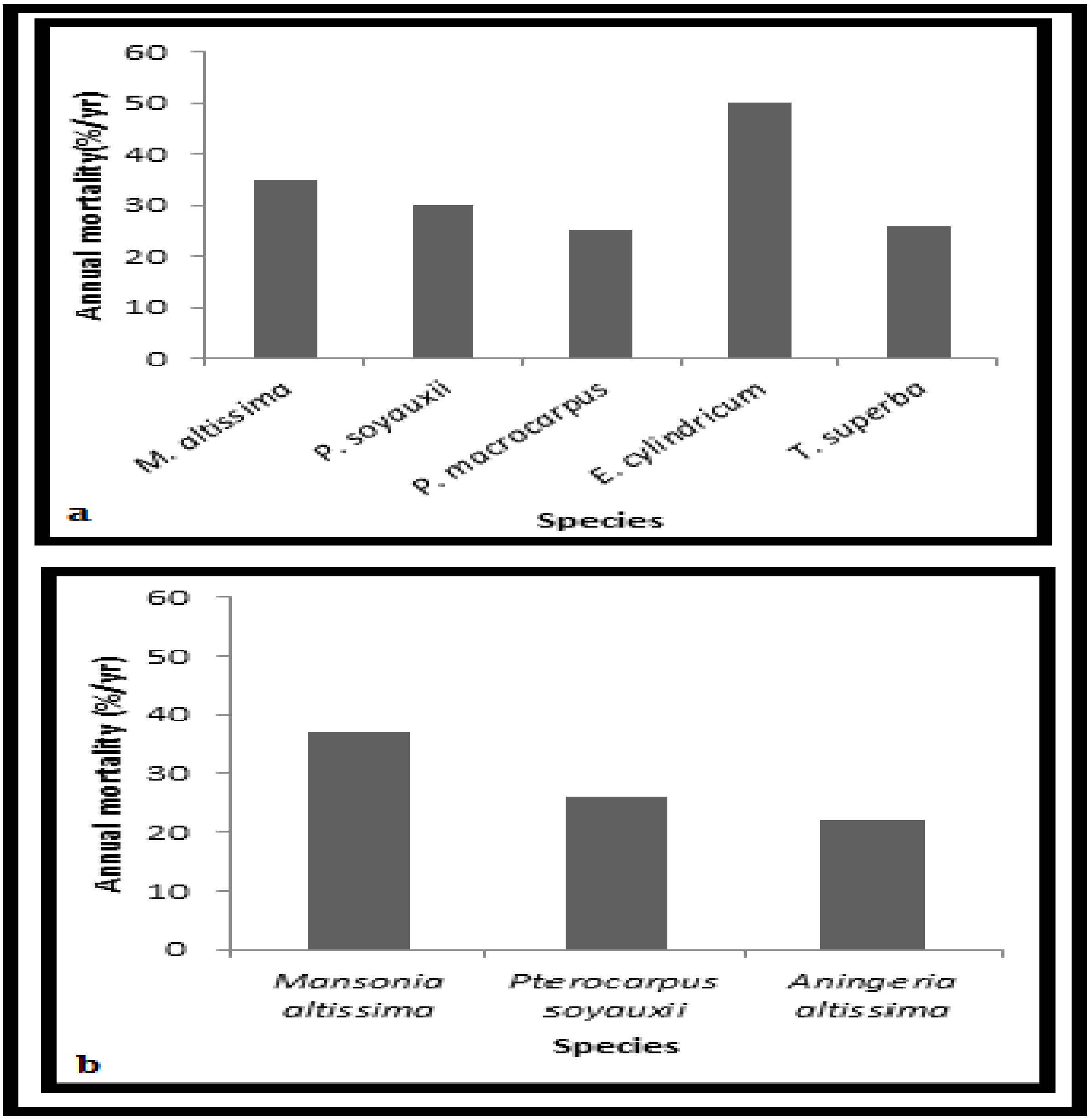

Fig. 6. Mortality across species in logged (a) and unlogged (b) forest type in the East region of Cameroon.

There are high winds in the logged forests causing small and wind dispersed seeds to fall. This might therefore be a strategy to ensure that their seeds find suitable sites for germination, ensuring their regeneration.

A higher reproductive success in *Klainedoxa gabonensis* is due to the large individuals usually left standing after logging (Oteng-Amoako, 2012). This species also has an average of three seeds per fruit and a hard seed coat increasing its resistance against predators and seed rot caused by diseases. This also increases its dormancy in the soil seed bank after compaction in the soil by selected logging.

Seedling establishment

The unlogged forest had a higher abundance of seedlings than the logged forest after 40 months of observation. Soil compaction and the removal of top soil have been shown to occur during mechanized logging (Fredericksen and Pariona, 2002) reducing the number of seedlings and sapling populations in logged forest. Gaps formation like tree fall or defoliation allows light intensity that favours the growth of seedlings in the forest floor. In selectively logged sites the high light quality is not of optimal quality for seedling establishment. Williamson and Ickes, (2002) indicated that droughts that causes defoliation and mortality of canopy trees, provide a favourable environment for seedling recruitment by improving light conditions in the unlogged forest floor. In tropical forests there is a high soil cover in logged forests than in unlogged forests reaching 81% in unlogged and 95-99 % in logged forests respectively as reported by Frederiksen and Mostacedo, (2000) and Vieira and Scariot, (2008) in a Bolivian forest. This may lead to a high herbaceous and shrub cover preventing tree regeneration of pioneer species after canopy disturbance. Lianas and climbers for example can dominate canopy gaps and prevent succession for years even in tropical moist forests (Vieira and Scariot, 2008). This is similar to the results obtained by Xue *et al.,* (2014) who investigated on the regeneration of seedlings in different recovery stages of *Quercus variabilis*and indicated that seedlings were predominant in the unlogged sites. This might be the reason why although the logged forest recorded seedlings in the final cohort, none survived at the end of 40 months of observation. Lobo *et al.,* (2007) indicated that selective logging negatively affects the abundance of seedlings of *C. costaricense* and *P. purpurea* in areas subject to forest management like selective logging and the effect was still noticeable 4–5 years after logging. Lemmens, 2007 also indicated that research in Uganda showed that large-scale logging operations in the forest negatively influence regeneration.

Moreover, high seed predation by small animals and seed rot caused by disease in the logged stand also reduced the available seeds in the soil seed bank, as observed by Ma *et al.,* (2010), who investigated a Chinese cork oak forest in Qinling Mountains. They reported that soil drought stress caused by loss of overstorey trees may result in low seed germination rate or high sapling mortality for Chinese cork oak in logged stand or forest gap. This is consistent with previous reports indicating that logged treatments experienced reduced recruitment to unlogged treatments in the first 31 years after logging (Bonnell *et al.,* 2011, Osazuwa-Peters 2015).

The highest number of seedlings in *Aningeria altissima* in the unlogged forest might be due to the fact that the fruits of this species are food for primates (Houle *et al.,* 2010) thus easily liable to predation through vertebrate mammal which in turn aid in its dispersal and regeneration as it passes through its gut. Also, these fruits are berries which limits its distribution to only around the parent plant. Small seeds have a better chance to enter into the soil easily than large seeds and therefore, would favour the buildup of persistent soil seed bank, crucial for regeneration of species following disturbance (Khurana and Singh, 2001). Finally these species are non-pioneer light demanders which are usually abundant around the parent tree. The fact that *Mansonia altissima* produced more seedlings in the unlogged than the logged forest type whereas the logged forest had more fruits than the unlogged forest is an indication of the effects of selective logging on forest dynamics. During selective logging, the use of heavy machinery causes the soil to be compact storing the seeds in the seed soil bank. There is also a high proportion of primates in tropical rainforests. A large proportion of rainforest trees produce fruits that are attractive to mammals and birds (Richards, 1996). Plumptre and Reynolds, (1994) reported that primate food trees appeared to be more affected by exploitation. This confirms why we observed more damaged fruits in the logged plot. The capability of seed dispersal and predation bestowed upon mammals has a role in the regeneration of tropical forests (Brewer and Rejmanek, 1999). According to van Roosmalen (1985), 87-90% of the woody species in the high forest of Guianas are animal-dispersed. Most of these species produce fruits that are fed by primates.

Also in logged forests these fruits become more visible to the primates and insects for damage. Most of these fruits are light and wind dispersed thus they can easily be carried by ants and wind to different locations.

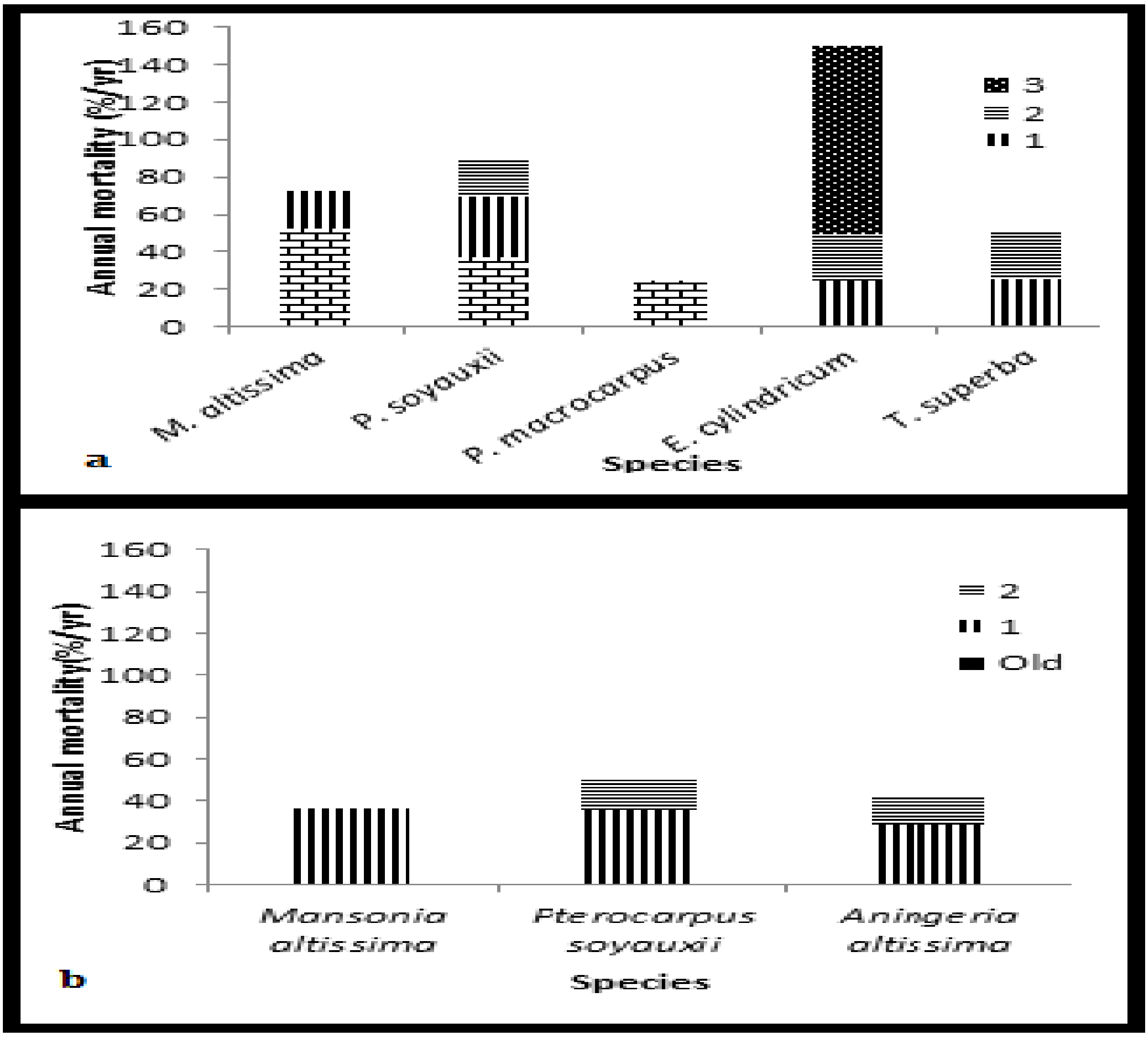

Fig. 7. Annualized mortality (%/yr.) for seeded species in both logged (a) and unlogged (b) forest types in the East region of Cameroon.

Klainedoxa gabonensis produced fruits but did not produce seedlings in both forest types and *Petersianthus macrocarpus* did not produce fruits in logged but had seedlings in both forest types goes to indicate the effect of the soil seed bank in the natural regeneration of timber species.

Also *Entandrophragma cylindricum* and *Pterocarpus soyauxii* did not produce fruits in the logged plot but had seedlings: an indication of the presence of seeds in the soil seed bank which will germinate when there is an opening in the forest canopy.

*Klainedoxa gabonensis*has a large seed with a thick seed coat which might cause it to be dormant in the soil seed bank for years preventing its dispersal and germination. In wind, water and animal-dispersed species, the dispersal efficiency decreases with seed mass (Ganeshaiah and Uma Shaanker, 1991).

Seedling performance

The reason why the unlogged forest had a higher height increment than the logged forest might be due to the simple fact that there were some species that are shade tolerant and do better in the understory.

Seedlings of certain Caribbean dry forest elements survived only in shaded treatments compared to open condition (Vieira and Scariot, 2008). Ma *et al.,* (2010) and Xue *et al.,* (2014) indicated that herbivores and drought stress after logging can lower the mean height of true seedlings. Logged site have a higher incidence of vertebrates and invertebrates that can cause shoot dieback resulting in lower heights (Ky-Dembele *et al.,* 2007). Also the high above ground biomass and undergrowth of herbs, shrubs and lianas after logging might have decreased the amount of light intensity and increase competition for nutrients and light resources therefore reducing the growth rates of pioneer seedlings. Although many liana species for example can persist under shade in mature forests, the diversity of lianas is often greatest in gaps and disturbed forests (Schnitzer and Bongers, 2002). High light intensity reduces the amount of soil moisture consequently less water will be available to the species for growth. 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). However the logged forest had a higher growth rate and net change in height compared to the unlogged forest. After logging, there is usually a high supply of water and increased light intensity available to the plants leading to their fast growth. This however depends on the shade tolerance of the species. Rincon and Huante, (1993) indicated that species associated with undisturbed habitats (dense shade), such as *Amphipterygium adstringens* and *Caesalpinia eriostachys*, showed a smaller increase in relative growth rate with an increase in light levels.

Aningeria altissima had the best growth in the unlogged forest indicating its tolerance to shade and the fact that it's a non-pioneer species (Kiama and Kiyiapi, 2001). However across forest types *Petersianthus macrocarpus* had the highest mean height in logged forest indicating that it's a shade intolerant species that would do better after canopy openness. Conversely, the high growth rate of *Pterocarpus soyauxii* and *Terminalia superba* in the unlogged and logged forest types respectively, may be due to the high antifungal and high ascorbic acid content of *Pterocarpus soyauxii* and the fact that *Terminalia superba* is a light demanding species mostly found in disturbed sites. The low growth rate of *Mansonia altissima* in unlogged forest indicates the shade intolerance of the species and its high number of leaves. The low growth rate of *Entandrophragma cylindricum* in the logged plot might be due to the fact that the species generally has a high mortality rate in the natural habitat and its shade tolerant.

Mortality being highest in the logged forest and least in the unlogged forest clearly indicates the effects of selective logging on seedling regeneration. Mechanical damage usually causes soil compaction and disturbance which impedes the survivorship of seedlings in logged plots thereby increasing its mortality. Also logging depletes the soil nutrients and reduces moisture which in turn leads to death of seedlings that depended on nutrient from the soil for survival. This goes further to indicate that some of the species were non-pioneer shade bearers that establish and grow in shade: reason why *Aningeria altissima* had the highest number of seedlings in the unlogged forest. The high survival versus rapid growth trade-off may act as a habitat partitioning mechanism by enabling tree species with high survival rates to persist in the forest understory and thus to have an initial size advantage when a tree fall creates a canopy gap, and by promoting species with high growth rates in larger gaps where sustained growth rates may be more important than initial size in determining success in reaching the canopy (Leigh *et al.,* 2004). This is contrary to the results observed by Ne Win *et al.,* 2012 in the Kabaung Reserved Forest, Myanmar and Duah-Gyamfi *et al.,* 2012 in a topical moist semi-deciduous forest in Ghana. High seedling densities are detrimental in some cases because they will attract predators or pathogens and lead to higher mortalities (Augspurger and Kelley, 1984). The highest mortality in 2014 might also be due to the fast growth of undergrowth herbs, shrubs and lianas and the general change of microclimate after logging.

The increase in light intensity after selective logging impedes the growth and survivorship of commercial seedlings. Although the increase in gap openings also increases the amount of light for plant growth, the quality of light might not be good for the regeneration of seedlings found on the forest floor. Also the intensity of the light in logged sites is high leading to increase evaporation of soil moisture and nutrients in logged plots. Curran and Webb, 2000; and Delissio, 2000 indicated that seedling mortality rates tend to be high initially, decreasing over 3-4 years.

Conclusion

This study reveals that selective logging has an influence on the natural regeneration of the forest in the East region of Cameroon. Though the logged forest recorded more fruits, the logged forest had more seedlings established at the end of 40 months of observation. Also though the net change in height and the growth ratewas higher in the logged forest, the height increment was higher in the unlogged forest. Finally mortality was higher in higher in the logged than in the unlogged forest type making the seedling performance better in the unlogged than in the logged forest type. In the logged forest type, most of the recorded fruits were mostly damaged or eaten by predators which are more abundant in exploited areas. The few fruits that survived or that were buried in the soil seed bank produced seedlings that had high mortality rates due to the high light intensity of the gap openings. Soil compaction and reduced moisture caused after selective logging reduces the ability of seeds found in the soil bank to regenerate overemphasizes the effects of selective logging of the natural regeneration of timber species. The rapid growth of the undergrowth shrubs and lianas in the logged plot out competes the slow growing timber species leading to a high mortality of the timber seedlings. Thus activities that are specifically designed to decrease the amount of light and control competing vegetation are necessary for logged sites to promote the natural regeneration of timber species after selective logging benefiting their long term development and consistency. From the perspective of maintaining sufficient genetic variation in selectively logged stands, the amount of true seedlings should be maintained at a reasonable level by protecting seedlings. Thus the most fecund individuals who are usually the larger individuals in a population should be identified and retained to restock areas where natural regeneration fails. Due to the low seedling establishment of these species in the logged forest, seed trees should be marked and protected prior and after logging as prescribed in the sustainable forest management. Enrichment planting should also be encouraged in order to improve on the commercial species diversity in logged forests.

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