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Response of *Pericopsis elata* (Harms) Meeuwen to sylvicultural treatments in some forest plantations of Cameroon

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Abstract

A study for analysing the response of *Pericopsis elata* on sylvicultural treatment consisting of pruning was conducted in abandoned plantations settled between 1972 and 1975 in the East and South regions of Cameroon. Inventory was conducted in two phases: phase I from 12th April to 13th June 2009 before the first sylvicultural treatment occurred in September 2009 and phase II, six years later from 3rd January to 25th March 2015 before the second sylvicultural treatment done in May 2015. During each inventory campaign, tree quality and diameter at breast high were appreciated and measured, with the aim to examine the effect of pruning on *Pericopsis elata*. The first pruning done in 2009 improved the quality and diameter growth rates of trees. The average percentage of winding trees dropped from 82.8% in 2009 to 44.1% in 2015. The most important average diameters are observed in the pruned plots (27 ±10.47 cm - 31 ±10.04 cm). These plots gained at least 6 cm in diameter in 6 years, which is trice compared to the 2 cm observed in the non pruned plots. The evolution of the growth rates is going to the same sense. The highest growth rates were observed in pruned plots, moving from 0.67 cm/year in 2009 to 0.74 cm/year in 2015 in P 73 and from 0.62 cm/year in 2009 to 0.68 cm/year in 2015 in P 75. The non pruned plots in the other hand registered a decrease in annual growth rates, which dropped from 0.60 cm/year to 0.56 cm/year in the two plots (P745 and P746). These results can be justified by the pruning which eliminated small trees. To better appreciate the effect of the pruning, we limited the analysis on the specific period of 6 years (2009-2015) and on the same trees. Pruned plots have gain at least 6 m²/ha in the stand basal area against 1 m²/ha for non pruned plots. The average annual growth rate in diameter is 0.45 cm/year in pruned plots against 0.34 cm/year in non pruned plots in the same period. These results illustrate the positive effect of the pruning on the development of *Pericopsis elata*. Results obtained tend to show that the diameter annual growth rate varies not only with the age of plantation, but also with other parameters such as the site, the planting method, and probably the sylvicultural treatment. This suggests that the diameter annual growth rate, which is an important parameter, used in the calculation of the reconstitution rate of *Pericopsis elata*, should be measured and carefully refined for each production site.

Key words: *Pericopsis elata*, CITES, sylvicultural treatment, pruning, annual growth rate, bump, winding.

Introduction

Cameroon is vast of 47. 565 millions of hectares and is located in Central Africa. It is often considered as Africa in miniature due to the presence of various types of ecosystems and climates within its frontiers. The forest area of Cameroon covers 22 millions of hectares (MINFOF 2016).

Cameroon vegetation is composed of two main groups including the humid forests in the southern zone and the Sudanian and sahelian savannah in the northern area. The zoning plan of the southern area (phases 1-4 of national inventory) led to division of the forest zone in two main domain types, namely the permanent domain (53.5%) and the non-permanent domain (46.5%). The non-permanent domain comprises the community forests, sales of standing volume (small forest concessions of not more than 2,500 ha), and mining zones. It is also composed of lands affected for agricultural and other agroforestry activities. The permanent domain is divided into the domanial or state forests which belong to the State, and communal forests which belong to the private domain of the council. The states forests are themselves divided into production forests, protected areas, and forest reserves. All state forests are supposed to be rigorously managed in the frame of management plans.

When someone is talking about management plans in Cameroon, he is thinking first to natural production forests composed mainly of forest management units (FMUs), and secondly to protected areas composed mainly of national parks and faunal reserves. Management plans of forest reserves or forest plantations are not accounted. No concrete effort has been made by the Cameroonian government regarding the elaboration and implementation of management plans of forest reserves/forest plantations.

In the framework of its reforestation and regeneration policy, the Cameroonian government has created many forest plantations in different agro-ecological zones. Within these plantations, silvicultural experiments on high-value timber species are being conducted. In total 35 800 ha of forest plantations were installed in the country, distributed as follows: 4 100 ha in dry savannah areas, 8 700 ha in humid savannah areas, and 23 000 ha in forest zone (MINEF 1995). For various reasons, these forestry plantations put in place were abandoned for over 20 years. All those plantations were settled without any management plan and many of them have been invaded by local populations.

Pericopsis elata is semi gregarious to gregarious tree and uses to grow on flat ground, valleys and slopes. In the Congo Basin, *P. elata* is a high-value furniture wood with excellent commercial potentials since it offers many technological options. It is used in, maritime constructions, flooring, veneer, furniture, and joinery. These different uses have contributed to its increasing demand in the wood mark. *P. elata* is classified by the World Alliance for Nature (IUCN) as endangered species, which led to its listing in the Appendix II of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES). As it is, the species is indeed endangered and has become all but locally extinct in some countries where the exploitation and international trade in this species had begun some 55 years ago. Significant stocks of the species still exist, however, in the Congo Basin, including Cameroon, Central African Republic (CAR), Democratic Republic of Congo (DRC), and Republic of Congo.

P. elata constitutes part of the timber wood whose silviculture has been tested in Cameroon. This species was introduced in three forestry stations, namely Makak (Beng-Nyong), Kumba, Mbalmayo (Bilik) in the national school of Forestry (ENEF), in Ndeng ndeng forestry reserve (Ke´be´ block) and in the Kienke south forestry reserve (Bidou II block) (Grison 1979; Engbwem 1988). These silvicultural plots had as objectives to search the best plantation density for this species. But it happened that the experiment sites were out of the natural milieu of this species and irregularity in the survey of the plantations hindered the collection of necessary data to explain the silviculture of this woody species. Some of the plantations like that of Bilik and Kumba did undergo illegal cutting and high land tenure pressure for urbanization and extension of farmer's fields. These external pressures have considerably reduced the total surface area planted initially estimated at 14 ha (Ngueguim et al. 2012).

The CITES Secretariat realized the challenges that range states of the CITES listing species face implementation of CITES requirements and it has teamed up with the International Tropical Timber Organization (ITTO) to help build capacities at the country level and promote the sustainable management of tropical forests including these species. This partnership in the frame of the so called "the ITTO-CITES program" has been strengthened considerably and is currently funding national activities to assist non-detriment findings (NDFs) by developing inventory, management and silvicultural plans, setting up tracking systems, providing training, and developing training and working material. Since 2008, under the ITTO-CITES Program, ITTO has, in consultation with the CITES Secretariat, funded 25 Activities (projects) in Africa distributed as follows: Cameroon (9 activities), Congo-Brazzaville (5), Democratic Republic of Congo (5), Ghana (2) and four activities at regional level. When the program started in 2008, *Pericopsis elata* was included in the process of the significant trade review (STR), with the lack of NDFs and management plans being the core problem for range countries in the Congo Basin (CITES 2003, Dickson et al. 2005). The assistance of the ITTO-CITES Program to date in Cameroon on *P. elata* has focused on the development of non-detriment findings for natural stands and simple management plans and resource inventories for plantation forests. The activity, "management of *Pericopsis elata* in forest plantation in Cameroon" funded in the frame of this program allowed the National Forestry Development Agency (ANAFOR), the CITES Scientific authority of Cameroon, to dress and start implementing the first management plan of a forest plantation in Cameroon.

The management plan was dressed for the Bidou II forest plantation, located in the Kienké South forest reserve for a period of 10 years, to be reviewed at the fifth year. The document of the management plan declined five measures including: (1) the conservation of the *Pericopsis* wood through careful and selective pruning, (2) the production of seedlings for the creation of new forest plantations, (3) the improvement of the

wellbeing of local populations, (4) the conservation of biodiversity for carbon storage, and (5) the realization of research (Tchatat 2009). The first measure implemented was the careful and selective pruning of trees, which occurred by the end 2009. The Bidou II plantation was pruned in September 2009 as recommended in the simple management plan. Results related to the growth and productivity of these plantations before sylvicultural interventions have already been published in 2012 (Ngueguim et al. 2012). This paper presents the response of *Pericopsis elata* upon the first selective pruning in term of quality of trees, growth, and stand basal area.

Materials and methods

Biological traits and ecology of *Pericopsis elata*

Pericopsis elata is a leguminous species of the Fabaceae family, normally known as Afromosia or Assamela. Assamela wood can be substituted with Teck which has similar properties; this is why it is often referred to as African Teck. *Pericopsis elata* is a semi-gregarious species; its tree can reach a height of 20 m with a diameter of 130 cm measured from the breast level (dbh). The trunk is often twisted and irregular especially for the young trees. Trees attaining large diameters of more than 100 cm often have internal hollowed cavities or are corroded inside and often attacked by gummosis (Vivien and Faure 1985; Ngueguim 2007). The bark of *P. elata* is characterized by its brown color and red spots with a thickness of 1 to 1.5 cm for mature trees. *P. elata* trees flower annually or every two years during the short rainy season (March–April) and fructification occurs between May and June. Sometimes, one can observe a late fructification during the months of September–October. Seeds from the pods of this second fruiting are infertile. Each pod is generally oblong containing 1–4 flat grains with a diameter of 0.5 to 1.2 cm (Ngueguim 2007).

P. elata is found in many areas in Central and West Africa precisely in Soudano-Zambezian areas in semi caducifolous forest (White 1983). In Cameroon, its natural habitat covers a surface area of 4 071 800 ha mainly concentrated in the south-east region of the country around the water basin of four rivers: Dja, Boumba, Ngoko, and Sangha. Despite this, some residual populations are found dispersed in the south region notably in the Dja and Lobo and the Ntem Divisions and also in the Manyu Division of the south west region. (Vivien and Faure 1985). Forty percent of this habitat is covered by Forest Management Units (Betti 2007, 2008).

Studied sites

This study was carried out in Kienke south and Ndeng Ndeng forest reserves.

Plantation of the Ndeng Ndeng Forest Reserve

Located at latitude 48300 N and longitude 138110 E, the Ndeng Ndeng forestry reserve is situated in the Belabo subdivision, Lom and Djerem division, East region. According to Letouzey (1985), Ndeng Ndeng is found in the dense humid semi-deciduous forest rich in Sterculiaceae and Ulmaceae. The relief is relatively flat with weak slopes and its altitude varies between 600 and 750 m. This reserve has three *P. elata* plots numbered P741, P745, and P746 with a total surface area of 5 ha. The letter P signifies parcel and the two first characters of each number refers to the year 1974 during which this plot was put in place by the Centre Technique Forestier Tropical, the institution that Cameroon confined forestry research to after 1960. The third number (1, 5, and 6) indicates the rank of the plot. Average annual rainfall is 1500 mm with dry months in December, January, and February. The average annual temperature varies between 22 and 258C. The soils of this forestry ecosystem are lateritic. In the east the bedrock is made of mainly granite, in the west it is mainly metamorphic rocks, in the north it is mainly clayey-sandy whereas at the foot of slopes it is typically ferralitic hydromorphous soils (Etoga 1991).

Plantation of Kienke south

Found in the south region, Kienke south is a forest reserve located in the Lokoundje Subdivision of the Ocean division, more precisely between the Kribi and Akom II sub-divisions. This reserve was classified in the state permanent domain as a forest production reserve by decision no. 393 of 8 November 1947. This forest reserve is linked to a plateau with an attitude between 100 and 200 m (ONADEF 1991). The Kienke south reserve has two *P. elata* plots numbered P73 and P75, with a total surface area of 0.7 ha. The first plot was planted in 1973 and the second one in 1975. The region has a Guinea equatorial climate, characterized by constant high temperatures. Highest rainfall is observed during the months of August and September. Annual precipitation varies between 1600 and 3300 mm and average monthly temperature is around 25.98 C (Moby et al. 1979). Soils are young, ferralitic with a yellow color. The natural vegetation of the Littoral Atlantic forest is rich in Caesalpiniaceae, *Saccoglottis gabonensis*, and *Lophira alata*.

Data collection and analysis

Description of the planting method used

The technique of the installation of the plantations is the worn-out method. It consists of going into the forest and identifying big worn-out trees and destroying them to increase sunlight penetration and avoid competition for sunlight with the young plants to be put in place. The silviculturist looks for a planting density which could help to obtain the best expression of the growth potentials of the tree. The planting densities were high in the Kienke south plots (P73 and P75) and low in the big corridors in the Ndeng ndeng plots (P745, P746) as shown in table 1.

Table 1: The initial characteristics of studied parcels

Sites	Planting year	Parcels	Spacing between trees (m)	Initial Number of trees	Initial Density of trees
Kienke south	1973	P73	3 x 3	424	1 111
	1975	P75	4 x 3	255	884
Ndeng ndeng	1974	P745	15 x 3	511	256
	1974	P746	20 x 3	383	192

Description of the inventory

Inventory was conducted twice in four plots including plots P73 and P75 in the Kienke south, and Plots P745 and P746 in Ndeng ndeng forest. Inventory was conducted in two phases: phase I from 12th April to 13th June 2009 before the first sylvicultural treatment occurred in September 2009 and phase II, six years later from 3rd January to 25th March 2015 before the second sylvicultural treatment done in May 2015. In each plot, all trees were systematically marked (numbered) on their eastern side, counted and their diameter measured at 1.30 cm above ground level with a metric tape. The numbers attributed to each tree were noted for each stand tree as described by Ngueguim et al. (2012). The trees considered dead include the dead standing trees or falling trees. In this last case, during inventories in a plantation where the initial spacing is 3m x 3 m, if for example the last marked stem carries the number "03" for instance and the next surviving stem is located at 12 m on the same line, we shall attribute the number "7". This indicates that the trees numbered 04, 05, and 06 are dead. For trees presenting bumps at 1.30 m above the ground level, the diameter was measured at 30 cm above that level. For trees presenting two stems, the diameter was measured for each stem. For each tree, we noted the quality of stems as: straight, bump, or winding.

Description of the sylvicultural treatment

A sylvicultural treatment, consisting of pruning was conducted after each inventory campaign, by the National Forestry Agency (ANAFOR), the CITES Scientific authority for plants in Cameroon, within the ITTO-CITES program in 2009 and 2015 respectively. In fact, since the plantations have been settled (1973 – 1975), no appropriate sylvicultural intervention was applied. In the beginning, the sylvicultural experiments conducted aimed among other objectives, to test the best tree spacing than can yield better wood production. The high density observed in the settlement was supposed to be reduced progressively after years with the aim to reduce intra-specific competition for the light and improve the growth and the wood production. The first sylvicultural treatment was supposed to occur when the crown of the trees was dense and started closing. For the Kienke south plantation for example, this was supposed to occur between 1980 and 1986, when the two plots had about 8 and 10-year-old respectively. But nothing was done. As a result, many trees were bump and winding.

In spite of the long delay observed, ANAFOR decided finally to elaborate the simple management plan of the Kienke south plantation with specific measures (Tchatat 2009). Because of the big delay observed, the document of the management plan suggested to make a prudent pruning with the aim to improve the wood production. The document suggested making urgently two consecutive prunings, the first in 2009 and the second in 2015. This should consist of cutting about 10-30% of trees, focusing on trees which are dominated, infested, or winding. Trees located on the border were left as to reduce the bad effect of winds. The first pruning was conducted in September 2009, cutting 23% of trees in plot P73 and 16% of trees in plot P75. The second pruning occurred in May 2015 (Kemkeng 2016), cutting 15% of trees in each of the two previous plots (about 30 trees were cut in P73 and 25 trees were cut in P75).

Estimating structural parameters

A total of five structural parameters were estimated for each plot inventoried including: the density of trees, medium/average diameter, the mortality rate, the annual growth rate, and the stand basal area.

Density of trees

This represents the report of the total number of trees with the total area of the plot. It is expressed in number of trees per hectare (ha).

The medium diameter

This is the mean of or the average diameter of all the trees measured at breast high.

The mortality rate

The mortality rate is the ratio in percent of the number of trees died naturally between the date of the last inventory and the current state of the plot.

The annual growth rate

The annual growth rate expresses in cm/year, the report of the average diameter (in cm) of the population on the number of years (age) of the plot/plantation.

The stand basal area

The stand basal area of a population is the sum of the stand basal area of each tree within a hectare.

$$G = \pi/4 \times \sum^n di^2$$

where G is the stand basal area measured in m²/ha and di the diameter in m.

Statistical analysis

Data analysis was performed using the Ri386 3.3.1 statistical package. Different sites or plots were compared using the one way ANOVA.

Results

Physiognomy of plantations in 2009

Table 2 presents the initial and 2009 feature of the plots. The survival rates were acceptable in plots which had irregular surveys. The Ndeng ndeng plantations with big transects had average survival rates of less than 69% (P746) compared with those found in Bidou II where the higher survival rates are estimated at 91% (P75).

Table 2: The initial and 2009 density of the parcels before pruning

Sites	Planting year	Parcels	spacing between trees (m)	Initial Number of trees	Initial Density of trees	2009 Number of trees	2009 Density of trees	2009 survival rate (%)	Number/ percentage of infested trees
Kienke south	1973	P73	3 x 3	424	1 111	331	871	78	16/4.8%
	1975	P75	4 x 3	255	884	232	765	91	5/2.1%
Ndeng ndeng	1974	P745	15 x 3	511	256	283	142	55,4	5/1.7%
	1974	P746	20 x 3	383	192	265	135	69	5/1.8%

The quality of the survived trees noted in 2009 is presented in table 3. Many trees were bump and winding as showed. About an average of 85.2% of trees were winding, distributed as follow: Ndeng ndeng (87.8%) and Kienke south (82.8%).

Table 3: Quality of survived trees in Kienke south and Ndeng ndeng parcels in 2009 before pruning

Sites	Parcel	Aspect of the stem	Number of trees	%
Kienke south	P73	Bump	26	7.9
		Bump and straight	4	1.2
		Bump and winding	39	11.8
		Straight	33	10.0
		Winding	229	69.2
	P75	Bump	11	4.7
		Bump and straight	1	0.4
		Bump and winding	12	5.2
		Straight	22	9.5
		Winding	186	80.2
Ndeng-ndeng	P745	Bump	3	1.1
		Bump and straight	1	0.4
		Bump and winding	33	11.6
		Straight	27	9.5
		Winding	220	77.5
	P746	Bump	9	3.4
		Bump and winding	47	17.7
		Straight	27	10.2
		Winding	182	68.7

The 2009 dendrometric characteristics of the parcels studied is presented in table 4. The most important average diameter is observed in plot P 73 with an average size of trees of 24 ±11 cm. The standard deviations are high (10-12 cm). The average stand basal areas and annual growth rates are high in the Kienke south compared to Ndeng ndeng.

Table 4: The dendrometric characteristics of the studied population in 2009 before pruning

	Planting year	Parcels	Spacing	Surface Area (ha)	Age	Density	G (m²/ha)	Dm	DGR (cm/year)	Revolution years
Kienke south	1973	P73	3 x 3	0.3825	36	871	46.25	24±11	0.67	149
	1975	P75	4 x 3	0.3060	34	765	32.78	21±10	0.62	161
Ndeng ndeng	1974	P745	15 x 3	2	35	142	6.34	21±12	0.60	167
	1974	P746	20 x 3	2	35	135	5.33	21±10	0.60	167

Till 2009 which was 34 or 36 years after for the Kienke south parcels, no sylvicultural treatment was made in spite of the development delay and the bad conformity of trees as shown in photo 1.
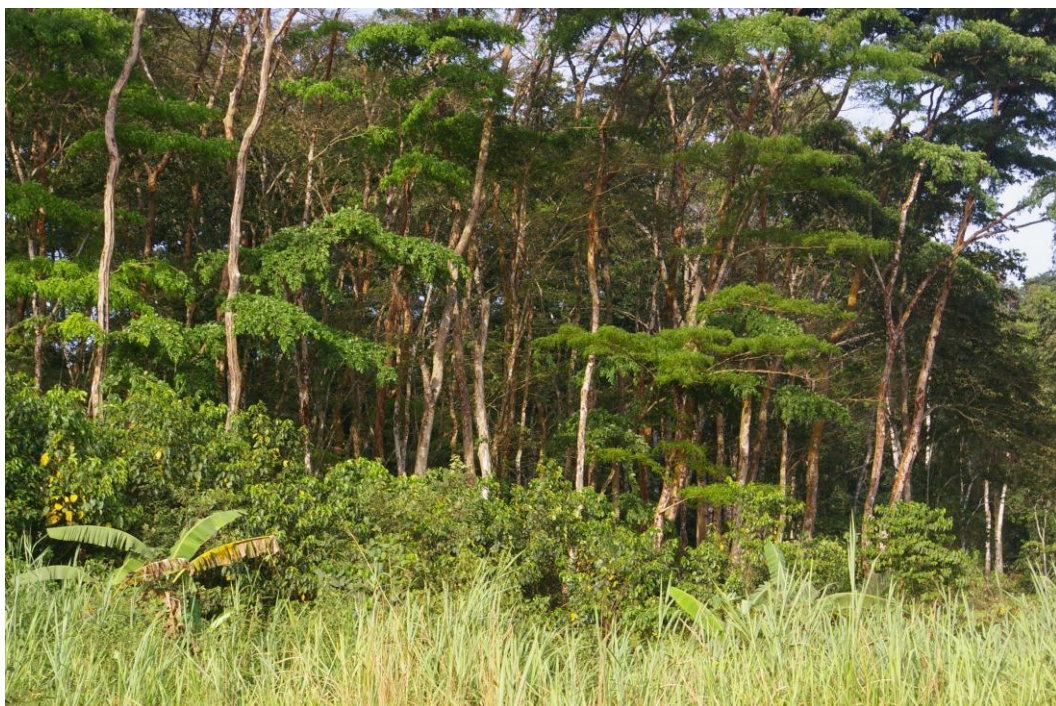

Photo 1: Physionomy of the Kienke south plantation in 2009. Photo Betti, Bidou II, Kribi, Cameroon, March 2009.

Diameter structure of plots

Figure 1 illustrates the diameter structures of *Pericopsis elata* plots in 2009. Higher diameter classes contain fewer trees. The modal class is Cl10-20 in all plots.
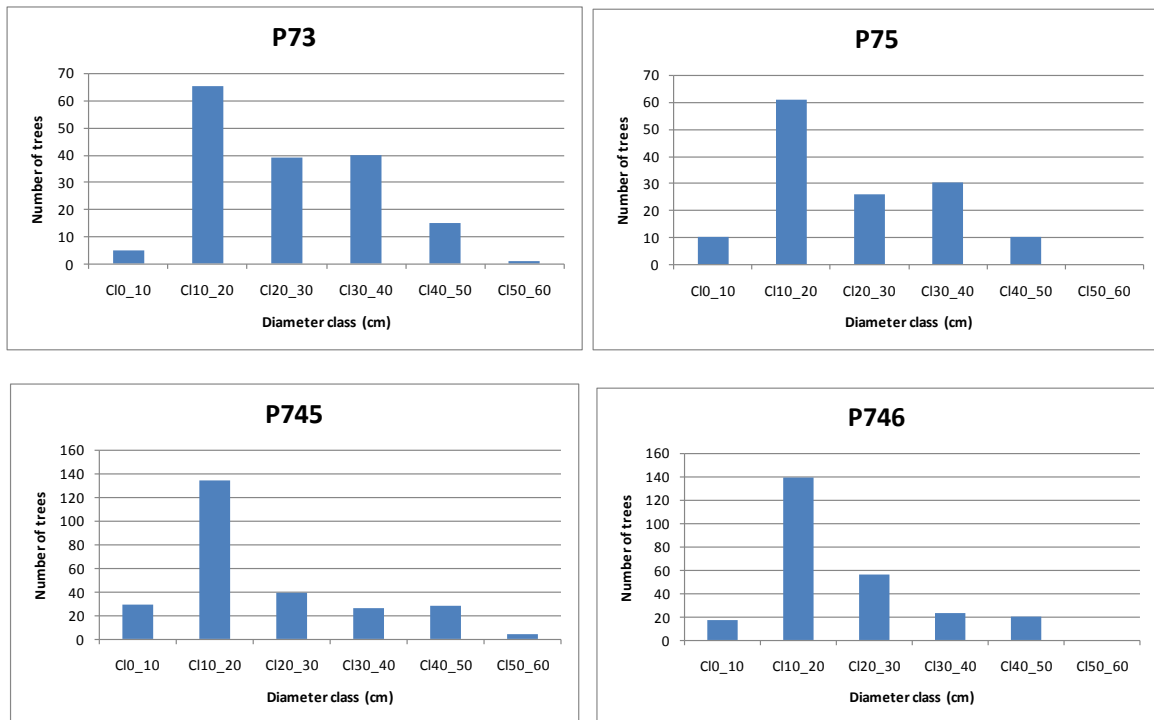
Figure 1: Diameter structure of *Pericopsis elata* in 2009 in Kienke south (P73, P 75) and Ndeng ndeng (P745, P746) forest reserve

Because of the big delay observed, the document of the management plan of the Kienke south suggested to start with a selective and careful pruning of trees and the reduction of the plantation density due to the delay already observed in this operation. The most suitable approach will necessitate: Pruning that eliminates very few stems especially in areas that can be fragile, avoid pruning the two first hedges of trees of each plot, they will serve as wind protection residues, a top pruning is good for dominant stems to provide a favorable interval for diameter growth for these stems by progressive and partial removal of dominant, regarding infested trees, remove only those that are seriously affected to avoid the risk of withering due to a high rate of pruning, eliminate trees with poor performance. Photo 2 illustrates the 2009 physiognomy of the pruned plots in the Kienke south forest reserve.

Photo 2: Physionomy of the Kienke south plantation in November 2010. Photo Ngueguim, Bidou II, Kribi, Cameroon, November 2010

Physiognomy of plantations in 2015

Table 5 presents the quality of the remaining trees upon pruning in the Kienke south site in 2015. The average percentage of winding trees is 44.1%.

Table 5: Quality of survived trees in Kienke south after pruning in 2015

Parcel	Aspect of the tree	Number of trees	%
P73	Straight	111	50.7
	Winding	52	23.7
	Bump and winding	56	25.6
P75	Straight	96	61.1
	Winding	23	14.6
	Bump and winding	38	24.2
Total		376	100

Table 6 presents the dendrometric characteristics of the studied plots in 2015. Densities in plots of Kienké south have been largely reduced. The highest stand basal areas and growth rates are found in pruned plots, Kienké south.

Table 6: The dendrometric characteristics of the studied population in 2015

Sites	Planting year	Parcels	Spacing between trees (m)	Age	Number of trees	Density of trees	G (m²/ha)	Dm (cm)	DGR (cm/year)
Kienke south	1973	P73	3 x 3	42	191	499	44.07	31±10.04	0.74
	1975	P75	4 x 3	40	139	454	31.32	27±10.47	0.68
Ndeng ndeng	1974	P745	15 x 3	41	261	130	7.31	23±13.11	0.56
	1974	P746	20 x 3	41	252	126	6.50	23±10.91	0.56

Diameter structure of plots

The diameter structure of *Pericopsis elata* plots in 2015 is illustrated in figure 2. The modal class of Cl10_20 remains the same for Ndeng ndeng plots. The new modal class of Kienke south plots is Cl20_30.
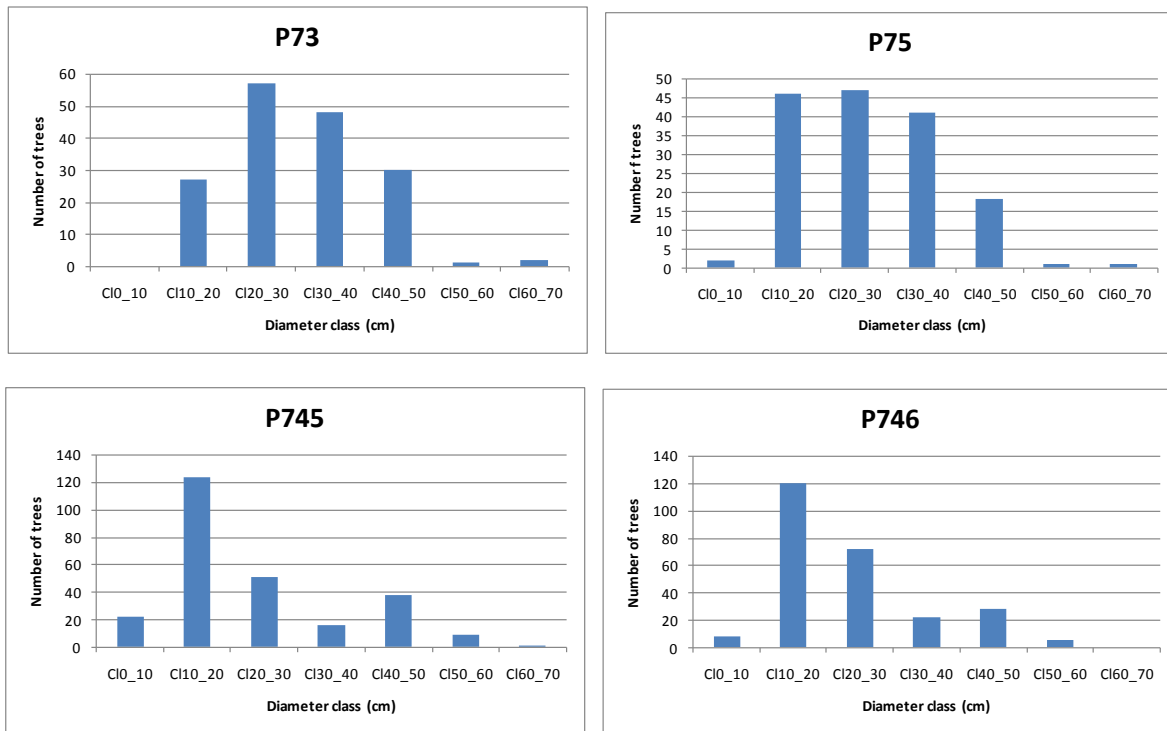
P73

P75

P745

P746

Figure 2: Diameter structure of *Pericopsis elata* in 2015 in Kienke south (P73, P 75) and Ndeng ndeng (P745, P746) forest reserve.

Change on dendrometric characteristics between 2009 and 2015

To understand the effect of pruning on the trees, we examined the change occurred between the 2009 and 2015, which is 6 years after the first pruning and for the same trees. Changes obtained on the stand basal area were examined between the two sites and inside each site as shown in table 7. We can see that changes in stand basal area are significantly different between the two sites. But change inside each site is not different. The gain in stand basal area seems to be the same in the parcels belonging to the same site.

Table 7: Comparison of sites and plots on changes in stand basal areas

Site	Number of trees (N1)	Number of trees (N2)	Stand basal area (Mean 1)	Stand basal area (Mean 2)	Df	F value	Pr(>F)
Kienke south x Ndeng ndeng	331	521	0.037	0.004	1	287.2	<2e-16 ***
Kienke south '(P73 x P75)	192	139	0.035	0.039	1	0.421	Ns
Ndeng ndeng (P745 x P746)	270	251	0.004	0.004	1	0.057	Ns

Table 8 presents the mean difference of the stand basal area in each plot. We can see that the Kienke south plots have gain more stand basal areas, about 10 times more than the Ndeng ndeng plots in 6 years.

Table 8: Changes on the stand basal area between 2009 and 2015 on the same trees

Site	Planting year	Parcel	Initial spacing between trees (m)	Age	Number of trees	Stand basal area in 2009 after clearing (m²/ha)	Stand basal area in 2015 (m²/ha)	Mean difference in stand basal area (m²/ha)
Kienke south	1973	P73	3 x 3	6	192	35.06	41.81	0.035±0.048
	1975	P75	4 x 3	6	139	22.24	29.93	0.039±0.034
Ndeng ndeng	1974	P745	15 x 3	6	270	6.15	7.24	0.004±0.005
	1974	P746	20 x 3	6	251	5.32	6.49	0.005±0.005

Table 9 and 10 present change occurred in annual growth rate between 2009 and 2015 for the same trees. Changes in annual growth rates differ from one site to another, and for the Ndeng ndeng site, from one parcel to another.

Table 10 presents the changes on annual growth rates. The annual growth rates in Kienke south plots are higher, than those in the Ndeng ndeng.

Table 9: Comparison of sites and plots on change in annual growth rates

Site	Number of trees (N1)	Number of trees (N2)	DGR Mean 1 (cm/year)	DGR Mean 2 (cm/year)	Df	F value Pr(>F)
Kienke south x Ndeng ndeng	331	521	0.45	0.34	1	15.83 7.52e-05 ***
Kienke south '(P73 x P75)	192	139	0.46	0.45	1	0.832 Ns
Ndeng ndeng (P745 x P746)	270	251	0.3	0.4	1	23.15 1.96e-06 ***

Table 10: Changes on the annual growth rate between 2009 and 2015 on the same trees

Site	Planting year	Parcel	Initial spacing between trees (m)	Age	Number of trees	Mean diameter 2009 (cm)	Mean diameter 2015 (cm)	Mean difference in diameter (cm)	DGR (cm/year)
Kienke south	1973	P73	3 x 3	6	192	28	31	2.6±3.4	0.46
	1975	P75	4 x 3	6	139	24	27	2.8±3.13	0.45
Ndeng ndeng	1974	P745	15 x 3	6	261	21	23	1.79±1.49	0.3
	1974	P746	20 x 3	6	252	21	23	2.41±1.74	0.4

Discussion

Physiognomy, dendrometric characteristics and diameter structure of plantations in 2009 before the first pruning campaign

The two plantations including Kienke south and Ndeng ndeng, differ on the sylvicultural method used. Planting densities were high in the Kienke south plots (P73, and P75) and low in the big corridors plots in Ndeng ndeng (P745, P746). The survival rates are high in Kienke south plots and low in Ndeng ndeng. But these survival rates are acceptable for plantations which were abandoned for many years. Tree mortalities were due less to human pressure than to natural death related to climatic and edaphic factors. As noted by Ngueguim et al. (2012), many falling trees were observed in plots with big corridors due to strong winds.

Density is an important parameter for the success of a plantation. During the creation of plantations, densities were projected to be reduced progressively with the aim to reduce shading. But this did not happened. As shown in photo 1, the tree canopies inter-cross in the Kienke south plantations, showing a high competition for light due to high tree density. Many trees were bump and winding. An average of 85.2% of the survived trees were winding. The stems have a twisted and cylindrical trunk which is a characteristic of *Pericopsis elata* (Assamela/Afrormosia). Natural pruning occurs very well in all the plantations due to the reduced number of trees with low branching. Parasite infestation specially by

black nut fungus was observed in all the plantations. Many trees were bump and winding.

The most important average diameter is observed in plot P 73 with an average size of trees of 24 ±11 cm. The relative high standard deviation indicates a high variability in the performance of the diameter growth of the trees. In fact, we noted that trees settled in the boundaries of each plot were quite big compared to those settled inside the plot. This illustrates competition between individual and predicts that a better follow-up and earlier intervention to reduce shade would have improved the yield (Ngueguim et al. 2012). The average stand basal areas and annual growth rates are high in the Kienke south compared to Ndeng ndeng. This may be linked to the high densities of trees practiced in the Kienke south forest reserve.

Studies on the growth of Assamela indicate annual diameter growth of 3 cm/year for 8-year-old plantations (FAO 2008). In the Democratic Republic of Congo (DRC), Donis (1986) obtained 0.39 cm/year in 13 year-old plantations after 13 years of monitoring. In Ghana, Anglaaere (2005) obtained 1.3 cm/year on 7 year old plantations. In Cameroon, in the Kienke south forest reserve, results were 1 cm/year when the parcels were 12-year-old (Engbwem 1988) and 0.75 cm/year when they reached 32-year-old (Ngueguim 2007). In the Ndeng ndeng forest reserve, Grison (1979) noted for 5-year-old plantation, 1.16 cm/year for parcel 745 and 1.32 cm/year for parcel 746. Results of the current study are as follow: 0.62 cm/year in 34-year-old plot (P75), 0.67 cm/year in 36-year-old plot (P73) and 0.60 cm/year

in 35-year-old plots (P745 and P746). These annual growth rates are low compared to results obtained in past years in the same plots. The drop in annual growth rate can be explained by the negative effect on mortality (diminution of the diameter size), competition between trees due to high planting densities and probably the normal growth rate which is a function of age. Results obtained in different studies conducted in range countries (Cameroon, DRC, Ghana) tend to show that the diameter annual growth rate varies not only with the age of plantation (young plantations seem to have high growth rates), but also with other parameters such as the site, the planting method, and probably the sylvicultural treatment.

The most important annual growth is 0.67 cm (P73) corresponding to a revolution of 149 years. This is the duration for the majority of trees in the plantation to reach the minimum cutting diameter allowed in Cameroon which has been increased from 90 cm in 2009 to 100 cm in 2010 for Assamela. Stems with diameters higher or nearer the minimum cutting diameter of 100 cm were noticed generally located at the boundaries of the plots illustrating the border effect. If a pruning intervention was done earlier, it would have reduced the population density and without doubt improved the diameter growth of the trees (Ngueguim et al. 2012).

The most important basal areas are estimated at 46.25 m2/ha (P73) and 32.78 m2/ha (P75) and the lower are estimated at 6.34 m2/ha (P745) and 5.33 m2/ha (P746). This parameter depends on tree density, the number and size of stems.

The specific curve of the diameter structures indicates that higher diameter classes contain fewer trees. The modal class is class 10-20 in all plantations and all plots. The structure of the population distribution is generally asymmetric to the right. As noted by Ngueguim et al. (2012), histograms are characterized by a very strong slope before the modal class of stems. This sudden and sharp elevation of number of stems after the diameter class of dbh 10 cm showed that the first diameter class is made up of stems which had the most difficult growth. This variability in distribution demonstrates not only the specific character of silvicultural methods on each plantation but also the huge disparity of the diameters around the mean. In silvicultural systems in which stands have an even-aged structure, it was expected that the diameter of trees should be distributed to give a graphical representation of a bellshaped curve (Gaussian distribution) where the top represents the average tree (Rondeux 1999 cit. Ngueguim et al. 2012). Generally, these plantations don't reflect the expected characteristics notable in those of an evenaged plantation structure. This confirms irregularity in the survey, absences of silvicultural interventions to accompany the tree growth process, the establishment of the trees out of their ecological zone, and the presence of other forms of perturbations due to abandonment (Ngueguim et al. 2012).

Physiognomy, dendrometric characteristics and diameter structure of plantations in 2015

The first sylvicultural intervention occurred n the Kienke south plots in 2009, while the plantations of the Ndeng ndeng forest were kept intact. We can note that the quality of trees has improved in the Kienke south plots. The average percentage of winding trees dropped from 82.8% in 2009 to 44.1% in 2015, which is the half. Knowing that the sylvicultural intervention moved an average of 19% of trees in the two plots, we can say that the quality of the survived trees has significantly improved.

The most important average diameters are observed in the Kienke south plantation; plot P 73 with an average size of trees of 31 ±10.04 cm followed by plot 75 with an average size of trees of 27 ±10.47 cm. The two plots gained at least 6 cm in diameter in 6 years, which is trice compared to the 2 cm observed in the Ndeng ndeng plantation. The evolution of the growth rates is going to the same sense as the average diameter size. The highest growth rates were observed in the Kienke south plots, 0.74 cm/year in P73 and 0.68 cm/year in P75. The P73 growth rate moved from 0.67 cm/year in 2009 to 0.74 cm/year in 2015, while that of the P75 moved from 0.62 cm/year in 2009 to 0.68 cm/year in 2015. The gain in growth rates is about 0.065 cm in the two plots. The Ndeng ndeng plantation in the other hand registered a decrease in annual growth rates, which dropped from 0.60 cm/year to 0.56 cm/year in the two plots (P745 and P746). Contrary to the diameter size, the stand basal area dropped a little bit in the Kienke south plots (46-44 m²/ha in P73 for example) and increased in the Ndeng ndeng plots (6-7 m²/ha in P745). The increase in average diameter size and annual growth rates in the Kienke south plots can be translated by the removal of small trees, since the sylvicultural treatment focused on dominated and winding trees. The decrease in stand basal area observed in the kienke south plots can be explained by the sylvicultural intervention which moved some trees and reduced the density. The stand basal area being largely linked to the density of trees, than to the size.

The specific curves for diameter structure have changed in the Kienke south plots, where the modal class has moved from 10-20 cm to 20-30 cm. This reflects the increase observed in diameter size. Till here, no concrete element has translated the positive or negative effect of the sylvicultural treatment operated.

Change on dendrometric characteristics between 2009 and 2015

To understand the effect of the sylvicultural treatment (pruning) on the trees, we examined the change occurred between the 2009 and 2015, which is 6 years after the treatment and for the same trees. Change was examined between the two sites and inside each site. Change in stand basal area is significantly different between the two sites. But change inside each site is not different. The gain in stand basal area seems to be the same in the parcels belonging to the same site. Parcels of the Kienke south have gain at least 6 m²/ha in the stand basal area against only 1 m²/ha for parcels of the Ndeng ndeng during the 6 years. This illustrates the positive effect of the sylvicultural intervention on the development of *Pericopsis elata*. Changes in diameter growth and annual growth rate are significantly different between the two sites. The annual growth rate is the same in the Parcels of the Kienke south site (0.45-0.46 cm/year), but differ between the two plots of the Ndeng

ndeng site. The average annual growth rate in diameter is 0.45 cm/year in pruned plots (Kienke south) against 0.34 cm/year in non pruned plots (Ndeng ndeng), which show again the positive effect of the sylvicutural intervention on the development of the trees. Our results are quite similar to those obtained in natural forests in Cameroon and Democratic Republic of Congo (DRC). The 0.31 cm/year obtained in the non pruned plots (Ndeng ndeng) is near the 0.31 cm/year obtained by Bourland (2013) on 51 trees monitored in the East region of Cameroon. The 0.45 cm/year obtained in the cleaned plots is quite similar those obtained by Vangu-Lutete (1974) and Boyemba (2011) in the Kisangani forest in DRC. In fact, Vangu-Lutete (opcit.) obtained 0.45 cm/year on 101 trees, while Boyemba (2011) obtained 0.42 cm/year on 422 trees using the same method. Schmitz (1962) followed 11 trees in Kisangani and obtained an annual growth rate of 0.68 cm/year. Annual growth rate depends of many environmental parameters including soils, climate, and the history of the forest in terms of the past usage. The difference observed between the work of Bourland (2013) in Cameroon and those conducted in DRC (Vangu-Lutete 1974 and Boyemba 2011) can be translated by this thesis, and also may be by the low number of trees monitored in Cameroon. By comparing our results with those obtained in natural forests in DRC, we can see that, in spite of the delay, the sylvicultural intervention has increased the growth rate and allowed the pruned plots to meet the normal annual growth rates of *Pericopsis elata* often observed in natural forests. The second pruning occurred in May 2015, retrieving 15% of trees in each of the two previous plots. The next campaign of forest inventory should be scheduled by 2020, as to re-examine the effect of this second pruning on the health and growth of *Pericopsis* trees.

The annual growth rate is one of the most important parameter that intervenes in the formula of the estimation of the reconstitution/recovery rate of *Pericopsis elata* in the production forests (forest management units) in the tree most range countries in the Congo basin including Cameroon, Republic of Congo, and DRC. In Cameroon (Betti 2007, 2008; Akoa et al. 2009) and Republic of Congo (Nzala et al. 2011; Betti et al. 2012), the respective forest administrations have fixed the value of 0.4 cm/year as standard, to be used in the calculation of the reconstitution rate in all forest management units settled in the range area of *Pericopsis elata* (East Cameroon and North Congo), while in DRC (ICCN 2014), the forest administration has adopted a value of 0.45 cm/year in Equator and province Orientale. Due to the differences observed in different sites, we suggest that this parameter should be more refined for each production site, as to better appreciate the reconstitution rate in each FMU.

Conclusion

This study aimed to analyse the response of *Pericopsis elata* to a delay pruning, conducted in abandoned plantations settled in 1973-1975 in the South and East regions of Cameroon. Because of the big delay observed, the tree canopies inter-cross, showing a high competition for light due to high tree density. Many trees were bump and winding. The annual growth rates

obtained in 2009 are low compared to results obtained in past years in the same plots, translating the negative effect on mortality, competition between trees, and probably the normal growth rate which is a function of age. The first pruning done in 2009, improved the quality, the stand basal area and diameter growth rates of trees. The most important stand basal area, average diameters and average diameter annual growth rates are observed in the pruned plots. The second pruning occurred in May 2015, cutting 15% of trees in each of the two previous plots. The next campaign of forest inventory should be scheduled by 2020, as to re-examine the effect of this treatment on the health and growth of *Pericopsis* trees. Results obtained in different studies conducted in range countries tend to show that the diameter annual growth rate varies not only with the age of plantation, but also with other parameters such as the site, the planting method, and probably the sylvicultural treatment. This suggests that the diameter annual growth rate, which is an important parameter, used in the calculation of the reconstitution rate, should be measure and carefully refined for each production site.

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