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Potential and measures for sustaining *Prunus africana* (Hook.F.) Kalkman (Rosaceae) in Tchabal Mbabo forest (Mf), Adamaoua Cameroon

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***Prunus africana* (Hook. F.) Kalkman is a medicinal plant for which the bark is used to treat benign prostate hypertrophy. *P. africana* is listed in Appendix 2 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Its exploitation has been regulated in Cameroon through the settlement of some management standards. This paper aims to assess the potential of *P. africana* in the Tchabal Mbabo forest (MF), vast of 25,671 ha in view to formulate guidelines for sustainable harvesting. Data collection took place from October 1st to 28th 2021. This consisted of conducting forest management inventories at a sampling rate of 0.72%. Three hundred and fifty-eight (358) stems of *P. africana* were counted on a surface area of 57.5 ha, which gives a density of 6.23 stems/ha. The average values of diameter, height and bark thickness of the stems (unharvested and harvested sides) are respectively 48.17 ± 19.8 cm; 7 ± 4.26 m; 14.1 ± 4.72 mm and 10.39 ± 4.22 mm. The average annual bark increment is 1.3 mm/year for a bark regeneration rate of 60%. A half rotation of 7 years was obtained for a dry bark quota of 164.6 tons/year. It would be wise to take into account the dynamic elements to review the calculation of the quota for the second rotation.**

Key words: *Prunus africana*, standards, parameters, sustainable management, Tchabal Mbabo.

INTRODUCTION

Cameroonian forests with 22.5 million hectares are among the vast and rich forest massifs in the Congo basin (Wete, 2022). During the last decade of the twentieth century, the role of forest was again redefined

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by include additional parameters such as carbon sequestration, biodiversity, regeneration status, and Non-Timber Forest Product (NTFP) (Tewari, 2016). The NTFP from these forests bring together food plants, medicinal plants and service products (Betti et al., 2016). The use of plants for therapeutic purposes has been known since the dawn of time (Lehmann, 2013). Today, the effectiveness of herbal medicine is proven and its undeniable benefits (Bene et al., 2016). Among the health problems listed, the prostate cancer is an important public health problem (Shenouda et al., 2007). According to Diarra (2006), apart from cancer proper, other prostate conditions are generally associated with it, amongst them we have the benign prostate hypertrophy (HBP). It is a non-cancerous prostate enlargement (Nyamai et al., 2016) which causes discomfort in elderly men, present in more than 50% of men over 60 years (Bodeker et al., 2014). Medicine by plants becomes daily (Bene et al., 2016) because,The conventional methods lead to severe side effects including erectile dysfunction and gynecomastia. So, people prefer to opt for phytotherapy for the management of the condition to avoid these adverse effects (Nyamai et al., 2015).

The use of *Prunus africana* in traditional African medicine (ATM) to treat prostate cancer and related conditions is not a new phenomenon in various communities in Africa (Ochwang'i, et al., 2014; Komakech et al., 2017). Mutuma et al. (2020) confirms that the dichloromethane stem bark extract of the *P. africana* presented anti-inflammatory activity, hence a possible candidate for extraction of active anti-inflammatory compounds. Its importance resides in the curative properties of its bark extracts used for the manufacture of more than 19 drugs, sold on the European and American markets for the treatment of benign prostatic hypertrophy (Cunningham et al., 2002). These extracts are mainly made up of of pentacyclic triterpenoids, ferulic esters of long-chain fatty alcohols, and phytosterols contained in bark and find in certain drugs, for e.g., Tadenan, Bidrolar and Pygenil (Nyamai et al., 2016; Komakech et al., 2017). The worldwide demand for these barks is estimated at 4000 tons (Simons et al., 1998). This high demand has therefore led to irrational harvesting of the plant species in the various production areas. Thus, trees have been felled abundantly and frequently before the maturation stage or debarked completely at the trunk level (Randriambololona, 1994; Rasoanandrasana, 2010). As a result of this intensive exploitation and poor harvesting methods, *P. africana* has become very scarce, the rootstock has disappeared and its natural regeneration has been reduced (Dawson and Rabevohitra, 1996; Sven and Rakotonirina, 1995; Rasoanandrasana, 2010; Momo et al., 2016). All this led to the listing of the species in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1995 (Tonye et al., 2000). In Cameroon the majority of *P. africana* populations are found in the North West, South West and Adamaoua regions where they have been widely exploited for their bark since 1980 (Momo et al., 2016).

A key requirement of CITES for any species listed in appendix II is the establishment of a non-detriment findings made by the Scientific Authority of the range State prior to export, certifying that export is not detrimental to the survival of the species. This requires information on the location, stocking, growth and condition of the species and on its ecology, regeneration and subsequent protection. Such information is often lacking, incomplete or imprecise making a proper evaluation of the sustainable levels of utilization and conditions attached to be difficult. The Scientific Authorities also face obstacles due to inadequately trained and resourced staff. Following irregularities observed in some range of countries, a conference was organized by CITES in September 2008 in Lima, Peru with a view to deciding on the management methods of *P. africana* in exporting countries. During this conference, some countries, such as Cameroon, were asked to voluntarily consider a zero-export quota before December 31st, 2008, in order to conduct forest inventories and develop the management plan for *P. africana*. Failure to comply with these recommendations could lead to an embargo on trade in this species from these countries (Ingram et al., 2009). In the meantime, this deficiency observed in the management of *P. africana* in Cameroon led the European Union (EU) to suspend exports from Cameroon in 2008 (Akoa et al., 2010). The exploitation of *P. africana* resumed in Cameroon only in 2010 after the first results of the management inventories which led to the development of a non-detriment finding document (NDF) for this species in the North-West Region, Cameroon (Akoa et al., 2010).

This work, carried out within the framework of the joint program of the International Tropical Timber Organization (ITTO) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), known as "The ITTO-CITES program", was extended in the southwest (Akoa et al. 2011a) and then in Adamaoua (Akoa et al., 2011b) regions and allowed Cameroon to be granted an annual quota of 630 tons of dry bark of *P. africana* in 2011 and distributed as follows: Adamaoua (350 tons), North-West (150), and South-West (170). All these interventions have enabled Cameroon to take ownership of the management mechanisms of CITES species. However, the reports of certain NGOs and in particular the Deutsche Gesellschaft fur Internationale Zusammenarbeit GmbH (GIZ) always mentioned the unsustainable management of the Pygeum, so, CITES called on Cameroon on this subject and in particular on the reduction of export quotas (https://cites.org/sites/default/files/fra/com/pc/22/ExSum/F-PC22-SR.pdf). Until September 2017, Cameroon had not yet provided clear answers to all CITES recommendations, especially on the real potential of each production unit of *P. africana.* The state of the art on the management/harvesting of *P. africana* in Cameroon revealed that, for the Adamawa Region, forest inventories carried out by trade companies themselves were not conducted in fair manner, using approved standards settled by the Cameroon forest management guidelines. Furthermore, the management parameters used to estimate the annual quota is based on studies conducted in the North west and South west regions of Cameroon (Wete, 2022). The commercialization of medicinal plants needs to account for the limits of the resource to ensure the sustainable, i.e., the long-term and continued, harvesting of the species (Bodeker et al., 2014).The present work attempts to assess the potential of *P. africana* with the view to ensure sustainable exploitation of the bark of this species in the Tchabal Mbabo forest (MF). The specific objectives are: (1) to analyze the sampling effort in mountain forests (2) to appreciate the structural parameters (density, diametric structure, basal area, carbon stock) (3) to characterize the response of *Prunus* trees to the harvesting (sanitary statement, bark regeneration) (4) and to propose sustainable management measures for bark harvesting (rotation, harvesting zones, harvesting techniques).

MATERIALS

Study site

Tchabal Mbabo is geographically located in the Adamaoua Region, on either side of the Departments of Mayo Banyo and Faro and Déo, in three subdivisions including Banyo in the Mayo Banyo Division, Galim Tignère and Kontcha in the Faro and Déo Division (Hiol Hiol, 2021). It culminates at an altitude of 2240 meters (MINFOF, 2018). The work was conducted in 4 localities namely: Foungoi with coordinates (07°14’04.51”N, 12°02’56.96”E), Yangare (07°13’42.47”N, 12°07’57.40”E), Botendji (07°14’49.41”N, 12°10’07.29”E) and Horé garba (07°19’22.98”N, 12°14’02.45”E). The human population of the area comprises diverse ethnic groups including Mbororos, Foulbes, Nyem Nyems and Hauossas. These groups are divided into traditional chiefdoms or Lamida and different native languages (Unsongo, 2019). The main vegetation of Tchabal Mbabo is made up of forest galleries, grassy savannas, dry altitude forests, and wooded savannas. Forest galleries are known to be predilection sites for *P. africana* (Wete, 2022). The North and south of the Adamaoua plateau is made up of metamorphic rocks and granitoids of African panic age. It is crossed in the north and east by basalt flows and cones, domes and trachyte-colored domes and phonolitis of mio-plicen ages (Fagny et al., 2017). Tchabal Mbabo hosts 294 bird species, 22 species restricted to the afro montane ecosystem, 10 of which are endemic to the mountain chain. The area is also known to harbour some Critically Endangered and Endangered reptiles and amphibians (Usongo, 2019). The hottest months are April and May with average daily temperatures of up to 30°C. Annual temperatures on the plateau average 18°C with daily amplitude of 13-15°C (Herrmann et al., 2007). Figure 1 present the ombrothermic diagram of the zone.

Description of the species

P. africana grows well in the sub-mountain and mountain forests at an altitude of 800-3000 m. In Cameroon, the plant is largely found in five regions including Adamaoua, North West, Littoral, South west, and West (Betti and Ambara, 2013). The description made by Vivien and Faure (2011) is as follows: Its base is a simple wheelbase or thick 8 -10 cm thick, deviating at 1 m of the tree at 1 m in height. It was straight with a crown with tortuous branches eased obliquely with young reddish twigs. It’s very dark brown bark (1.5 cm) formed large or less square platelets in the aged trees; It tender, fibrous, pink turning brown, with characteristic odor of bitter almond little differentiated, pinkish white (3 cm). Its wood is brown pink in light with leaves persistent, alternate, simple (6-15 x 3-6 cm), with a tender and shiny then tough and matt blade, on a crenellated edge with a small black gland at each point, sometimes 1 or 2 glands at the base of the blade, At 6-12 pairs of side veins. Its fruit is a drupe with 2 red lobes, with a small point at the top.

METHODS

The method used is a combination of surveys and forest inventories. The surveys were conducted using the participatory method to get an idea of the actual production sites of *P. africana* in the Tchabal Mbabo forest. Discussions were conducted with administrative officials, including forestry services, community representatives, traditional chiefs or Djaouro, village populations (elderly and non-elderly), and field-based staff of companies that harvest *P. africana* in Cameroon. *P. africana* inventories were carried out in areas previously identified as *P. africana* production sites from October 1st to 28th 2021. The method used is, the classical forest inventory method standardised (arêté n° 222) for management inventories (MINEF, 2001).

Sampling design

The surveys carried out made it possible to map and delimit the potential sites of predilection of *P. africana* in altitudes ranging from 1,400 to 2,100 m. Maps were made in three stages ,including: (1) document review and exploration of photos and images (2) identification of areas to be surveyed, and (3) refinement of the data. The BING and (Open Street Map) OSM aerial funds were used for this purpose. The elevation factor proved to be of primary importance in the spatial distribution of *P. africana* in the inventory area, so we made a Digital Terrain Model (DTM) on which the information layers were draped. The DTM was made by downloading a LANDSAT 8 image of March 2021 of the inventory area and then processed on QGIS 3.0. For this inventory, “layons” were oriented in the direction perpendicular to the general direction of slope, according to the national standards (MINFOF, 2019), the sampling is systematic and stratified to 1 degree when the statistical unit is the plot. The samples or plots of 0.5 ha (250 m long × 20 m large) are distributed systematically throughout the entire population and not by stratum (forest type). The stratification is done definitively after the sampling. The systematic disposal of plots allows the assumption that the intensity of sampling for each stratum is proportional to its area in the forest. Results of the inventory and their accuracy are calculated for each stratum. In practice, sampling is carried out along straight and continuous axes called “layons” or transects. These “layons” are oriented along a predetermined magnetic direction but are systematically arranged in such a way that they are mostly parallel, equidistant and perpendicular to the general direction of both drainage and slopes. In Cameroon, the sampling intensity for management inventories, the surveys conducted have estimated the useful area of *P. africana* in the Tchabal Mbabo to be 28,456 ha. For this work, a total of four villages were selected because of (1) their accessibility and (2) of the consent of the village leaders. The total area selected is 8,000 ha distributed as follows in the four villages: Foungoi (1,846.48 ha), Yangaré (3,018.97), Botendji (1,011.14) and Horé

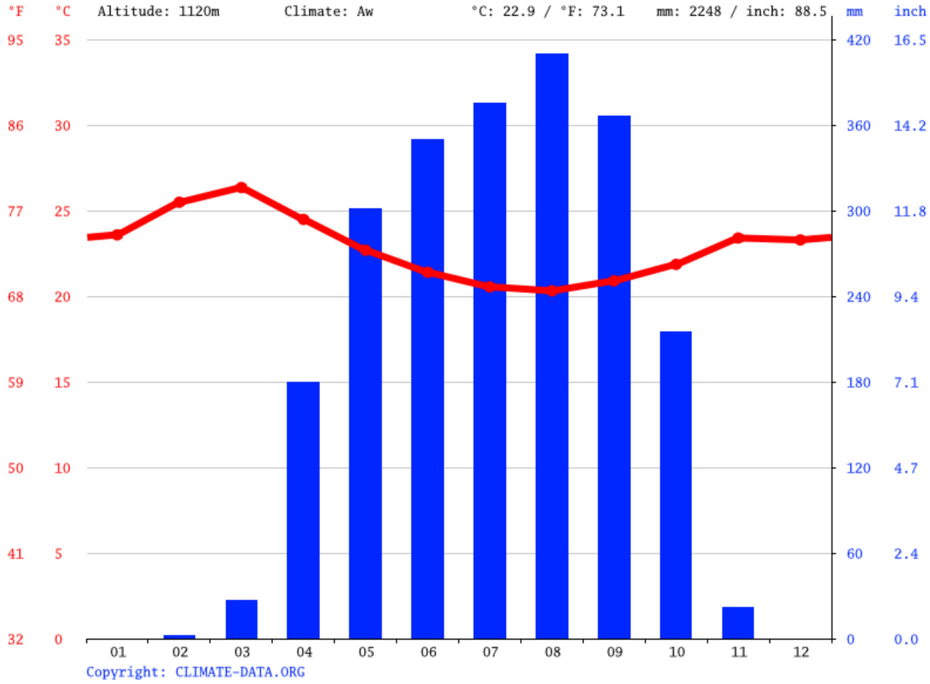

Figure 1. Ombrothermic diagram.
Source: Authors

Garba (2,123.41). A provisional sampling rate of 2% was designed. Figure 2 illustrates the sampling design.

Implementation of the sampling design

The implementation of the sampling design (or the inventory) consists of two steps: “layons” or line opening/transect cutting and counting. Line opening/transect cutting: This step consists of opening or cutting according to a defined magnetic direction, corridors or alleys of 1.5 m wide. These corridors are clearly cleaned by cutting shrubs, vines and branches that obstruct the passage. They are then identified by marks. “Layons” constitute the reference system which will be used by the subsequent counting team. It is during the “layons” opening that details on topography, habitat types, rivers and the corrected horizontal distance of the “layon” (after reading the slopes) are given. It is also during this stage that the sample plots are identified and numbered. The data collected are recorded on specific sheet. Counting: The counting step includes all operations relating to dendrological and dendrometric records. During the counting, several operations are made including: Identification of stems of *P. africana*, the measurement of stems with diameter at breast height (dbh = 1.30 m)>= 5 cm, appreciation of the health state of the tree in three classes (dead trees, damaged trees, and living trees). The appreciation of the healthy status of the tree is mainly based on the health of the leaves and number of dried branches. Lines and plots are identified and numbered with their geographical coordinates and altitudes. For each *P. africana* stem encountered, the height, diameter at breast height, bark thickness was measured. The thickness was measured for each exploited stem on the face of the bark not yet exploited as well as on the face of the bark already exploited, that is, the bark in regeneration. For this purpose, a square or rectangular bark core was taken and the thicknesses of the four sides were measured. The average thickness of the four sides was taken as the bark thickness of this tree and for the indicated side. The harvesting techniques used were described and the year of harvesting was noted.

Data analysis

The processing of the collected data allowed highlighting density, basal area, diametric structure, bark reconstitution rate, carbon stock, and half-rotation. The formulas used are the following:

Density is expressed as:

$D = Ni / Ss$

with *Ni*: number of stems counted; *Ss*: area surveyed.

Basal area is $G = \sum (\pi D^2/4)$

with *D*: stem diameter and $\pi = 3.14$.

The average annual increment of reconstituted bark is:

$AAMEr = EMCe / t$

where *EMCe*: average thickness on logged side; *t*: time between logging and collection date.

The rate of reconstitution in thickness of the exploited bark is:

$TREee = EMCe / EMCne$

with *EMCne*: average of the thicknesses on the non-exploited side.

The evolution of the average annual increase in thickness of the unharvested side over time was assessed from the ratio of the

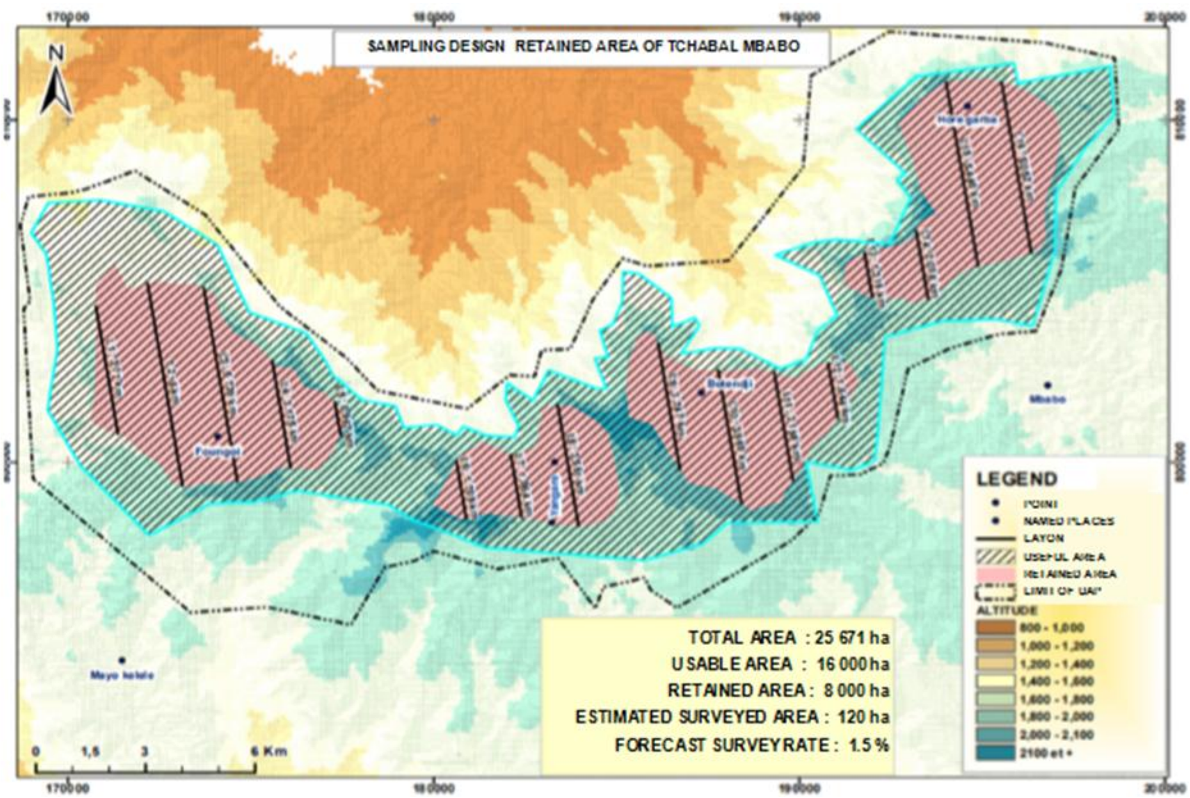

Figure 2. Sampling design.
Source: Authors

thickness of the unharvested side to the diameter. *RCneD = EMCne / MDhp* with *MDhp*: mean diameter at breast height. The Ho assumption here is that the average annual increase in thickness of the unharvested bark increases with diameter over the same period of time. The formula for calculating quotas is: *Qa = De × R × Su / T* where *Qa*: Annual harvesting quota; *De*: Density of harvestable stems; *R*: Productivity or yield in kilograms of dry stem bark from a stem harvested using the 2/4-opposite technique; *Su*: Useful area; *T*: Demi-rotation. The average productivity of a stem (*R*) is as determined by Betti and Ambara (2013); it is equal to 30 kg of dried bark for the 2/4 opposite sides harvesting technic. For carbon stock assessment, the allometric equation developed by Chave et al. (2014) was used for epigenetic biomass estimation: *AGB = exp[-1.803-0.976E+0.976ln(φ) + 2.673ln(D)-0.0299* (ln(D)2] with *AGB*: estimated epigenetic biomass in kg; *E*: environmental index that depends on the geographical coordinates of each plot; *φ*: the specific gravity of the wood in g/cm³; *D*: diameter at breast height in cm. Thus, the carbon stock (in t C / ha) is deduced from the biomass according to the following formula: *(AGBx0.47)/1000* (Zapfack et al., 2013); then it will be converted into ton of carbon per hectare. The graphs and curves were made with Excel 2013, the statistical analyses used are the chi^2 test of independence, one-factor ANOVA, and simple linear regressions using R software version 3.3.2.

RESULTS

Sampling effort

The inventory conducted required 3 production teams. A production team is the one which combines both lining and counting. Each team is composed of six members including 1 GPS operator, 2 botanists, 2 macheters, and one secretary. The three teams counted *P. africana* trees on 23 km for an average sampling effort of 1.9 ≈ 2 km per day per team (Table 1). Twenty-four forest galleries were inventoried by the teams in the four selected villages. A total of 115 plots were delimitated and inventoried, representing a sampling area of 57.5 ha and a sampling rate of 0.72%. The observation made is that the final sampling rate is somewhat different from the theoretical sampling rate designed in advance. Table 2 gives the overall results from the implementation of the sampling design.

Structural features

Stem density

Table 3 presents the densities of *P. africana* stems counted by locality/village. The average density of all villages is 6.23 stems/ha. The density of harvestable stems is 4.8 stems/ha. The sites with the highest density of harvestable stems were Hore Garba (6.93 stems/ha), Foungoi (5.16) and Yangaré (4.61). The total basal area of the Mbabo forest is 57.35 m^2/ha. The most covered

Table 1. Work effort for the inventory conducted in Tchabal Mbabo

Team	Employees	Plots	Length (km)	Period (j)	Work effort (km/j)
1	6	27	5.4	4	1.4
2	6	52	10.4	5	2.1
3	6	36	7.2	3	2.4
Total	**18**	**115**	**23**	**12**	**1.9**

Source: Authors

Table 2. Characteristics of the inventory conducted in Tchabal Mbabo.

Locality	Botendji	Foungoi	Horé Garba	Yangaré	Total MF
Total area	3244.74	5925.34	6814	9687.85	25671.95
Surveyed area (ha)	2022.28	3692.96	4246.82	6037.94	16000
Useful area retained (ha)	1011 .14	1846.48	2123.41	3018.97	8000
Estimated area surveyed (ha)	15.17	27.7	31.85	45.28	120
Predicted sampling rate	0.1	0.5	0.2	0.7	1.5
Number of plots	8	38	15	54	115
Area surveyed (ha)	4	19	7.5	27	57.5
Sampling rate	**0.4**	**1.03**	**0.35**	**0.89**	**0.72**
Sampling effort	**3.3**	**15.64**	**6.17**	**22.22**	**47.33**

Source: Authors

Table 3. Density and basal area of *P.africana* stems in different localities of Mbabo.

Locality	Surveyed area (ha)	Diameter of stems < MDE	Diameter of stems ≥ MDE	Total stems	Density of stems diameter < MDE	Density of stems diameter ≥ MDE	Total density	Basal area
Botendji	4	16	10	26	4	2.5	6.5	1.74
Foungoi	19	41	98	139	2.16	5.16	7.32	17.32
Horé Garba	7.5	5	52	57	0.67	6.93	7.6	16.98
Yangaré	27	20	116	136	0.85	4.61	5.04	21.31
Total MF	**57.5**	**82**	**276**	**358**	**1.48**	**4.8**	**6.23**	**57.35**

Source: Author

locality is Yangaré (21.31 m^2/ha) and the least covered is Botendji (1.74). The average basal area per stem is 0.16 m^2/ha. Figure 3 shows that basal area increases with tree size (diameter at breast height) and not with stem density per unit area.

Distribution of P. africana stems by diameter class

The distribution of the 358 stems recorded by diameter class is illustrated in Figure 4. The general shape of the distribution of the species is bell-shaped with a modal class located in the 30-39 cm range, indicating a limited renewal capacity of the species. Note the presence of a few young stems (10-20 cm in diameter) which are represented at 7.8% of the total number. Ninety-one stems have a diameter smaller than the minimum exploitability diameter (MED) which is 30 cm. Those non-harvestable trees represent 25.42%. The average diameter of the stems is 48.17 ± 19.8 cm. The average height of the stems is 7 ± 4.26 m while the average thickness of the bark on the unharvested side is 14.1 ± 4.72 mm. There were significant differences in these three parameters between the four locations with respective probabilities of 5.68E-13, 0.000293 and 0.000224 for diameter, height and bark thickness (Table 4).

Assessment of epigeous carbon stock

The epigeous woody biomass of the Mbabo forest is

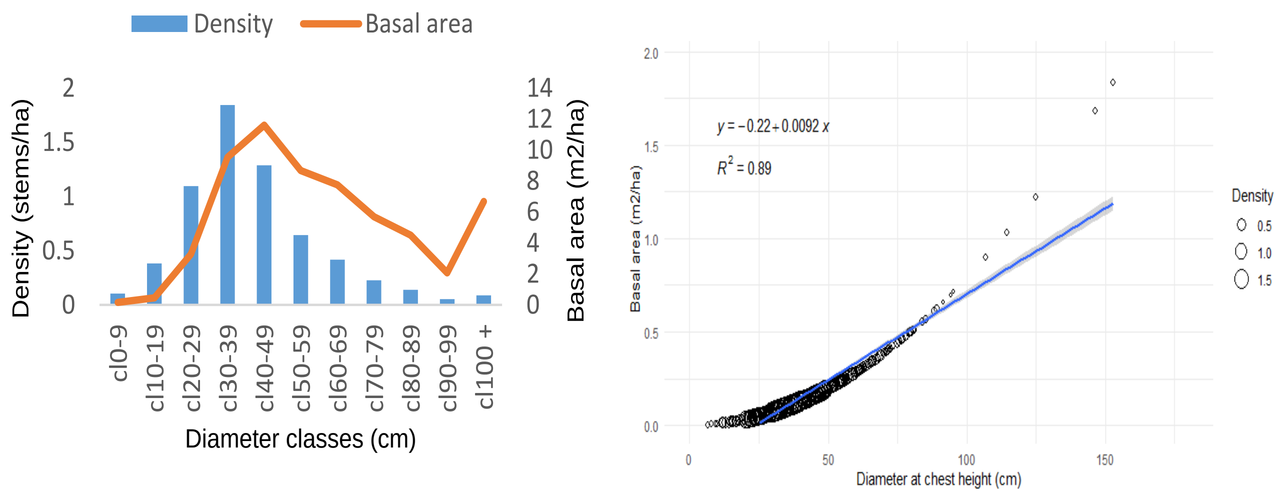

Figure 3. Evolution of basal area per unit area.
Source: Author

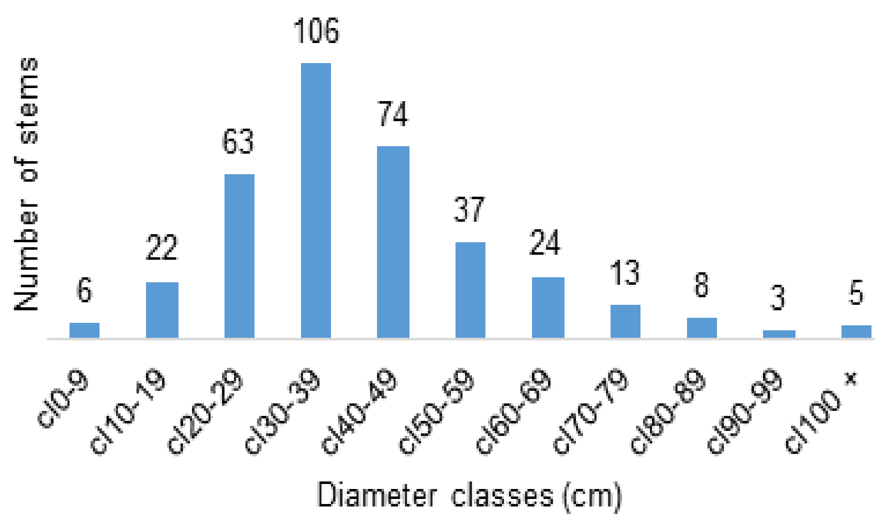

Figure 4. Diameter structure of *Prunus africana* from MF.
Source: Author

Table 4. Average harvestable diameter, average height and average thickness of unharvested bark at Tchabal Mbabo.

Locality	Number of stems	Diameter average (cm)	Height average (m)	Average thickness_not exploited (mm)
Botendji	26	37.3	5.8	15.04
Foungoi	139	43.7	6.2	12.8
Horé Garba	57	60.5	6.7	15.4
Yangaré	136	47.3	8.2	14.9
Average MF	-	48.17	7	14.1
F value	-	21.77	6.444	6.648
Pr (>F)	**-**	**5.68e-13*** **	**0.000293*** **	**0.000224*** **

Source: Author

Table 5. Sanitary status and mortality rate of MFM.

Sanitary status	Causes	Stems (%)	Rate M (%)
Alive	-	342 (95.53)	-
Dying	Previous exploitation, disease	3 (0.84)	-
Dead	Previous exploitation	4 (1.12)	3.63
	Other reasons	9 (2.51)	-

Source: Author

estimated at 1432.75 kg/ha, for an overall epigeous carbon stock (for stems ≥10 cm) of 67.3 ± 0 .0015t C /ha. This corresponds to an estimated financial value of 1,749,800 FCFA/ha (USD 2 859.54).

Response of *Prunus* trees to harvesting

Harvesting technique

Of the 358 stems counted, 94 have been previously harvested, representing 26.25%. Figure 7 shows that several harvesting techniques have been used, including 1/2 (1 over 2) opposite sides, 1/4 (1 over 4) side, 2/4 (2 over 4) opposite sides, 3/4 (3 over 4) sides and 4/4 (total debarking). The technique known as two quarters (2/4) opposite is the most used (79.65%).

Sanitary state of the stems and mortality rate

The majority of the stems exploited or not is alive with a percentage of 95.53%. The few dead and dying stems represent only 4.47% of the total, i.e. a density of 0.28 stems/ha. Mortality due to exploitation is 1.12%, while mortality induced for all other reasons (natural, bush fire, felling, broken tree) is 2.51%. This results in a global mortality rate of 3.63% (Table 5).

Growth parameters and dynamics

The average annual increment of regenerated bark varies among localities depending on the years of harvesting. The average annual increment is 1.3 mm/year, and the significant difference was noted between the four localities (F value = 3.597; Pr(>F) = 0.0166). The greatest is recorded in Botendji (1.48 mm/year). On the other hand, although Botendji has the highest rate of thickness recovery (70%), there is no general difference between the four localities (F value = 2.365; Pr(>F) = 0.0763) (Table 6). A relationship exists between the thickness of unharvested bark and the diameter at breast high (dhp) (X-squared = 4544.9, df = 4224, p-value = 0.0003206). The average annual increment in unharvested bark thickness is assessed here on the basis of the ratio: bark thickness by diameter. This shows that for a mature stem, the growth (size) of the unharvested bark is 3.7% of that of the diameter for the same growth period (Table 7). Figure 8 illustrates this relationship. It can be deduced that the growth rate of unharvested bark decreases with the growth in diameter during the same period. This is explained by the exponential equation $y = 10.05e^{-0.209x}$ with a correlation coefficient $R^2 = 0.9542$.

Management measures

Distribution of P. africana according to the elevation and distinction of suitability zones

Figure 5 illustrates the distribution of stems by altitude or elevation class. Most of the *P. africana* stems are found in the 1700-2100 m altitude classes, representing 90%. Ten percent are between 1500-1700 m and no stems were found above 2100 m. One significant difference is noted (F value = 11.31; P(>F) = 4.19e-07) between these spatial positions of stems in the 4 surveyed localities. The analysis of the distribution of *P. africana* stems according to their elevation allows to estimate its density by zone including: the low altitude zone (below 1300 m) where the species is almost absent, the altitude zone between 1300 and 1700 m where *P. africana* exists but at low densities, the zone between 1700 and 2100 m considered as the occupation zone per excellence (high densities) and the zone above 2100 m, marked by the absence of *P. africana* but colonized most often by grassy meadows Figure 6 illustrates the spatial distribution of *P. africana* densities in the four villages. The analysis of the distribution of *P. africana* stems by altitude class makes it possible to propose a map of activities to be carried out specifically in relation to *P. africana* (Figure 9) in the four altitude zones identified:

1. Altitude zone below 1400 m (the species is almost absent): no activities related to *P. africana* should be carried out;
2. Zone of altitude between 1400 and 1700 m (the species exists but at low densities): zone with favorable conditions for the development of *P. africana* which could

Table 6. Annual growth and recovery rate of harvested stems at Tchabal Mbabo.

Locality	Year	Period	Stems	Height	Dhp	EMCne	EMCe	AAMEr	TREee
Botendji	2011	10	9	7.22	31.68	21	14.78	1.48	70
Foungoi	2011	10	13	5.47	44.11	13.17	8.62	0.86	65
	2013	8	26	5.87	38.23	18.73	8.88	1.11	47
Average Foungoi	2012	9	39	5.73	40.2	15.95	8.75	0.97	56
Hore garba	2015	6	22	6.73	64.92	16.82	8.45	1.41	50
Yangare	2014	7	24	8.92	48.08	15.79	9.58	1.37	61
Average MF	2013	8	94	7.15	46.22	17.39	10.39	1.3	60
F value				4.359	9.686	3.274	6.486	3.597	2.365
Pr (>F)				0.00649**	1.32e-0.5***	0.0247*	0.000504***	0.0166*	0.0763

EMCne: Average bark thickness on the unharvested side (mm); EMCe: Average bark thickness on the harvested side of harvested stems (mm); AAMEr: Average annual increment of regenerated bark (mm/year); TREee: Thickness recovery rate of logged bark (%).
Source: Author

Table 7. Ratio of unmined bark thickness to diameter in the wild.

Locality	Stems	EMCne	Dhp	RCneD
Botendji	26	15	292.03	5.2
Foungoi	143	12.81	365.88	3.5
Hore garba	57	15.37	574.61	2.7
Yangare	135	14.89	426.29	3.5
Average MF		14.53	414.70	3.7
F value				3.343
Pr (>F)				0.0194*

EMCne: Average bark thickness on the unmined side (mm); Dhp: Diameter at breast height (mm); RCneD: Ratio of unmined bark thickness to Dhp (%).
Source: Author

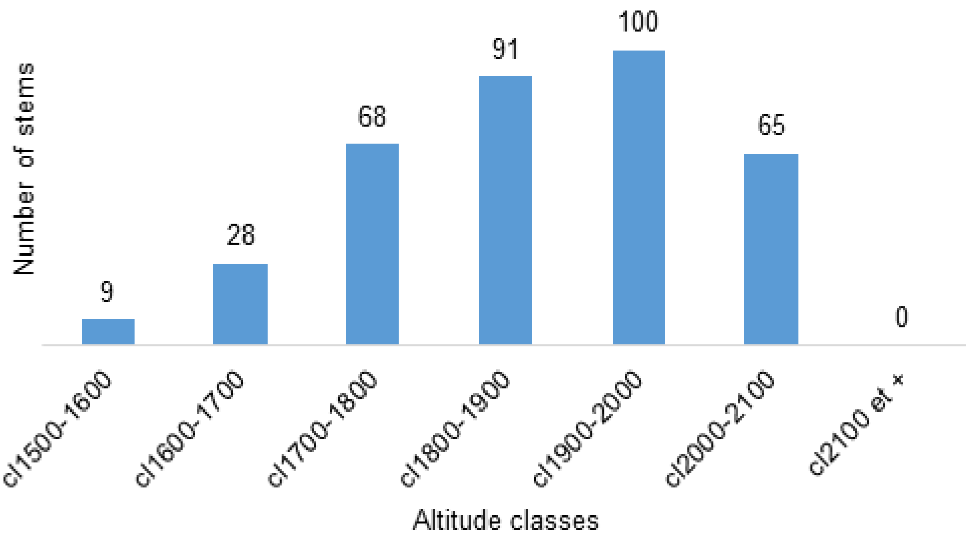

Figure 5. Distribution of *P. africana* stems according to altitude classes.
Source: Author

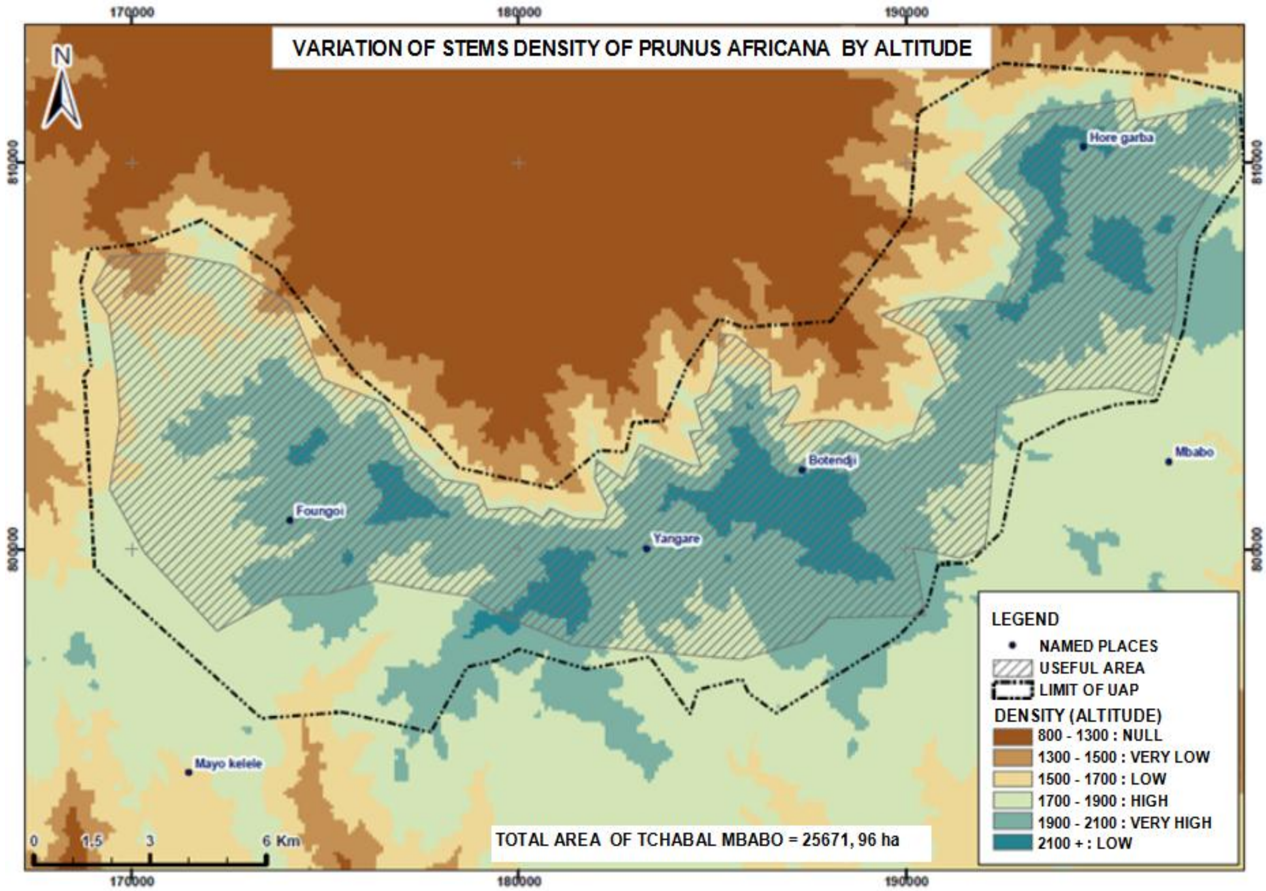

Figure 6. Relative suitability zones of *P. africana* in the MF.
Source: Author

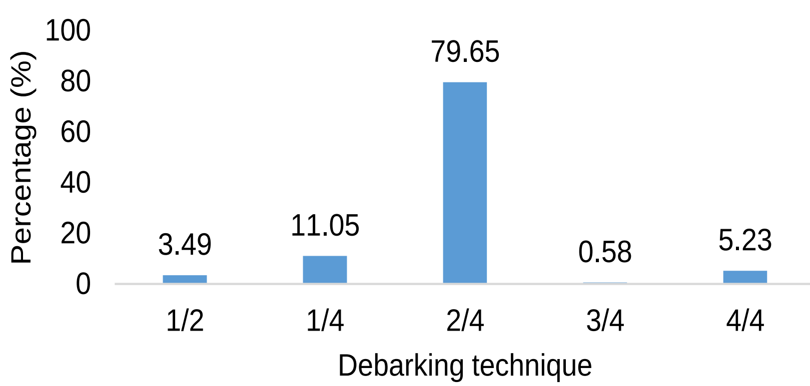

Figure 7. Identified harvesting techniques.
Source: Author

constitute a favorable area for the establishment of *P. africana* plantations (agroforestry). There should be no exploitation of natural populations of *P. africana* in this area;

3. Zone between 1700 and 2100 m (high densities of the species): zone where the bark of *P. africana* should be harvested in the wild and where agroforestry is still possible, but using enrichment practices;

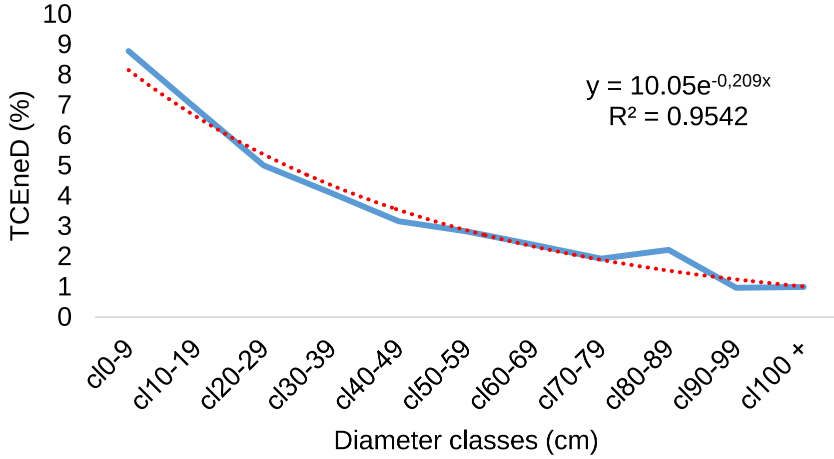

Figure 8. Growth of unharvested bark as a function of diameter
Source: Author

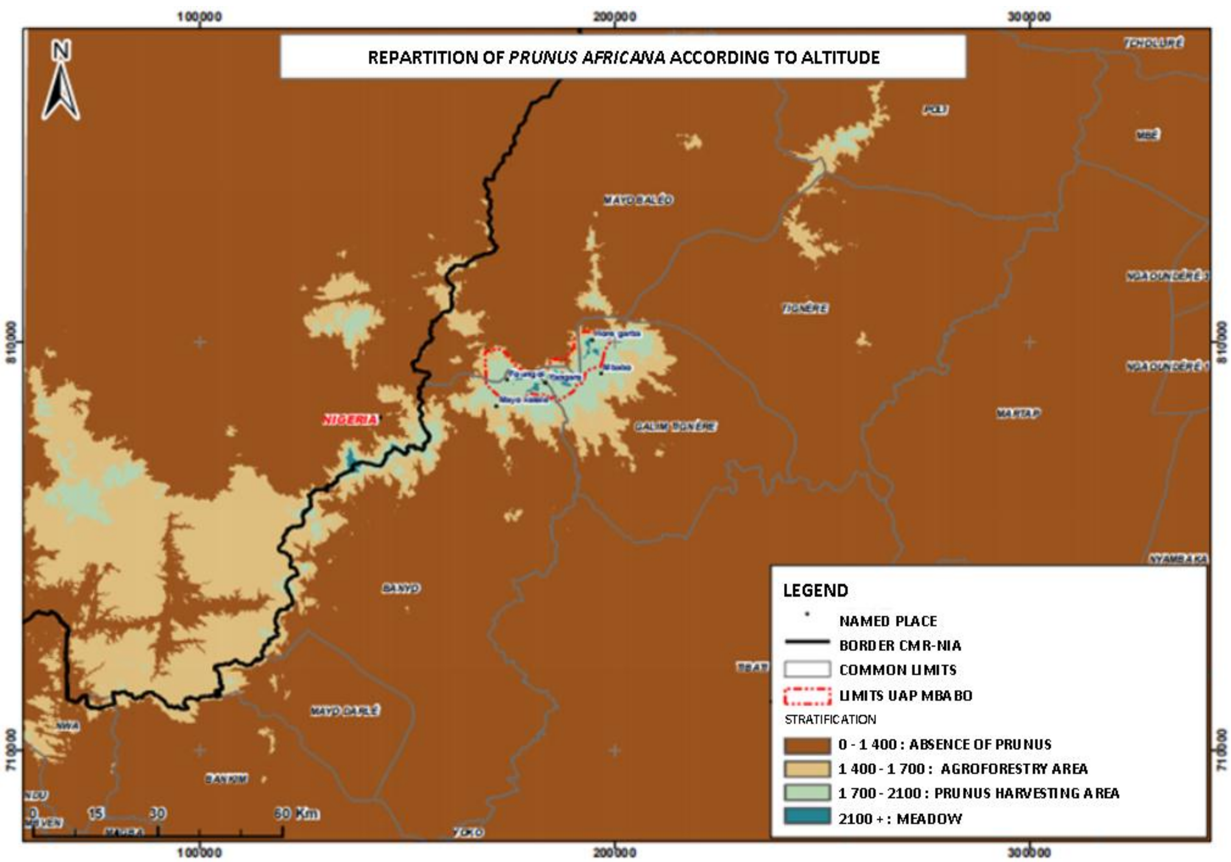

Figure 9. Activities by area based on stem density variations by altitude.
Source: Author

4. Zone of altitude more than 2100 m (almost null or accidental presence of the species): zone colonized most often by the grassy meadows.

Debarking techniques

Several debarking techniques guarantee the regeneration

Table 8. Unharvested bark growth as a function of diameter in the wild.

MF	EMCne	AAMEr	Rotation	Half-rotation
	17.39	1.3	13.39	6.69

EMCne: Average bark thickness on the unharvested side (mm); AAMEr: Average annual increment of regenerated bark.
Source: Author

of the bark after the exploitation. Taking into account the ageing aspect of the stems, the weak regeneration recorded in this massif, for practical reasons on the ground and to facilitate the follow-up of the rotation; two techniques can be proposed to know:

1. Two opposite 1/ 4 or (2/4) for stems between 30 and 70 cm;
2. Four opposite 1/8 or (4/8) for stems over 70 cm

Rotation

The time required for a second harvest is presented in Table 8. It is obtained from the AAMEr (Average Annual Increase in the Regenerated Bark). To harvest bark from the same strip of regenerated bark at Tchabal Mbabo, it would require an average time of 13.39 years or 14 years. This means that to come back on the same tree but on the remaining opposite side, the harvester will need to wait 6.69 ≈ 7 years, representing the half rotation.

Annual possibility or annual quota (case of localities)

The annual exploitable quota in dry tons of *P. africana* bark is presented by explored locality in Table 9. This quota is 164.6 tons for the entire Tchabal Mbabo Forest.

DISCUSSION

Sampling effort

A total of 115 plots were scanned by the inventory teams representing a sampling area of 57.5 ha. The survey rate is 0.72%. The actual sampling data obtained in the field, are somewhat different from the theoretical sampling data designed. This discrepancy is due to the difficulties encountered in the field, the most significant of which are those related to the excessively uneven terrain in some places. Nevertheless, the sampling rate obtained, which is not too far from the 1% proposed by the forest inventory standard (MINFOF, 2019) is still very high, at least time 6 higher compared to similar inventory campaigns conducted in previous years in the same area including the sampling rate of 0.1% realized in 2004 by ONADEF (2005), 0.12% in 2011 by ANAFOR under the ITTO-CITES Program (Akoa et al., 2011b), and 0.04% in 2021 by TRAFFIC International (Hiol Hiol, 2021). At Lume (North Kivu) in the Democratic Republic of Congo, *P. africana* inventories were carried out at a sampling rate of 1.2

Structural features

The average density of all stems is 6.23 stems/ha. This density is lower than 7.94 stems/ha found in Mbabo (Akoa et al., 2011b), 7.18 found in Bioko Island/Equatorial Guinea (Navarro-Cerrillo et al., 2008; Muñoz et al., 2006) and 7.2 stems/ha in Ethiopia (Chaffey, 1978). However, our density is higher than the 3.43 stems/ha found in Mount Cameroon (Betti et al., 2011). On the other hand, the exploitable stem density is 4.8 stems/ha, which is much higher than 1.79 stems/ha and 2.68 stems/ha obtained respectively at Tchabal Ngandaba and Tchabal Mbabo (Akoa et al., 2011b). This shows that the growth of future stems inventoried in 2011 is effective. The low density of young stems shows that Tchabal Mbabo suffers from regeneration problems. The *Prunus* basal area is 57.35 m^2/ha. The average basal area for a stem is 0.16 m^2/ha, which is lower than the 0.94 m^2/ha obtained in the Bioko Island (Navarro-Cerrillo et al., 2008). Basal area increases with diameter at breast height, not with stem density. Betti et al. (2021) found for *Pericopsis elata* that the stand basal area increases with both tree density and diameter at breast high. Contrary to Yankam, (2013) in Mount Cameroon and Ronoh et al. (2018) in South west Mau Forest (Kenya) found an inverted "j" structure, the distribution of the 358 stems surveyed is bell-shaped. This clearly shows that *P. africana* suffers from some regeneration problems in Mbabo. *P. africana* is a light demanding tree species. For this reason, the number of small stems is often low in primary or non-perturbed forest, due to the lack of light (Durieu de Madron, Forni and Meok, 1998), which tends to suggest that forest logging can be a tool for sustaining ligh demanding tree species. The very low presence of young stems (10-20 cm in diameter) at 7.8% could be due to the death of shoots by competition linked to the absence of light, or to bush fires. In Gabon, Bayol and Borie (2004) present the bell-shaped as the dominant structure of highland forests. Damage caused to the regeneration of stands can constitute a risk for the future of the sustainability of stands (Ellis and Putz, 2019) because the future of forests depends on adequate and safe natural regeneration (Cruz et al., 2021). These regeneration problems can also be explained by its low rate of propagation by its seeds due to its long flowering cycle and its recalcitrant seeds (Komakech et al., 2020). In Mbabo, the average stem diameter is 48.17 ± 19.8 cm and the average height is 7 ± 4.26 m. These are respectively lower than the 101.17 cm and 23.87 m

Table 9. Distribution of annual quota in the different localities explored.

Localities	Useful area (ha)	Useful area of Mbabo (ha)	Density of stems diameter≥ MDE	Average productivity of a stem in dry matter weight (Kg)	Half-rotation	Annual quota (Tons)
Botendji	1011.14		2.5	30	7	
Foungoi	1846.48		5.3	30	7	
Horé Garba	2123.41		6.9	30	7	
Yangaré	3018.97		4.4	30	7	
Total/Mean	**8000**	**16000**	**4.8**	**30**	**7**	**164.6**

Source: Author

obtained in Kenya in the South Nandi forest (Koros et al., 2016). Betti and Ambara (2013) obtain an average diameter of 68.07 cm in Mbabo. In Equatorial Guinea (Pico de Basilé and Moca) stems reach 24 m in height (Muñoz et al., 2006). When the trees reached 50 cm in diameter, they reached their maximum height (Namuene and Egbe, 2022). In three Mugaga plantations in Kenya (Nyamai et al., 2015) obtained an average diameter of 34.73 ± 13.51 cm for stem 8.36 ± 1.22 m in height.

In Mbabo, the average thickness of the bark on the unharvested side is 14.1 ± 4.72 mm. This value is high than the 12.03 mm found by Lekefack (2016) in Mount Cameroon. The high value of the thickness of the bark obtained in Mbabo may be link to the presence of frequent bush fires in the area compared to North west and South west regions. Shafer et al. (2015) demonstrated that large bark thicknesses are correlated with the time necessary for Cambium to reach dead temperatures and, thus, constituted a strong predictor of resistance from the rod to the bush fire.

Response of trees to harvesting

In Mbabo, 95.53% of the stems, whether harvested or not, are alive, showing a mortality rate of 3.63%. Stewart (2001) estimated the annual mortality of adult trees in *P. africana* natural populations at 1.5% in Mount Oku, North west Cameroon. The bush fires is one of the main causes of mortality *of P. africana* stems in Mbabo area. The exploitation of tree bark very often has a very high impact on biodiversity because an intense exploitation of bark exposes the sapwood to the attacks of pests. This weakens the biological functioning of the tree and can cause their death and this, especially in the rainy season (Bayoi et al., 2021). Across the Mbabo forest, the average annual increment in regenerated bark thickness is 1.3 mm/year, with a significant difference between the 4 localities (F value = 3.597; Pr(>F) = 0.0166). This increment is much higher than the 0.61 mm/year in Kumbo plantations (Betti et al., 2019). However, it is smaller than the 1.85 mm/year found at Mount Cameroon (Lekefack, 2016) and also the 2.15 mm/yr obtained from Fundong plantations (Betti et al., 2019). Interestingly, tree size has an effect on bark recovery rate for *P. africana* (Momo et al., 2016). Nkeng et al. (2010) found that for the first two years after debarking, increment is 0.15 cm/year and this decreases over time at 0.06 cm/year. Solefack and Kinjouo (2017) show in their study in the South west Cameroon that, the bark levy causes a sharp reduction or a slowdown in the growth in thickness of the rod for the benefit of the renewal of the bark surface taken. The reconstitution rate of regenerated bark in thickness is 60%. This rate of over 50% shows that the species has a great capacity for regeneration. However, this regeneration can be influenced by the harvesting period, the spatial position (altitude) or by the diameter of the tree. According to Momo et al., (2016), the rate of bark recovery is influenced by several factors: season and intensity of landing, tree size and altitude. In the montane southern Cape forests of South Africa, the differences in the regeneration process observed at the levels of species and individuals are associated with the intensity of tissue damage and the cutting season (Beltrán et al., 2021). The correlation between unharvested thickness and diameter shows that the growth rate of unharvested bark is 3.7% of diameter growth. The growth rate of the bark decreases over the years with the growth of the diameter of the tree. The younger is the tree, the more important is the growth rate. Betti et al. (2019) found that the thickness of the bark increases with the diameter of the tree beyond a certain level before it starts decreasing. The average bark thickness varies from one diameter class to another. Changes in diameter classes result in variations in bark thickness of *P. africana* (Tadjuidje, 2011). Light also could play an important role in this report. It is an environmental factor that influences plant growth because it is a crucial requirement for photosynthesis (Nyamai et al., 2015).

Management measures

Four major zones of variable Prunus density can be identified between 1400 and 2100 m. It is practically in this altitude interval (1400 to 2500 m) that the stems are found in Equatorial Guinea (Navarro-Cerrillo et al., 2008). In Tchabal Mbabo, 90% of *P. africana* stems are found at altitudes of 1700 to 2100 m (very high density). This can be explained by the fact that it is in this interval where the majority of forest galleries are present, which favors a low temperature climate (favorable environment for the species). In the same line, Awono et al. (2015) stated that the distribution is significantly influenced by altitude, temperatures, rainfall and cloud cover. For the area below 1300 m the temperature is higher, thus not favoring the development of the species. Given these regeneration problems and its low density, it would be interested in turning to the agroforestry or plantations. A study at the center of the Uganda noted that 73% of the population (farmers) around the forests received and granted a favorable opinion to the domestication of the species (Galabuzi et al., 2021). Five harvesting techniques are identified: 1/2, 1/4, 2/4, 3/4 and 4/4. The technique known as two quarters (2/4) opposite sides is the most used (67.8%). This result is close to that of Betti et al. (2019) where six harvesting methods were recorded in northwestern agrosystems. In both of these cases, the 2/4 opposite technique was also the most used. Wete (2022) noted that two legal techniques including 2/4 and 4/8, and two illegal techniques 3/6 and total debarking were used in the Mount Cameroon production site. The so-called legal techniques resulted in the death of 4.12% of stems and the decline of 20.58% of stems. In the North-west Region, three harvesting techniques were identified in community forests and six techniques in agroecosystems. This observation of several harvesting techniques may be justified by the incompetence of the harvesters, or by their desire to increase the amount of the bark harvested in order to earn more money. However, precious efforts have been made to establish good standardization, as well as specific guidelines for good practices of harvesting medicinal plants (Pandey and Das, 2013). Betti et al. (2016) reveal during a socioeconomic study in Mount Cameroon and the state of the exploitation measures of *Prunus africana* in the South west that operators do not regularly apply the recommended methods because of the very damaged relief for some and the price per kilometer very low for others. Geudje et al. (2016) evaluated the capacity of *Garcinia kola* trees to regenerate their bark after the harvest. A debarking species can survive if it can overcome the trauma of the targeting and develop new tissues (hardening and thickening of the epidermis) which allow it to ensure its survival (Solefack and Kinjouo, 2017). The rate of stand recovery is influenced by the natural diametric growth rate of the tree. During a half rotation there are stand dynamics, including stem recruitment and bark growth. If stem recruitment is not high, this will have a negative impact on the harvestable quota for the new half rotation. Wete (2022) obtained an annual diameter increment for *P. africana* of 0.42 cm/year in Mount Cameroon. For plantations in the Northwest the increment is 0.91 cm/year (Betti et al., 2019). Bark regrowth is more reliable and accurate in some areas with favorable climatic conditions than others (Cunningham et al., 2016). However, aside from environmental conditions, poor harvesting practice could increase mortality rate or diameter growths, which are also key factors in recovery/recruitment. Damage to young trees has a long -term impact on the regeneration process (Danilović et al., 2015), and diameter growth can be reduced by 10 to 20 % due to surface injuries (Yilmaz and Akay, 2008). Using the productivity of a stem which is 30 kg (Betti and Ambara, 2013), the annual exploitable quota of dry matter of *P. africana* bark is 164.6 tons for the 8 000 ha of useful forest delimitated in the four villages inventoried. This represents about 0.021 tones/ha. This quota could be important if the useful area was even greater. But Bodeker et al., (2014 notes a great decrease in the geographic distribution in sub -Saharan Africa of this species of canopy caused by farming, slash-and-burn agriculture and the construction of habitats. This is also the case with Tchabal Mbabo. All the same, this quota is higher, times 8 than the 473.245 tons obtained on 120 994,08 ha for a half rotation of 5.5 years in Mbabo in 2011 by ANAFOR (Akoa et al., 2011b) and which represents 0.003 tons/ha for the same half rotation (7 years). This could be explained by the fact that our inventory focused on sites indicated by local people as production sites of *P. africana.*

Conclusion

Forest inventories conducted in the Mbabo forest reveal that *P. africana* has a good stem density (6.23 stems/ha) with a basal area of 57.35 m^2/ha. The average bark thicknesses are 14.1 ± 4.72 mm and 10.39 ± 4.22 mm for the unharvested and harvested sides respectively. The annual bark growth is 1.3 cm/year for a recovery rate of 60%. The surveys and forest inventories conducted have made it possible to estimate a first annual exploitation quota for *P. africana* of 164.6 tons/year in Tchabal Mbabo for a half rotation of 7 years. This quota is to be harvested from a useful area of 8000 ha between the altitudes of 1700 and 2100 m. This massif suffers from regeneration because young trees are not very abundant. Agroforestry would be beneficial for this forest in areas where the species is present but at low density to increase its potential, at the altitude 1 300-1 700 m to be precise.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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