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Original Research Article

Monitoring the harvesting of the barks of *Prunus africana* (Hook.f.) Kalkman (Rosaceae) in the agroforest systems of North-West region of Cameroon

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Prunus africana **(Hook.f.) Kalkman is a specie of the Rosaceae family, known under its trade name as pygeum or African cherry. The bark is the major source of an extract used for the treatment of benign prostatic hyperplasia. From 2008-2011, Cameroon government with the assistance of the ITTO-CITES Program has managed to regulate the harvesting of *Prunus africana* in natural forest. The reality is quite different in the field since harvesters have focused on the *Prunus* found in agroforest systems to satify the demand of the international market. This paper therefore aims to monitor the harvesting of barks of *P. africana* in agroforest systems found in the North west region of Cameroon. Inventories were conducted in August, 2016, in 17 *P. africana* plantations located in the following three subdivisions: Fundong in the Boyo division, Kumbo in the Bui division, and Tubah in the Mezam division. The density of *P. africana* recorded is 5.15 trees/ha. The exploitable stems represent only 7.5%, illustrating that these plantations are still very young. This feature is confirmed by the low value of the average diameter of trees 10.79±5.67 cm and the average thickness of the bark 5.01±1.71 mm. The average diameter annual increment is 0.91±0.46 cm/year, while the average regeneration rate of the bark is 1.91±1.03 mm/year. The diameter annual increment increases, while the regeneration rate of the bark decreases with diameter at least till 40 cm diameter. The harvesting of *Prunus* bark done in those plantations till now is non-sustainable, since harvesters do not respect advised norms which are the minimum exploitable diameter (MED) of 30 cm and the use of 2/4 and 4/8 techniques of debarking. The combination of the two elements related to the respect of norms (MED and the harvesting technique), reveals that 91% of trees are harvested unsustainably. The analysis done on the regeneration rate tends to show that, the more the young *Prunus* trees are traumatized, the more they develop capacity of regenerating their bark, at least till ages of 10-12 years and at diameters 30-40 cm. Harvesting activity does not induce the death of trees, but it causes the wilting of some trees. The use of non-sustainable harvesting techniques including the ½ side and the total debarking is the main cause of the wilting of trees.**

Key words : Agroforest systems, *Prunus africana*, CITES, monitoring, harvesting techniques, sustainable, growth rate, regeneration rate, thickness of the bark.

INTRODUCTION

Prunus africana (Hook.f.) Kalkman (formerly *Pygeum africanum* Hook.f.) is a specie of the Rosaceae family, known under its trade/pilot name as pygeum or African cherry. It is a mountain tree specie of tropical Africa, found in Côte d'Ivoire, Bioko, Sao Tome, Ethiopia, Kenya, Uganda, South Africa, Madagascar, Congo, the Democratic Republic of Congo, Mozambique, Tanzania, Burundi and Cameroon. *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 Adamawa, North-west, Littoral, South-west, and West. *P. africana* is an evergreen canopy tree of about 30 m tall with thick, fissured bark and straight bole that can reach a diameter of 1.5 m. It requires adequate sunlight and responds well to cultivation (Hall et al., 2000; Vivien and Faure, 1985; Fraser et al., 1996; Tchouto, 1996).

More wild harvested barks from *Prunus africana* are internationally traded than from any other African medicinal plant species (Cunningham et al., 2016). The bark is the major source of an extract used for treatment of benign prostatic hyperplasia, an increasingly common health problem in older men in the western world. By 2003, the trade on dried pygeum bark and its extract was in the order of 3 000 to 5 000 tonnes a year (Page, 2003) and the main sources were in Cameroon, Madagascar, Equatorial Guinea, Kenya, Uganda, and Tanzania. *P. africana* is classified by the World Alliance for Nature (IUCN) as vulnerable species, which led to its listing in the Appendix II of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) in 1994, and became effective in 1995 (Sunderland and Tako, 1999).

The CITES Secretariat realized the challenges faced by the states of the CITES listing species in implementing CITES requirements and 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 *P. africana*. This partnership in the frame of the so called "the ITTO-CITES program" has been strengthened considerably and has funded national activities to assist non-detriment findings (NDFs) by conducting inventories, developing 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 projects in Africa. The assistance of the ITTO-CITES Program to date in Cameroon on *P. africana* has focused on the development of non-detriment findings (NDFs), simple management plans (SMPs) and resource inventories for key production regions (Adamawa, North West and South West) using limited funds provided by the private sector. The NDFs reports and SMPs proposed the following specific measures to consider prior to or during harvesting of the bark: adoption of a rotation (length of time between successive debarkings), dividing the useful area of each forest in equal annual blocks (clusters) according to the rotation, conducting 100% inventory of exploitable trees with standard methods and equation for calculating harvestable yield quotas for each cluster prior to setting annual quota and proper exploitation, applying prescribed norms for harvesting the *Prunus* barks such as the minimum exploitable or harvesting diameter (MED = 30 cm), the use of 2 x ¼ opposite sides or 4/8 methods of harvesting, harvesting only living trees, and setting tracking systems (Betti et al., 2016). The harvesting quota proposed within the ITTO-CITES program was restricted to the natural resource (wild *Prunus*).

However, the reality is quite different in the field. The harvesters do not respect the established rules ; harvesting is not limited to managed forests (community forests) and to the defined annual plots, the MED and the rotation are not respected. Also, the harvesters together with their partners have versed to the *Prunus* found in agroforests systems (plantations) to satify the demand of the international market. They use documents (way bills) of the natural *Prunus* to convey their products to the exit points (Betti et al., 2016). In their review of the power, policy and trade of *P. africana* bark, Cunningham et al. (2016) emphasized the future of the *Prunus* trade on cultivated products/plantations. They considered that the costs of inventory, monitoring and managing sustainable wild harvests are far greater than the benefits to harvesters. Without the current substantial international donor subsidies, the exploitation of *Prunus* barks cannot be sustained. What is required to supply the current and future market is to develop separate, traceable *P. africana* bark supply chains based on cultivated stocks. On-farm production would benefit thousands of small-scale *P. africana* farmers , including local women, for whom wild harvesting is too dangerous. Since then (2016), Cameroon CITES Management authority requests the CITES Secretariat to allow some quota of *Prunus* barks to be harvested in plantations. But the CITES Secretariat still have some doubts regarding those products, and is waiting to have clearer perspective on their potential in order to avoid confusion. A follow-up study showed that cultivation of *P. africana* was an economically viable option and suggested it (Cunningham et al., 2002). However the production potential of planted stands is still poorly documented (Cunningham et al., 2016).

This paper aims to monitor the harvesting of *Prunus africana* in agroforest systems found in the North-west region of Cameroon in respect of the harvesting norms and the impact of the harvesting on trees.

MATERIALS AND METHODS

Study area

The North-west region of Cameroon is located between 5°4' and 7°15' latitude North and 9°30 and 11°15 longitude East. The North-west region is composed of 7 divisions including: Mezam (Bamenda being the capital), Boyo

(Fundong), Bui (Kumbo), Ngoketunjia (Ndop), Donga Mantung(Nkambé), Menchum (Wum) and Momo (Mbengwi). This region covers a total surface area of 17 812 km^2 and hosts a population of 1 840 500 inhabitants; which gives a density of 103 inhabitant/km^2. It is characterized by hilly landscape with steep slopes increasing the rate of erosion. Deep valleys and flat plain-like features are limited to some depressions like Baiso. The climate is characterized with two seasons: the rainy season which starts from March and ends in October, and the dry season which is from October to March with February having the highest mean monthly temperature of 23°C. The average annual rainfall is 2400 mm, with an air humidity of 82%. The vegetation of this area is afro-montane, ranging from 500 m to 2230 m above sea level and is dominated by humid savannah with patches of sparse or thick montane forest galleries within depressions (Letouzey, 1985). Farming is the main economic activity in the area with coffee, cola nuts, beans, corn and Irish potatoes being the main cash crops (Focho et al., 2009; Sop et al., 2015; INS, 2015).

The city of Fundong is the sub-divisional headquarter of the Fundong subdivision, in the Boyo division. The sub-division falls between latitudes 6° 04' and 6° 20' N and between longitudes 10° 11' and 10° 30' E. Fundong is located at 68 km from Bamenda, the political capital of the North-west region. The average annual temperature ranges from 24.5 to 29.7°C, while the average annual rainfall is 2 400 mm. The subdivision of Fundong has a total surface area of 1519 km^2 with an estimated population of about 200000 inhabitants unevenly distributed across the entire surface area with Fundong city alone having 47104 inhabitants. The subdivision has 34 villages.

Kumbo city is the headquarter of the subdivision of Kumbo, in the Bui division. It is located at an altitude of about 2 000 m. The subdivision of Kumbo falls between 06°12'00'' latitude North and 10°39'36'' longitude East. The total surface area of the subdivision is 83 079 km^2. The average annual temperature is 19°C, while the average annual rainfall is 1 873 mm.

Tubah subdivision belongs to the Mezam division. The city is situated at 15 km from Bamenda, and falls between 05°59' and 06°10' latitude North and 10°10' and 10°15' of longitude East. The average annual temperature is 19.7°C, while the average annual rainfall is 1 800 mm.

Data collection and analysis

Field trips were carried out in August, 2016 in the following three subdivisions Fundong, Kumbo and Tubah. Before embarking on the field (plantations), the study team held several meetings with different forest administration officers in the external services (regional and divisional delegates of forestry and wildlife). *Prunus* plantations were selected with the assistance of the divisional Delegate of Forestry and Wildlife (DDFW) of each division. A field guide with adequate knowledge of *P. africana* plantations owners was assigned by the DDFW. He facilitated the contact with the farmers and assisted in data collection.

For each farmer identified and who accepted to participate in the study, information on the age of the plantation (settlement year) and the year of the last harvesting campaign was collected. The second step consisted of measuring the total surface area of the Plantation, the counting of *Prunus* trees, and the gathering of dendrometrical and dendrological parameters.

Dendrometrical parameters recorded for each *Prunus* tree included: diameter of the stem at breast high (DBH) and the thickness of the bark. The thickness of the bark was measured with the aim to appreciate the regeneration rate of the bark. For each harvested tree, measurements were taken on the two sides including the harvested side and the non-harvested side. For each side, a small rectangular portion of the bark was collected, prepared, and the thickness of the bark was measured on each of the four sides of the portion using a calliper rule.

Dendrological parameters recorded on each *Prunus* tree included: the harvesting technique used during the last harvesting campaign and the health of the tree. The following harvesting techniques are advised by the forest administration, to sustain the harvesting of *P. africana*: harvesting the two opposite quarters (2/4 opposite sides) for trees with diameter between 30 and 90 cm, and the harvesting of the 4/8 of the bark in opposite layers for trees with diameter greater than 90 cm (Parrot, 1989; Ndam, 1996). Anyother technique used apart from the two cited is considered as non-sustainable. The health of each *Prunus* tree was appreciated and classified as follows: living trees or trees with no health problem, with all leaves and branches alive, wilting trees or trees with some leaves and branches dead, and dead trees or trees which have all leaves and branches dead.

For data analysis, we calculated the density (D) of *Prunus* in each farm, the diameter increment or diameter growth rate (DGR) and the regeneration rate of the bark (BRR):

- Density (D): density represents the number of stems recorded (N) /surface area (S), D = N/S; it is expressed in number of stems/ha;
- Diameter increment (DGR): DGR = d/Ap, where d = diameter of the tree at breast high (cm) and Ap = age of the plantation (years); it is expressed in cm/year;
- Regeneration rate of the bark (BRR): BRR = Th/Ad, where Th = thickness of the bark (mm); and Ad = age of debarking (years); it is expressed in mm/year.

Quantitative data were analyzed with the Microsoft EXCEL 2013 and R version 3.5.1 (2018-07-02), Ri 386 computer packages. Analysis of variance (One-way ANOVA) was used to assess different parameters between different subdivisions and different diameter classes.

RESULTS

Sample

A total of 17 plantations belonging to 15 farmers

Table 1. Agroforest systems of *Prunus africana* inventoried in the North West region of Cameroon

Subdivision	Village	Owner (farmer)	Number of plantation	Year of settlement	Surface area (ha)	Number of Prunus stems
	Abuh	Song Nelson	1		4	151
	Fujua	Garba dalladji	1	2005	5	301
		Inconnu	1	2005	0.2	48
		Kuma flaurence	1		0.6	31
	Muteff	Mbang cyprien	1		2	4
		Mbang john	1	2006	3	35
		Fuchi clement	1	2006	4	36
		Sani Clement	1	2002	0.5	30
		Sani Françis	1	2002	1.5	15
		Timnge Augustin	1	2010	2	15
	Laikom	Nyankan hermanous/Ngoh tadious	1		1.5	62
Fundong		Peter	1		2	37
Kumbo	kumbo	Joseph	2	2004	0.25	24
				2007	0.25	42
		Uncle of Joseph	1	2002	0.7	37
Tubah	Kedjom	Alenghang mose	2	1995	164	45
	Ketinguh			2006	5	100
Total	06	15	17		196.5	1 013

Table 2. Dendrometrical parameters of *Prunus* plantations in the North West region

Subdivision	Fundong	Kumbo	Tubah	total
Number of plantations	12	3	2	17
Surface areas (ha)	26.3	1.2	169	196.5
Total number of stems	765	103	145	1013
Number of exploitable stems (diameter ≥ 30 cm)	69	4	3	76
Density of total stems (stems/ha)	63.75	85.83	0.86	5.12
Density of exploitable stems (stems/ha)	2.62	3.33	0.02	0.38

distributed in 06 villages and three subdivisions was prospected (Table 1). The plantations were settled between 1995 and 2010. A total of 1013 *Prunus africana* trees were inventoried systematically in these plantations distributed in the three subdivisions prospected as follows: Fundong (765 trees), Kumbo (103), and Tubah (145).

Dendrometrical parameters

Table 2 presents the distribution of dendrometrical parameters per subdivision. The density of *P. africana* in agroforest systems in the Boyo division was 5.15 trees/ha. A total of 76 trees recorded were considered as exploitable, or trees with diameter at least equal to 30 cm. Their density was 0.38 stems/ha, representing only 7.5% of the total number of trees. The Kumbo subdivision had the highest density of exploitable trees, 3.33 stems/ha.

Diametric structure of *Prunus* stems

Diameters of *Prunus* stems were distinguished in seven classes of 10 cm. The distribution of stems in different diameter classes is illustrated in Figure 1. The figure shows a reversed J-Shape which indicates that the plantations are still too young, with classes 0-10 cm and 10-20 cm representing 77% of the whole population. Exploitable stems are mostly illustrated by two classes: 30-40 cm and 40-50 cm which represents 97.2% of the 76 exploitable stems recorded

Health of the plantations

A total of 38 trees were dead (3.7%), while 17 were wilt (1.7%). The remaining 964 representing 95.16% were composed of living trees, which shows the global good physionomy of the plantations of *P. africana* in the North-west region.

Respect of harvesting norms

Respecting of harvesting norms was assessed through the harvesting diameter and the harvesting techniques.

Harvesting diameter

A total of 331 trees, representing 32.6% of the total number

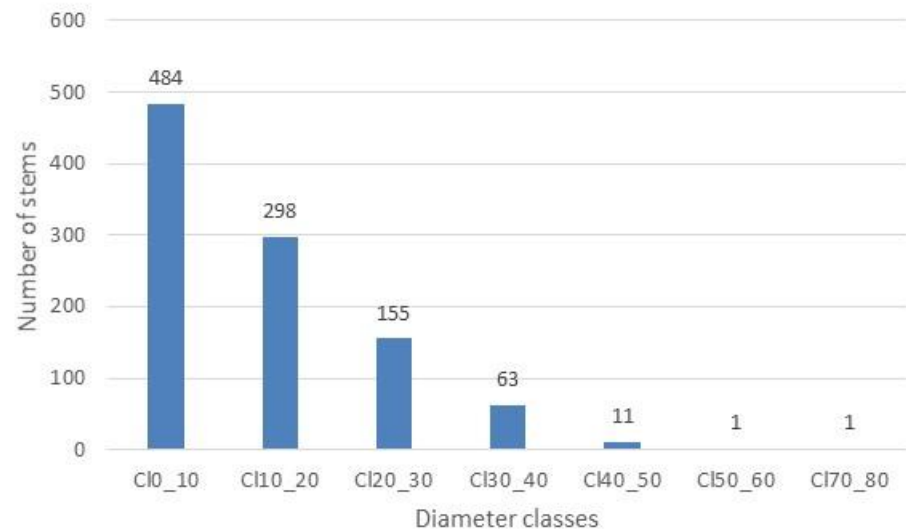

Figure 1. Distribution of *Prunus* trees in different diameter classes

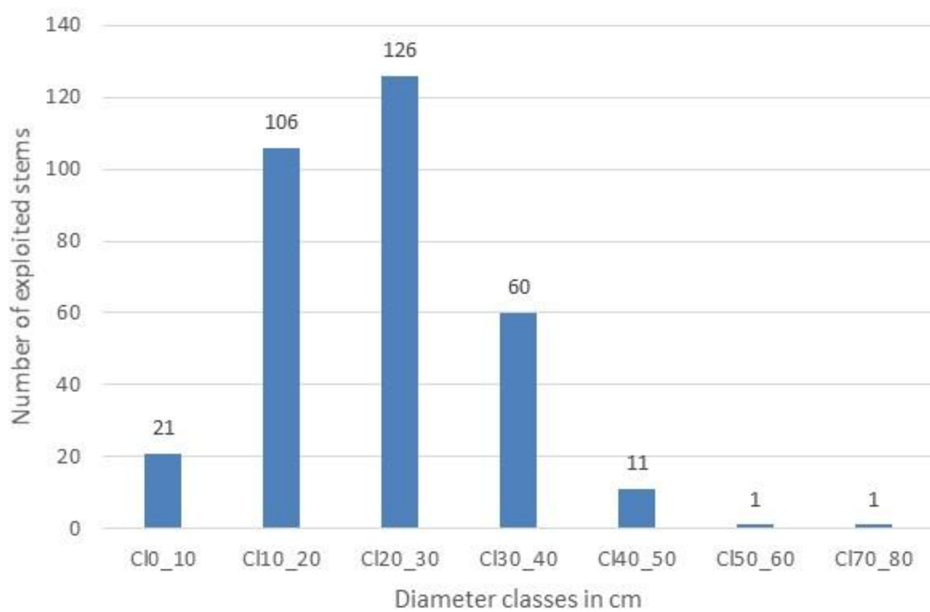

Figure 2 : Distribution of exploited trees in different diameter classes

of trees inventoried were harvested. Figure 2 illustrates the distribution of exploited stems in different diameter classes. It should be noted that all diameter classes were harvested with the majority being the diameter class 20-30, which represents 38% of the exploited stems. A total of 253 stems representing 76.43% were exploited below the minimum harvesting diameter which is 30 cm. The average harvesting diameter recorded for the 324 trees harvested in Fundong and Kumbo subdivisions is presented in Table 3. The average harvesting diameter recorded was 23.18±7.48 cm. This diameter which is less 1.30 times the advised MED (30 cm) does not significantly vary from one area to another (P>0.05).

Techniques of harvesting

A total of six harvesting techniques were recorded: ½ (1 over 2) side, 1/3 (1 over 3) side,¼ (1 over 4) side, 2/4 (2 over 4) opposite sides, 4/8 (4 over 8) opposite sides, and the total de-barking. The technique of 2/4 opposite sides was the most used on 47.2% of the trees followed by the unsustainable technique or the total de-barking, on 26% of

Table 3. Average harvesting diameter of *Prunus* in Fundong and Kumbo subdivisions, North west region of Cameroon

Subdivision	Average or mean (cm/year)	SD	Number of trees	F value = 0.342 Pr < 0.559
Fundong	23.29	9.89	287	
Kumbo	22.30	7.44	37	
Total (Global average)	23.18	7.48	324	

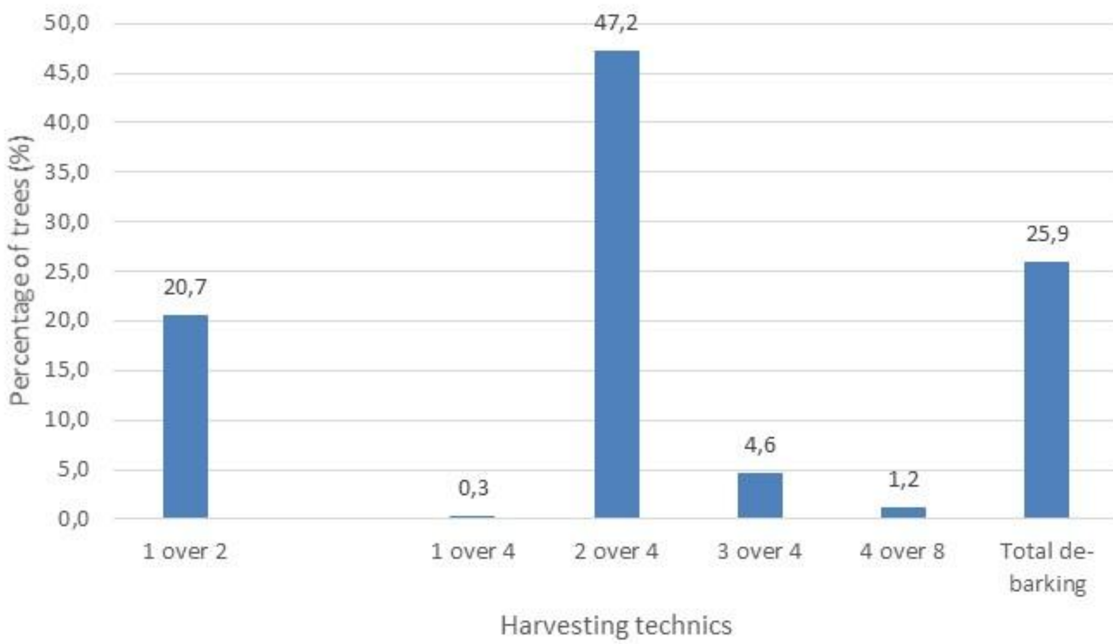

Figure 3 : Relative importance of different harvesting techniques of *Prunus* bark in the Northwest of Cameroon

Table 4. Distribtion of *Prunus africana* harvested trees in diameter classes and harvesting technics in the North west region of Cameroon

	1 over 2	1 over 4	2 over 4	3 over 4	4 over 8	Total de-barking	Total
Cl0_10	4		10	4		6	24
Cl10_20	19	1	54	7		24	105
Cl20_30	20		60	4		41	125
Cl30_40	19		**24**		2	12	57
Cl40_50	4		**5**		1	1	11
Cl50_60	1						1
Cl70_80					1		1
Total	**67**	**1**	**153**	**15**	**4**	**84**	**324**

trees (Figure 3). Table 4 presents for each diameter class the distribution of harvested trees in different harvesting techniques. It should be noted that, only 29 trees out of the 324 harvested and described were exploited in respect of the prescribed or advised norms which is 2 over 4 opposite sides for trees with diameter between 30 and 90 cm. The other 295 trees representing 91% of the total were exploited unsustainably. The 29 trees had diameters between 30 and 50 cm; and represent 19% of trees harvested with the 2 over 4 opposite sides technique.

Growth and regeneration parameters

Diameter annual increment/Growth rate in diameter

We were able to have the exact settlement year of 12 plantations (Table 1). The average age of the 12 plantations is 12 years. The diameter annual increment is presented in

Table 5. *Prunus africana* diameter annual increment (DGR) in different subdivisions in the North west region of Cameroon

Subdivision	Average DGR (cm/year)	SD	Number of trees	F value = 9.732 Pr < 0.0000678 ***
Fundong	0.88	0.66	478	
Kumbo	1.16	0.50	103	
Tubah	0.83	0.56	119	
Total (Global average)	0.91	0.46	700	

Table 6. Relation between the diameter annual increment and the diameter of tree

Diameter class	Average DGR (cm/year)	SD	Number of trees	F value = 536.1 Pr < 2e-16 ***
Cl0_10	0.55	0.23	419	
Cl10_20	1.19	0.37	198	
Cl20_30	1.86	0.53	58	
Cl30 and +	2.65	0.85	25	

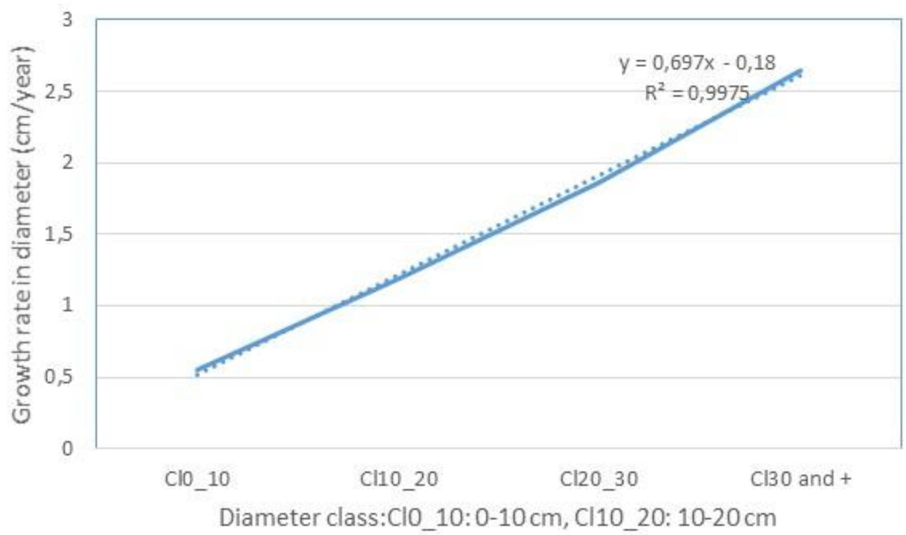

Figure 4 : Evolution of the growth rate of *Prunus* trees according to the diameter class in the North West region of Cameroon

Table 5 for the three subdivisions prospected. The global diameter annual increment is 0.91±0.46 cm/year. It should be noted that a significant difference exist in diameter annual increment between the three subdivisions ($p < 0.05$). The Kumbo subdivision has the highest diameter annual increment, 1.16 ±0.50 cm/year.

Relation between the diameter annual increment and the diameter

Table 6 presents the diameter annual increment per diameter class. It should be noted that a significant difference exist in diameter annual increment between different diameter classes ($p < 0.05$). The diameter annual increment increases with the diameter, at least till diameter is greater than 40 cm. This evolution can be best approximated by the linear equation $y = 0.697x – 0.18$, with the correlation coefficient $R^2 = 0.9975$ (Figure 4).

Variation of age of plantations in different subdivisions

The average age of the *Prunus* plantations is presented per subdivision in Table 7. A significant difference exists in the age of plantations between the three subdivisions ($p < 0.05$). The global average age of plantation is 12 years, with the highest age being observed in Tubah subdivision (17 years old).

Variation of *Prunus* diameters among different subdivisions

Table 8 presents the average diameter of *P. africana*

Table 7. Average age of *Prunus africana* plantations in different subdivisions

Subdivision (years of plantation)	Average age (years)	SD	Number of trees	F value = 306.3 Pr < 2e-16 ***
Fundong (2002-2010)	10.9	1.33	478	
Kumbo (2002-2007)	11.5	2.21	103	
Tubah (1995-2006)	17.4	5.18	119	
Total (Global average)	12.14	2.45	700	

Table 8. Average diameter of *Prunus africana* in different subdivisions

	Average (cm)	SD	Number of trees	F value = 18.74 Pr < 0.0000000118 ***
Fundong	9.64	7.36	478	
Kumbo	13.95	8.04	103	
Tubah	12.72	7.52	119	
Total	10.79	5.67	700	

Table 9. Thickness of the bark for non-harvested sides in different subdivisions

	Average (mm)	SD	Number of trees	F value = 2.106 Pr < 0.122
Fundong	4.96	2.28	666	
Kumbo	5.74	1.58	36	
Tubah	5.10	2.38	116	
Total	5.01	1.71	818	

obtained for each subdivision. The global average diameter is 10.79±5.67 cm. This diameter is significantly different from one subdivision to another ($p < 0.05$). Kumbo is the subdivision with the highest average diameter for *Prunus* trees (13.95 cm).

Variation of the thickness of the bark for non-exploited sides (un-harvested sides) of trees among different subdivisions

The thickness of the bark was recorded on non-harvested sides of 818 *Prunus* trees (Table 9). There is no significant difference in the thickness from one subdivision to another ($p > 0.05$). The global average thickness of the bark for non harvested sides is 5.01±1.71 mm.

Variation of the thickness of the bark for non-exploited sides in different diameter classes

Table 10 presents the variation of the thickness of the bark for non-harvested sides of trees in different diameter classes. There is a significant difference in the thickness of the bark from one diameter class to another ($p < 0.05$). The thickness of the bark increases with the diameter, beyond a certain level before it starts decreasing as illustrated in Figure 5. This evolution can be best approximated by the equation $y = 2{,}5705\ln(x) + 3{,}8052$, with the correlation coefficient $R^2 = 0.9916$.

Impact of the harvesting on *Prunus* trees

The impact of the harvesting on *Prunus* trees is appreciated through the regeneration rate of the bark and the health of trees. A total of six harvesting techniques were recorded in the North West region. This analysis is limited to the techniques which were applied on at least 30 trees in the sample including: the 1 /2 opposite sides, the 2/4 opposite sides, and the total debarking (100%).

Regeneration rate of the bark in different sudivisions

Regeneration rate was appreciated for 224 stems of *Prunus* harvested in Fundong and Kumbo subdivisions (Table 11). The global average regeneration rate of the *Prunus* bark is 1.91±1.03 mm/year. The regeneration rate of the bark on harvested sides varies significantly from one subdivision to another ($p < 0.05$). The Fundong subdivision has the highest regeneration rate (2.15±1.25 mm/year).

Regeneration rate in different diameter classes

Table 12 presents the variation of the regeneration rate in different diameter classes. There is no significant difference in the regeneration rate between diameter classes ($p > 0.05$). However a deep illustration made in Figure 6 tends to show that the regeneration rate decreases with the diameter. That decrease can best be approximated by equation $y = -0.2472x + 2.6503$, with the $R^2 = 0.745$.

Table 10. Variation of the thickness of the bark for non-harvested sides in different diameter classes

Diameter class	Average (mm)	SD	Number of trees	F value = 60.01 Pr < 2e-16 ***
Cl0_10	3.80	1.53	396	
Cl10_20	5.68	1.81	243	
Cl20_30	6.43	2.53	113	
Cl30 and +	7.48	2.77	63	

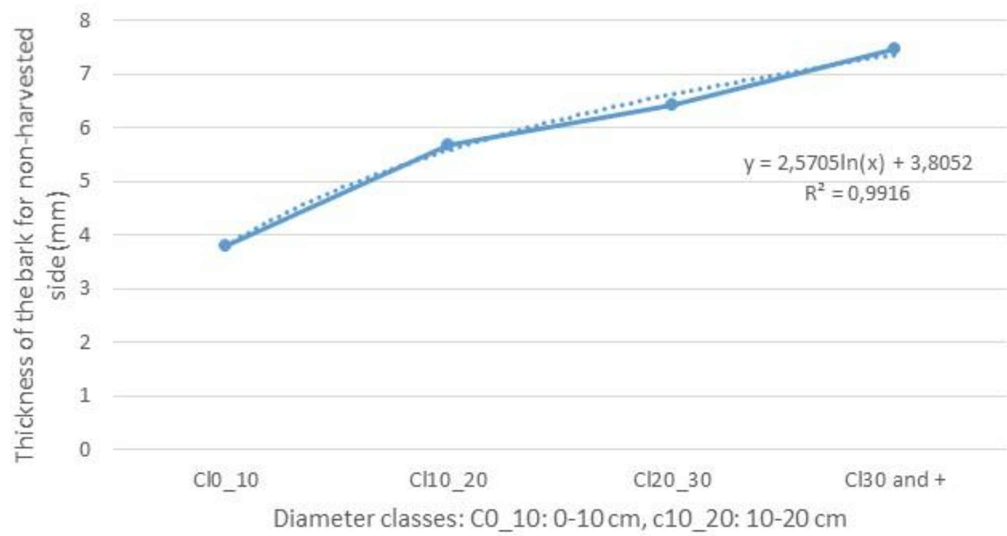

Figure 5. Evolution of the thickness of *Prunus* barkwith the diameter for non harvested sides in the North West region

Table 11. Variation of the regeneration rate of the bark (BRR) in different subdivisions

	Average BRR (mm/year)	SD	Number of trees	F value = 52.31 Pr < 7.66e-12 ***
Fundong	2.15	1.25	188	
Kumbo	0.61	0.32	35	
Total	1.91	1.03	223	

Table 12. Variation of the regeneration rate of the bark (BRR) in different diameter classes

Diameter class	Average BRR (mm/year)	SD	Number of trees	F value = 1.353 Pr < 0.258
Cl0_10	2.57	1.32	12	
Cl10_20	1.89	1.32	70	
Cl20_30	1.92	1.29	95	
Cl30 and +	1. 75	1.18	46	

Regeneration rate in different harvesting techniques

The variation of the regeneration rate of the bark in different harvesting techniques is presented in Table 13. There is a significant difference in the regeneration rate between the three harvesting techniques ($p < 0.05$). The highest regeneration rate is observed with the total harvesting technique, 2.64±1.16 mm/year.

Health of trees

A total of 1013 *Prunus* trees were assessed in the three

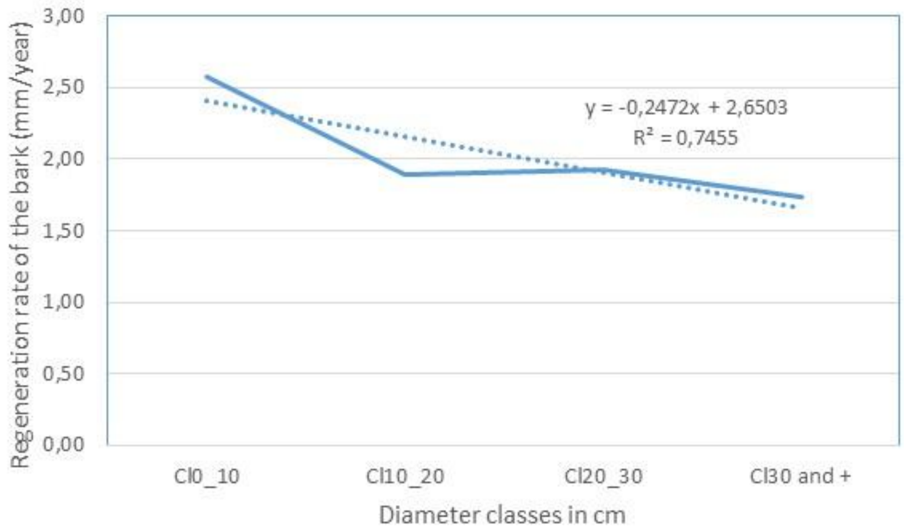

Figure 6: Evolution of the regeneration rate of the bark with the diameter of trees

Table 13. Variation of the regeneration rate of the bark in different harvesting techniques

Harvesting technique	Average BRR (mm/year)	SD	Number of trees	F value = 12.84 Pr < 0.00000531 ***
1/2	1.36	0.68	40	
2/4	1.81	1.35	136	
Total harvesting	2.64	1.16	47	

Table 14. Health of *Prunus* trees following harvesting

Health status of trees	Harvesting technics	Number of stems	Average diameter	Average age of harvesting
Wilt				
	½ (1 over 2) side	7	34.3	5
	2/4 (2 over 4) opposite sides	2	26.9	6
	Total debarking	5	27.0	1
	Sub-Total	14	30.6	4.5
Living				
	½ (1 over 2) side	60	24.8	2.5
	1/4 (1 over 4) side	1	18.2	3
	2/4 (2 over 4) opposite sides	151	22.6	2.7
	3/4 (3 over 4) side	15	16.3	2
	4/8 (4over 8) opposite sides	4	49.8	5
	Total debarking	79	21.8	1.2
	Sub-Total	310	22.8	2.3
Total		324	23.2	2.4

subdivisions. A total of 687 out of those trees were not harvested, including 646 living trees (94%), 38 dead trees (5.5%) and 3 wilt trees (0.43%). A total of 326 out of the 1 013 were harvested, including 324 in Fundong and Kumbo and 2 in Tubah. All harvesting methods used had some impact on the health of *Prunus* trees. The impact of harvesting on the health of *P. africana* is limited here to the 324 trees harvested in Fundong and Kumbo subdivisions. Table 14 presents the relative importance of trees' health according to the harvesting technique used. We can note that, only 14 out of the 324 trees harvested in the two subdivisions are wilt, representing 4.32% of the total. Their average harvesting years (time spent since harvesting activities) is 4.5 years, while their average diameter is 30.6

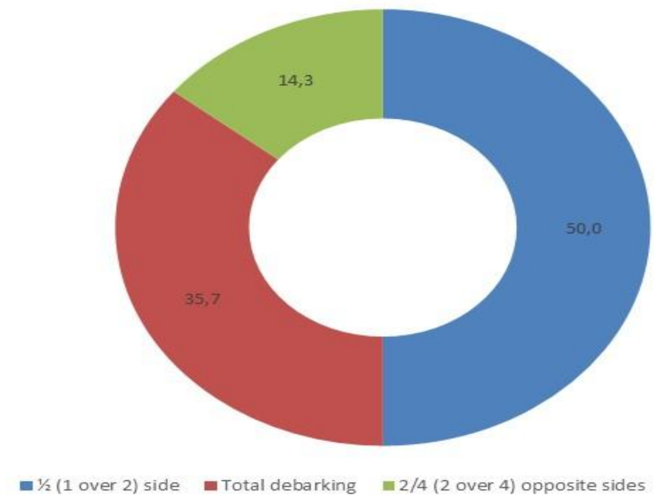

Figure 7: Relative importance of wilt trees recorded after harvesting in different harvesting techniques

cm. The remaining 310 trees (95.7%) were living trees with an average diameter of 22.8 cm. Their average harvesting time is 2.3 years. There were no registered dead trees among the harvested trees. The relative importance of wilt trees recorded in different harvesting techniques is illustrated in Figure 7. The wilt trees were observed only in three techniques: ½ (1 over 2) side, 2/4 (2 over 4) opposite sides, and total debarking. The ½ technique recorded the highest number of wilt trees, 50%, followed by the total debarking technique (35.7%). The two techniques known as non-sustainable or non-advised techniques represent 85.7% of the wilt trees recorded. The 2/4 technique was observed only for 14.3% of trees, and precisely on two young trees (diameter 27 cm) harvested in 2010, which is six years ago.

DISCUSSION

Density and structure of *Prunus* plantations

The density of *Prunus* in the 17 plantations inventoried is 5.15 trees/ha. This density is high compared to the 3-3.52 stems/ha obtained in the natural forests in Cameroon (Foham et al., 2009). But this density remains low compared to the minimum request for a plantation. The density of exploitable stems, which are stems of diameter at breast height at least equal to 30 cm, is 0.38 stems/ha, representing 7.5% of the total. This proportion is high, compared to the 2.42% obtained in 52 plantations inventoried in the same region in 2010 (Akoa et al., 2010). This shows an increase of exploitable stems of 5% in six years. The average structure of all the trees sampled shows a shift towards predominantly smaller sized classes, which are not economically viable to harvest but do represent a future resource. Cunningham and Mbenkum (1993) noted that many farmers have planted *P. africana* since 1977. Cultivation of *Prunus* is known as a viable economic proposition (Cunningham et al., 2002).

Health of the plantations

Only 5.58 % of trees are wilt or dead, which illustrates the global good health of the plantations. This result is closed to the 4.37% obtained in plantations of the same region in 2010 (Akoa et al., 2010).

Respect of exploitable norms

In this paper, by respect of norms we mean the respect of the minimum exploitable diameter (MED) and the use of advised techniques of harvesting.

For the MED, the average harvesting diameter recorded in the North-west region is 23.18±7.48 cm. This diameter is too low, 1.30 times less than the advised MED (30 cm). A total of 326 trees were harvested out of which 253 did not yet reach the MED (30 cm), representing 77.6%. This percentage is high compared to the 50% and 60% obtained, respectively in plantations of the Elat-Oku in the North-west and in plantations of Tolé in the South-west (Kourogue, 2010). Our result is close to the 73% obtained in the community forests and plantations inventoried in the Fundong subdivision (Betti et al., 2016). Harvesters do not respect the MED of 30 cm set by the forest administration, mostly for *Prunus* found in plantations.

A total of six harvesting techniques were recorded in the three subdivisions assessed including: ¼ (1 over 4), 2/4 (2 over 4) opposite sides, 1/3 (1 over 3) sides, 4/8 (4 over 8) opposite sides, and the total de-barking. Two techniques are advised including 2/4 for trees with diameter between 30 cm and 89 cm, and 4/8 for trees with diameter more than 90 cm (Parrot, 1989; Ndam and Ewusi, 2000). The forest administrations provided more details, indicating that, only trees with diameter at breast height (dbh) >30 cm can be debarked. Trees with dbh <50 cm should be debarked with two strips in opposite sides, with each not wider than 1/4 of the tree circumference. Lateral roots with a minimum diameter of 20 cm on trees >dbh 50 cm can be debarked. Each debarked tree should completely recover before subsequent debarking (Ministry of Agriculture, 1986; Ndibi and Kay, 1997). Our results indicate that, the technique of 2/4 opposite sides is the most used with 47.2% of the trees, followed by the unsustainable technique or the total de-barking, with 26% of trees. The advised techniques represent 67.5%. This result is close to the 63.7% obtained in the Fundong subdivision (Betti et al., 2016). In the Tolé plantations, South West, 80% of trees assessed were harvested with unsustainable techniques (Kourogue, 2010). The majority (61%) of trees in all the main harvest zones surveyed inside and around Mount Cameroon were debarked unsustainably (Ingram et al., 2009). In most cases, far more bark is taken than recommended, despite training and the best practice standards and decree (Ingram et al., 2009; Cunningham et al., 2016). The combination of the two elements of norms which are the MED and the harvesting technique shows that only 29 trees out of the 324 harvested and described were exploited in respect of the prescribed norms. The other 295 trees representing 91% of the total were exploited unsustainably in regard to the norms. This confirms that the harvesting of *Prunus* in agroforest systems in the North West is not sustainable.

Management parameters

We analyzed the management parameters through the age of the plantation, the diameter, the thickness of the barks, and the growth rate.

The average age of *Prunus* trees in plantations inventoried in the three subdivisions of the North-west is 12 years old with the youngest being the Fundong subdivision with 11 years old.

The average diameter of trees is 10.79±5.67 cm, with the lowest being observed in Fundong 9.64±7.36 cm. This diameter is too low, at least 10 times the 100-115 cm observed in mature trees in natural forest (Hall et al., 2000, Vivien and Faure, 1985). This confirms that these plantations are still too young.

The average diameter annual increment is 0.91±0.46 cm/year. This varies significantly from one subdivision to another, with the Kumbo having the highest, 1.16 ±0.50 cm/year. These differences observed in diameter annual increment can be explained by many factors including the genotipic feature and the external influence such as the climate, soil, and the management of the plantations. The diameter annual increment increases with the diameter, at least till diameter class 40 cm. This may once again be explained by the young age of the plantations.

The average thickness of the bark for non harvested sides is 5.01±1.71 mm, and this does not significantly vary from one subdivision to another. This result is too low compared to the 13.0 mm obtained by Nkeng et al. (2010) for wild *Prunus* populations assessed in the key production sites in Cameroon. Our finding is also low compared to the 13.01 mm obtained by Sunderland and Tako (1999) in the Bioko Island, in Equatorial Guinea. The thickness of the bark increases with the diameter of the tree beyond a certain level before it starts decreasing. Nkeng et al. (2010) noted that there was an increase of bark thickness of un-harvested trees from smaller to greater diameters.

Impact of the harvesting on the *Prunus* trees

Thousands of Cameroonian farmers have cultivated *P. africana* since the late 1970's (Cunningham et al., 2016), but no assessment of the state of those plantations nor the impact of the harvesting on trees have been conducted yet. The impact of the harvesting on *Prunus* trees is appreciated in this paper through the regeneration rate of the bark and the health of trees.

The regeneration rate of the bark does not vary significantly from one diameter to another. But a deep analysis of results tends to show that the regeneration rate decreases slightly with the diameter, which contradicts the result obtained by Nkeng et al. (2010) who noted a general increase of recovery rate (0.065-0.098cm/year) for normally harvested trees from lower to higher diameter classes in natural populations. The regeneration rate varies significantly according to the subdivisions and according to the harvesting techniques used. The average regeneration rate of the bark is 1.91±1.03 mm/year, with the highest being recorded in the Fundong subdivision (2.15±1.25 mm/year). This may be linked to the young age of the plantations found in Fundong and also to the local climate conditions. Assessment conducted in *Prunus* wild populations in Cameroon concluded that bark recovery rates (or regeneration rate) were significantly affected depending on the site. Bark recovery rates were not influenced by altitude, but appear to be more significantly affected by harvesting pressure, the age of trees and method of harvesting used (Nkeng et al., 2010).The Fundong subdivision is a more moist area (rainfall of 2 400 mm) compared to Kumbo (1 873 mm). Our results confirm some findings which tend to show that the bark regrowth is more feasible and accurate in moist areas compared to other areas (BirdLife project. Cit Akoa et al., 2011, Cunningham et al., 2016). This led the Birdlife project and the CITES Scientific authority in Cameroon to adopt a five year half rotation. Research activities conducted within the Birdlife project revealed that the length of the rotation varies with the zone (division). Hence, in the Boyo division where the weather is too hot, results obtained tend to show that the harvester can return to the same tree after 4-5 years, while in the Bui division where it is too cold, this harvester must wait 5-6 years before returning back to the same tree (Akoa et al., 2011). The high rainfall coupled with the high temperatures may stimulate and accelerate the regeneration of the bark. The climate of Fundong seems to be more close to that of the South-west region, Mount Cameroon to be precise where we have rainfall of more than 3000 mm and average annual temperature of 22-29°C. If we transpose the average regeneration rate of the bark of 2.15±1.25 mm/year obtained in Fundong to the Mount Cameroon situation, the side of a tree harvested will recover its bark in 5.5 years at an equivalent of 11.55 mm, which is higher, that is, 1.36 times the average thickness of the bark (8.49 mm) assessed in Mount Cameroon. If we use the average regeneration rate of 1.91±1.03 mm/year, the bark will recover at 10.5 mm, representing 1.24 times the 8.49 mm mentioned. This means that whatever be the regeneration rate used, the bark can regrow clearly in the Mount Cameroon in 5.5 years as suggested in the document of the non-detriment findings of *Prunus* in Mount Cameroon (Akoa et al., 2011). This result contradicts what was stated in the review made by Cunningham et al. (2016).

For harvesting techniques, the highest regeneration rate was noted in the total debarking technique (100% of the bark stripped), with 2.64±1.16 mm/year, followed by the "two bark quarters" technique. The technique of harvesting ½ of the bark has the less regeneration rate. These results show two things: the first is that, harvesters do not like to spend their time using the advised technique for *Prunus* found in plantations, and mostly for young trees. They prefer to move all the bark found on young trees such as in Fundong. The second thing is that, the more the surface of the bark harvested is high on young trees, the more the regeneration rate is high. The regeneration rate increases therefore with the quantity of the bark harvested on very young trees. The more the young *Prunus* trees are traumatized, the more they develop capacity of regenerating their bark, at least till age of 10-12 years. The most important thing being that, the cambium which is responsible for the regeneration of the bark be preserved and should not be injured. This result can be explained by what was observed in natural populations (Nkeng et al., 2010). These authors noted that higher dbh classes showed the reverse trend in health where a larger number of harvested trees were found in critical conditions, especially those from dbh 70+ where all over-exploited trees were likely to die. They concluded that the younger, smaller trees are more able to withstand overexploitation and that larger size trees are considered most vulnerable, with exploitation, particularly over-exploitation, resulting in poor health or death.

It is known that crown health is a good indicator of overall tree health (Hall et al., 2000; Stewart, 2009). Field teams in Equatorial Guinea noticed that crowns of *P. africana* trees exploited using the ring harvesting technique displayed considerable senescence and dieback (21%) (Sunderland, 1999 cit. Nkeng et al., 2010). Analyses done on the health of trees showed that harvesting activity did not induce the death of trees between 2010 and 2016 but it caused the wilting of some of them. This supports the observation made by Cunningham and Mbenkum (1993) who noted that, *P. africana* does indeed have a remarkable ability to withstand bark removal. The percentage of wilt stems recorded among harvested trees (4.32%) is very high, representing 10 times that recorded among non-harvested trees (0.43%). Among harvested trees, those that are wilt were harvested 4.5 years ago, while trees that are still alive were harvested only 2.3 years ago. This tends to show that the percentage of wilt trees will increase among the harvested trees in the incoming years. No result can predict the percentage of dead trees among harvested trees in the incoming years. Stewart (2009) however noted in the sample plots settled in Oku (Nord-west region) that, 46% of harvested trees died over a period of ten years and that, all trees had the same chance of dying regardless of their size classes. Our study does not characterize the health problems, however Nkeng et al. (2010) outlined that the health of harvested and un-harvested trees in both plantations and natural forests is often affected by xylophagous insects, rodents and parasitic plants. The wilt trees recorded in our sample were harvested using three techniques: ½ (1 over 2) side, 2/4 (2 over 4) opposite sides, and total debarking. The ½ (1 over 2) side recorded the highest number of wilt trees, 50%, followed by the total debarking technique (35.7%). It can be noted that, 85.7% of the wilt trees recorded among harvested trees, were debarked using the 1/2 (1 over 2) and the total debarking techniques, both known as non sustainable or non-advised techniques. The two techniques were used on slightly big trees (average diameter 30.6 cm). The 2/4 technique was observed only for 14.3% of trees, and precisely on two young trees (diameter 27 cm) harvested in 2010, which is six years ago. These results tend to confirm that, harvesting methods used have some impact on health of *Prunus* trees (Nkeng et al., 2010). Unsustainable techniques which include the ½ and the total debarking, lead to the wilting of trees. The negative impact of the advised technique which is 2/4 (2 over 4) opposite sides is only observed on young trees and after 6 years. The presence of this advised technique in this specific sample of wilt trees can also be explained by the possible damage caused on the cambium. It is known that even "correct" bark stripping can damage the cambium, inhibit bark regeneration, and affect the health of the tree (Ingram et al., 2009). It has been noted that the majority of normally exploited trees were in perfect condition and none had died (Nkeng et al., 2010).

CONCLUSION

Inventories conducted in 2016 in plantations of *Prunus africana* found in the North-west region of Cameroon allowed the recording of 1013 *Prunus* trees with a density of 5.15 trees/ha. The exploitable stems represent only 7.5%, illustrating that those plantations are still very young, which is not yet suitable for harvesting. This feature is confirmed by the low values of the thickness of the bark and the average diameter. The harvesting of *Prunus* bark done in those plantations is non-sustainable, since harvesters do not respect advised norms of harvesting. The combination of the two elements of norms which are the MED and the harvesting technique shows that 91% of trees are harvested unsustainably. The analysis done on the regeneration rate tends to show that, the more the young *Prunus* trees are traumatized, the more they develop capacity of regenerating their bark, at least till age of 10-12 years. Further research should be conducted in other subdivisions and regions of Cameroon where the specie is cultivated such as the South-west region.

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Conflict of interests

The authors declare that they have no conflicting interests

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