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RESEARCH ARTICLE

EFFECTS OF ANTHROPOGENIC DISTURBANCES ON BIOMASS AND POTENTIAL CARBON STORAGE IN LAF FOREST RESERVE (CAMEROON)

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Abstract

Forested zones represent habitats where the greatest quantity of biomass and carbon are concentrated. The survey assessed the spatio-temporal dynamics of the landscapes of Laf forest reserve and the effect of human activities on its biomass and carbon storage. We used diachronic analysis of two Landsat satellite images LCOS_LITP of 1999 and 2019, which were processed using ArcGIS software. Three collection units (CU) were considered: i) CU₁ at the periphery; ii) CU₂ installed at 200 m from CU₁, and iii) CU₃ at the middle of the reserve in order to estimate biomass and carbon storage in relation to anthropogenic disturbances. In each CU, transects of 1000 m x 20 m were installed, and within each transect, all trees with a diameter at breast height (dbh) ≥ 10 cm were recorded and characterized by the following attributes: species name, dbh at 1.30 m above ground level and height. Individuals which branch before 1.30 m were measured at 10 cm from the soil. The results indicate that the extension of the agricultural land passed from 630.42 ha in 1999 to 3094.17 ha in 2019. A total of 6866 trees was recorded, representing 55 species, 37 Genera and 21 Families. Basal areas were: CU₁ (BA = 6.11 m²/ha); CU₂ (BA = 18.00 m²/ha) and CU₃ (BA = 16.81 m²/ha). All the collection units were characterized by low Shannon diversity index (ISH < 3.5 bits). The woody biomass and carbon storage were: CU₁ (TB= 6.33 t/ha; CS= 2.98 tC/ha); CU₂ (TB= 16.12 t/ha; CS= 7.6 tC/ha); CU₃ (TB= 12.46 t/ha; CS= 5.86 tC/ha). The equivalent carbons were as follows: CU₁ (CO₂ eq= 10.93 t/ha); CU₂ (CO₂ eq= 27.89 t/ha) and CU₃ (CO₂ eq= 21.5 t/ha). There was a significant difference between CU₁ and the two other collection units (p < 0.001). The Laf Forest Reserve appears to be heavily disturbed particularly near villages. CU₂ performs the most important quantity of carbon storage due to enrichment plantations. Management efforts are required for the recovery of the reserve's ecosystems.

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Introduction:-

Global surface temperatures have increased by 0.8°C since the late nineteenth century, and 11 out of the 12 warmest years on record have occurred since 1995 (IPCC, 2007). Earth's mean temperature is projected to increase by 1.5-5.8°C during the twenty-first century. The rate of increase in global temperature has been 0.15°C per decade since 1975 (IPCC, 2001). The observed climate changes are reportedly caused by emission of greenhouse gases (GHGs) through anthropogenic activities including land-use change, deforestation, biomass burning, draining of wetlands, soil cultivation and fossil fuel combustion. There's a strong interest in stabilizing the atmospheric abundance of CO₂ and other GHGs in order to mitigate the risks of global warming (Kluger, 2007; Walsh, 2007). Understanding the patterns of storage and production of organic matter in forests in relation to the disturbances is critical for management purposes and an essential aspect of studies of carbon cycle (Keller et al., 2001; Cairns et al., 2003). This can also be used to understand changes in forest structure resulting from succession or to differentiate between forest types (Cairns et al., 2003).

In the last few years, there has been increasing interest in the quantification of the biomass of forest ecosystems and its potential carbon fixation (Jhariya et al., 2014; Ibrahima et al., 2019). Living tree biomass pool is an important source of uncertainty in carbon balance from the tropical regions in part due to scarcity of reliable estimates of tree biomass and its variation across landscapes and forest types (Alves et al., 2010). In developing countries, protected areas are facing high anthropogenic disturbances due to fire, grazing, logging, felling, fuel wood extraction and collection of non-timber forest products (NTFPs) for livelihood of forest dwelling populations (Souare et al., 2012; Froumsia et al., 2012; Jhariya et al., 2014). Various anthropogenic activities are developed around and inside the Laf forest reserve since its creation in 1948, namely overgrazing, logging, biomass burning and agricultural activities. Fotsing et al. (2003) observed that between 1987 and 1999, the spaces occupied by muskuwari fields passed from 13.5% to 35%. This situation has not been improved despite the green sahel project set up by the government in the sudano-sahelian zone of Cameroon in 2008. There is severe ongoing anthropogenic pressure on the Laf forest reserve which needs to be raised in order to integrate and protect local and global forest values. The need for a local assessment of land cover, particularly in developing countries has been highlighted by several studies (Lambin et al., 2003; Vadrevu et al., 2015). The study was carried out specifically to:

- assess the spatio-temporal extension of the land use/ land cover of the Laf forest reserve in 1999 and 2019;
- inventory the woody species of the reserve;
- estimate the biomass and carbon storage of the reserve.

Materials and Methods:-**Study site:**

The study was carried out in the Laf Forest Reserve (LFR) in the sudano-sahelian zone of Cameroon. The Reserve, at its creation in 1948, covered an area of 5 000 ha and lies between 10°14'24" to 10°19'12" N and 14°15'0" to 14°21' 0" E (Figure 1). The average altitude is about 450 m and the vertisols (karal) are the most represented soils where muskuwari (dry season sorghum) is cultivated, and ferruginous soils or planosols where rainy season crops are grown (maize, groundnuts, millet). Laf is situated in the domain of thorny steppe, but the general physiognomy is that of the savannah. The most represented species are: *Acacia hockii*, *Albizia chevaleri*, *Balanites aegyptiaca*, *Bauhinia rufescens*, *Combretum aculeatum*, *Dichrostachys cinerea*, *Ziziphus mauritiana*, *Piliostigma reticulatum*, *Strychnos spinosa* and *Ximenia americana* (Letouzey, 1985). More than 18 915 people (Bucrep, 2005) live at the periphery of the reserve and rely on agriculture, livestock, and forest resources such as non-timber forest products to meet their basic needs.

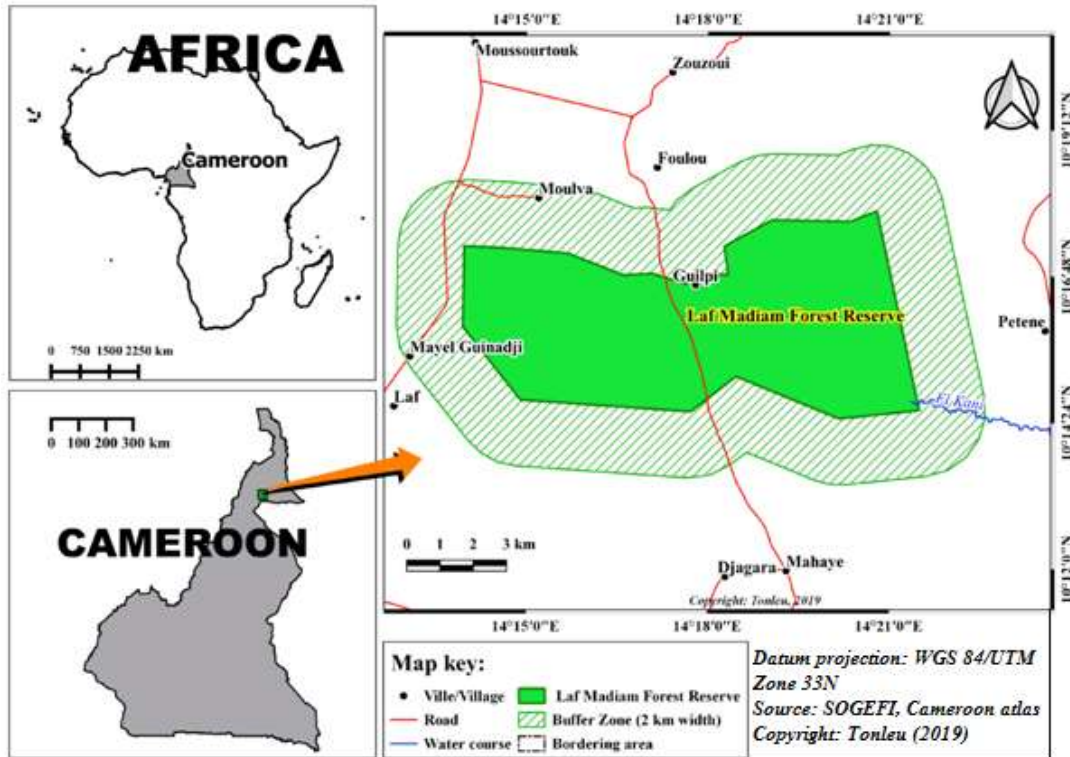


Figure 1:- Map of location of the study site.

Data collection:

Estimation of land use/land cover change:

The approach is based on a diachronic analysis of satellite images, and direct observations on the field. The remote sensing data consists of Landsat images LCOS_LITB and data base SOGEFI 1999 and 2019 showing land cover taken in 1999 and 2019, respectively. The images contain location information provided by the National Geospatial Agency and the US Geological Survey which are freely downloadable. Geocover images have the advantage of being orthorectified Landsat images, so they can be easily integrated into a geographic information system (GIS). The images were acquired at the same period, on January in dry season. Images captured in dry season have the advantage of low cloud cover.

Woody species inventory:

The transect method developed by Lejoly (1993) and Guedje (2002) was used for the inventory of the woody species. Three collection units (CU) constituting the treatments were established at the periphery (CU₁), CU₂ at 200 m from CU₁ and CU₃ at the middle of the reserve. Four transects (1000 m x 10 m) constituting the replications were installed in each collection unit, following the four points of the compass, with a total of twelve 1-ha. Along each transect, all woody individuals with a diameter at breast height (dbh) ≥ 10 cm were measured. Individuals that plug in before 1.30 m in height were measured at 10 cm from the ground (Jiagho et al., 2016).

Estimation of biomass and carbon storage of the woody species:

The total biomass of standing woody plants is constituted of the Above Ground Biomass (AGB) and Below Ground Biomass (BGB). We used the non-destructive method to evaluate the biomass, and as such the AGB was estimated with the allometric model developed by Djomo et al. (2010) for dry forest of tropical Africa and the BGB with the method developed by the IPCC (2006). We used the method developed by IPCC (2006) to estimate the carbon stock. The method consists in multiplying the estimated total biomass by 0.47.

Data processing and analysis:

For the image processing, the first phase of the treatment consisted of the combination of different spectral bands and allowed to obtain the images of two dates: 1999 and 2019. The images were all geo-rectified with UTM WGS 84 with radiometric corrections. Coloured compositions were created after adjusting the images, and then the study

area was extracted from the scene to determine the land cover types by classifying images. The images were segmented into sub-classes, namely wooded savannah, shrub savannah, fields and naked soils. These sub-classes allowed appreciating the land cover in 1999 and 2019. The ArcQGIS software was used to perform the images.

We assessed diversity of plant species with Shannon-Weaver diversity index (H') (Magurran, 2004) and Shannon's Evenness index (EQ). Diversity index takes into account not only the number of species but also whether species are more or less equally abundant, or whether in contrast one or a few species dominate.

$H' = -\sum Ni/N \log_2 Ni/N$, where H' = index of species diversity (bits), Ni = number of individuals of a given species i , N = total number of individuals, \log_2 = logarithm in basis 2.

$EQ = H'/\log_2 N$, this index varies from 0 to 1.

To describe the ecological importance of species and families within each transect as well as for the total flora, the species importance value index (IVI) and family importance value index (FIV) (Mori et al., 1983), were also calculated:

Relative abundance = (number of trees of the species or family/total number of trees) \times 100

Relative frequency = (frequency of a species/sum of all frequencies) \times 100

Family relative diversity = (number of species in a family/total number of species) \times 100

IVI = relative density + relative frequency + relative dominance

FIV = family relative diversity + relative density + relative dominance

Relative dominance = (basal area of a species/basal area of all the species) \times 100

Basal area (BA) = $\sum_i^s \left(\frac{\pi D^2}{4} \right)$ where D : diameter at breast height (cm); π : 3.141593

The estimation of Above Ground Biomass (AGB) was performed by using the mathematical model of Djomo et al. (2010) with the following formula:

$AGB = \exp(-2.29016 + 0.1651(\ln D)^2 + 0.6620 \ln(D^2 H) + 0.1309 \ln \rho)$

Where ρ = specific density of the wood (g/cm^3) which corresponds to $0.58 g/cm^3$ for species with unknown density (Brown et al., 1997); H = height (m); D = diameter.

The Below Ground Biomass was calculated by using the following formula:

$BGB = AGB \times R$, where R is the ration stem/root, $R = 0.24$ (IPCC, 2006).

The carbon storage was calculated by the following formula:

$CS = TB \times 0.47$, where CS (tC/ha) is the carbon storage; TB ($AGB + BGB$) is the total biomass (t/ha) and 0.47 is a constant (IPCC, 2006).

The CO_2 equivalent was calculated using the following formula:

$CO_2 eq = CS \times 3.67$ (IPCC, 2006).

Analysis of variance (ANOVA) was used to compare the difference of means between the collection units and principal component analysis (PCA) to measure the correlation between index values, and between density and basal area. Statistical analysis was performed with Origin 6.0 Software.

Results:-

Evolution of the land cover and land use of Laf forest reserve:

The land cover and land use mapping identified four (04) classes, namely wooded savannah, shrub savannah, fields and naked soils. The diachronic land cover obtained for the two periods, namely 1999 and 2019 are presented in Figure 2.

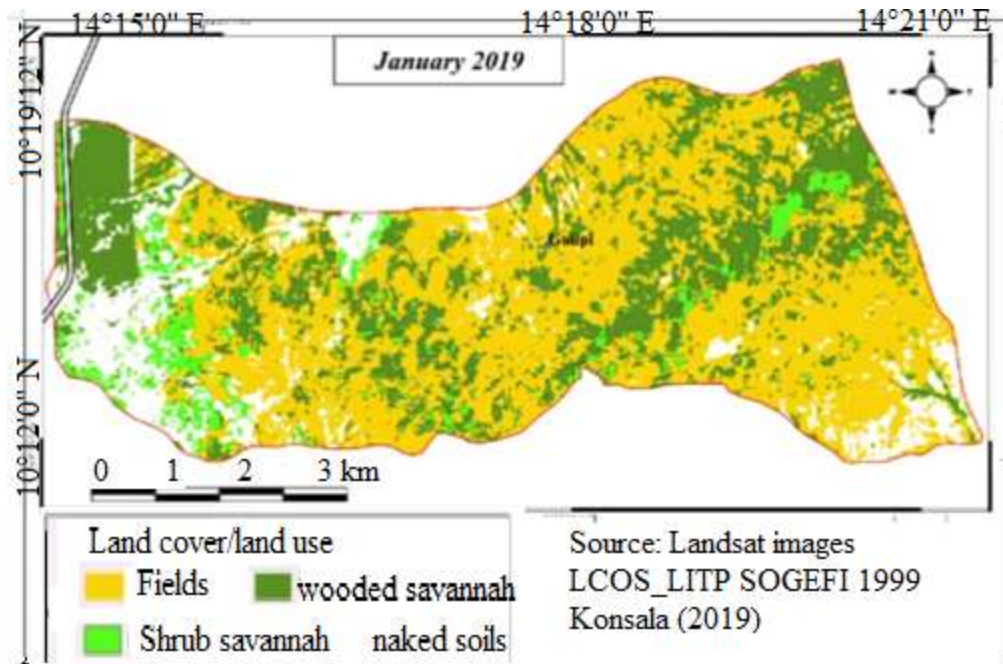


Figure 2:- Maps of land occupations in January 1999 and January 2019 in the Laf forest reserve.

Land cover statistics throughout the period of observation showed the dominance of the class of agricultural land (fields) which is extending. It passed from 630.42 ha in 1999 (10.54 %) to 3094.17 ha in 2019 (51.78 %). Wooded savannah increased gradually from 1999 (890.45 ha) to 2019 (1476.54 ha) representing 14.89 % and 24.71 % respectively. Shrub savannah decreased from 1999 (4161.30 ha) to 2019 (653.87 ha) corresponding to 69.62 % and 10.94 % respectively. Naked soils gradually passed from 1999 (294.77 ha) to 2019 (750.20 ha), representing 04.93 % and 12.55 % respectively (Table 1).

Table 1:- Area and proportions of land use/land cover types in Laf forest reserve in 1999 and 2019.

Land use/land cover types	1999		2019	
	Area (ha)	%	Area (ha)	%
Wooded savannah	890.45	14.89	1476.54	24.71
Shrub savannah	4161.30	69.62	653.87	10.94
Fields	630.42	10.54	3094.17	51.78
Naked soils	294.77	04.93	750.20	12.55
Total area	5976.94		5974.78	

In January 1999, the forest reserve was dominated by wooded savannah and shrub savannah which together represented 84.51 % of the area. In 2019 at the same period, both represented together 35.75 % of the area. Agricultural land expanded gradually and became more than five times in 2019 (10.54 % in 1999 and 51.78 % in 2019).

Diversity and species richness within the collection units (CU):

A total of 6 866 individual trees with dbh \geq 10 cm was recorded within the three collection units (CU), representing 55 species, 37 genera and 21 families. All the trees were identified at the level of the species, and the number of species varied from 22 to 47 species per CU. The number of species was lower in CU₁ at the periphery of the reserve (22 species), moderate in CU₂ (38 species) and higher in CU₃ (47 species) (Table 2). The Shannon diversity index (H') value was moderate in CU₃ ($H' = 3.05$ bits) and weak in CU₁ and CU₂ (2.42 bits and 2.51 bits respectively), with an average of 2.66 bits. The Shannon evenness index (EQ) values varied from 0.31 to 0.47, namely EQ = 0.31 for CU₁ and CU₂, and EQ = 0.47 for CU₃. The total basal area (BA) values varied from 6.11 m²/ha to 18.00 m²/ha. Basal area value was higher in CU₂ because of the reforestation in this unit. Principal component analysis showed a high significant correlation between density and basal area (Pearson, $r = 0.99$), and between Shannon index value

and Shannon's evenness index value (Pearson, $r = 0.99$) (Figure 3). There was a significant difference between CU_1 and the two other collection units (ANOVA, $p < 0.001$).

Table 2:- Number of taxa, diversity indices and structural characteristics of the three collection units.

Parameters	CU_1	CU_2	CU_3
Density (individuals ha^{-1})	277	758	689
Basal area (m^2/ha)	6.11	18.00	16.81
Number of family	11	15	19
Number of genera	15	27	36
Number of species	22	38	47
Shannon index (H')	2.42	2.51	3.05
Shannon's evenness index (EQ)	0.31	0.31	0.47

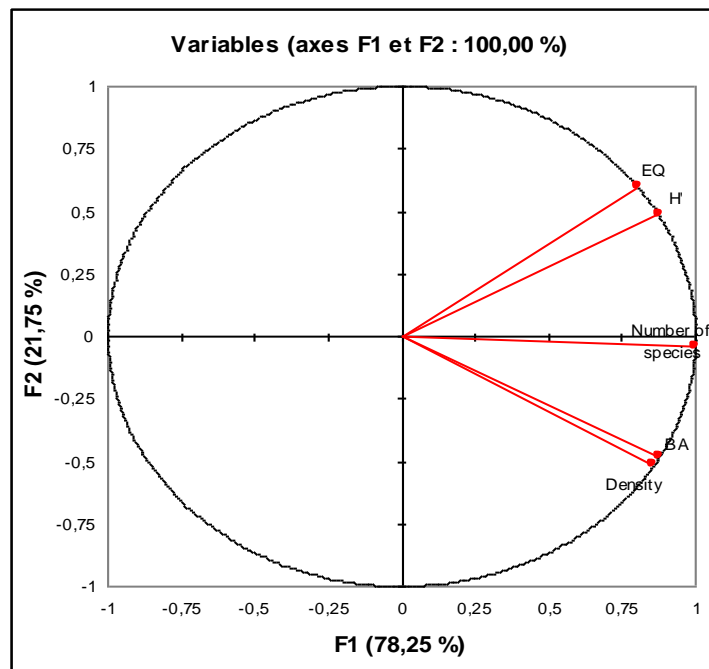


Figure 3:- Correlation between Shannon's diversity index (H') and Shannon's evenness index (EQ), and between density and basal (BA) showed by PCA.

Floristic composition:

The seven most important families (those of the highest values of FIV index) accounted for 56.16 % of the total FIV of all collection units considered together. These families with the highest FIV and number of individuals were: Mimosaceae (FIV = 57.62); Combretaceae (FIV = 45.21); Anacardiaceae (FIV = 17.04); Fabaceae (16.25); Balanitaceae (FIV = 11.92); Rhamnaceae (FIV = 10.47) and Meliaceae (FIV = 10.04) (Table 3). The least important families with FIV index < 1 were: Loganiaceae (FIV = 0.83); Bignoniaceae (FIV = 0.85); Sapotaceae (FIV = 0.5); Capparaceae (FIV = 0.44) and Celastraceae (FIV = 0.42) which accounted for 1.01 % of the total FIV.

Table 3:- Family importance value (FIV) of the seven most important families (in bold) for all the collection units.

Families	Number of species	Global FIV
Anacardiaceae	5	17.04
Annonaceae	2	2.29
Balanitaceae	1	11.92
Bignoniaceae	2	0.85
Burseraceae	3	4.43
Capparaceae	1	0.44
Celastraceae	1	0.42

Caesalpiniaceae	4	9.56
Combretaceae	9	45.21
Ebenaceae	1	1.04
Euphorbiaceae	2	1.28
Fabaceae	5	16.25
Loganiaceae	2	0.83
Meliaceae	2	10.04
Mimosaceae	9	57.62
Myrtaceae	1	2.20
Olacaceae	1	4.91
Rhamnaceae	1	10.47
Rubiaceae	3	9.67
Sapotaceae	1	0.50
Sterculiaceae	1	1.87

The analysis of importance value index (IVI) of the species showed that *Acacia hockii* (IVI = 19.54); *Anogeissus leiocarpus* (IVI = 19.03); *A. senegal* (IVI = 13.59); *Balanites aegyptiaca* (IVI = 11.92) and *Ziziphus mauritiana* (IVI = 10.47) were the five most dominant species of the forest reserve. They represented 37.7 % of the total IVI of all collection units considered together. The least dominant species with IVI < 1 represented 3.04 % of the total IVI, and were: *Acacia albida* (IVI = 0.43); *Annona senegalensis* (IVI = 0.95); *Bridelia scleroneura* (IVI = 0.84); *Commiphora africana* (IVI = 0.83); *Commiphora kerstingii* (IVI = 0.90); *Crateva adansonii* (IVI = 0.44); *Euphorbia sudanica* (IVI = 0.43); *Feretia apodanthera* (IVI = 0.46); *Lannea acida* (IVI = 0.49); *Maytenus senegalensis* (IVI = 0.42); *Pterocarpus erinaceus* (IVI = 0.45); *Sterospermum kunthianum* (IVI = 0.85); *Strychnos spinosa* (IVI = 0.83); *Terminalia glaucescens* (IVI = 0.43); *Terminalia macroptera* (IVI = 0.97) and *Vitellaria paradoxa* (IVI = 0.49) (Table 4).

Table 4:- Importance value index (IVI) of the 5 most important species (in bold) for all three collection units.

Species	Number of individuals	Global IVI
<i>Acacia albida</i> Del.	1	0.43
<i>Acacia gerrardii</i> Benth.	41	3.01
<i>Acacia hockii</i> De Willd.	1037	19.54
<i>Acacia nilotica</i> (L.) Willd. ex Del.	21	1.14
<i>Acacia polyacantha</i> Willd.	34	2.94
<i>Acacia senegal</i> (L.) Willd.	629	13.59
<i>Acacia seyal</i> Del.	374	9.91
<i>Acacia sieberiana</i> DC.	7	1.31
<i>Albizia zygia</i> (DC.) J.F. Macbr.	8	1.74
<i>Annona senegalensis</i> Pers.	10	0.95
<i>Anogeissus leiocarpus</i> (DC.) Guill. & Perr.	1000	19.03
<i>Azadirachta indica</i> A. Juss.	380	8.80
<i>Balanites aegyptiaca</i> (L.) Del.	511	11.92
<i>Boswellia dalzielii</i> Hutch.	17	2.43
<i>Bridelia scleroneura</i> Müll. Arg.	2	0.84
<i>Combretum collinum</i> Fresen	9	1.36
<i>Combretum fragrans</i> Steud. ex A. Rich.	99	5.48
<i>Combretum glutinosum</i> Perr. ex DC.	353	9.16
<i>Combretum molle</i> R. Br. ex G. Don	86	3.68
<i>Commiphora africana</i> (A. Rich.) Engl.	2	0.83
<i>Commiphora kerstingii</i> Engl.	4	0.90
<i>Crateva adansonii</i> DC.	2	0.44
<i>Dalbergia melanoxylon</i> Guill. & Perr.	419	9.74
<i>Dichrostachys cinerea</i> (L.) Wight & Arn.	9	1.75
<i>Diospyros mespiliformis</i> Hochst ex A. Rich	13	1.03
<i>Entada africana</i> Guill. & Perr.	61	3.71

<i>Eucalyptus camadulensis</i> Dehnh.	67	2.20
<i>Euphorbia sudanica</i> A. Chev.	1	0.43
<i>Feretia apodanthera</i> Del.	3	0.46
<i>Gardenia aqualla</i> Stapf & Hutch.	10	1.35
<i>Guiera senegalensis</i> J.F. Gmel.	86	1.66
<i>Hexalobus monopetalus</i> (A. Rich.) Engl. & Diels	4	1.30
<i>Khaya senegalensis</i> (Desr.) A. Juss.	7	1.04
<i>Lannea acida</i> A. Rich.	5	0.49
<i>Lannea fruticosa</i> (Hochst ex A. Rich.) Engl.	332	7.30
<i>Lannea humilis</i> Oliv. Engl.	43	2.27
<i>Lannea schimperi</i> (Hochst ex A. Rich.) Engl.	28	1.62
<i>Maytenus senegalensis</i> (Lam.) Exell	1	0.42
<i>Mitragyna inermis</i> (Willd.) Kuntze	419	7.74
<i>Piliostigma reticulatum</i> (DC.) Hochst.	11	1.78
<i>Pterocarpus erinaceus</i> Poir.	1	0.45
<i>Pterocarpus lucens</i> Guill. & Perr.	5	1.78
<i>Sclerocarya birrea</i> (A. Rich.) Hochst.	35	4.59
<i>Senna siamea</i> (Lam.) Irwin. & Barn.	26	1.25
<i>Senna singueana</i> (Del.) Lock	3	1.30
<i>Sterculia setigera</i> Del.	7	1.86
<i>Sterospermum kunthianum</i> Cham.	2	0.85
<i>Strychnos spinosa</i> Lam.	2	0.83
<i>Tamarindus indica</i> L.	42	4.67
<i>Terminalia glaucescens</i> Hochst.	1	0.43
<i>Terminalia laxiflora</i> Engl.	26	1.60
<i>Terminalia macroptera</i> Guill. & Perr.	9	0.97
<i>Vitellaria paradoxa</i> Gaertn. f.	1	0.49
<i>Ximenia americana</i> L.	117	4.91
<i>Ziziphus mauritiana</i> Lam.	443	10.47

Biomass and potential carbon storage of woody species :

Total biomass (TB) in the different collection units varied from 6.33 t/ha to 16.12 t/ha and the total biomass in the three collection units of 12 ha inventoried were 34.91 t/ha. CU₂ recorded the most important biomass and carbon storage (TB = 16.12 t/ha; CS = 7.6 tC/ha), and the lower values were recorded in CU₁ (TB = 6.33 t/ha; CS = 2.98 tC/ha). The total carbon storage for the three collection units was 16.44 tC/ha. The carbon equivalent was also higher in CU₂ and less in CU₁ (CO₂eq = 27.89 t/ha; 10.93 t/ha respectively) (Table 5).

Table 5:- Biomass and carbon storage in the different collection units.

Collection units	AGB (t/ha)	BGB (t/ha)	TB (t/ha)	Carbon stock (tC/ha)	CO ₂ eq (t/ha)
CU ₁	4.82	1.51	6.33	2.98	10.93
CU ₂	13.05	3.06	16.12	7.6	27.89
CU ₃	10.03	2.42	12.46	5.86	21.50
Total	27.9	6.99	34.91	16.44	60.32

Discussion:-

Spatio-temporal evolution of land occupations between 1999 and 2019:

The diachronic analysis of Laf forest reserve landscape developed from Landsat images allowed an effective monitoring of the land occupations which occurred between 1999 and 2019. Gilani et al. (2015) stated that land cover change studies are important for the development of effective natural resource management plan. The remote sensing data processing allowed us to observe that changes had occurred in land cover and land use. We observed a decline of shrub savannah, from 4161.30 ha in 1999 to 653.87 ha in 2019, and increase of fields from 630.42 ha in 1999 to 3094.17 ha in 2019. This evolution is due to human activities, mainly agriculture (10.54 % in 1999 and 51.78 % in 2019). The appropriation of land for the installation of fields has evolved over time, from the

neighboring villages to the center of the reserve, given the increasing of the populations around and the growing needs for arable land. The clearing carried out for the installation of the fields is done by a systematic cutting of almost all the trees. This practice helps to protect fields from grain-eating birds and limit competition with crops. Similar studies in Koupa Matapit gallery forest in western Cameroon (Momo et al., 2018) and sudano-sahelian zone in Cameroon (Wafo et al., 2006) have shown population growth and resource pressures result in a decline in land cover and uncontrolled exploitation of arable land. Mather and Needle (2000); Geist and Lambin (2002) and Jansen et al. (2008) stated that in the tropics, the development of human activities such as agriculture has an immediate impact on land use and an indirect impact on vegetation cover.

Tree diversity and floristic composition:

The three collection units installed from the periphery to the middle of the protected area showed different values of Shannon index. Only CU₃ installed at the middle of the reserve had moderate value of Shannon's diversity ($H' = 3.05$ bits). Kent and Cooker (1992) stated that forest communities considered rich are characterized by a Shannon diversity value of about 3.5 bits or higher. This moderate diversity seems to be derived from moderate anthropogenic activities at that level. Such value in savannah indicates a relative stability (constancy) for the experimental year. All the collection units have shown low evenness index values ($EQ \leq 0.6$). Dajoz (1982) cit. Souare (2015) reported that ecosystems that are in a transitional state or that are subject to permanent disturbances have low evenness index value. The low evenness values of the collection units could be attributed to the anthropogenic disturbances. In terms of family index value (FIV) (Table 3), Mimosaceae (57.62) and Combretaceae (45.21) were the most important families throughout the collection units. In fact, they had one species each with highest IVI values (Table 4): *Acacia hockii* (19.54) and *Anogeissus leiocarpus* (19.03). The importance of Mimosaceae and Combretaceae in the study site is due to the fact that drought in the Sahel has allowed natural selection of the most robust species like these families. They are resistant to the lack and insufficient rains but also to high temperatures. These families are the most common and highly represented in tropical countries, particularly in African savannahs and more typical in sudano-sahelian zones. Similar results were found by Bognounou et al. (2009) and Froumsia et al. (2012), respectively in the sahelian zones of Burkina-Faso and Kalfou forest reserve in the sahelian zone of Cameroon.

Biomass and carbon storage:

In Laf forest reserve, characteristics of woody biomass and carbon storage varied from a collection unit to another. These characteristics constituted a good tool of appreciation of the anthropogenic activities in the sector. They turned out to be weak in CU₁ at the periphery but moderate in CU₂ and CU₃ (Table 5), and the total biomass and carbon storage were respectively 34.91 t/ha and 16.44 tC/ha. The high values of biomass and carbon storage in CU₂ (TB = 16.12 t/ha; CS = 7.6 tC/ha) is justified by the enriching plantings through several reforestation actions which were carried out between 1975 and 1986 by the National Forest Fund and the National Office for Forest Regeneration which planted 385 ha. Almost 200 ha of trees were planted in the western part of the reserve by the "Green Sahel Operation" lead by the Ministry of Youth and Sports in 2008. The planted species were: *Azadirachta indica*, *Acacia nilotica*, *Dalbergia melanoxylon*, *Khaya senegalensis*, *Eucalyptus camaldulensis* and *Cassia siamea*. Similar results were obtained by Ilboudo (2018) in the woody savannahs of Burkina-Faso with a total carbon storage of 17.66 tC/ha, and in the woody savannahs of Kedia and Ediolomo in the center region of Cameroon, that is 15.47 tC/ha and 16.40 tC/ha respectively (Amougou et al., 2016). The quantities of biomass and carbon stock are low in savannahs because of their grassy character, therefore less rich in tree species. In the Laf forest reserve, this situation is exaggerated by the anthropogenic activities, namely logging, overgrazing and agricultural activities. However, our results are much lower than those of the Sudano-Guinean savannahs of Ngaoundere in Cameroon, between 81.48 tC/ha and 118.36 tC/ha (Ibrahima and Fanta, 2008). In fact, the Sudano-guinean zone of Cameroon is situated between the tropical rain forests of the South and the dry savannahs of the North which present similar climatic characteristics of wet savannahs. Now, the carbon storage capacity is higher in wet savannahs compared to those of dry savannahs (Ciesla, 1997).

Conclusion:-

Anthropogenic activities in tropical areas threaten biodiversity and protected area integrity and then affect global ecosystem function and services. The survey aimed at assessing the effect of anthropogenic disturbances on biomass and carbon storage within Laf forest reserve in 1999 and 2019. The results showed that anthropogenic activities have negative impact on the stability of the reserve. The appropriation of land for the installation of fields has evolved over time, from the neighboring villages to the center of the reserve, given the increasing of the populations around and the growing needs for arable land. We observed a decline of shrub savannah, from 4161.30 ha in 1999 to

653.87 ha in 2019, and an increase of fields from 630.42 ha in 1999 to 3094.17 ha in 2019. This evolution is due to human activities, mainly agriculture (10.54 % in 1999 and 51.78 % in 2019). Only CU₃ installed at the middle of the reserve had moderate value of Shannon's diversity ($H' = 3.05$ bits). Mimosaceae (FIV = 57.62) and Combretaceae (FIV = 45.21) were the most important families throughout the collection units. The total biomass and carbon storage were respectively 34.91 t/ha and 16.44 tC/ha in the collection units. Collection unit 2 (CU₂) performed a good woody biomass (TB = 16.12 t/ha) and carbon storage (CS = 7.6 tC/ha) because the reforestation actions established in the unit. There was a significant difference between CU₁ and the two other collection units (ANOVA, $P = 0.001$). The Laf Forest Reserve appears to be heavily disturbed particularly near villages. Therefore, forestry agents of the Laf Forest Reserve can benefit from this study by planting local species in order to enrich the Reserve.

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Conflict of interests;

There's no conflict of interests

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