Annales des sciences agronomiques 20 (2) : 13-32, 2016   ISSN 1659 - 5009

VARIATION IN CARBON BUDGET, DIVERSITY AND DEMOGRAPHY TRENDS OF SELECTED TREE POPULATIONS OF WARI MARO FOREST RESERVE BETWEEN 2009-2014

F. SINSIN, R. GLÈLÈ KAKAÏ**, S. GUENDÉHOU*** & B. SINSIN **

** Laboratory of Applied Ecology, Faculty of Agronomic Sciences, University of Abomey-Calavi, 03 BP 1974 Cotonou (Benin) - f.sinsin@gmail.com*

*** Laboratory of Biomathematics and Forest Estimations, Faculty of Agronomic Sciences, University of Abomey-Calavi, 03 BP 2819 Cotonou (Benin)*

**** Centre Béninois de la Recherche Scientifique et Technologique, 03 BP 1665 Cotonou, (Benin)*

ABSTRACT

Illegal timber logging and bush fire in tropical savanna woodlands create an uncontestable mortgage for climate change mitigation. To investigate this hypothesis, we proposed a three-dimensional methodology based on a diachronic analysis to establish half-decade changes in floristic diversity and carbon budget. Data on trees and stump density, diameter at breast height, tree heights and crown diameter were collected from all trees whose diameters equal or exceed 10 cm at the breast height. And these were investigated from a permanent plot of 1 ha set up in savanna-woodland vegetation. With these data, diversity index, crown cover of trees, biomass and carbon budget were estimated. Dynamics of these structural descriptors and demography of tree-populations with a special focus on tree logging, mortality and recruitment rates were considered with the aim of appraising how deforestation contributes to emission of greenhouse gases. Key outcomes of this research revealed that from 2009 to 2014, the woody average species' richness of the Wari Maro Forest Reserve dropped from 15 to 14 species per hectare. The Shannon & Wiener diversity index and the equitability index of Pielou were almost invariable. Conversely, considerable changes were observed as regard to tree density, basal area, crown cover and carbon pool. Occurred modifications were negative for species coveted for their timbers, and positive for species less desired for timbers as well as for fire-resistant species. A huge loss in both trees density and carbon budget was observed with *Daniellia oliveri* timber which is not even yet subjected to logging. As compared to natural tree mortality and recruitment rate, the timber logging rate makes the fight against illegal timber logging as the sine qua non condition for expecting reduction of emission from deforestation and forest degradation in tropical savanna-woodlands.

Keywords : REDD+, greenhouse gases, biomass, tree mortality rate, timber logging rate.

BALANCE DU STOCK DE CARBONE, DIVERSITÉ ET DÉMOGRAPHIE DE QUELQUES POPULATIONS D'ARBRES DE LA FORÊT CLASSÉE DE WARI-MARO ENTRE 2009 ET 2014

RÉSUMÉ

L'exploitation illégale du bois et les incendies au sein des savanes boisées compromettent la résilience des changements climatiques. Pour le test d'une telle hypothèse, nous avions adopté une méthodologie tridimensionnelle portant sur une analyse comparative diachronique des indices clés de la diversité floristiques et du budget en carbone. Les données relatives à la densité des arbres vivants et des souches des arbres déjà exploités, les diamètres à hauteur de poitrine (DBH), les hauteurs et les diamètres des couronnes ont été mesurées pour tous les arbres ayant au moins 10 cm comme DBH et se retrouvant à l'intérieur du placeau permanant de 1ha (100m x 100m) installé au sein de la savane boisée. Grâce à ses données, les indices de diversité, l'aire occupée par les couronnes des arbres, ainsi que la biomasse et le budget en carbone ont été estimés. La dynamique de ces descripteurs structuraux ainsi que la démographie des populations d'arbres, notamment, les taux annuels d'extraction du matériel ligneux, les taux de mortalité et de recrutement ont été estimés pour la Forêt Classée de Wari Maro (Centre Bénin) pour la période 2009-2014 dans le but majeur d'apprécier comment la déforestation contribue à l'émission des gaz à effet de serre, notamment le CO_2. Les grands résultats renseignent que pour cette demi-décennie, la richesse spécifique des ligneux est passée de 15 à 14 espèces par hectare. Les indices de diversité de Shannon & Wiener ainsi que les indices d'équitabilité de Piélou étaient presque constants. Contrairement à ces observations, les modifications les plus inquiétantes avaient été observées avec les paramètres sylvicoles tels que la densité, la surface terrière, la couverture ligneuse et le budget de carbone de l'écosystème représenté par l'aire d'échantillonnage. Pour certaines espèces, notamment celles dont les bois ne sont pas encore démontrés utiles pour l'exploitation ligneuse au niveau local, les changements observés se sont traduits par des gains. Ce fût le cas de *Combretum* spp. et de *Monetes kerstinguii*. L'espèce *Daniellia oliveri* fait la différence à cette règle, fait lié à sa forte sensibilité aux feux de végétation, surtout au jeune âge.

Mots clés : REDD+, Gaz à effet de serre, biomasse, taux de mortalité, taux d'exploitation du bois.

INTRODUCTION

With 170-250 t/ha of biomass and a global annual uptake of 1.3 Gt of carbon, tropical forest ecosystems grasp the greatest world active carbon sink (FAO, 2015), and are thereby playing a significant role in climate change mitigation. Nonetheless, these ecosystems are experiencing continuous regressive changes in terms of forest cover and carbon sequestration power. For instance, recent research carried out in the Amazon rainforest indicated a crucial drop in the carbon budget of the largest world forest during the last two decades (Davidson *et al.*, 2012). Besides, from 2000 to 2010, 3.4 million hectares of African forests were yearly lost on the behalf of anthropogenic deforestation consisting of illegal timber logging (ITL), uncontrolled forest fires, extensive agriculture and pasture (FAO, 2014). This situation constrained the UN frame convention on forest and climate change (UNFCCC) to ratify a carbon credit mechanism for reducing emissions from deforestation and forest degradation (UN REDD, 2010). European Union through the intermediate of forest law enforcement, governance and trade (FLEGT) concluded, that the target of REDD mechanism would not retire from the stage of dream as much as illegal timber logging (ITL) remains in force with twentieth share of atmospheric CO_2emission. And outside fossil energy, the post-logging carbonization which induces forest fires associated to emission of greenhouse gases seems to be the second main driver of climate change (Huntingford *et al.*, 2013, Sinsin *et al.*, 2015). The World Meteorological Organization's annual Greenhouse Gas Bulletin counseled that from 1984 to 2013, the global average atmospheric concentration increase of carbon dioxide (CO_2) was at its peak level (2.9 ppm) in 2012-2013. The observed concentrations for this gas (396.0 ± 0.1 ppm) and for methane (CH_4, 1824±2 ppb) were respectively 142 % and 253 % of pre-industrial levels (Secretariat WMO *et al.*, 2013). Being responsible of 84 % of the increase of radiative forcing over the decade 2004-2013, CO_2 is acknowledged to be the dominant greenhouse gas in the atmosphere (Secretariat WMO *et al.*, 2013). In principle, living trees store more carbon than they release into the atmosphere (Kirschbaum, 2003). In addition, carbon stocking capacity of forest ecosystems strongly depends on latitude, climate, vegetation, species and soil regimes (Hobbie *et al.*, 2000 ; Jobbágy & Jackson, 2000 ; Lal, 2005 ; Davidson & Janssens, 2006). Savanna-woodlands, predominant forest ecosystems of West Africa, annually contribute to emission of 0.5 - 4.2 Gt C through ITL and wildfires; and an annual uptake of roughly 0.5 Gt through the photosynthesis function (Grace *et al.*, 2006). Thus, a considerable gap is expected between the carbon sequestration potential and the emission rate from deforestation. Because of this situation, industrialized and developing countries concluded to eradicate net global emissions from tropical forests by 2030 (Gullison *et al.*, 2007). Achievement of such goal may pass through the fight against emission from deforestation as recommended by the UN-REDD+ program. Though West and Central Africa hold the second important world green carbon sink, knowledge on native trees' capacity at carbon stocking is rather indefinite (Worbes *et al.*, 2003 ; Vincke, 2011). Woodlands and savannas of West Africa shelter over 1,000 endemic plant species in the ecoregion (White, 1983). They continuously undergo considerable human pressures of various natures, the most conspicuous being converting these ecosystems into agricultural lands, wildfires from the charcoal production and illegal timber logging (Sinsin *et al.*, 2015). These actions resulted in the fragmentation of ecosystems exposing the endemic species to extinction. Only 6 % of the area covered by West African savanna-woodlands was preserved throughout protected areas covering 90,000 km². With climate change effects characterized by long and severe dry seasons, these protected areas which were supposed to be the ultimate guarantee for the conservation of biodiversity are subjected for decades to similar human pressures (Magin, 2015). These anthropogenic disturbances may induce changes in the floristic composition and in biomass potential. As an eco-demographical case study in a multi-facets anthropogenic degraded forest ecosystem, this study aims at discussing fundamental forces of carbon dynamics in Wari-Maro savanna-woodlands. To achieve such goal, two major hypotheses were tested: i) Due to deforestation, Savanna Woodland stands of Wari-Maro Forest Reserve are experiencing a loss of biodiversity; ii) Occurred changes in diversity and in structural descriptors have significant effects on biomass and carbon stocks of Wari-Maro Forest Reserve tree populations.

MATERIAL AND METHODS

Study area

This research was carried out in the degraded savanna-woodland of Wari-Maro Forest Reserve located in Central Benin, at 09°10'N, 02°10'E (Figure 1), where the mean annual rainfall is estimated to 1050 mm and temperatures are ranged between 19 and 40°C.

Data and samples collection

As indicated in the vegetation map presented below, the data come from a permanent plot of 1 ha set up in savanna-woodland vegetation (Figure 2). Diachronic (2009 and 2014) dendrometrical menstruation including trees' circumference, total heights, main stems' heights and crowns size were determined. Figure 3 shows the concerned tree parts.

Circumferences of trees were measured with a tape at breast height and, breast height diameter (DBH) values were deducted. Heights were calibrated with a SUUNTO clinometer. The crown diameter was obtained by projecting two opposite broadsides of the tree crown into the ground and the segment delimited by the orthogonal projections corresponds to the crown diameter (Figure 3). As far as samples were concerned, 56 wood cores were taken from the main stem of 28 trees from 14 species. They were appropriately stored and pre-dried in the field.

Sample processing

The standard dendrochronology technique was applied for the determination of trees' ages. This was done through pre-drying of wood cores in the field followed by gradual polishing with sandpapers of various grades. After that, tree-rings identification was done and boundaries were identified and examined using microscope. Cross-dating was applied and mistakes in chronologies were subsequently corrected. Exact trees' ages were established by counting growth rings from the final fitted time series. The mean annual diameter increment was induced by dividing the diameter at breast height by age of sampled trees.

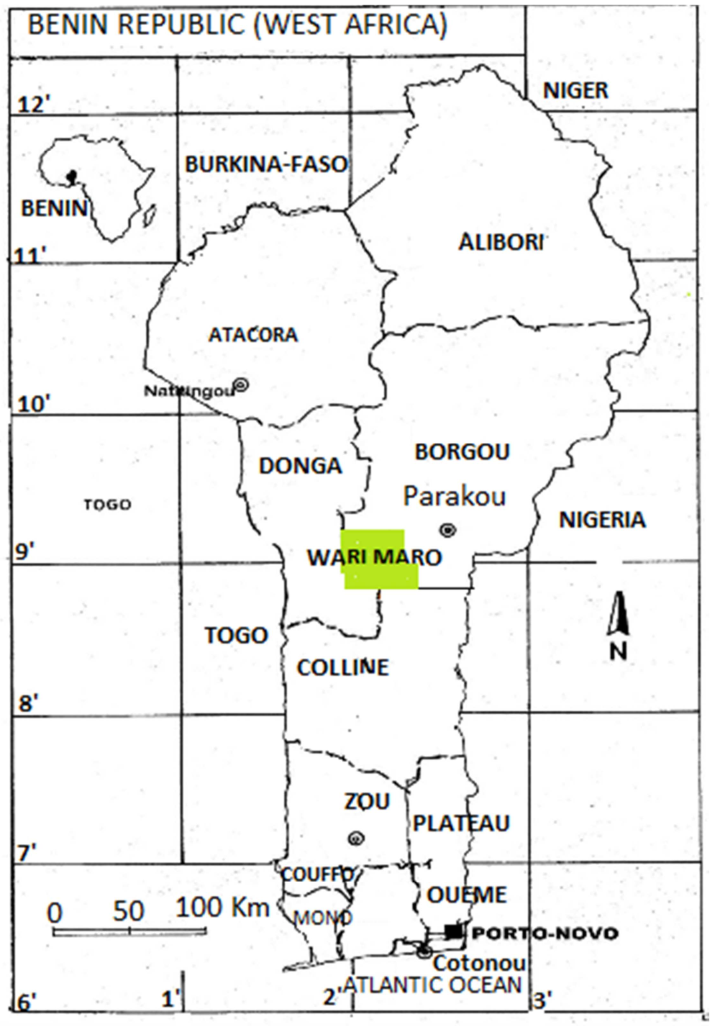

Figure 1. Localization of the study area

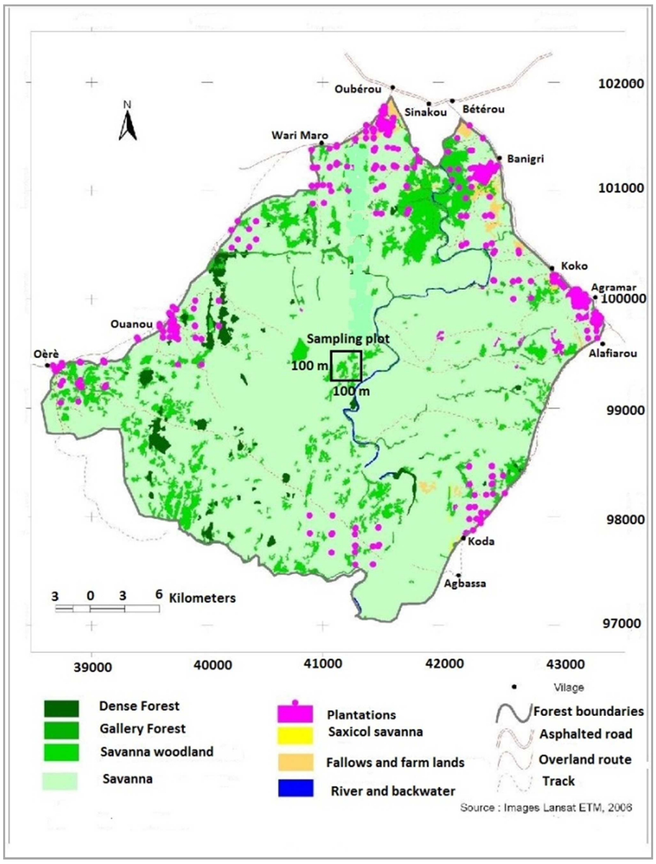

Figure 2. Vegetation map of Wari Maro Forest Reserve indication the geographical position of the sampling plot

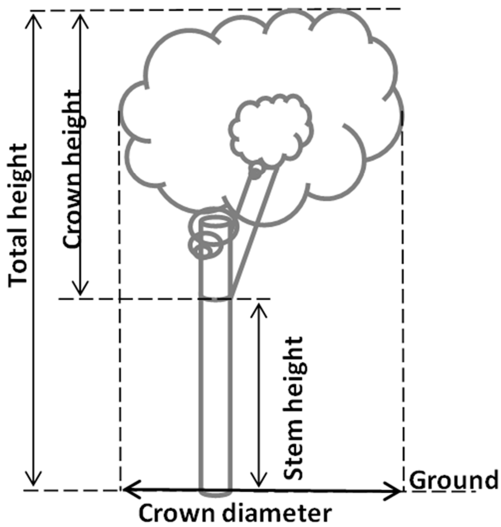

Figure 3. Measured parts of tree

Data analysis

Evaluation of eventual changes in diversity

Four diversity parameters were used to assess the changes in tree diversity between 2009 and 2014. These are the species richness (*S*) which represents the number of tree-species per hectare; the Shannon & Wiener index (*H'*) which includes the tree-species abundance and the equitability index of Pielou (*E*).

$H' = -\sum_{i=1}^{n} Piln(Pi)$,

Where $Pi = Ns/N$is the abundance of tree species i in the population, *Ns* is the number of individuals of the species i and *N*, the total number of individuals in the populations.

$$E = H'/Hmax = H'/Logs$$

In the above equation, H_{max} represents the maximal diversity.

Dynamics of structural descriptors

The following parameters were analyzed and different dates values obtained for each one of them were compared.

Tree population density (*Ns*, trees.ha^{-1}) : number of trees by species per hectare.

Stand tree density (*N*, trees.ha^{-1}) : number of trees per hectare including all woody species.

$$N = \sum_{1}^{s} Ns$$

o Contribution to the basal area (CBA) : this is the contribution of each species to the basal area of the stand. It was computed as follows:

$$CBA\,(i) = 100Gi/\sum_{1}^{s} Gi$$

where the unit metric of G is m^2.ha^{-1} and i is related to the species.

o Mean diameters in cm

Both diameter at breast height (for population: *DBHp* and for stand: *DBHs*) and mean quadratic diameter (*Dg*) were evaluated.

$DBHp = \sum_{1}^{Ns} DBH/Ns$,$DBHs = \sum DBHp/S$,

$$Dg = \sqrt{\sum DBH^2/N}$$

o Basal area (m^2.ha^{-1})

$$G = \sum \pi(DBH/2)^2/S$$

o Mean heights

Stem height (MH_s, m): this was the height measured from ground until the intersection of the first big branch (Figure 3).

$MHs\,(population) = \sum_{1}^{Ns} Hs/Ns$,
$MHs\,(stand) = \sum(\sum_{1}^{Ns} Hs/Ns)/S$

MHsp is linked to the population of the same species whereas for *MHss*, stem height of all trees found in the stand were considered.

Total height (*MHt*, m): height of the tree from ground to the upper leave (Figure 3).

$\sum_1^{Ns} Ht/Ns$, $MHt(stand) = \sum(\sum_1^{Ns} Ht/Ns)/S$

o Crown area ($m^2.ha^{-1}$)

Crown cover (C, $m^2.ha^{-1}$) equals to the total area occupied by trees 'crown. The form of tropical trees crown being compared to a half-ellipsoid (Vincent & Harja, 2005).

$$C = \sum_1^N \pi * (CD/2)^2 \Big/ A$$

With *CD* and A being respectively the crown diameter expressed as meters and the plot area as ha.

Demographic data

o Mortality rate

We differentiated the natural mortality from the felled trees by analyzing the transversal section of stumps. It may happen that stems of big dead trees are collected by illegal timber loggers. In that case, dead trees are mixed up with logged trees as it was no longer possible to make the difference.

Natural tree mortality rate (γ, %) concerns trees of which death is either due to age, climatic hazards, attack of insects, fire occurrence, bark harvesting, tree pruning or wind. Except logged trees, this includes all living subjects whose existence was proved at the beginning of the study (2009) and whose absence was remarked at the end of the investigation (2014). Based on that, natural mortality occurred at a constant rate along the five years of experimentation, its rate was calculated as proposed in several studies (Phillips *et al.*, 1994 ; Condit *et al.*, 1995 ; Sheile, 1995 ; Madelaine-Antin, 2009) :

$\gamma = 100\,(\ln[N0/Ns + Nl])/t,$

Where N_0 is tree density in 2009 ; Ns : surviving trees in 2014 ; N_l : number of logged trees between 2009 and 2014 ; t = 5 years. Trees with DBH > 10 cm were investigated. They were marked and numbered in 2009 and the standing marked trees observed in 2014 were considered as the surviving trees.

o Annual tree logging rate ($\mathcal{E}$, %)

$\gamma\mathcal{E} = 100\,(\ln[N0/Ns + Nd])/t$, where N_d, number of dead trees from 2009 to 2014 ; *Ns* and *No* are defined as above.

o Tree mortality rate (α, %) : it includes both natural mortality and logged trees.

$$\alpha = 100(\ln[N0/Ns])/t$$

o Tree recruitment rate (μ, %)

$\mu = 100\,(\ln[Nf/Ns])/t$ with *Nf*, the observed tree density in 2014.

Quantification of aboveground woody carbon stock

o Tree volume estimation

In the absence of accurate allometric equations linking the biomass to the basic dendrometrical parameters measured in the field such as DBH and height, the quantification of the aboveground biomass (*AGB*) of a tree requires the computation of its volume which may be split up into three major components: crown, stem and roots volumes. Tree stems are compared to a geometrical figure as a cylinder characterized by a continual decrement in diameter moving from the base to the apex of the tree. Because of the variability in forms from a tree-species to the other, a form factor *f* is applied to the theoretical formula of the cylinder volume. Such form coefficients may also be influenced by the type of vegetation. The stem form coefficients of *A. leiocarpa*, *Isoberlinia spp* and *D. oliveri* for Wari-Maro tree-populations were established by Fonton *et al* (2009). Their variation according to diameter class as indicated by the authors was taken into account. For the leftover species, we used the mean values of stem form coefficients of these three species (Table 1).

Table 1. Variation of following species and diameter classes (Fonton *et al.,* 2009)

Diameter class (cm)	*Isobelinia spp*	*A. leiocarpa*	*P. erinaceus*	Mean values
[10-20[	0.81	0.91	0.93	0.88
[20-30[	0.83	0.84	0.92	0.86
[30-40[	0.82	0.8	0.86	0.83
[40-50[	0.83	0.75	0.88	0.82
[50-60[	0.77	0.65	0.87	0.76

> 60	0.79	0.67	0.85	0.81

Regarding the crown, this includes the branches, the leaves and sometimes the fruits. A rigorous assessment of crown volume is almost impossible with a non-destructive tree volume computation. However, with information on diameter and height of the crown, an estimation of its volume can be done. And in that case, a species-specific crown form must be determined in order to apply this to the theoretical cylinder formula. When such datum is missing, the stem coefficient form may be used to approach crown volume of course with some bias. But, considering the framework of this study which endeavors at monitoring the carbon dynamics with data of two different dates from a permanent plot, we definitely assumed that the error related to the crown form coefficient used is reduced by the subtraction operation between the sequestrated carbon values of the two experimentation dates.

$$Vb = \pi * DBH^2 * Hb * f * 10^{-4}/4$$

$$Vc = \pi * CD^2 * Ch * f * 10^{-4}/4$$

$$Vt = Vb + Vc$$

$$Vt = \pi * f[DBH^2 * Hb + CD^2 * Ch] * 10^{-4}/4$$

Dendrometric parameters Vb, Vc and Vt expressed as m^3 are respectively the bole volume, the crown volume and the total volume of a tree. Dendrometric characteristics such as *DBH*, *Hb*, *CD*, *Ch* are respectively the diameter at breast height in cm, the bole height in m, the crown diameter in cm and the crown height in m.

- Aboveground biomass (AGB) of ligneous species

AGB is the mass of aboveground organic material of living trees. *AGB* values were obtained by multiplying the total volume by the wood density. The sum of individual tree biomass gives the stand biomass. The average wood densities are obtained from "local data for wood density, Reference No. 16a". But, some species were missing on that list and we referred to regional and international wood databases websites. Average wood densities of the species of this study are summarized in Table 2.

$AGB = Vt * WD * 10^{-3}$ with *WD,* the wood density and *AGB* expressed in ton.

Table 2. Average species-specific wood density according to local data for wood density, Reference No. 16a

Species	Wood density (kg/m³)
A. africana	780
B. africana	840
D. microcarpum	730
D. oliveri	550
K. senegalensis	775
P. erinaceus	750
L. lanceolata	640
M. kestingii	1050
P. biglobosa	600
V. paradoxa	720
Combretumspp	640
L. laxiflora	580
Terminaliaspp	640
A. leiocarpa	960
Isoberliniaspp	640

o Carbon dynamics

The carbon stock (Q, ton) was directly quantified from the wood volume as follows:

$Q = 0.27Vt.$

Carbon stocks at two different dates (2009 and 2014) were evaluated and the variation in this stock was straightforwardly computed with a subtraction operation.

$$\Delta Q = Q\ (2014) - Q\ (2009)$$

RESULTS

Analysis of changes in diversity and structural descriptors of the stand

Table 3. Variation in diversity and in dendrometric parameters of the stand

Key parameters	2009	2014
Tree-species richness (S)	15	14
Shannon &Wiener index (H')	2.4	2.39

Equitability index of Pielou (E)	0.89	0.91
Tree density (Tree/ha)	269	208
Mean age of stand (year)	23.34	22.81
Mean DBH (cm)	23.95	23.48
Mean quadratic diameter (Dg. cm)	25.9	25.23
Mean stem height (m)	4.67	3.94
Mean total height (m)	9.96	9.16
Basal area (G. m²/ha)	13.335	10.405
Crown cover (m²/ha)	3670.48	2912.99
Total volume (m3)	29169.91	24645.91
Biomass (ton/ha)	20006.51	16620.23
Carbon stock (ton/ha)	7875.90	6654.40

As shown in Table 3, indices of tree's diversity have not undergone major changes during the period 2009-2014. Shannon & Wiener index was almost constant and the equitability index of Pielou increased from 0.89 to 0.91. However, in the sampling plot of 1 ha area, the only one *A. africana* tree identified in 2009 no longer existed in 2014. In consequence, the tree-species richness decreased from 15 in 2009 to 14 species in 2014. During this half-decade, a quarter of the stand tree density was lost. The mean age of the stand that logically should increase remained almost constant (approximately 23 years). Similar observations were made for the mean diameters at breast height and mean quadratic diameters which experienced a slight decline. The mean height of trees (free bole and total) experienced a decrease of about half meter. However, the basal area, the crown cover, the total volume, the biomass and the carbon stock have experienced a considerable decline of about 20 % of the initial stock. However some tree-populations responded positively to these changes and Table 4 provides the details about these tree-populations.

Description and analysis of changes in structural descriptors of tree-populations

Analysis of Table 4 reveals that observed regression in the stand tree density comes from the high pressure on tree-populations of *K. senegalensis*, *P. erinaceus*, *D. oliveri*, *B. Africana, Isoberlinia spp*, *Terminallia spp*, *A. leiocarpa* and *L. laxiflora*. Except the last two species of this list, the drop in tree-density was positively correlated with the decrease in biomass. With eight species, increases of biomass stocks were noticed and six tree-populations have experienced regressive changes (Figure 4). For a number of these species, the mean age and the index of importance value also experienced a downward trend. On the other hand, the tree-densities of *L. lanceolata*, *Combretum spp*, *M. kerstingii*, *P. biglobosa*, *D. microcarpum* and *V. paradoxa* increased ; this increase is perfectly correlated with the evolution of their mean ages, the index of importance value and the biomass.

Table 4. Details on dynamic of tree-population characteristics

Tree-Populations	Density (tree/ha)		Meanage ± σ (year)		CBA (%)		Biomass (ton/ha)	
	2009	2014	2009	2014	2009	2014	2009	2014
A. africana	1	0	27 ± 0		0.17	0	2.91	0
A. leiocarpa	19	13	10.79 ± 5.33	12.69 ± 1.6	4.87	5.26	940.34	1097.23
B. africana	31	13	30.65 ± 8.73	19.62 ± 7.14	6.37	4.06	4284.25	548.43
Combretumspp	27	31	12.56 ± 5.28		8.47	17.45	1220.23	2684.44
D. oliveri	18	6	42.5 ± 15.96	51.17 ± 23.51	9	5.21	2511.39	1175.73
D. microcarpum	24	27	20.54 ± 3.8	23.52 ± 4.22	3.45	6.56	132.67	251.61
Isobeliniaspp	49	33	12.12 ± 7.12	9.17 ± 4.43	26.39	15.71	3361.44	1860.09
K. senegalensis	4	1	Indetermined		5.06	0.5	1296.09	127.06
L. laxiflora	16	12	19.31 ± 3.09	21 ± 4.02	2.41	2.75	19.02	32.62
L. lanceolata	2	4	12.5 ± 0.71	11.5 ± 4.65	0.6	1.44	42.26	43.07
M. kerstingii	3	7	40.33 ± 10.02	29.29 ± 16.99	1.8	3.45	118.65	559.84
P. biglobosa	12	15	35.83 ± 5.81	34 ± 12.56	6.9	10.81	2186.31	3127.41
P. erinaceus	5	3	19.6 ± 6.11	20.67 ± 4.04	1.35	0.85	328.93	121.52
Terminaliaspp	37	21	12.41 ± 4.15	10.86 ± 3.41	10.72	5.83	1461.34	804.33
V. paradoxa	21	22	26.61 ± 6.34	29.68 ± 8.99	12.44	20.12	2100.66	4186.34

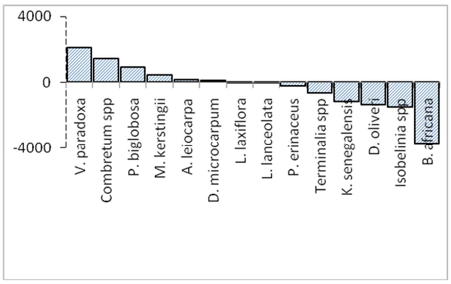

Figure 4. Variation in biomass as gain/loss (ton/ha) from 2009-2014

In sum, the analysis demonstrates that pressures on species were selective and the response of trees to the disturbances varied from one species to another. The confirmation of such comment could be made with the analysis of Table 5.

Table 5. Tree-populations demography

Tree-Populations	Recruitment (%/year)	Logging (%/year)	Natural mortality (%/year)	Annual loss (%)	Viability index (%/year)
A. africana	0				
A. leiocarpa	1.6	9.19	0	9.19	-7.59
B. africana	7.35	24.74	0	24.74	-17.39
Combretum spp	6.86	0	4.1	4.1	2.76
D. oliveri	3.65	0	25.62	25.62	-21.97
D. microcarpum	6	2.8	0.85	3.65	2.35
Isobeliniaspp	17.15	24.65	0.41	25.06	-7.91
K. senegalensis	0	27.73	0	27.73	-27.73
L. laxiflora	5.75	0	11.51	11.51	-5.76
L. lanceolata	13.86	0	0	0	13.86
M. kerstingii	16.95	0	0	0	16.95
P. biglobosa	6.2	0	1.74	1.74	4.46
P. erinaceus	8.11	18.33	0	18.33	-10.22
Terminaliaspp	12.93	20.72	3.54	24.26	-11.33
V. paradoxa	1.91	0	0.98	0.98	0.93
Stand	7.78	10.05	2.87	12.92	-5.14

Demography of the stand and tree-populations

By analyzing the data presented in the Table 5, we see that Wari Maro Forest Reserve is regressing. The viability index of the stand is less than zero as the rate of timber extraction far exceeds the gains due to recruitment of saplings. In addition to timber logging rate of about 10 %, the annual mortality rate was estimated at 2.87 % widening the gap between gains and losses in terms of density. It is an evidence that the regressive changes occurred in Wari Maro Forest Reserve was due to selective timber logging characterized by an annual rate ranged between 9-28 % of the initial potential for species such as *K. senegalensis*, *P. erinaceus*, *A. leiocarpa*, *Isobelinia spp*, *B. africana* and *Teminalia spp*. Moreover, *D. oliveri* whose timber was not yet coveted looks to be one of the most endangered tree species of the stand. A low tree-recruitment rate (< 4 %) was noticed with four species. And in the same conditions, recruitment rates were above 15 % for *M. kerstingii* and *Terminalia spp.*, demonstrating that the factors that are critical for the conservation of some species may be favorable to the survival of other species.

Correlations between tree age – biomass, density – biomass and basal area – biomass

Tree age, tree-density of populations and basal area are all correlated with biomass, │R│values being ranged between 0.6 and 0.8. Meanwhile, the best correlation was observed with the basal area followed by tree's age. As shown in Figure 5, R^2 values were ranged between 0.37 and 0.60.

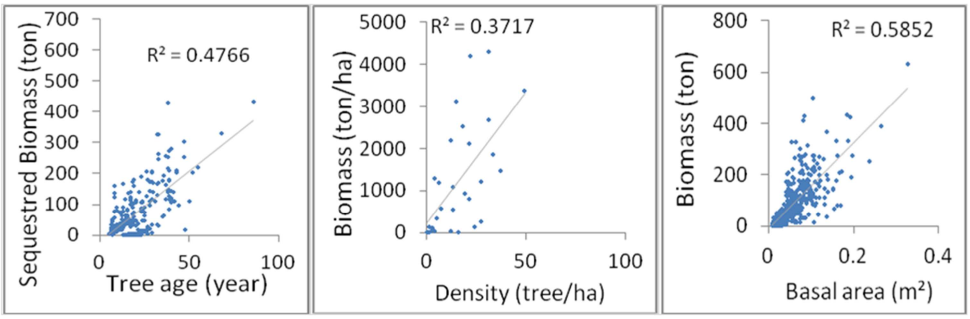

Figure 5. Correlations degree between tree age-biomass, density-biomass and basal area-biomass

DISCUSSION

In the sampling area, one tree-specie disappeared between 2009-2014, but the Shannon & Wiener and the equitability index of Pielou were almost constant. Twenty five per cent of the stand tree density was however lost. The mean diameters and the mean heights experienced a slight decline. And a depletion of about 20 % was recorded for the basal area, the crown cover, the biomass and the carbon stocks. Similar observations were made by other researches and authors of these investigations concluded, that tropical savannas are instrumental in the CO_2 emission (Sasaki & Putz, 2009, Bicknell *et al.*, 2015 ; Cavanagh *et al.*, 2015). In contrast, there are other tropical vegetations, which efficaciously assume the carbon sequestration function (Gifford, 1994, Fisher *et al.*, 2015). A study carried out in 2154 savannas and published in the review Science revealed that in savannas areas, climate change results in increased moisture availability, leads to repeated fires, which contribute to the reduction of stand basal area (Lehmann *et al.*, 2014). The triangulation of several research results on the population structure of West African woodland woody species looks to confirm this observation. Densities of *Pterocarpus erinaceus, Isoberlinia doka* and *Anogeissus leiocarpa* were respectively estimated in 2004 at 498-523, 349-376 and 186 trees/ha (Sokpon *et al.*, 2006). In 2007, tree-density was 200-225 trees/ha for *Isoberlinia* genus together amounting to an average of 113 trees/ha by species (Glèlè Kakaï & Sinsin, 2009). This density has fallen to 49 trees/ha in 2009 and to 33 trees/ha in 2014. Although these results may be attributed to the geographical positions of sampling plots, they all testified high human pressure. In Wari-Maro Forest Reserve, due to illegal timber trees logging, about 244 t/ha of carbon are annually exported. Carbon pools were estimated to a minimum of 141-571 Mg/ha (Kauffman *et al.*, 2009) and 1-12 tons/ha/year respectively for the Neotropical primary forests and the tropical savannas (Grace *et al.*, 2006). For instance, in Mozambique's woodlands, stems stored about 22.2 t/ha of carbon (Ciais *et al.*, 2011). Illegal timber logging was demonstrated as an important driver of carbon loss in tropical woodlands. Beyond this, adopted regime of timber harvesting has a high influence on tree-populations' structure and demography. Being indirectly linked to forest fires, it causes the suppression of seedlings and some saplings (Tredennick *et al.*, 2014). Biomass gains from tree recruitment, cumulative growth and regrowth should be far higher than losses generated by natural tree mortality. There is no tropical forest totally free of all ecological disturbances (Hoffmann *et al.*, 2012).

Studies on populations' demography in Neotropical protected savanna revealed a recruitment rate of 1.7-2.2 %, which is similar to the data obtained for *A. leiocarpa* in this study. Illegal and selective timber harvesting affects productivity of seed trees and increases the sensitivity of the species to vegetation fires, compromising tree recruitment. In C4 grasslands and savannas as in national parks of Benin, surface fires caused mortality of seedlings (Bond *et al.*, 2008 ; Sinsin *et al.*, 2015).

The largest carbon reservoirs in tropical regions are the first to face ravages from deforestation. And this deforestation is through biomass combustion with the emission of greenhouse gases. Long-term data related to carbon stock fluctuation at the ecosystem level and demography of tree-populations are two fundamental challenges for the evaluation the biotope efficiency in environment purification (Chansomwong *et al.*, 2014 ; Mauseth, 2014 ; Neba *et al.*, 2014 ; Temesgen *et al.*, 2015). Management plans should be proposed taking into account outcomes of such studies. Outside of all anthropogenic disturbances and all natural disasters, forest ecosystems were expected to evolve following a progressive succession (Thrippleton *et al.*, 2014). Technical interventions which are supposed to design sustainable management are really effective when they are oriented towards the restoration of degraded stands.

CONCLUSION

Investigation on carbon stock dynamic at habitat level is more informative and essential than analysis of static data. With such approach, we demonstrate in this study how some tree populations of Wari Maro Forest Reserve were experiencing severe anthropogenic deforestation which was negatively affecting the carbon budget of these ecosystems. Coming forest management projects have to offer a special consideration to the combat against illegal timber logging; and with this, we expect a significant set-back in forest fire frequency.

REFERENCES

BICKNELL J. E., GAVEAU D. L., DAVIES Z. G., & STRUEBIG M. J. 2015. Saving logged tropical forests: closing roads will bring immediate benefits : Peer-reviewed letter. *Frontiers in Ecology and the Environment*, *13* (2), 73-74.

BOND N. R., LAKE P. S. & ARTHINGTON A. H. 2008. The impacts of drought on freshwater ecosystems: an Australian perspective. *Hydrobiologia*, *600* (1), 3-16.

CAVANAGH C. J., VEDELD P. O., & TRÆDAL L. T. 2015. Securitizing REDD+? Problematizing the emerging illegal timber trade and forest carbon interface in East Africa. *Geoforum*, *60*, 72-82.

CHANSOMWONG A., ZANGANEH K. E., SHAFEEN A., DOUGLAS P. L., CROISET E. & RICARDEZ-SANDOVAL L. A. 2014. Dynamic modelling of a CO 2 capture and purification unit for an oxy-coal-fired power plant. *International Journal of Greenhouse Gas Control*, *22*, 111-122.

CIAIS P., BOMBELLI A., WILLIAMS M., PIAO S. L., CHAVE J., RYAN C. M. & VALENTINI R. 2011. The carbon balance of Africa: synthesis of recent research studies. *Philosophical Transactions of the Royal Society of London A : Mathematical, Physical and Engineering Sciences*, *369* (1943), 2038-2057.

CONDIT R., HUBELL S. P., FOSTER R. B. 1995. Mortality rates of 205 neotropical tree and schrub species and the impact of a severe drought. *Ecological Monographs*, 65: 419-439.

DAVIDSON E. A. & JANSSENS I. A. 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, *440* (7081), 165-173.

DAVIDSON E. A., DE ARAÚJO A. C., ARTAXO P., BALCH J. K., BROWN I. F., BUSTAMANTE M. M., & WOFSY S. C. 2012. The Amazon basin in transition. *Nature*, *481* (7381), 321-328.

FAO, 2014. State of world forest. United Nations Organization for Food and Alimentation, Rome.

FISCHER R., ENSSLIN A., RUTTEN G., FISCHER M., COSTA D. S., KLEYER M. & HUTH A. 2015. Simulating Carbon Stocks and Fluxes of an African Tropical Montane Forest with an Individual-Based Forest Model. *PloS one*, *10* (4).

FONTON N. H., YABI C. C., DAH-DOVONON J. Z., ADOKO F. K. & DOTCHAMOU T. 2009. Modelling stem volume for the sustainable management of Sudanian forest ecosystems. *Bois et Forêts des Tropiques*, (300), 95-100.

GIFFORD R. M. 1994. The global carbon cycle : a viewpoint on the missing sink. *Functional Plant Biology*, *21* (1), 1-15.

GLÈLÈ KAKAÏ R., SINSIN B. 2009. Structural description of two *Isoberlinia* dominated vegetation types in the Wari–*Maro Forest* Reserve *(*Benin*). South African Journal of Botany* **75** (1), 43-51.

GRACE J., JOSÉ J. S., MEIR P., MIRANDA H. S. & MONTES R. A. 2006. Productivity and carbon fluxes of tropical savannas. *Journal of Biogeography*, *33* (3), 387-400.

GULLISON R. E., FRUMHOFF P. C., CANADELL J. G., FIELD C. B., NEPSTAD D. C., HAYHOE K., &NOBRE C. 2007. Tropical forests and climate policy. *SCIENCE-NEW YORK THEN WASHINGTON-*, *316* (5827), 985.

HOBBIE S. E., SCHIMEL J. P., TRUMBORE S. E., & RANDERSON J. R. 2000. Controls over carbon storage and turnover in high-latitude soils. *Global Change Biology*, *6* (S1), 196-210.

HOFFMANN W. A., GEIGER E. L., GOTSCH S. G., ROSSATTO D. R., SILVA L. C., LAU O. L., & FRANCO A. C. 2012. Ecological thresholds at the savanna-forest boundary: how plant traits, resources and fire govern the distribution of tropical biomes. *Ecology Letters*, *15* (7), 759-768.

HUNTINGFORD C., ZELAZOWSKI P., GALBRAITH D., MERCADO L. M., SITCH S., FISHER R. & COX P. M. 2013. Simulated resilience of tropical rainforests to CO2- induced climate change. *Nature Geoscience*, *6* (4), 268-273.

JOBBÁGY E. G., & JACKSON R. B. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological applications*, *10* (2), 423-436.

KAUFFMAN J. B., HUGHES R. F., & HEIDER C. 2009. Carbon pool and biomass dynamics associated with deforestation, land use, and agricultural abandonment in the neotropics. *Ecological Applications*, *19* (5), 1211-1222.

KIRSCHBAUM M. U. 2003. To sink or burn? A discussion of the potential contributions of forests to greenhouse gas balances through storing carbon or providing biofuels. *Biomass and Bioenergy*, *24* (4), 297-310.

LAL R. 2005. Forest soils and carbon sequestration. *Forest ecology and management*, *220* (1), 242-258.

LEHMANN C. E., ANDERSON T. M., SANKARAN M., HIGGINS S. I., ARCHIBALD S., HOFFMANN W. A. & BOND W. J. 2014. Savanna vegetation-fire-climate relationships differ among continents. *Science*, *343* (6170), 548-552.

LUOGA E. J., WITKOWSKI E. T. F. & BALKWILL K. 2002. Harvested and standing wood stocks in protected and communal miombo woodlands of eastern Tanzania. *Forest Ecology and Management*, *164* (1), 15-30.

MADELAINE-ANTIN C. 2009. Tropical forests dynamics: intraspecific and interspecific variability of the growth of trees and growth trajectories in wet evergreen forest. PhD dissertation, Université Montpellier II, Sciences et techniques du Languedoc.

MAGIN C. 2015. Tropical and subtropical grasslands, savannas and schrublands. Western Africa: stretching from Senegal through Niger. World Wildlife Fund, Washington.

MAUSETH J. D. 2014. *Botany : an introduction to plant biology*. Jones & Bartlett Publishers.

NEBA S. G., KANNINEN M., ATYI R. E. A., & SONWA D. J. 2014. Assessment and prediction of above-ground biomass in selectively logged forest concessions using field measurements and remote sensing data: Case study in South East Cameroon. *Forest Ecology and Management*, *329* : 177-185.

PHILLIPS O. L. & GENTRY A. H. 1994. Increasing turnover through time in tropical forests. *Science*, 263 : 954-958.

SASAKI N. & PUTZ F. E. 2009. Critical need for new definitions of "forest" and "forest degradation" in global climate change agreements. *Conservation Letters*, *2* (5) : 226-232.

SECRETARIAT W. M. O., SECRETARIAT W. M. O., WARN E. & ADAMO S. B. 2013. The journal of the World Meteorological Organization.

SINSIN F., GLÈLÈ KAKAÏ R., ORTHMANN B., SINSIN B. 2015. Tree Ring: a suitable implement for spatial and temporal fire distribution analysis in Savanna-Woodlands and dry Forests. *Journal of Forestry Research*, **26** (2) : 435-446.

SINSIN F., GLÈLÈ KAKAÏ R., SINSIN B. 2015. Multidisciplinary approach for detecting long-term changes in dry forests and savanna-woodlands. *Biological Conservation*, Manuscript under Review.

SOKPON N., BIAOU S. H., OUINSAVI C. & HUNHYET O. 2006. Bases techniques pour une gestion durable des forêts claires du Nord-Bénin: rotation, diamètre minimal d'exploitabilité et régénération. *Bois et forêts des tropiques*, (287), 45-57.

SHEIL D., 1995. A critique of permanent plot methods and analysis with examples from Budongo Forest, Uganda. *Forest Ecology and Management*, 77 : 11-34.

TEMESGEN H., AFFLECK D., POUDEL K., GRAY A. & SESSIONS J. 2015. A review of the challenges and opportunities in estimating above ground forest biomass using tree-level models. *Scandinavian Journal of Forest Research*, *30* (4), 326-335.

THRIPPLETON T., DOLOS K., PERRY G. L., GROENEVELD J. & REINEKING B. 2014. Simulating long-term vegetation dynamics using a forest landscape model: the post-Taupo succession on Mt Hauhungatahi, North Island, New Zealand. *New Zealand Journal of Ecology*, *38* (1), 26-38.

TREDENNICK A., KAREMBÉ M., DEMBÉLÉ F., DOHN J., & HANAN N. 2014. *Weak effects of fire, large herbivores, and their interaction on regrowth of harvested trees in two West African savannas* (No. e718v1). Peer J PrePrints.

UN-REDD 2010. UN-REDD programme strategy 2011-2015.

VINCKE D. 2011. Élaboration d'une méthodologie d'estimation de la biomasse ligneuse aérienne de populations d'espèces commerciales au Sud-Est du Cameroun. Mémoire de Master. Université de Liège.

WHITE F. 1983. The vegetation of Africa, a descriptive memoir to accompany the UNESCO/AETFAT/UNSO Vegetation Map of Africa (3 Plates, Northwestern Africa, Northeastern Africa, and Southern Africa, 1:5,000,000). UNESCO, Paris

WORBES M., STASCHEL R., ROLOFF A. & JUNK W. J. 2003. Tree ring analysis reveals age structure, dynamics and wood production of a natural forest stand in Cameroon. *Forest Ecology and Management*, *173* (1) : 105-123.