Journal of Agriculture and Environment for International Development - JAEID 2015, 109 (2): 271-289
DOI: 10.12895/jaeid.20152.363

Ecological consequences of anthropogenic pressure in Wari-Maro Forest Reserve (Benin, West Africa)

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Submitted on 2015, 17 Avril; accepted on 2015, 27 November. Section: Research Paper

Abstract: This study assessed ecological consequences of anthropogenic pressure in Wari-Maro Forest Reserve (WMFR). First, the dynamics of the forest cover was assessed using a diachronic analysis of land cover maps from Landsat images of 1986, 1995 and 2006. Then, structure of the forest was described. To this end, twenty five (25) one-hectare plots were established using a stratified random sampling technics. The strata were the two main vegetation types (Tree savannah *versus* woodland) in the WMFR. Within each one-hectare plot, two subplots of 50 m x 30 m were established. All stumps of logged trees and all trees of diameter at breast height (DBH) $\geq$ 10 cm were counted and identified in the one-hectare plots to reveal the most logged tree species. In the subplots, all standing tree species of DBH $\geq$ 10 cm were measured for DBH and total height. Stumps of logged trees in the subplots were also measured for diameter at 0.10 m. Data of subplots were used to estimate volume of trees from which we derived carbon stock and carbon loss using conversion and expansion factors. For the two periods 1986 to 1995 and 1995 to 2006, there was a general decline in forest cover, which was however slowed down in the second decade (0.196 %. $year^{-1}$ versus 0.083 %.$year^{-1}$ respectively). Top five (5) targeted species in illegal logging were: *Pterocarpus erinaceus* Poir., *Afzelia africana* Sm., *Isoberlinia* spp., *Anogeissus leiocarpa* Guill., and *Daniellia oliveri* (Rolfe) Hutch. & Dalziel. Mean values of carbon stock and carbon losses for the whole forest was 147.84 tons $C.ha^{-1}$ and 17.57 tons $C.ha^{-1}$ respectively and did not depend on the vegetation type. Results from this study suggest that management strategies should focus on selectively logged species. Monitoring should be enhanced to reduce the illegal logging pressure under a certain level over which survival of the targeted species might be problematic.

Keywords: anthropogenic pressure, forest cover, structure, carbon stock, Wari-Maro forest reserve, Benin.

Introduction

Forests provide a variety of timber and non-timber products including firewood, medicinal plants, flowers, fruits, leaves, roots that contribute to the households economy, strengthen food security, conserve biological diversity, and regulate CO_2 (Sinsin *et al.,* 2004). However, forests face a high rate of depletion, leading to critical threats to the multiple ecosystem services they offer. The worldwide loss of forests was estimated at 5,211,000 ha.year^{-1} from 2000 to 2010. In Benin, the loss was 50,000 ha.year^{-1} for the same period (FAO, 2011). A case study of the land cover change in the Upper Ouémé Forest reserve (Central Benin), revealed that between 1991 and 2000, 8% of forest stands were devastated while 20% of savannah woodland and 5% of shrub savannah were respectively converted to shrub savannah and croplands (Orekan, 2007). Apart from FAO data on land cover change, there are very few attempts to analyze land cover change at ecosystems level in developing countries. For example in Benin, only the Savalou Hill Forest Reserve, the Monts Kouffé Forest Reserve and the Upper Alibori Forest Reserve out of 46 forest reserves have been subject to land cover change. What's more, while most of these studies conclude to a decline of forest covers and associates it to logging and agriculture, there have been few data on the most depleted tree species as well as the loss of the carbon storage ability of the studied forests.

Many forest species are subject to selective logging in Benin (Glèlè Kakaï *et al.,* 2009). Investigations of the geographical distribution, natural regeneration and dendrometric pattern of trees showed that *Khaya senegalensis* (Desr.) A. Juss., *P. erinaceus*, *A. africana* and *A. leiocarpa* were threatened in Benin (Sinsin *et al.*, 2004; Glèlè Kakaï *et al.,* 2009) and that merchantable individuals of these species are no longer likely to be found in free lands and protected areas as well. With the decline of the habitats of these species, the growth of population and the increasing demand for timber commodities, people living adjacent to the forests are now turning toward new tree species. The first reported species in that case in Benin is the *Isoberlinia* spp., considered previously as not valuable tree species (Glèlè Kakaï and Sinsin, 2009). There might be more than one species in such a situation. This is an evidence of a dynamic of selective logging practices. As a result, monitoring of species subject to logging becomes crucial to inform decision makers.

Moreover, in recent years, Carbon storage and fluxes in forests have been the focus of many researches because of the role of carbon dioxide (CO_2) in the global climate change (Prentice *et al.*, 1998). Discreet CO_2 is stored in structures of plants in form of organic carbon (C) to ensure their growth. That makes forests a major earth reservoir of carbon, which could as well, become a source when they are logged and burnt (GIEC, 2007). Forests play therefore a leading role in the regulation of atmospheric CO_2 level. However, this role could be mortgaged by illegal tree logging, especially when the latter targets the biggest and most valuable tree species within the forest.

This study evaluates how anthropogenic pressure affects the WMFR focusing on the (i) analysis of the land cover change in the WMFR, (ii) identification of the most targeted species in illegal logging (wood logging which goes against the forestry administration regulations) practices and (iii) estimation of carbon stock and carbon loss (due to forest resource depletion) in the reserve. Because of the global decline of natural forests especially in West Africa (FAO, 2011), we expect a decline of forest cover in the WMFR. We also expect to show out new species, which are facing illegal selective logging.

Study area

The Wari-Maro Forest Reserve (WMFR) is located in Central Benin between latitudes 8°80-9°10 N and longitudes 1°55-2°25 E. It covers 120,686 hectares. Woodland and tree-savannah are the two (2) major vegetation types; the remaining part of the reserve is composed of shrub and grass savannas (Glèlè Kakaï and Sinsin, 2009). This was confirmed by our land cover change analysis where we found "woodland and savannah woodland" and "Tree and shrub savannahs" as the dominant classes (see Table 2). The reserve is located in the Guineo-Sudanian transition zone defined as "Sudanian woodland mainly composed of *Isoberlinia* spp.". As regard climate, the study area is characterized by two seasons: a dry season from November to March and a rainy season from April to October. Between 1982 and 2011, the insolation varied between 2,200 and 2,400 hours.year^{-1}. Annual rainfall ranged from 641.6 mm to 1,614.6 mm with a mean of 1,149.5 mm. The annual mean temperature varies between 25 and 29° C and the monthly relative humidity between 50 and 80 % (Glèlè Kakaï and Sinsin 2009; Assogbadjo *et al.*, 2009).

Material and methods

Inventory design and data collection

The land cover change within WMFR was studied using three Landsat images acquired from the National Institute of Geography of Benin in August 2013: Landsat TM images of 1986 and 1995, and Landsat ETM image of 2006. Data for the assessment of the ecological consequences of anthropogenic pressure in the WMFR came from an inventory carried out in the woodland and tree-savannah between June and July 2013 using a random stratified sampling technique. Twelve (12) and thirteen (13) plots of one-hectare were respectively established in woodland and tree-savannah.

Within each one-hectare plot, two (2) rectangular subplots of 50 m × 30 m were established. In each one-hectare plot, all stumps and all trees of diameter at breast height (DBH) ≥ 10 cm were counted, while in the rectangular subplots all standing tree species of DBH ≥ 10 cm were measured for their DBH and total height. Stumps were also counted in the subplots and were measured for diameter at 0.10 m.

Data analysis

Dynamics of forest cover

Classification comparison was used to assess the change of forest cover within the WMFR. The Landsat TM images of 1986 and 1995, and Landsat ETM image of 2006 were therefore classified on the same methodological basis: supervised classification by maximum likelihood (Barima et al., 2010; Tabopda and Fotsing, 2010; Tsayem Demaze, 2010) with Erdas Imagine 9.1 software. Pre-processing manipulations (geometric correction and haze reduction) were carried out in order to enhance the quality of the images and readability of the features as described in Mas (2000) and Song et *al.* (2001). Kappa coefficient ($\hat{k}$) were used to assess the classification accuracy (Congalton, 1991; Girard and Girard, 1999). The $\hat{k}$ values may range from 0 (biased classification) to 1 (unbiased classification). Each interpreted image was exported to a Geographic Information System (GIS) and the raster format file was converted to a vector format file using ArcView GIS 3.2. The areas corresponding to the different land cover classes were thus identified and the land cover maps of 1986, 1995 and 2006 were established. The forest cover includes all land cover classes except fields, fallows and water body, i.e. the natural forest and plantations. These analyses were made from August to September 2013.

Identification of the most targeted species in illegal logging

This identification was based on the logging rate (T, in percent), computed as the proportion of individuals of a species logged in relation to the total number of individuals of the same species in the considered plot. Analysis of variance was performed and the Student-Newman-Keuls test followed to separate the species according to logging rate. This allowed establishing a typology of threat and hence, the classification of species according their level of logging. All the statistical analyses were done using Minitab 14 software. For these analyses, the type I error (α) was fixed to 5 %.

Structural characterization of the WMFR

The structural characterization of the WMFR consists in computing ecological and dendrometric parameters and establishing the size class distribution (SCD) of trees diameter. Three (3) ecological parameters were considered: 1) species richness (S), 2) Shannon's diversity index (H, in bits) and 3) the Pielou's evenness (Eq) (see Gillet, 2000 for details). Dendrometric parameters include: 1) tree-density of the stands (N, in trees.ha^{-1}), 2) quadratic mean diameter (Dg, in cm), 3) basal area of the stands (G, in $m^2.ha^{-1}$), and 4) Lorey's mean height (H_L, in m) (see Rondeux, 1999; Kangas *et al.*, 2007 for details). These parameters were computed first for the whole plot, and then for each of the tree species most targeted in illegal logging. For each of the most targeted tree species in illegal logging, the basal area contribution (Cs, in per cent) was computed. Cs is defined as the percentage of the basal area of all individuals of a tree species in the overall basal area of the plot. Since the structural parameters were not normally distributed (from Ryan–Joiner test for normality), the natural log transformation was used to meet this condition. Two-independent samples t-tests was applied on each of the above dendrometric parameters. The SCD was established first for the whole stand, and then for standing trees belonging to the top five (5) logged species (logging rate > 1 %). The observed structures were adjusted to the 3-parameter (c: shape, b: scale and a: threshold) Weibull distribution (Johnson and Kotz, 1970).

Evaluation of carbon stock and the carbon loss within WMFR

To evaluate Carbon stock, species having an established volume equation were distinguished from the species for which a volume equation was not yet established. For trees species with available volume equations, the total volume of standing trees was computed using the volume equations (Table 1) established for species of the Sudanian zone of Benin (Fonton *et al.*, 2010).

For species without volume equations, the stem volume of standing trees was estimated as follows:

$$V = \frac{D^2 H_T f}{4}$$

V = volume of stem (m^3); D = DBH (in cm); HT = Total height of the tree (in m); f =0.55 (shape coefficient of the stem volume by Dawkins, 1961).

Assuming that the branches volume represents from 13% to 38% (i.e. 25.5% in average) of a tree total volume (Fonton *et al.,* 2010), the total volume (in m^3) was deduced by dividing the volume of stem by 0.745 (i.e. *1-branches volume (0.255)*). The total volume was then converted into Aboveground Biomass (AB) by multiplying the total volume by the Biomass Conversion and Expansion Factors (BCEF, in tons.m^3). The BCEF was 0.95 for tropical natural forests (FAO, 2010a; 2010b). Finally, the carbon stock ($m^3.ha^{-1}$) was obtained by multiplying the Aboveground Biomass (AB) by 0.47, where the 0.47 coefficient is the default value recommended by the Intergovernmental Panel on Climate Change (FAO, 2010a). Indeed, all these default coefficients (0.95

Table 1 - Total and bole volume equations of species of the Sudanian zone of Benin.

TREE-SPECIES	TOTAL VOLUME EQUATIONS	CONFIDENCE INTERVAL
A. africana	$Ln(V_T) = - 2.58 + 2.35\ Ln(D) + 0.34\ Ln(H_T)$	$11 \leq D \leq 88$; $4.3 \leq H_T \leq 18.0$
A. leiocarpa	$Ln(V_T) = - 1.54 + 2.33\ Ln(D)$	-
Bombax costatum Pellegr. & Vuillet	$Ln(V_T) = - 2.51 + 2.58\ Ln(D)$	-
B. africana	$Ln(V_T) = - 2.17 + 2.24\ Ln(D) + 0.42\ Ln\ (H_T)$	$14 \leq D \leq 68$; $6.4 \leq H_T \leq 21.7$
Crossopteryx febrifuga (G.Don) Benth.	$Ln(V_T) = - 2.18 + 2.14\ Ln(D) + 0.39\ Ln(H_T)$	$10 \leq D \leq 65$; $5.2 \leq H_T \leq 15.4$
D. oliveri	$Ln(V_T) = - 3.34 + 2.77\ Ln(D)$	-
Isoberlinia spp.	$Ln(V_T) = - 2.52 + 2.40\ Ln(D) + 0.35\ Ln(H_T)$	$13 \leq D \leq 70$; $8.2 \leq H_T \leq 29.6$
K. senegalensis	$Ln(V_T) = - 2.56 + 2.17\ Ln(D) + 0.55\ Ln(H_T)$	$10 \leq D \leq 86$; $4.0 \leq H_T \leq 31.2$
Lophira lanceolata Tiegh. ex Keay	$Ln(V_T) = - 2.81 + 2.34\ Ln(D) + 0.48\ Ln(H_T)$	$12 \leq D \leq 62$; $7.5 \leq H_T \leq 25.2$
Prosopis africana (GuilI. & Perr.)	$Ln(V_T) = - 2.43 + 2.53\ Ln(D)$	-
Pseudocedrela kotschyi (Schweinf.)	$Ln(V_T) = - 2.29 + 2.09\ Ln(D) + 0.61\ Ln(H_T)$	$13 \leq D \leq 73$; $6.5 \leq H_T \leq 20.4$
P. erinaceus	$Ln(V_T) = - 1.86 + 2.39\ Ln(D)$	-
Terminalia spp.	$Ln(V_T) = - 1.84 + 2.26\ Ln(D) + 0.21\ Ln(H_T)$	$13 \leq D \leq 73$; $1.2 \leq H_T \leq 25.2$
Uapaca togoensis Pax	$Ln(V_T) = - 2.34 + 2.44\ Ln(D) + 0.19\ Ln(H_T)$	$11 \leq D \leq 50$; $6.7 \leq H_T \leq 19.3$
Vitellaria paradoxa C.F.Gaertn.	$Ln(V_T) = - 2.19 + 2.34\ Ln(D) + 0.30\ Ln(H_T)$	$15 \leq D \leq 85$; $3.7 \leq H_T \leq 23.2$
Tree-species	Bole volume	Confidence interval
A. africana	$Ln(V_B) = - 1.64 + 2.06\ Ln(D)$	$11 \leq D \leq 88$
A. leiocarpa	$Ln(V_B) = - 1.04 + 2.03\ Ln(D)$	-
B. africana	$Ln(V_B) = - 0.47 + 1.71\ Ln(D)$	$14 \leq D \leq 68$
D. oliveri	$Ln(V_B) = - 2.34 + 2.29\ Ln(D)$	-
Isoberlinia spp.	$Ln(V_B) = - 1.27 + 2.07\ Ln(D)$	$13 \leq D \leq 70$
P. erinaceus	$Ln(V_B) = - 1.29 + 2.01\ Ln(D)$	-

and 0.47) are those provided to tree species for which, appropriate biomass and carbon allometric equations are not available (e.g. Henry *et al.*, 2011 for available allometric equations according to geographic areas).

In order to estimate the carbon loss (CL, in $m^3.ha^{-1}$), a model linking DBH to diameter at 0.10 m for standing trees was first established. Using this model, DBH was estimated for all inventoried logged trees. It was then possible to estimate the volume of logged trees. The carbon loss was finally determined following the same steps as described above for carbon stock. The proportion of carbon loss was computed by dividing the carbon loss (CL) by the sum of carbon stock (CS) and carbon loss (CL) and then converted into percentage. The two (2) main types of vegetation covers (tree-savannah and woodland) were statistically compared using the Student *t*-test applied on CS, CL and proportion of CL values.

Results

Dynamics of forest cover

Results of supervised classification showed that $\hat{k}$ value was equal to 0.87, which guarantees a good accuracy of interpretation (see Pontius (2000) for details). The diachronic analysis of land cover maps between 1986 and 1995 revealed a depletion of 2,060 hectares of forest cover i.e. 0.2 %.year $^{-1}$ (Table 2, Figures 1 and 2). The dense forest, woodland and savannah woodland regressed, and in particularly, woodland and savannah woodland regressed about -40,450.50 hectares, which represented more than 75 % of the forest area in 1986. On the contrary, gallery forest, tree and shrub savannahs as well as the saxicol savannah (savannah established on hill) increased, the increase being most important for tree and shrub savannahs (36,200 hectares). Plantations regressed for 29 hectares; they constituted the relic of the productive plantations of cashew nut (299 hectares) established in 1960 by the State in Agramarou village. The mosaic of field and fallow and water body as for them increased by 137 hectares and 1,921 hectares, respectively.

Between 1995 and 2006, the decline in forest cover was much lower compared with that of the previous decade (from 2,060 hectares to 1,073 hectares). The depletion of dense forest worsened (from 0.006 %.year $^{-1}$ in 1986-1995 to 0.278 %.year $^{-1}$ in 1995-2006) while that of woodland and savannah woodland decreased (from 40,451 hectares in 1986-1995 to 14,739 hectares in 1995-2006). The gallery forest did not experience appreciable expansion between 1986 and 1995 compared to the period between 1995 and 2006 while the reverse was true for the tree and shrub savannahs. As for the saxicol savannah and water body, they moved from a progressive trend (1986-1995) to a regressive trend (1995-2006) compared to plantations that exhibited

Table 2 - Land cover state of 1986, 1995 and 2006: areas and percent.

Land cover classes	1986		1995		2006	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Dense forest	6 006.75	5.13	5 949.92	5.08	2 365.09	2.02
Gallery forest	3 035.30	2.59	3 049.53	2.60	5 245.69	4.47
Woodland and savannah woodland	89 832.80	76.67	49 382.30	42.15	34 643.83	29.57
Tree and shrub savannahs	17 128.91	14.62	53 329.22	45.51	70 137.71	59.86
Plantation	152.13	0.13	123.64	0.11	1 239.29	1.06
Saxicol savannah	651.83	0.55	2 915.03	2.49	45.09	0.04
Mosaic of croplands and fallow	5.86	0.01	143.20	0.12	3 058.29	2.61
Water body	356.74	0.30	2 277.48	1.94	435.33	0.37
Total	117 170.32	100.00	117 170.32	100.00	117 170.32	100.00
Total of forest cover	116 807.72	99.69	114 749.64	97.94	113 676.70	97.02

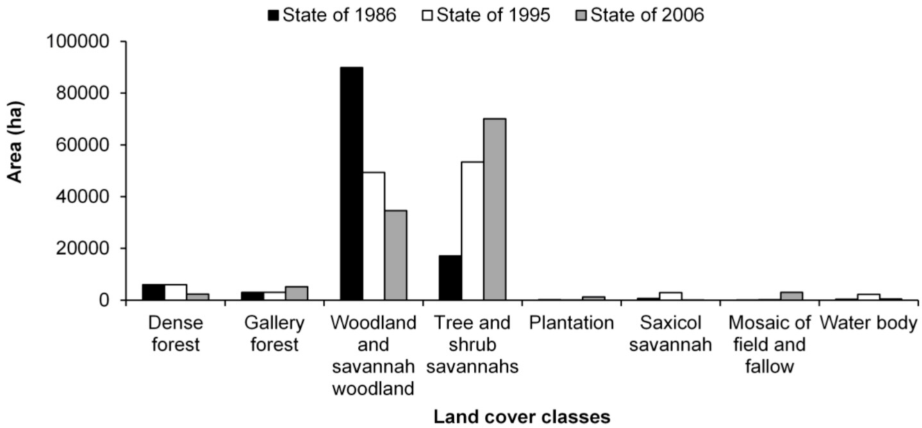

Figure 1 - Trend in land cover types between 1986, 1995 and 2006.

a reverse trend. The increase in croplands and fallow intensified from 1986-1995 (137 hectares i.e. 0.012 %.year $^{-1}$) to 1995-2006 (2,915 hectares i.e. 0.226 %.year $^{-1}$).

Structural parameters and the most targeted species in illegal logging in the WMFR

We considered the two (2) most represented vegetation types of the WMFR: woodland and tree-savannah, which structural parameters and logging rate of most logged tree-species are reported in Table 3. For these two (2) vegetation types, only mean height showed significant difference (12.81 m in woodland and 12.44 m in tree-savannah: *p*-value (0.002) < 0.05). Values of the other parameters were statistically similars (*p*-value > 0.05) for the two vegetation types (Table 3).

Mean values and coefficient of variation of dendrometric parameters for the most logged tree-species (logging rate > 1 %) revealed that, in the two vegetation types, *P. erinaceus, A. africana* and *Isoberlinia* spp. constituted the group of the most logged species (logging rate > 25 %) followed by *A. leiocarpa* and *D. oliveri* with logging rate less than 10 %. *A. africana* was the most logged tree-species in woodland whereas in tree-savannah, *P. erinaceus* recorded the highest value of logging rate. No significant difference (*p*-value> 0.05) was found between woodland and tree-savannah with regard to logging rates (Table 3).

Only *A. africana* showed significant differences between woodland and tree-savannah as far as dendrometric parameters (mean diameter, basal area, height and basal area contribution) were concerned (Table 3). In general, biggest and tallest trees were found in the woodland. For the other tree-species (*P. erinaceus, Isoberlinia spp., A. leiocarpa* and *D. oliveri*), non-significant difference was observed between the two vegetation types, except for the tree-height of *Isoberlinia* spp. and *A. leiocarpa* which

Table 3 - Structural parameters and logging rate of species most targeted in illegal logging by vegetation types: Mean, standard deviation (SD) and p-values of the t-tests.

PARAMETERS	WOODLAND		TREE-SAVANNAH		*p*-value
	Mean	SD	Mean	SD	
Global					
Density (N, stems.ha^{-1})	189.42	39.11	182.00	32.98	0.612
Mean diameter (Dg, cm)	27.84	4.05	27.93	3.03	0.927
Basal area (G, m^2.ha^{-1})	13.86	6.76	12.12	3.52	0.254
Height (H_L, m)	12.81	2.62	12.44	2.99	0.002
Species richness (S, species)	33.00	-	34.00	-	-
Shannon Index (H, bits)	4.01	-	4.12	-	-
Pielou evenness (Eq)	0.79	-	0.81	-	-
P. erinaceus					
Logging rate (%)	26.27^a	22.42	40.39^a	28.45	0.199
Density (N, stems.ha^{-1})	10.83	9.06	6.15	4.39	0.110
Mean diameter (Dg, cm)	22.72	9.28	28.71	10.60	0.050
Basal area (G, m^2.ha^{-1})	0.59	0.51	0.75	0.60	0.303
Height (H_L, m)	11.97	2.19	12.35	2.30	0.491
Basal area contribution (Cs, %)	4.67	4.73	6.40	6.01	0.212
A. africana					
Logging rate (%)	30.44^a	31.73	30.28^a	25.87	0.990
Density (N, stems.ha^{-1})	3.75	3.14	4.62	4.50	0.611
Mean diameter (Dg, cm)	33.71	11.14	26.16	3.99	0.035
Basal area (G, m^2.ha^{-1})	0.92	0.63	0.45	0.20	0.019
Height (H_L, m)	12.74	2.40	10.93	1.81	0.023
Basal area contribution (Cs, %)	9.12	5.94	3.71	2.15	0.007
***Isoberlinia* spp.**					
Logging rate (%)	28.04^a	18.87	26.19^a	27.97	0.856
Density (N, stems.ha^{-1})	48.75	24.50	54.92	29.43	0.576
Mean diameter (Dg, cm)	33.11	7.47	33.66	8.56	0.818
Basal area (G, m^2.ha^{-1})	5.74	3.69	6.07	4.16	0.772
Height (H_L, m)	14.09	2.47	14.60	2.60	0.033
Basal area contribution (Cs, %)	41.62	20.39	44.90	24.10	0.623
A. leiocarpa					
Logging rate (%)	6.43^b	13.94	7.94^b	12.44	0.850
Density (N, stems.ha^{-1})	14.40	36.90	27.10	38.70	0.211
Mean diameter (Dg, cm)	24.36	10.84	31.36	11.15	0.224
Basal area (G, m^2.ha^{-1})	2.99	3.12	2.27	1.51	0.510
Height (H_L, m)	13.56	2.99	11.58	3.35	0.002
Basal area contribution (Cs, %)	21.33	22.47	22.48	15.71	0.901
D. oliveri					
Logging rate (%)	7.85^b	12.70	6.44^b	11.98	0.825
Density (N, stems.ha^{-1})	9.75	12.17	2.54	3.26	0.073
Mean diameter (Dg, cm)	31.93	11.23	30.75	10.36	0.787
Basal area (G, m^2.ha^{-1})	0.15	0.12	0.13	0.13	0.861
Height (H_L, m)	12.34	2.78	11.06	2.24	0.563
Basal area contribution (Cs, %)	1.07	0.90	0.92	0.94	0.861

For the same vegetation type, values with the same letter are not significantly different (Student-Newman-Keuls test).

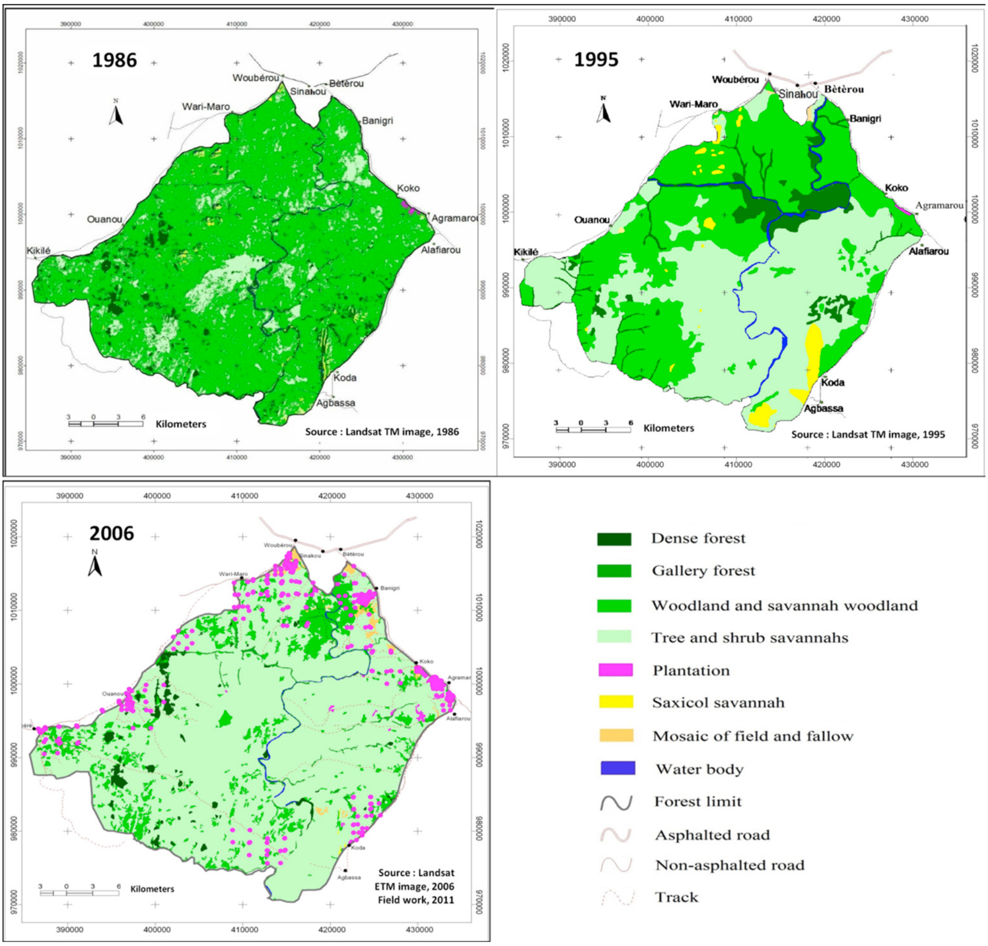

Figure 2 - Land cover maps of the Wari-Maro forest reserve in 1986, 1995 and 2006.

was significantly different between the two vegetation types. Tallest trees of *A. leiocarpa* were found in woodland while the opposite was observed for *Isoberlinia* trees (Table 3). In both woodland and tree-savannah, *Isoberlinia* spp. recorded the highest density, height, basal area and basal area contribution. *A. africana* and *D. oliveri* showed absolutely the lowest density, respectively in woodland (3.75 stems.ha^{-1}) and in tree-savannah (2.54 stems.ha^{-1}) while *P. erinaceus* recorded the lowest mean height (11.97 m in woodland and 12.35 m in tree-savannah). With regards to mean diameter, *A. africana* and *Isoberlinia* spp. showed the highest values respectively in woodland (33.71 cm) and in tree-savannah (33.66 cm), while *P. erinaceus* and *A. africana* showed the lowest values respectively in woodland (22.72 cm) and in tree-savannah (26.16 cm).

Table 4 - Logging rates of species used for different other needs.

Species	Woodland		Tree-savannah		*p*-value
	Mean	SD	Mean	SD	
Aeschynomene indica L.	-	-	1.39	4.17	-
Blighia sapida Konig	-	-	13.89	22.15	-
B. costatum	12.50	25.00	10.00	22.36	0.771
Combretum molle R.Br. ex G.Don	-	-	2.78	8.33	-
Diospyros mespiliformis Hochst. ex A.De.	-	-	3.85	5.44	-
Ficus spp.	4.76	12.60	-	-	-
Lannea barteri (Olïv.) Engl.	1.04	3.61	10.74	10.81	0.008
L. lanceolata	3.13	6.25	28.57	48.80	0.337
Monotes kerstingii Gilg	2.02	3.64	10.00	19.54	0.244
Parinari curatellifolia Planch. ex Benth.	-	-	1.19	3.15	-
Parkia biglobosa (Jacq.) R.Br. ex Benth.	-	-	4.76	12.60	-
P. kotschyi	4.76	6.73	-	-	-
Sarcocephalus latifolius (Sm.) E.A.Bruce	-	-	6.97	13.20	-
Sterculia tragacantha Lindl.	-	-	7.99	13.20	-
Stereospermum kunthianum Cham.	1.81	5.72	5.54	13.75	0.445
Terminalia superba Engl. & Diels	-	-	0.93	2.27	-
U. togoensis	5.15	6.65	-	-	-
V. paradoxa	5.47	7.10	1.65	4.94	0.198
Vitex doniana Sweet	4.00	8.94	-	-	-

Apart from species targeted for their valuable timber, other species were used as support for on-field timber processing. Their logging rates for woodland and tree-savannah are summarized in table 4.

Table 4 shows ten (10) and fifteen (15) others tree-species which are used to shape/process valuable timber in woodland and tree-savannah respectively. Among the six (6) tree-species which were used for on-field timber processing in both woodland and tree-savannah (*B. costatum*, *Lannea barteri* (Olïv.) Engl., *L. lanceolata*, *Monotes kerstingii* Gilg, *Stereospermum kunthianum* Cham. and *V. paradoxa*), only *L. barteri* exhibited significant (p-value < 0.05) difference in logging rate when the two vegetation types were compared. For these tree-species, *B. costatum* and *L. lanceolata* were the most used species. The other tree-species (four (4) in woodland and nine (9) in tree-savannah) were only used in a single vegetation type (Table 4).

Diameter size class distribution, SCD

Figure 3 shows the diameter SCD of the two (2) vegetation types, and for each of the top five (5) logged species (*P. erinaceus, A. africana, Isoberlinia* spp., *A. leiocarpa* and *D. oliveri*) in the forest. The diameter structure of the two (2) vegetation types shows a strong left dissymmetric distribution ($1 < c < 3.6$) which is distinctive of multi-specific

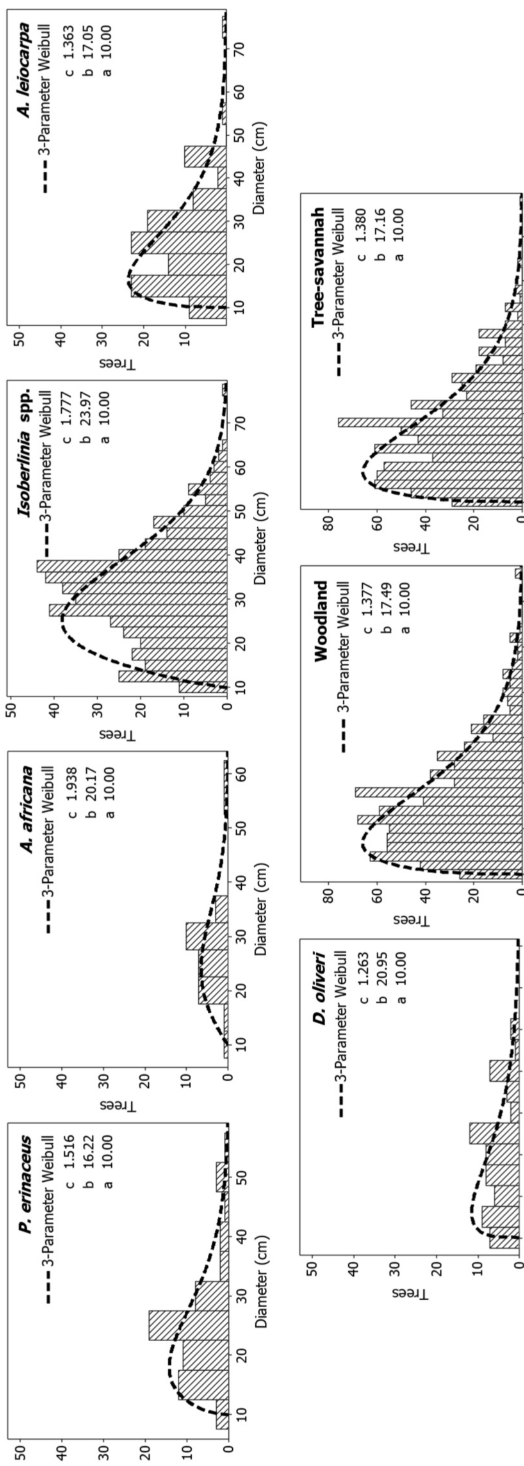

Figure 3 - Diameter size class distribution (SCD) of the top five (5) illegally logged tree-species and the two (2) main vegetation types within the WMFR.

Table 5 - Carbon stock and carbon loss in vegetation types: means, standard deviation (SD) and p-values of t-tests.

PARAMETERS	WOODLAND		TREE-SAVANNAH		*p*-value
	Mean	SD	Mean	SD	
Carbon stock (tons.ha^{-1})					
Total	166.77	111.05	130.43	52.06	0.150
P. erinaceus	1.95	1.84	2.69	2.42	0.243
A. africana	3.47	2.82	1.36	0.59	0.004
Isoberlinia spp.	28.98	19.27	31.03	21.97	0.739
A. leiocarpa	11.61	12.55	8.65	6.04	0.500
D. oliveri	5.79	11.06	4.30	5.00	0.477
Total for top five illegally logged species	51.8	33.60	48.03	46.50	0.999
Carbon loss (tons ha^{-1})					
Total	18.22	16.64	16.98	13.88	0.963
P. erinaceus	1.03	1.45	0.72	0.72	0.885
A. africana	0.29	0.51	0.21	0.37	0.540
Isoberlinia spp.	1.25	1.60	1.26	1.44	0.989
A. leiocarpa	0.19	0.55	0.45	0.88	0.225
D. oliveri	0.02	0.11	0.01	0.07	0.664
Proportion of total carbon loss (%)	10.93	9.38	13.02	11.18	0.516

stands with a predominance of individuals with small diameter (Figure 3) (Husch et al., 2003). The 20-30 cm diameter class was the best represented, respectively 37% in woodland and 35% in tree-savannah. Individuals with diameter ≥ 70 cm were scarce in both vegetation types. The *Isoberlinia* spp. dominated all diameters classes.

The SCD also showed a bell-shape and a strong left dissymmetric for each of the top five (5) species targeted in illegal logging (Figure 3). Apart from *A. africana*, individuals with diameter less than 20 cm were the best represented in the whole stand. For all species, individuals with diameter more than 60 cm were scarce in the whole stand.

P. erinaceus, A. africana and *Isoberlinia* spp. were the most targeted tree species in illegal logging for diameters ranging from 40 to 80 cm, while *A. leiocarpa* was preferred for diameters ranging from 40 to 50 cm. On the contrary, the most exploited individuals of *D. oliveri* had a diameter less than 30 cm.

Carbon stock and carbon loss

There was no significant variation (p-value>0.05) of Carbon Stock (CS) between woodland and tree-savannah (Table 5). CS was 148.6 tons C.ha^{-1} for the average whole stand. The top five (5) illegally logged species encompassed more than 30 % of the carbon sequestration potential of the forest (49.92 tons C.ha^{-1} for the whole stand: *P. erinaceus*: 2.32 tons C.ha^{-1}, *A. africana*: 2.42 tons C.ha^{-1}, *Isoberlinia* spp.: 30.01 tons

C.ha^{-1}, *A. leiocarpa*: 10.13 tons C.ha^{-1} and *D. oliveri*: 5.05 tons C.ha^{-1}). *Isoberlinia* spp. trees showed high carbon stock (28.98 tons C.ha^{-1} in woodland and 31.03 tons C.ha^{-1} in tree-savannah). The lowest carbon stock was observed for *P. erinaceus* trees in woodland (1.95 tons C.ha^{-1}) and *A. africana* trees in tree-savannah (1.36 tons C.ha^{-1}). Only carbon stored by *A. africana* trees varied significantly (p-value<0.05) between the two vegetation types. Table 5 also revealed that total carbon loss was not so different for the two vegetation types and estimated at 17.6 tons C.ha^{-1} as average for the whole stand, representing 11.84 % of the carbon sequestration potential of the reserve. The distribution of carbon loss among the top five logged species showed a loss of storage mainly for *Isoberlinia* spp. and *P. erinaceus* (1.26 tons C.ha^{-1} and 0.88 tons C.ha^{-1} as averages).

Discussion and conclusion

Causes of dynamics of forest cover

The diachronic analysis of land cover change of the Wari-Maro Forest Reserve (WMFR) showed a decline of forest cover between 1986 and 2006 (Figure 1). A similar trend was observed in the District of Djidja (Sudano-Guinean zone of Benin) where the area of natural vegetation types decreased from 88 % in 1986 to 44 % in 2006 for croplands and fallows which expanded from 7 % in 1986 to 52 % in 2006 (Arouna *et al.*, 2010). Several land cover classes had regressed especially woodland and savannah woodland. In Benin, reasons often assigned for this regressive trend were the growth of population (2.32 % between 2000 and 2005) and decline in rainfall: from 15 to 30 % after 1970 (Orekan *et al.,* 2010). Actually, although the population density is currently low (11 inhabitants.km^{-2}), the study area experienced high immigration and hence a strong population growth rate (higher than 13 % for some villages; see Orekan, 2007). The increase in population resulted in high anthropogenic pressure especially agricultural and pastoral activities which were stretching into the reserve. Indeed, croplands and fallows had exponentially increased in the reserve, from 5.86 hectares in 1986 to 3,058.29 hectares in 2006. Similar trend was noticed in Togo where 75 % of forest reserve was replaced by fields with a rate more than 10 % of their area between 1975 and 2000 (Tarchiani *et al.*, 2008). Other factors such as insufficient protection could have also justified fluctuations of forest cover. Between 1995 and 2006, the forest cover increased compared with the previous decade. This is likely due to the project "Projet d'Aménagement des Massifs Forestiers d'Agoua, des Monts Kouffé et de Wari-Maro (PAMF)" implemented from 2002 to 2007 and that focused on reforestations and forest enrichments (from 2003 to 2006). Altogether, WMFR still faces a decline of its forest cover. Possible management actions include: (i) a more restricted access to the forest and an increase of control to avoid infraction of the boundaries of the reserve by agricultural activities, and (ii) development of policies for a sustainable land use around the reserve.

Structural characteristics of Wari-Maro Forest Reserve

The WMFR covers an area of about 120,686 hectares with mainly 50,057 hectares of woodland and 56,088 hectares of tree-savannah (Glèlè Kakaï and Sinsin, 2009). With regards to the ecological parameters, species richness was low compared with the 94 species recorded by Wala et al. (2012) in the protected area of Alédjo (between latitudes 9°14 –9°17 N and longitudes 1°11 –1°14 E, Togo), which is located at the same latitude and with a low area (765 hectares) compared with the WMFR. Equal values of species richness and Shannon diversity index between the two vegetation types suggest similar floristic diversity.

The observed similar dendrometric parameters between the two vegetation types suggests that the latters are structurally closed. Such closeness may greatly be attributed to the fact that both were dominated by Isoberlinia spp., although some species abundance and characteristics (e.g. *A africana, P. erinaceus* and *D. olivera*) relatively differentiate the two vegetation types.

The obtained shape parameter value for SCD of the two vegetation types, suggests a monospecific distribution and hence the abundance of at least, one species, here, Isoberlinia spp. This is confirmed by its basal area contribution (about 42 and 45 %, respectively in woodland and in tree-savannah). The same conclusion was drawn by Glèlè Kakaï and Sinsin (2009). Moreover, the fact that WMFR is located in the Guineo–Sudanian transition zone defined as “Sudanian woodland mainly composed of Isoberlinia spp.” means that Isoberlinia spp. trees imprint their structure to the vegetation. Indeed, the species presented the same SCD (a strong left dissymmetric distribution) as the two vegetation types.

Most targeted species in illegal logging

This study showed that five (5) main species were targeted in the following order of importance: P. *erinaceus, A. africana, Isoberlinia* spp., *A. leiocarpa* and *D. oliveri.* Indeed, logging for a long time, limited to *K. senegalensis*, *A. africana* and P. *erinaceus* is now a concern with other species such as *Isoberlinia* spp. and *A. leiocarpa*. Moreover, most of these species, mainly *P. erinaceus, A. africana* and *K. senegalensis* are considered as plant species with high conservation priority in Benin (Adomou *et al.*, 2010) and endangered on the red list of plant threatened species of Benin (Neuenschwander *et al.*, 2011). Thus, a continued illegal logging of these species may implies severe threats to their populations. Apart from *P. erinaceus* and *D. oliveri,* results on main exploited species showed a clear decrease in their densities in the same vegetation compared with past investigations: *A. africana:* 142 stems.ha^{-1} by Fandohan *et al.* (2008); *Isoberlinia* spp.:78.70 to 89.90 stems.ha-1 by Glèlè Kakaï and Sinsin (2009) and *A. leiocarpa*: 80.00 to 108.67 stems.ha^{-1} by Assogbadjo *et al.* (2009). This decrease is likely due to the increasing human pressures on these species since the end of the participatory management project "PAMF" in 2007. The woodland and savannah woodland, which accounted for 76.67 % of the forest cover in 1986, has been reduced to only 29.57 % in 2006 (Table 2). On the contrary, the tree and shrub savannahs, which accounted for 14.62 % of the forest cover in 1986, have been increased to 59.86 % in 2006 (Table 2). Illegal logging and land clearing could be main sources of decrease in trees-density and driving the "savannization" of forest stands.

Analysis of possible consequences of anthropogenic pressure on the stem SCD of the five (5) main species showed very low number of individuals of DBH higher than 60 cm, likely due to selective uncontrolled logging targeting the big trees in the stand as suggested by Gaoue and Ticktin (2007). This could impact production of seeds and then regeneration of species. For example, *A. africana* has very few individuals from lower diameter to 20 cm, suggesting a very low regeneration of the species in the reserve. However, this could also due to its multiple uses (animal feeding by species pruning, traditional medicine, and wood) in West Africa (Bonou *et al.,* 2009) which could have impacted its reproductive performance.

Structure of the logged individuals of the five species confirm that selective uncontrolled logging targeted big trees. However, in the case of *D. oliveri*, the high frequency of individuals of small diameter shows that this species was less used as wood but rather served as support when processing on-field logged big trees (Amagnidé A., Field observation).

Therefore, necessary actions should be taken mainly to define relevant conservation strategies for *P. erinaceus, A. africana* and *Isoberlinia* spp. within this forest in order to avoid a long term extinction of those species. Results also suggest that management strategies should focus not only on selectively logged species but also species used for on-field processing of logged tree-species which may be at risk in the future. Other conservation actions can include cultivation of cultural important species and zoning with important economics species (*Tectona grandis*, *Acacia auriculiformis* and *Gmelina arborea*) on the boundaries of the reserve, which will be manage by resident populations.

Carbon stock and carbon loss

Average carbon stock (148.6 tons C.ha^{-1}) for the two main ecosystem, woodland and tree-savannah was higher compared with the 58 tons C.ha^{-1} reported by FAO (2011) for aerial biomass of forest cover (including all vegetation types) in Benin. Our results are however closed to estimated carbon stock in other parts of the world: 118

tons $C.ha^{-1}$ for the aboveground biomass in the Mondah forest reserve in Gabon (Nasi *et al.,* 2008) and 160 tons $C.ha^{-1}$ in the Gola forest in Sierra Leone (Lindsell *et al.*, 2013). At species scale, difference in mean diameter and mean height of *A. africana* in the two considered vegetation types had led to different carbon stocks of the species confirming a close relationship between carbon stock and dendrometric parameters. Main exploited species represent about 53 % of carbon sequestration potential of the forest. Hence, illegal tree-logging seems to be the important factor of disturbance in carbon storage of the forest. Carbon loss in the WMFR represented 11.84 % of the carbon sequestration potential of the forest. It is known that anthropogenic activities increased significantly greenhouse gas emissions in the troposphere, which results in climate warming and contributes from 20 to 25 % (GIEC, 2007) in carbon dioxide emissions worldwide.

The indirect approach used to estimate the carbon loss (from stumps of logged trees) may have induced an underestimation or overestimation. It would have however been difficult in estimating such a quantity unless an experimental tree logging is done and actual data collected. While acknowledging this bias we believe our data provide useful insights in quantifying the consequences illegal logging may have on CS potential of forest reserves.

Conclusion and implications for management

The current study can be summarized in three (3) aspects: 1) the study reveal a dynamics of illegal selective logging from *P. erinaceus, A. africana* and *K. senegalensis* to *Isoberlinia* spp., *A. leiocarpa* and *D. olivera*; 2) it contrasts with many of studies on tree-species illegal logging which focus only on main logged species, while the this study shows the fact that many other species (may be at risk in the future) are used for on-field processing/shaping of valuable timber; and 3) it also shows that it is possible to estimate the aboveground biomass loss and the final carbon loss starting from stumps of logged trees. In spite of the management of the forest reserve by the project PAMF from 2002–2007, effects of human disturbances on the stands have been noticed. Thus, WMFR still faces a decline in its forest cover and resources (e.g. shortage of valuable species, implying a loss of storage of carbon), which suggests a more effective conservation actions and developing appropriate strategy for restoration purposes.

These conservation actions such as the development and diversification of income generating activities as well as education for rural populations living adjacent to the forest reserve should be implemented with the agreement and participation of fringe communities living adjacent to the forest reserve.

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