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Assessing dynamics and productivity of tropical natural forest using permanent plots: case study of mounts kouffè and warimaro forests reserve.

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Abstract*— *The dynamic and productivity of natural reserves in Benin were assessed in the Mounts Kouffè and Wari Maro forest reserves on the basis of sixty circular permanents plots of 1000 m^2 size each installed in 2006. The factorial correspondences analysis of the based on a matrix of 60 records and 81species. Four different plants community were discriminated:

- *dry woodland of Diospyros mespiliformis and Anogeïssus leïocarpa*
- *woodland of Pterocarpus erinaceus and Isoberlinia doka*
- *Wooded savanna of Vitellaria paradoxa and Burkea africana*
- *Shrub savanna of Vitellaria paradoxa ans Isoberlinia doka*

The specific richness of individualized plant communities varies between 42 and 75 species. The Shannon index values calculated (dbh≥10cm) ranged between 1.25 and 4.66 bits; those of Pielou evenness ranged between 0.24 and 0.87. The diameter size classes distribution is best adjusted to Weibul three parameter function and showed a left skewed distribution.

Trees basal area decreased by 0.80 m²/ha/year for the dry woodland and 0.25 m²/ha/year for the woodland while the one of wooded and shrub savanna increased by 0.50 m²/ha/year. The density of trees decreased by 120 trees/ha for dry woodland and by 108 trees/ha for woodland over the last five years. The diameter of individuals of average basal area has increased by 2.1 cm for dry woodland. 3.95cm for woodland. 2.8cm for Wooded savanna and 3.09cm for shrub savanna. The minimum exploitable diameter (MED) of 45cm allowed for 50% of Anogeïssus leïocarpa and Isoberlinia doka basal area reconstitution while this MED allowed for 75% of Diospyros mespiliformis reconstitution.

***Keywords*— Dynamic. Productivity. natural forests and plants community. Bénin.**

I. INTRODUCTION

In Benin, the sustainable management of forest ecosystems has gained awareness for a while after the adoption of a new forestry regulation that seeks to promote sustainable management approaches. Sustainable management policy requires a minimum understanding of forest dynamic which is a critical component in the designing of forests ecosystems management (Sokpon. 2006). Benin has many forest reserves which are recognized as protected areas at the national scale. Although, they provide timber wood and various non-timber forest products to the local population, these forest reserves are undergoing severe anthropogenic pressure that affects their dynamic. It is then of paramount importance to periodically lead floristic inventory in these reserves for monitoring their growth and their management. The Mounts kouffé and Wari maro forest reserves are two of the country forest reserves that have gained permanent plots-based monitoring approach over a period of five years. This monitoring approach has become usual for the surveillance and management of both ecosystems identified by Marsch in 1979 and which are of paramount resources importance to the local population compared to other regions of Benin. Although some species of high cultural, food and commercial values within the country natural forests are experiencing high anthropogenic pressure, there is still lack of information to appreciate the ecological and structural dynamic of the country forest reserves in general and in particular the one of the Mounts kouffè and Wari maro which are subjected to a restrictive mode of forest regulation application. By comparing the results of five years (2006 to 2011) dynamic study, it was possible to appreciate the dynamic and the productivity of these forest reserves. The objective of the current study is then to investigate structural and ecological dynamic of the Mounts kouffè and Wari maro forest reserves in order to provide baseline information for their sustainable management.

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II. STUDY AREA

The Mounts Kouffè and Wari maro forest reserves are shared by three Departments (Donga. Collines and Borgou) and are located between latitude 1° 40 ' and 2° 25 ' North and longitude 8° 25 ' and 9° 10 ' West. They are bordered by four municipalities including Bassila at North. Ouèssè at South. Tchaourou at East and Bantè at West (Figure 1)

The climate is of Sudano-Guinean type. It corresponds to the transition zone of Benin.

The annual average rainfall ranges between 1100 mm and 1200 mm and the annual average temperature is estimated at 27°c approximately. The annual average values of the maximum and the minimum temperature are respectively of 33.2°c and 21°c.

The relief is uniform and is dominated by plateau with an altitude that varies from 200 to 350m. The soil is of tropical ferruginous type. However hydromorphic and ferralitic soils are also met at some areas (Kakpo, 1992).

The vegetation is majorly composed of savannas. There are also community managed forests, gallery forest, dry dense forests and woodland.

The population surrounding the forest reserves is estimated at **150,618** inhabitants composed of **21,783** households with an average density of 8 inhabitants /km ² (INSAE/RGPH4, 2013).

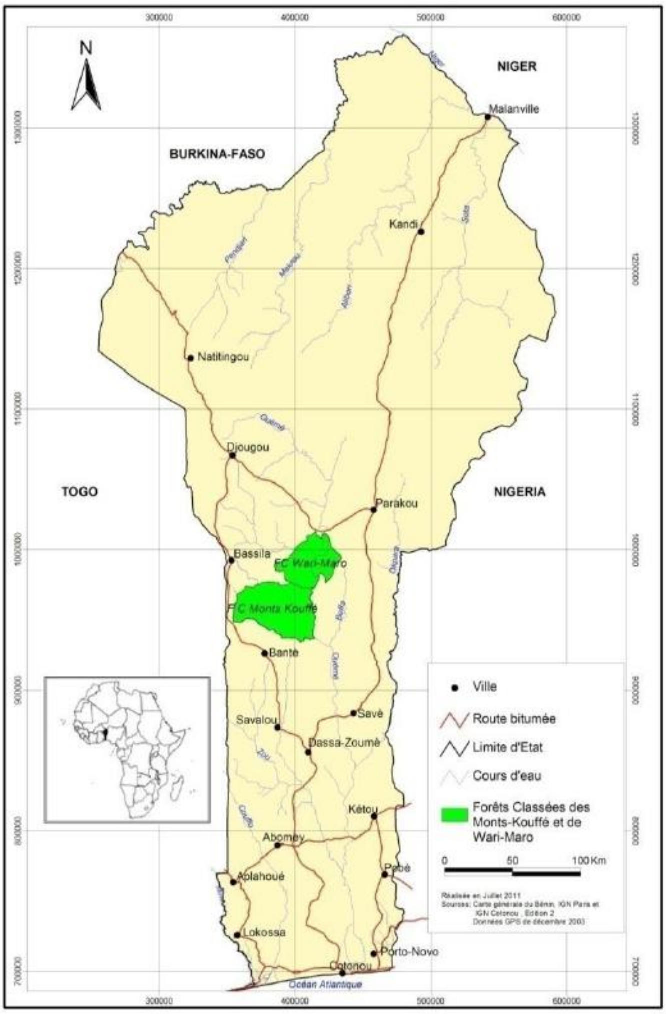

Fig.1: The localization of the Monts Kouffé et de Wari-Maro forest reserve

III. METHODS

Data collection

The data were collected in 60 permanent circular plots of 1000 m² size previously established in 2006. A number of 14 to 16 plots were established per types of vegetal formation. Table 1 shows the distribution of the inventoried plots among types of vegetal formations according to each forest reserve.

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Table.1: Distribution of the inventoried plots per types of vegetal formation according to each forest reserve

	Dry woodland	Woodland	Wooded savanna	Tree savanna	Total forest reserves
Mont kouffè forest reserve	12	13	13	12	50
Wari maro forest reserve	2	3	2	3	10
Total vegetation types	**14**	**16**	**15**	**15**	**60**

Adult trees were measured within 1000 m² size plots. To count the regeneration (dbh<10 cm), four circular subplots of 50.24m² size were established within each plots. Floristic inventory was carried out based on Braun-Blanquet (1932) phytosociological approach. This approach has been previously used by several authors (Sinsin. 1993; Sokpon. 1995). We first collected preliminary data related to plots ecological variables (type of vegetation, presence of anthropogenic pressure, type of soil, altitude and the slope). Then we measured the diameter at breast height (dbh) of all adult trees (dbh≥10cm) within the plot and numbered the regeneration (individuals' with dbh< 10cm). In order to individualize plant community groups, the phytosociological data collected were submitted to factorial correspondences analysis (AFC) using CANOCO software. Each group was after characterized in terms of structure and diversity.

Data analysis

Ecological characterization of plant communities

Three diversity metrics (species richness. Shannon and Wiener diversity index and Pielou evenness) mostly used to describe vegetation diversity were calculated to appreciate each plant community group.

the specific richness is the total number of species observed in each plant community

the Shannon and Wiener diversity index is given by the following equation (Eq1).

$$ISH = -\sum pi \log 2\, pi \quad \text{(Equation 1)}$$

where pi = Ni/N; Ni is the number of the species i within the plots; N is the total number of species within the plots and pi is the occurrence probability of a species within the plots. H varies from 0 to 5 bits and is minimal (H = 0) at plot level if all the individuals within the plot belong to one species and is maximum when all the individuals are equally distributed across all the species.

The diversity is low when H is less than 3 bits; average if H lies between 3 and 4 bits; Then high when H ≥ 4 bits.

Pielou evenness measure how individuals are distributed among species. This index is defined by the Eq.2.

$$EQ = ISH/\log 2S \quad \text{(Equation 2)}$$

Where N is the total number of species. EQ varies from 0 (community represented by one species) to 1 (all the species have the same importance). Pielou evenness is very useful to compare potential predominance between sites or dates of sampling.

Structural characterization of individualized plant communities

structural parameters including trees density (N) and the diameter of trees with average basal area (D_g) were estimated using Equations 3 and 4.

$$N = \frac{n \times 10000}{s} \quad \text{(Equation 3)}$$

n is the total number of species recorded within the plot. S is the plot size.

Diameter of trees with average basal area

$$D_g = \sqrt{1/n \sum_{i=1}^{n} d_i^2} \quad \text{(Equation 4)}$$

Where n is the total number of trees within all the plots and di is the diameter of a given tree.

the average basal area (m²/ha) was calculated using the equation 5.

$$G = \prod / 40000s \sum_{i=1}^{n} d_i^2 \quad \text{(Equation5)}$$

The diameter size classes distribution was adjusted using Weibull 3 parameters distribution. This distribution has widely been used due to its great flexibility. Its function of density of probability is given by the following formula (Rondeux, 1999).

$$f(x) = c/b\left((x-a)/b\right)^{c-1} \exp\left[-\left((x-a)/b\right)^{c}\right] \quad \text{(Equation 6)}$$

Where x is tree diameter; a is the position parameter; a is null if all trees stages are considered; it is different from zero if the dbh ≥ a. in the present study, a equals to 10 cm for dbh structure and equals to 5 m for height structures. b is the scale parameter and c the shape parameter. Parameters b and c where estimated based on the method of maximum likelihood (Burk and Newberry, 1984).

Determination of harvesting rotation period and the MED of some high commercial value species

The rotation period and the MED were calculated based on the basal area size classes distribution (Sokpon, 2006).

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The rotation period is the laps of time taken by trees of diameter less than the MED to be shifted to a tree of diameter greater than the MED. This periodicity is a function of the speed of trees growth and the diameter size classes distribution of species population. The rotation period calculation is based on the percentage of the basal area reconstitution rate. This reconstitution rate is a function of exploitable basal area, rate of trees exploitation, the growth and mortality rates. The percentage of the basal area reconstitution (P) is given by the Equation.7

$$P = \frac{[G_o\ (1 - \Delta)]\ (1 - \alpha)^T \times 100}{G_p} \qquad \text{(Equation 7)}$$

where P (%) is the percentage of the basal area reconstitution at time 0; Go = basal area of the three or four diameter classes immediately below the MED; α =rate of annual mortality (0.01); Δ = rate of damage due to the exploitation (Δ =0.1); Gp = exploitable basal area; T is the time of passage = (MED - Dbi) /AAM; with Dbi = lower limit of the diameter class below the MED; AAM = average annual diameter growth in mm/an.

IV. RESULTS

Individualization of plant communities

The factorial correspondences analysis displayed three groups of plants communities (Fig3.) including the dry woodland of *Diospyros mespiliformis* and *Anogeïssus leïocarpa* (07 plots); woodland of *Isoberlinia doka* and *Pterocarpus erinaceus* (05 plots), the wooded savanna of *Vitellaria paradoxa* and *Burkea africana* (09 plots), and shrub savanna of *Vitellaria paradoxa* and *Isoberlinia doka* (33 plots).

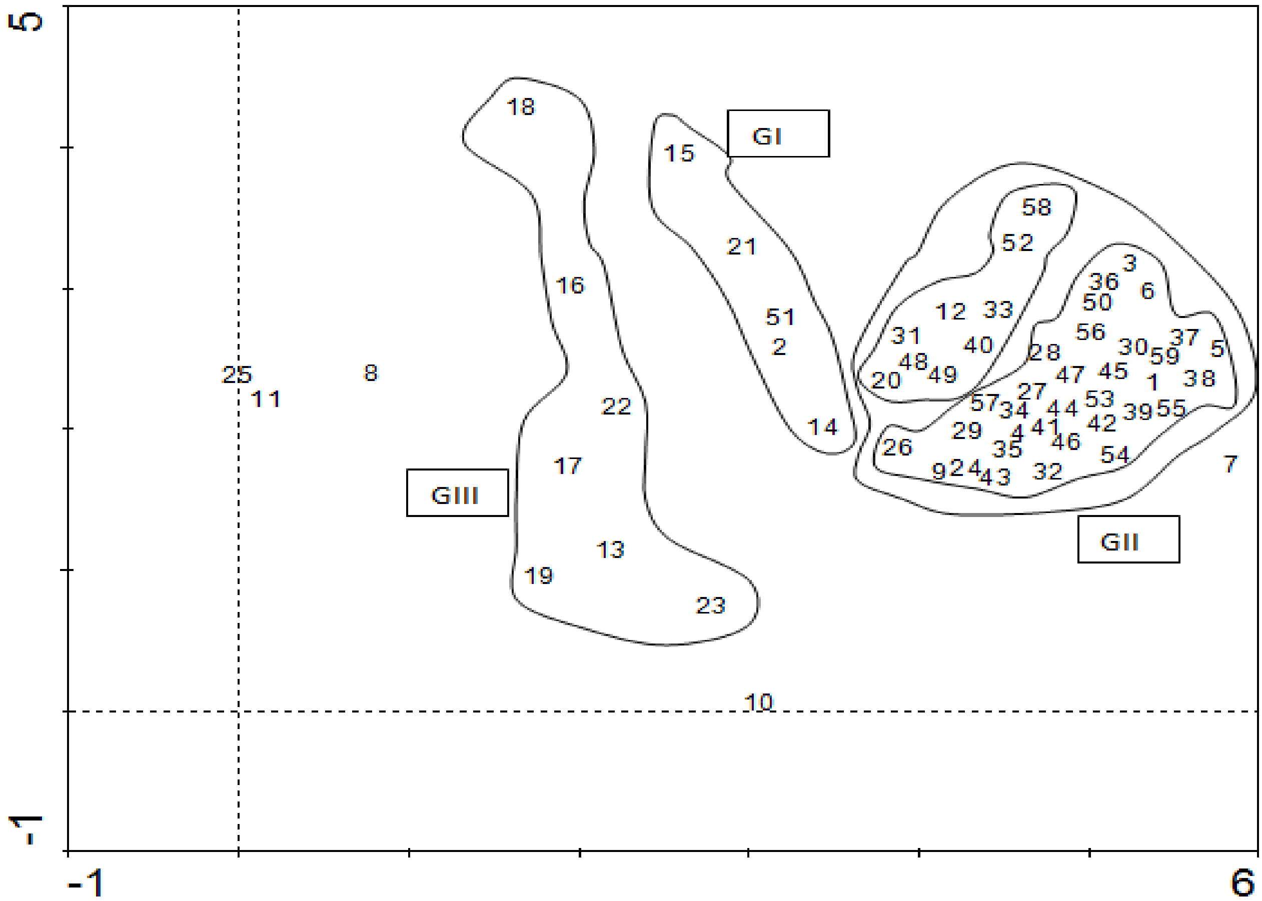

Fig.2: Individualized plant communities groups using Factorial Corespondance Analysis in CANOCO

Legend: GI=dry woodland of *Diospyros mespiliformis* and *Anogeïssus leïocarpus*. GII1= wooded savanna of *Vitellaria paradoxa* and *Burkea Africana*. GII2=Shrub savanna of *Vitellaria paradoxa* and *Isoberlinia doka*. GIII=woodland of *Isoberlinia doka* and *Pterocarpus erinaceus*.

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Table.2: structural and ecological characteristics of individualized plant communities

	Groupe I (n=05)		Groupe II_1 (n=09)		Groupe II_2 (n=33)		Groupe III (n=07)		Prob(%)
	m	se	m	se	m	se	m	se	
Structural parameters									
Shape coefficient (C. 3 Weibull parameters)	1.03	-	0.93	-	0.95	-	0.91	-	-
Dendrometric parameters									
Diameter (D. cm)	23.59ab	1.19	20.92b	0.77	21.16b	0.43	25.26a	0.99	0.000***
Density (N. trees/ha)	277a	51.57	368a	38.43	319a	20.07	287a	43.58	0.53 ns
Average diameter (Dg. cm)	27.65a	2.84	24.3a	2.12	24.59a	1.10	29.1a	2.40	0.71 ns
Basal area (m²/ha)	15.76a	2.82	16.15a	2.10	14.36a	1.1	19.35a	2.38	0.299ns
Ecologic parameters									
Species richness (S. species)	29	-	33	-	58	-	33	-	-
Shannon index (H. bits)	4.22	-	1.25	-	4.66	-	4.18	-	-
Pielou evenness (Eq)	0.87	-	0.24	-	0.79	-	0.83	-	-
Plant community Species	Forêt claire *-Ptérocarpus erinaceus ; -Isoberlinia doka*		Savane boisée *-Vitellaria paradoxa ; -Burkea africana*		Savane arborée *- Isoberlinia doka -Vitellaria paraodoxa*		Forêt dense sèche *-Diospyros mespiliformis ; -Anogeissus leiocarpus*		-

Mean with the same letter are not significantly different (test of Tukey at the threshold of 5%). ***: significant difference at the threshold of 0.1 % ; ns=not significant. Mean (m). standard error (se). probability (Prob).

The average diameter differed significantly (Tukey) between plant communities' groups. The average diameter is of 25.26cm for trees in the dry woodland, 23.5 cm for trees in woodland. 20.9cm for trees in the wooded savannas and 21.16cm for trees in the shrubby savannas.

Diameter structure of individualized groups of plant communities

The diameter size classes distribution translates the high pressure on woodland (c=1). On the whole, all the studied plant communities showed a skewed distribution.

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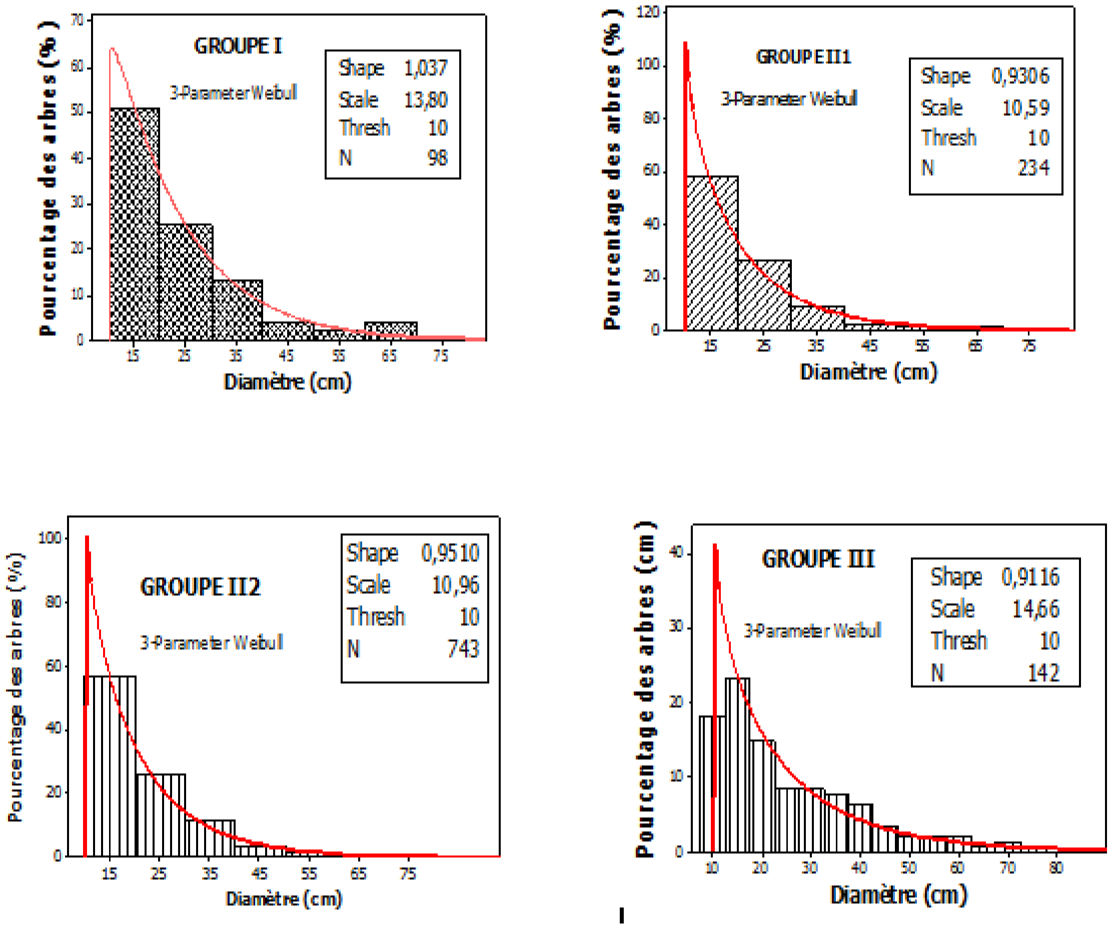

Fig.3: Diameter size classes distribution of individualized plant communities within the Monts kouffè and Wari maro forest reserves

Evolution of the structural characteristics of individualized plant communities

Over a period of five years, the density and basal area in both the dry woodland and woodland declined. The basal area decreased by 0.80 m^2/ha/an in the dry woodland and by 0.25 m ^{2} /ha/an in the woodland. Considering the trees density, it has decreased by 120 trees/ha in the dry woodland and by 108 trees/ha in the woodland. Reversely, the basal area has increased by 2.74 m^2/ha and 2.64 m^2/ha respectively in wooded savanna and shrub savannas. Considering both savanna types, the basal area has overall increased by 2.68m ^{2}/ha over the period of five years. The diameter of trees of average basal area has averagely increased by 2.1cm in the dry close forests ; 3.95cm in the woodland; 2.8cm in the wooded savannas and 3.09cm in the shrub savannas.

Table.3: Evolution of structural characteristics of individualized plant communities over five years

	2006			2011			2011-2006		
Plant communities	Ni	G	Dg	Ni	G	Dg	Ni	G	Dg
Dry woodland (GI)	407	23.35	27	287	19.35	29.1	-120	-4	2.1
Woodland (GII1)	385	17.02	23.7	277	15.76	27.65	-108	-1.26	3.95
Wooded savanna (GII2)	368	13.41	21.5	368	16.15	24.3	-	2.74	2.8
Tree and shrub savanna (GIII)	323	11.72	21.5	319	14.36	24.59	-	2.64	3.09

Ni = Density (trees/ha). **G** = basal area (m^2/ha)
Dg = diameter of trees of average basal area (cm).

Minimal exploitable diameter and periodicity of tree exploitation

The MED of species of high commercial values is 25 cm for *Pterocarpus erinaceus*. 45cm for *Isoberlinia doka* and *Anogeïssus leïocarpa*. 65 cm for *Diospyros* *mespiliformis* and *Danielia oliveri*. The MED of 35 cm allowed 50% of species (*Anogïssus leïocarpa*, *Isoberlinia doka*) basal area reconstitution while this MED allowed 75% of species (*Diospyros mespiliformis*, *Pterocarpus erinaceus*, *Danielia oliveri*) basal area reconstitution. The average harvesting rotation period is estimated at 41 years and was species dependent. The highest exploitation was recorded for *Pterocarpus erinaceus*.

Table.4: Minimal exploitable diameter and percentage of reconstitution in the Mounts kouffè and Wari maro forest reserves

MED (cm)	*Anogeïssus leïocarpa*		*Danielia oliveri*		*Diospyros mespiliformis*		*Isoberlinia doka*		*Pterocarpus erinaceus*	
	%R	D	%R	D	%R	D	%R	D	%R	D
25	22.82	19	5.05	25	70.57	25	25.7	25	44.9	30
35	55.16	31	81.82	42	78.57	42	53.61	42	185.2	50
45	96.98	44					136.7	58		

R=reconstitution rate, D=Minimum Exploitable Diameter

V. DISCUSSION

This study has documented the structural and ecological dynamic of Mounts kouffè and Wari maro forest reserves over five years.

The study recorded low specific richness in the dry woodland (33 species), in woodland (29 species) and wooded savannas (33 species) while the richness was higher in shrub savannas (58 species). In the same Wari-Maro forest, Mensah et al. (2018) noted high species richness in 2004 compared to 2014 in dense dry forests and wooded savannas. The low number of species recorded in dry woodland and woodland is due to the degradation of these natural stands. The specific richness observed in this study is far greater than the one (39 species) observed by Sokpon and Ouinsavi (2006) in the Mounts kouffè and Wari maro forest reserves. Forest dynamics and productivity are highly dependent of plant groups and are function of time. Over the period of five years, the basal area in the dry woodland and woodland declined to 4m^2/ha and 1.26 m^2/ha respectively. Similarly, trees density declined to 120trees/ha and 108 trees/ha respectively for dry woodland and woodland. The decrease in density over time is also observed by Mensah et al. (2018). The low density and basal area values of ligneous trees in 2011 reflect the impact of human activities on natural formations. These density values are lower than the value obtained by Toko Imorou (2008) in the upper Ouémé catchment and by Mensah et al (2018) in the Wari-Maro classified forest. Values closer to those of this study were obtained by Wala (2004) in woodlands of northern Benin. These analyzes indicate that logging increased after the implementation of the management plan and especially at the end of the PAMF project. This logging is practiced mainly in dry forests, woodlands and savanna woodlands. This indicates a low level of implementation of the requirements of the management plan. The basal area declined to 2.68m^2 considering wooded and shrub savannas. The current basal area of wooded savanna and shrub savanna are respectively 16.15m ^{2}/ha and 14.36m ^{2}/ha compared to those obtained in 2006 respectively of 13.41m ^{2}/ha and 11.72m ^{2}/ha. The diameter size classes distribution of individuals showed that almost plant communities are skewed in structure. Regardless the group of plant communities, more than 50% of the individuals are of small diameter size (10–20 cm). The diameter of trees of average basal area has increased by 2.1cm in the dry woodland; 3.95cm in the woodland; 2.8cm in the wooded savannas and 3.09cm in the tree and shrubby savannas over the period of five years. In Benin like in other countries, the MED and the harvesting rotation period were often fixed in an empirical way by the forestry administration. But this empirical approach lies on the forest composition and structural dynamic majorly caused by human pressures. This is the case of the Mounts kouffè and Wari maro forest reserves which have undergone high anthropogenic pressure over the period of five years. In such context, the MED of 35 cm allowed 50% of *Anogïssus leïocarpa* and *Isoberlinia doka* basal area reconstitution while this MED allowed 75% of *Diospyros mespiliformis, Pterocarpus erinaceus. Danielia oliveri* basal area reconstitution. The average harvesting rotation period is estimated at 41ans and differed between species. The MED found in our study is not much different than that observed by Biaou (1999). Hunhyet (2000) and Sokpon et al. (2006). But the harvesting rotation period found by these authors is lower (22ans) than the one observed in the current study (41ans). This difference may result from the overexploitation of wood resources that would have increased the time of the basal area reconstitution. Trees density and the state of natural regeneration are good indicators for determining the possibilities of natural forests reconstitution (Sokpon. 1999). Also, understanding of the regeneration dynamic remains a priority for the maintenance of forest productivity (Dupuy. 1998). In the framework of this study, the regeneration has increased by 27.47% in the dry woodland, 25.71% in the woodland, 31.39% in the wooded savannas and 26.85% in the shrub savannas. This implies an improvement of the regeneration rate over the period of five years compared to that found by Sokpon (2006) (12.6% in the dry woodland, 17.9% in the woodland, 9.4% in the wooded savanna and 16.1% in the tree and shrubby savanna).

VI. CONCLUSION

This study has examined the dynamic and productivity of the Mounts kouffè and Wari maro forest reserves. On the whole, four types of plant communities were identified including the dry woodland of *Diospyros mespiliformis* and *Anogeïssus leïocarpus*, the woodland of *Isoberlinia doka* and *Pterocarpus erinaceus*, the wooded savannas of *Vitellaria paradoxa* and *Burkea africana* and the tree and shrubby savannas of *Vitellaria paradoxa* and *Isoberlinia doka*. We observed decline in the basal area and trees density in both dry woodland and woodland. The basal area declined to 0.80 m²/ha/an in the dry woodland and by 0.25 m ² /ha/an in the woodland. Similarly, trees density has declined to 120 trees/ha in the dry woodland and 108 trees/ha in the woodland over the past five years. Reversely, trees basal area increased by 2.74 m ² /ha and 2.64 m ² /ha respectively for the wooded savanna and tree and shrub savanna. The MED calculated allowed for more than 50% of trees basal area reconstitution and the harvesting rotation period range between 30 years and 50 years. The MED and the harvesting rotation period are baseline indicators in defining policy for the sustainable exploitation of high commercial value species.

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