Dynamics of Vegetation in Managed Forests: A Case Study from Missirah Forest, South-Eastern Senegal

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Abstract:- Floristic and forest structural analyses were carried out to determine the impact of charcoal production in a community-managed forest in south-eastern Senegal. The results showed that at present Missirah Forest shelters 62 species belonging to 18 families and 42 genera. The structural parameters (diameter at breast height, tree density, stem density, Lorey height and basal area) were found to be significantly different among the vegetation types encountered in Missirah Forest ($p < 0.05$), and the highest values was observed in gallery forest. From 2002 to 2013 the species richness decreased whatever the vegetation type as well as the species evenness. This decrease observed is confirmed by the trend of Shannon diversity index. The K-mean of the Importance Value Index (IVI) identified three classes: species with improved, declined, and relatively stable IVI. The parameters analysed for the recovery of the forest with the exception of stem density showed significant difference after the rotation period indicating a non-replenishment of the resources. This study showed that the conditions under which the forest is managed currently do not constitute a sustainable response to deforestation and degradation induced by charcoal production. We recommended a revision of the management plan and an enforcement of the strict adherence to the technical prescriptions of the management plan.

Keywords:- *Community based forest management; Sustainability; Biodiversity conservation; Species change; Forest recovery; Senegal.*

I. INTRODUCTION

The concept of sustainability in forest management arouses growing interest worldwide because of the role of forest in climate change mitigation and in local communities' livelihoods particularly in developing countries. The major challenge in assessing sustainability in forest management is to find a consensus on a framework that can be applied universally (Mendoza and Prabhu 2003a; Wolfslehner and Vacik 2008). Broad concept, encompassing various aspects of natural resources management, sustainability was subjected to different definitions (Heinberg 2010; Mebratu 1998). However, globally, sustainability can be summarized as a management integrating the socio-economic, ecological, and biophysical components (Hermanides and Nijkamp 1998; Renning and Wiggering 1997) in such a way to meet current and future needs. Sustainable forest management emerges from the collective willingness to make use of forests while protecting them. Sustainable forest management has principles ensuring broad social, economic and environmental goals. Here we consider the ecological principle that is the rate of use of forest resources is "less than or equal to the rate of natural replenishment" (Heinberg 2010). Then understanding how the forest resources evolved in managed forests in comparison with less disturbed areas of the same vegetation type is decisive in assessing the success of forest management. However, so far still few studies have incorporated this aspect in their analyses.

Number of studies focused in assessing forest management (Blomley et al. 2008; Gustafson et al. 2007) to see in which extend it contributes to prevent deforestation and forest degradation. Forests under management are subjected to management plans based on legal and technical prescriptions (Bettinger et al. 2007; Cerutti et al. 2008; Nasi and Frost 2009). Technical prescriptions refer to regulations that specify parameters like limits of areas to be exploited, rotation and harvesting periods, annual allowable cut, minimum harvesting diameter, target species. The respect of these prescriptions enables the continuity of replenishment of the resource through time. Then in theory carrying out a forest management plan built on reliable prescriptions should allow a recovery of the forest in the long term.

Although forest management has been cited as a response to the effects of anthropogenic activities on vegetation, evaluations conducted so far to test its sustainability show weaknesses.

First, given the scientific basis of management plans particularly in the Sahel that fail to win unanimous support (Fredericksen 1998; Putz et al. 2000) combined to the fact that what is stated in the management plan is often completely different from how the forest is actually managed (Kaimowitz 2003), an assessment based on the analysis of the management only may fail to actually give a good picture of the situation. Therefore, an approach based on the comparison between the reference state and the situation of the forest after a complete rotation period is crucial to see whether the initial objectives are being achieved (Blomley et al. 2008).

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Secondly, the use of criteria and indicators in assessing forest management can be questioned in the light of the complexity of forest ecosystems. Indeed, forests are determined by complex biophysical, chemical, and physiological functions that are not entirely understood (Mendoza and Prabhu 2003b). Fuzzy methods developed to thwart this shortcoming may also be subjected to uncertainty when it comes to determine the thresholds values that should determine the success or failure as well as the degree of success between the threshold values. The use of criteria and indicators is one more limited by the multiplicity of forest management objectives. Then, an assessment based on the achievement of management objectives can help to bypass these difficulties cited above. However, so far many authors focused their assessment on criteria and indicators (Mendoza and Prabhu 2000; Mendoza and Prabhu 2003a; Wolfslehner et al. 2005).

Thirdly, assessment of the success of forest management also focused on the economic value of the flow of benefits generated ignoring damages caused in their creating even if these wealth are generated at the expense of forest. This omission can constitute a bias since the cost of production represented here by the impacts on vegetation is not counted. On the contrary if the dynamic of the resource is known, management plan can be adapted to the dynamic of the resource (Kaimowitz 2003) and management guidelines provided.

The main objective of this study is to assess the success of forest management in achieving management objectives in south-eastern Senegal. It was measured firstly in term of biodiversity conservation regarding plant species composition. Secondly, we assessed the success of forest management in terms of the recovery of the forest after a full rotation period. This assessment was preceded by a characterization of the current state of the forest. To this end, we used the data of the forest inventory realized in 2002 that we compared to the data collected in 2013.

II. MATERIALS AND METHODS

➢ *Study Area*

This study was conducted in Missirah in the southeastern Senegal located in the Sudanian zone characterized by one rainy season and one dry season (Figure 1).It covers 63121.54 ha. The rainfall is unimodal and the annual mean rainfall from 1961 to 2014 is estimated at 754mm. The region is characterized by very high temperatures (40°C) in heat period while in cold months; they can drop below 20°C. Missirah Forest was a traditional area of agriculture and breeding until 2004 when began the participatory forest management. Indeed, local communities depend mainly on forest resources for their livelihoods. With the management charcoal production became the main economic activity that support the livelihood of local population. For management purpose, the forest was divided into five blocks split up into eight parcels. Each parcel was assigned to a year of exploitation corresponding to a rotation period of eight years.

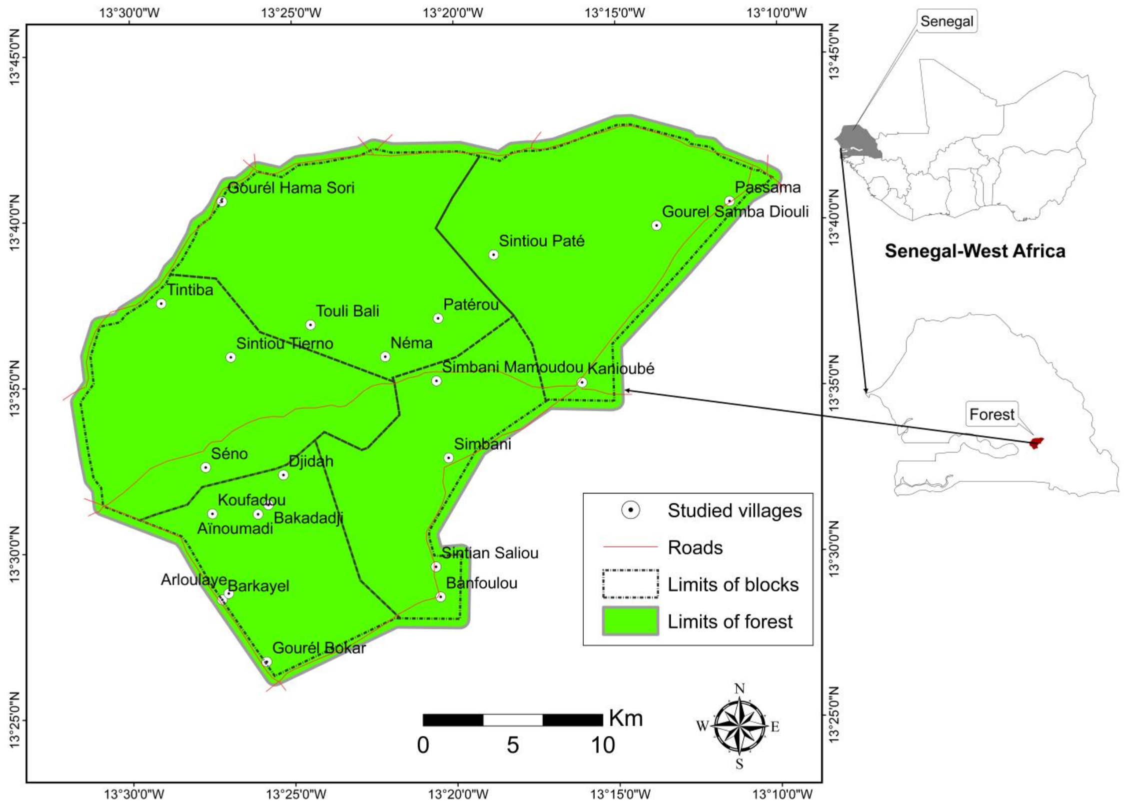

Figure 1:- Location of the study area

➢ *Vegetation Inventory*

The inventory covered trees and shrubs on a set of 185 permanent sample plots established in 2002 throughout the forest. The sample size of plots inventoried was computed with a margin error of 8% using the properties of the t distribution of Dagnelie (1998) as follow:

$$n = t^2_{1-\alpha/2} \frac{CV^2}{d^2}$$

where $t^2_{1-\alpha/2}$ equals to 1.96, i.e. the value of the t Normal random distribution at probability of 1-α/2 (0.975); CV = coefficient of variation of the number of stems per hectare in shrub savanna is equal to 55.6%. Considering these values, 94 plots were inventoried in the different vegetation types in elevated lands. For consistency with the baseline data of 2002, we used the same inventory method. Data in 2002 were stem dbh between 3cm and 9 cm, 10cm and 19cm, and dbh equal or greater than 20 cm that were collected from circular plots with three size of radius: 10 m, 15 m, and 20 m respectively. Additionally to plots set in elevated lands, 57 rectangular plots of 40 m x10 m were inventoried in gallery forest. The 57 plots were also obtained using Dagnelie (1998) with a CV of 38.7 % and a margin error of 7 %.

➢ *Data analysis*

We used the different vegetation cover types identified through the mapping of the land use and land cover using 2013 Landsat image. The characterisation of the state of the vegetation included all the vegetation types. However the sections on species change analysis and recovery of the forest did not consider the gallery forest because it was not inventoried in 2002. Similarly the degraded shrub savanna was not included because it was not present in 2002.

➢ *Characterization of the vegetation types*

The state of the vegetation was characterized through floristic and structural analysis within each vegetation types and the whole forest.

The floristic analysis was achieved considering three floristic parameters namely the species richness (S), the Shannon diversity index (H'), and the Pielou evenness index (Eq).

The species richness (S) is the cumulative number of species listed in the plots inventoried.

The Shannon diversity index (H') is obtained using the formula:

$$H' = \sum \left(\frac{n_i}{n}\right) \log_2 \left(\frac{n_i}{n}\right)$$

where *ni* is the number of trees of species *i*, *n* is overall number of inventoried trees in all plots

The Pielou evenness index (*Eq*) is computed as follow:

$$Eq = \frac{H'}{H_{max}}$$

where *H'* represents the Shannon diversity index and H_{max} is $Log_2 S$

In addition, the IVI of each species was used for characterizing each vegetation type and the whole study area. It is defined as:

$$IVI = RtD + RtC + RtF$$

where RtD_i is the relative density of species *i*: RtD= $Ni / \sum_{i=1}^{p} Ni$ with p = the total number of species and Ni = the tree density of species *i*; RtC_i is the relative coverage of the species *i*: RtC_i = $Ci / \sum_{i=1}^{p} Ci$, Ci= $\frac{aiNi}{ni}$ where Ci is the coverage of species *i* (i.e. the proportion of the ground occupied by a vertical projection to the ground from the aerial parts of the plant), ai is the basal area of species *i*, Ni is the tree-density of species *i*, and ni is the total number of individuals recorded for that species.

RtF_i is the relative frequence of species *i*: RtF_i = $fi / \sum_{i=1}^{p} fi$, fi= $\frac{ji}{g}$ where *fi* is the frequency of species *i*, *ji* is the number of plots in which species *i* was observed, and *g* is the total number of plots.

With regard to dendrometric analysis, the following parameters were computed:

- tree density of the stand (*N*), indicates the average number of trees recorded by plot expressed as trees per hectare;
- stem density of the stand represents the average number of stems per plots expressed as stems per hectare
- basal area of the stand (*G*) is the sum of the cross sectional areas at 1.30 above ground level for all trees in a plot express as m^2/ha defined as:

$$G = \frac{\pi}{4s} \sum_{i=1}^{n} 0.0001 d_i^2$$

where d_i is the dbh of the i^{th} tree in cm in a plot area *s*;

- mean dbh is the mean dbh of all individual trees in a plot

$$D = \sqrt{\frac{1}{n} \sum_{i=1}^{n} d_i^2} \quad (6)$$

where n is the number of trees in a plot and d the dbh of tree in cm;

- mean Lorey's height is the average height of all trees in a plot weighted by their basal area as follow:
-

$$L = \frac{\sum_{i=1}^{n} a_i h_i}{\sum_{i=1}^{n} a_i} \quad a_i = \frac{\pi}{4} d_i^2$$

where a_i and h_i are respectively the basal area (m^2/ha) and the total height (in m) of tree *i*.

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The mean and the CV were computed for these dendrometric parameters and an Analysis of Variance (ANOVA) was applied to test significant difference between vegetation types.

➢ *Species change*

Tree species captured in 2002 and 2013 were pooled and categorized in three classes: (1) the constant species that refer to those ones recorded in the two years in the sampled area, (2) species found only in 2002, and (3) species found only in 2013. Furthermore, I performed general linear models based on Poisson, quasi Poisson or negative binomial distribution to test the effect of vegetation type and year and their interaction on tree species diversity. The best fitted error distribution was chosen based on compliance of the assumption for the three distributions taking into account the relationship between mean and variance for the different vegetation types in the two years. Plot species richness per vegetation type was used as response variable to run the model selected with the function "glm.nb" of the MASS library. Function ANOVA with Chi-square test was applied to determine significant effect of each factor on species composition. Finally, differences in species IVI were used to implement a supervised clustering based on centroid mean where three classes were defined: species with increased IVI, species with declined IVI, and species with relatively stable IVI.

➢ *Recovery of the forest*

The recovery of the forest was assessed by testing the hypothesis about the validity of the eight-year rotation period prescribed in the management plan. To this end the same dendrometric parameters calculated for the characterization of the state of the vegetation was compared to the 2002 situation. A mixed model of ANOVA considering the vegetation type as random variable and the year as fixed variable was applied to test if the forest was able to recover from harvesting.

III. RESULTS

➢ *Tree and shrub populations across vegetation types*

A total of sixty-two (62) species were counted, 54 of which had stems of dbh ≥ 3 cm whilst eight consisted of regeneration. The 54 species came from 18 families and 42 genera. The most represented families were the Fabaceae (12 species), the Combretaceae (9), the Rubiaceae, (7), and the Anacardiaceae (5) respectively. A total of 2686 stems from 3 cm to114.38 cm of dbh were recorded. The shrub savanna had the highest number of tree species with 41.64 % of trees inventoried followed by tree savanna (30.45 %), and gallery forest (25.91 %). Only 0.60 % of the trees inventoried were located in degraded shrub savanna. Two species, *Combretum glutinosum* and *Pterocarpus erinaceus* were found in all vegetation types and constituted 20.84 % and 5.58 % respectively of the trees recorded. The computation of the IVI of species showed that only 9 species from the 54 listed were ecologically important with an IVI greater than or equal to 10. The most important were *Mitragyna inermis* (55.64), *Combretum glutinosum* (40.43), and *Pterocarpus erinaceus* (23.28).

In the tree savanna, a total of 830 trees were countered. The species richness was 32, the Shannon's diversity index 3.58, and the Pielou evenness index 0.72. The *most* represented species were *Combretum glutinosum, Cordyla pinnata*, *Pterocarpus erinaceus*, *Strychnos spinosa*, and *Bombax costatum*. They accounted for 57.83 % of the trees inventoried. Species specific to this vegetation type are *Entada africana* and *Pavetta cinereifolia.* In terms of IVI the most important species were *Combretum glutinosum*, *Pterocarpus erinaceus*, *Cordyla pinnata*, and *Bombax costatum*. The mean tree density was estimated at 182 trees/ha and the mean dbh 10.72 cm. The mean Lorey's height and the regeneration density were estimated at 9.51 m, and 96.7 plants/ha respectively (Table 1).

The shrub savanna had 52 plots where we recorded 1099 individuals. The species richness and the Shannon's diversity index were 34 species and 3.32 respectively while the Pielou evenness index was estimated at 0.64. In terms of species distribution, *Combretum molle*, *Detarium microcarpum*, *Gardenia ternifolia*, *Maytenus senegalensis*, *Stereospermum kunthianum*, and *Terminalia laxiflora* were found only in this vegetation type. The dominant species were *Combretum glutinosum*, *Acacia macrostachya*, *Lannea acida* and *Strychnos spinosa* that represent 63.78 % of the trees recorded. The tree density was equal to 167.6 trees/ha while the stem density reached 248.6 stems/ha. The mean dbh and mean Lorey's height of the stand were estimated at 11.13cm and 9.31m respectively (Table 1). The IVI computed for species showed the dominance of 4 species *Combretum glutinosum*, *Bombax costatum*, *Acacia macrostachya* and *Lannea acida.*

On the degraded shrub savanna four plots were set up on which only 16 trees were counted. Its species richness was nine and its Shannon diversity index 2.64. Apart from *Combretum glutinosum* which had seven individuals and *Terminalia avicennioides* two, all the seven species listed had only one individual each. *Sclerocarya birrea* was recorded only in this vegetation type. The tree and stem density were estimated at 31.8 trees/ha and 63.7 stems/ha respectively. It had the lowest values for the dendrometric parameters analysed except its mean dbh of 11.80cm.

In the gallery forest, 684 trees and 3466 stems from 34 species were recorded with a plot diversity ranging from 1 to 10 species. The most important species in terms of IVI were *Mitragyna inermis*, *Combretum micranthum*, *Pterocarpus erinaceus*, *Piliostigma thonningii*, and *Sapium ellipticum.* The gallery forest was dominated by *Mitragyna inermis* that had 54 % of the trees inventoried. The tree density was about 300 trees/ha and the stem density 1524 stems/ha. The mean dbh was estimated at 28.19cm.

Table 1 is a summary of the structural and floristic parameters of the whole forest and the different vegetation types. In terms of species richness, variation between different vegetation types and the whole forest is high. It is estimated at 54 species for the forest against 34 for gallery forest and shrub savanna, 32 for tree savanna and 9 for degraded shrub savanna. Shannon's diversity and Pielou evenness indexes showed their highest values in tree savanna with 3.58 and 0.72 respectively. All the parameters analyzed were significantly different from one vegetation type to another. The overall tree density was estimated at 216.7 trees /ha and stem density 735.5 stems/ha. The mean diameter, Lorey's height, and basal area were respectively estimated at 17.09cm, 10.38m, and 11.38m^2/ha. The highest value for all the parameters was recorded in gallery forest. The lowest mean diameter was observed in tree savanna while for the basal area degraded shrub savanna showed the smallest value (0.51 m^2/ha).

Parameters	Tree savanna		Shrub savanna		Gallery forest		Deg. Shrub savanna		ρ-value	Whole forest	
	mean	CV	mean	CV	mean	CV	mean	CV		mean	CV
Tree density (N trees/ha)	182	39.11	167.6	45.72	299.5	58.46	31.8	113.64	0.0001	216.7	65.26
Stems density (N stems/ha)	303.2	38.36	248.6	47.97	1524	61.36	63.7	152.4	0.0001	735.5	115.1
Basal area (m2/ha)	4.39	55.25	3.52	55.65	22.54	59.49	0.51	109.91	0.0001	11.38	110
Reg. density (N plants/ha)	96.7	152.7	126.9	99.85	286.8	139.1	47.8	82.77	0.005	178.9	155.4
Lorey's height (m)	9.51	19.85	9.31	22.72	12.36	22.3	5.88	70.36	0.0001	10.38	27.69
Mean dbh (m)	10.72	25.41	11.13	3.47	28.19	35.26	11.81	143.7	0.0001	17.09	60.42
Species richness	32	-	34	-	34	-	9	-	-	54	-
Shannon index	3.58	-	3.32	-	2.79	-	2.65	-	-	4.13	-

Table 1:- Structural parameters of the vegetation types and the whole Missirah Forest mean (m), coefficient of variation (CV, in %) and probability values (*p*) of ANOVA

➢ *Changes in tree population*

The species richness in Missirah Forest was estimated at 42 species that represent only 1.2 % of the species recorded at national level. This gives an account of the state of degradation for a region known for the richness of its biodiversity. Indeed, in 2002, the species richness was estimated at 50 species indicating a reduction of 16 % in species numbers. This figure did not take into account the regeneration. Added together, the floristic composition was about 60 species consisting of 32 species listed in both inventories, 18 listed only in 2002 and 10 "new" species identified in 2013 within the sampled area. The species richness decreased in all vegetation types (Table 2). The highest decline was observed in shrub savanna which experienced a decrease of 11 species. The lowest decline was noticed in tree savanna with a species richness of 36 species in 2002 and 32 in 2013. With regard to species evenness, it follows the same trend as the species richness. The trend observed in species richness and evenness is confirmed by Shannon's diversity index that showed also a decrease in the vegetation types and the whole forest.

Vegetation types	Species richness		Diff.	Shannon index		Diff.	Pielou index		Diff.
	2002	2013		2002	2013		2002	2013	
Tree savanna	36	32	-04	3.86	3.58	-0.28	0.77	0.72	-0.05
Shrub savanna	45	34	-11	3.66	3.32	-0.34	0.71	0.64	-0.07
Whole stand	50	42	-08	3.85	3.52	-0.33	0.71	0.62	-0.09

Table 2:- Comparison of diversity indices between 2002 and 2013

The model output that fitted with the data was the negative binomial model with the difference between the mean and the variance estimated at 9.85. The ANOVA conducted on the negative binomial model showed that from one vegetation type to another the difference in terms of diversity was highly significant ($p < 0.05$) while from one year to another it was not significant ($p = 0.397$). The interaction between year and vegetation types indicated a significant difference (Table 3).

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Parameter	Df.	Deviance Resid.	Df Resid.	Dev.	Pr(>Chi)
Vegetation type	3	69.439	188	199.78	0.000
Year	1	0.717	187	199.07	0.397
Vegetation type*year	3	18.756	184	180.31	0.0003

Table 3:- Results of the ANOVA conducted on the Negative binomial model

The supervised classification executed through the K-means methods showed three classes (Figure 2) defined based on the IVI class centres means. The first class included 10 species with an IVI mean of 4.768 corresponding to species with increased IVI. The second class hosted 47 species with a mean of -0.425. This cluster comprised species with a relatively stable IVI. The third class with a mean of -11.26 embodied 3 species namely *Combretum glutinosum*, *Terminalia avicennioides,* and *Acacia ataxacantha* that experienced a declined IVI.

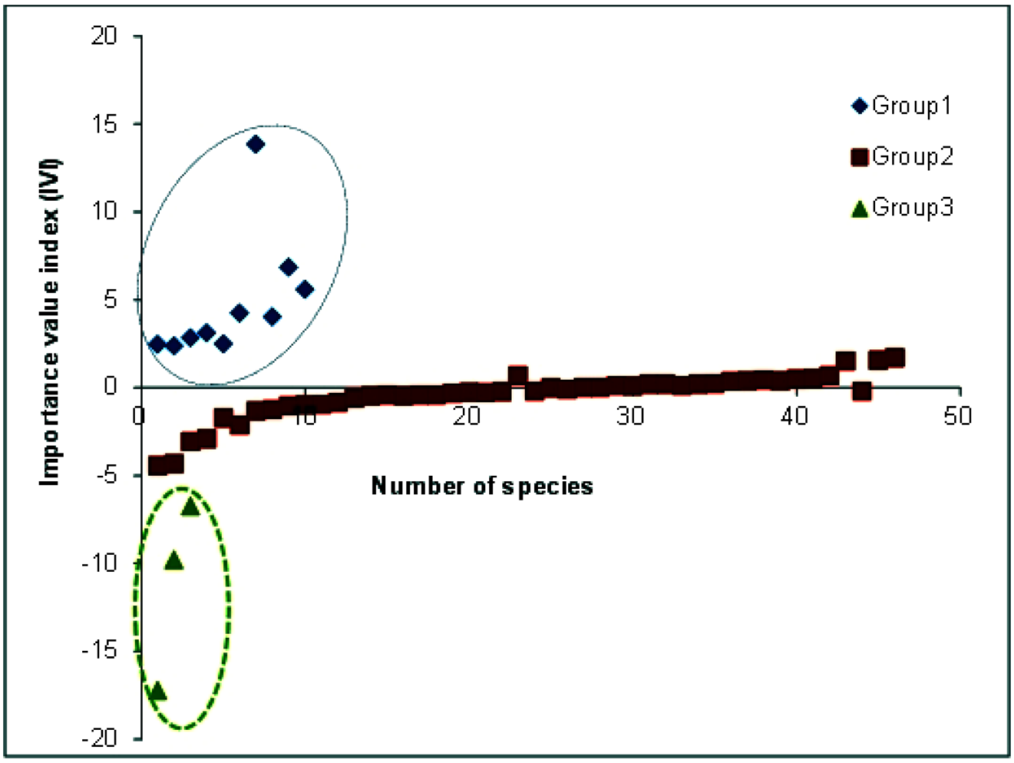

Figure 2:- Clusters of species based on difference in species IVI between 2002 and 2013

- *Recovery of the forest*

Mean values of structural parameters for 2002 and 2013 are presented in Table 4. The results showed that apart from the stem density of tree savanna, all parameters were characterized by a negative trend. With the exception of stem density (p = 0.43), the differences observed were statistically significant. This would suggest that the natural recovery of the forest was not achieved as forecast in the management plan. In 2002 the highest values were observed in shrub savanna except for mean basal area and mean Lorey's height. However, shrub savanna recorded also the most important losses except for the mean Lorey's height where it experienced a decrease of 2.17 m against 2.7 m in tree savanna. Its stem and tree density experienced a decrease of 60 stems/ha, and 61 trees/ha respectively. On the other hand, in 2013 the highest values were recorded in tree savanna except the mean dbh estimated at 10.72 m against 11.13 m in shrub savanna. Stems density in tree savanna increased from 276.5 stems/ha to 303.2 stems/ ha between 2002 and 2013 in spite of a decrease of 21.8 trees/ha of its tree density. The tree density of the whole forest was estimated at 214.16 trees/ha in 2002 and 156.6 trees/ha in 2013 and the mean dbh 12.32m and 11.12m respectively in the two periods. The basal area decreased from 5.64 m^2/ha to 3.86 m^2/ha indicating a loss of 31.56 %.

Parameters	Vegetation types	2002	2013	Difference	P-value
Tree density (N tree/ha)	Shrub savanna	228.90	167.60	-61.30	0.004
	Tree savanna	203.80	182.00	-21.80	
	Whole forest	214.16	156.60	-57.56	
Stem density (N stem/ha)	Shrub savanna	309.00	248.60	-60.40	0.43
	Tree savanna	276.50	303.20	26.70	
	Whole forest	290.00	257.30	-32.10	
Mean dbh (m)	Shrub savanna	13.28	11.13	-2.15	0.05
	Tree savanna	11.79	10.72	-1.07	
	Whole forest	12.32	11.12	-1.20	
Basal area (m2/ha)	Shrub savanna	5.42	3.52	-1.90	0.02
	Tree savanna	6.09	4.39	-1.60	
	Whole forest	5.64	3.86	-1.78	
Mean Lorey's height (m)	Shrub savanna	11.48	9.31	-2.17	0.000
	Tree savanna	12.21	9.51	-2.70	
	Whole forest	11.71	9.48	-2.23	

Table 4:- Evolution of structural parameters of the vegetation types and the whole forest

IV. DISCUSSION

➢ *Tree and shrub population*

The vegetation types had almost the same species particularly in elevated lands. Few species were listed as specific to the different vegetation types and almost all of them contained only one individual. Only gallery forest had 12 species specific to it. This variation in species composition between elevated lands and gallery forest was probably due to differences in physical conditions as reported elsewhere (Ganglo 2005; Houéto et al. 2014). In terms of structural parameters, gallery forest also recorded the highest values. Its tree density far surpasses by 100 trees/ha the tree density in elevated lands. This did not match with the findings of Lykke (1994) and Madsen et al. (1994) who observed higher tree density in elevated lands. This contradiction can be explained first by the fact that vegetation types in elevated lands are subjected to regular cutting for charcoal production while gallery forest is protected from carbonization; secondly the invasion of valleys by the multi-stemmed tree species *Mitragyna inermis* strongly contributed to the increase in the number of trees recorded. Despite its species richness compared to other vegetation types, gallery forest showed signs of degradation with savanna species becoming more common in the plots. This progression of gallery forest into savanna has already been described by Lykke (1994) in Delta du Saloum National Park and in the Niokolo-Koba National Park (Madsen et al. 1994) both in Senegal. The process may result from a decrease in rainfall and an increase in human activities. The presence of many dead trunks observed in the valleys, and the establishment of farms particularly in areas where sandbanks have been formed indicates the impacts of human footprint.

➢ *Species change*

Missirah Forest experienced a decline in the number of species by eight. These species did not have many individuals in 2002 except for *Hannoa quasia* (21), and *Acacia ataxacantha* (115). The disappearance of these two species, identified as preferred species in making charcoal may have resulted in their overexploitation as reported by Guédou (2005) in Benin, and Kouami et al. (2009) in Togo, who disclosed that preferred species for charcoal production were no longer available. The loss of species richness in areas of charcoal production was also reported in the region by comparing Simpson diversity index in undisturbed and harvested plots (Wurster 2010). It was estimated at 3.24 in undisturbed plots and 1.38 in harvested plots. A loss of species richness was also observed in areas which are not under management by Gonzalez (2001) who found that species richness fell from 63 species in 1945 to 43 species in 1993 in the northwest of Senegal. Similar findings were also reported in central Senegal between 1983 and 2010 (Herrmann and Tappan 2013). The same trend observed in managed forest as well as in non-managed forest indicates that forest management as implemented presently did not uphold rational use of forest.

The classification of species based on the dynamics of their IVI demonstrated that three species *Combretum glutinosum*, *Acacia ataxacantha*, and *Terminalia avicennioides* used for charcoal were characterized by a

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significant decrease of their IVI. In the Welor Reserve where charcoal production is not allowed Sambou et al. (2008) did not detect any reduction of IVI of these species confirming the suspicion that charcoal production is having a negative effect on these species.

- *Recovery of the forest*

All the parameters analysed for the recovery of the forest showed a negative trend implying the recovery of the forest was not evident. On the contrary it indicates a condition of degradation of the forest. Tree density for the whole forest was estimated at 214.16 trees/ha in 2002 as against 156.69 trees/ha in 2013. The highest decline in tree density was observed in shrub savanna with a drop of 61.3 trees/ha. The highest decline may be explained by the fact that shrub savanna shelters more energy species and is consequently more liable to cut. Elsewhere in Senegal decline in tree densities have been recorded (Gonzales 2001; Herrmann and Tappan 2013; Vinckle et al. 2010). Vinckle et al. (2010) documented a decrease of tree density from 868 trees/ha to 680 trees/ha between 1976 and 1995.

Given the slow growth rate of dry forests, the decrease observed in mean dbh and mean basal area may in the long-term lead to the absence of exploitable stems in the forest and therefore unsustainable production of charcoal. Already in the field one can observe a scarcity of big diameter trees in charcoal species especially *Combretum glutinosum* meaning without proper management forest recovery may be seriously impaired after exploitation.

V. CONCLUSION

This study evaluated the impact of charcoal production on the forest in terms of changes in tree species composition and structure of the forest after a full rotation. Species richness decreased by 16 % between 2002 and 2013 whilst one of the three recommended species for charcoal production experienced more than 50 % reduction in its density suggesting charcoal production may be depleting its resource base. Besides, significant differences were found for most of the dendrometric parameters that serve as indicators for the potential of the forest to recover from harvest disturbance. We therefore conclude that charcoal production will not be sustainable if the production continues under the same present conditions. Accordingly, arrangements should be made to reverse the situation. First gallery forest constitutes an important natural habitat that shelters many species used for feeding by local communities and have the particularity to remain green longer than elevated land. For this reason, it needs a high conservation priority to protect the remaining species and allow seedling to grow. In elevated lands, charcoal is produced everywhere in the exception of farmlands, and areas surrounding ponds. The loss of biodiversity indicates a necessity of rezoning of the protected area that should suggest sustainable ways to include areas of high biodiversity and those hosting threatened species. Furthermore, in gallery forest as well as in elevated land, assisted seedlings especially for species showing a decline should be promoted.

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