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Analysis of tree communities' characterization in a seasonally dry forest for guiding forest management decision in South Benin, West Africa

Analyse de la caractérisation des groupements végétaux d'arbres dans une forêt saisonnièrement sèche pour guider les prises de décision dans sa gestion dans le sud du Bénin, Afrique de l'Ouest

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Abstract

Sustainable management of forest resources requires technical information's for decision-making. This study aimed to characterize tree communities in the forest of Dogo-Kétou wide of 42.850 ha in South Benin in order to reveal the silvicultural problems, which can contribute to its sustainable management. A forest inventory was achieved with fifty plots of 1 ha each installed and 250 quadrats of 100 m² each were used to study the forest' regeneration. Different dendrometrical parameters were calculated. The diameter structures, the factorial correspondence analysis followed by the ascending hierarchical classification were also carried out with the software Ri386 3.5.3.
The results revealed three tree communities with the densities varying between 23 and 26 trees/ha. The Shannon index of each tree community varies between 2.80 and 3.58 bits. *Anogeissus leiocarpa*, *Daniellia oliveri* and *Vitellaria paradoxa*' community is the most diversified with an overall specific richness of 34 species and the high Shannon index obtained. The biotope of this tree community is the most productive of the forest. Despite the low floristic indices, this forest is exposed to strong anthropogenic pressures, which prevent the establishment of a mature dense forest. The analysis of the diameter structures reveals that the forest show the lack of big trees with dimeter superior than 45 cm, which are both mature and seed trees able of ensuring good regeneration for the future. The biological diversity of this forest is therefore threatened and deserves to be restored through strong sustainable management actions such as assisted regeneration, enrichment with commercial value species, strengthening the surveillance to prevent illegal exploitation and promoting participatory management.

Keywords

Forest, inventory, sustainable management, decision-making, Benin.

Résumé

La gestion durable des ressources forestières nécessite des informations techniques pour la prise de décision. Cette étude vise à caractériser les groupements végétaux d'arbres dans la forêt de Dogo-Kétou d'une superficie de 42.850 ha au Sud-Bénin afin de révéler les problèmes sylvicoles pour contribuer à sa gestion durable. Un inventaire forestier a été réalisé avec l'installation de 50 placeaux de 1 ha chacun et 250 quadrats de 100 m² pour l'étude des régénérations. Différents paramètres dendrométriques ont été calculés. Les structures en diamètre et l'analyse factorielle des correspondances, suivie de la classification hiérarchique ascendante ont été aussi réalisées avec le logiciel Ri386 3.5.3. Les résultats ont révélé trois groupements végétaux d'arbres avec des densités variant entre 23 et 26 arbres/ha. L'indice de Shannon de chaque groupement d'arbres varie entre 2,80 et 3,58 bits. Le groupement à *Anogeissus leiocarpa*, *Daniellia oliveri* et *Vitellaria paradoxa* est le plus diversifié avec une richesse spécifique globale de 34 espèces et l'indice de Shannon le plus élevé. Le biotope de ce groupement d'arbres est le plus productif de la forêt. Malgré les faibles indices floristiques, la forêt de Dogo-Kétou est exposée à de fortes pressions anthropiques, qui empêchent l'établissement d'une forêt dense mature. L'analyse des structures en diamètre révèle que la forêt montre l'absence de grands arbres de diamètre supérieur à 45 cm, qui sont à la fois des arbres matures et semenciers capables d'assurer une bonne régénération pour l'avenir. La diversité biologique de cette forêt est donc menacée et mérite d'être restaurée par des actions fortes de gestion durable comme la régénération assistée, l'enrichissement en espèces à valeur commerciale, le renforcement de la surveillance pour prévenir l'exploitation illégale et la promotion de la gestion participative.

Mots clés

Forêt, inventaire, gestion durable, prise de décision, Bénin.

1. Introduction

Forests are widely recognized for their environmental and social contributions to people and planet (Gross-Camp 2017). In particular, tropical forests play a significant role in the livelihoods of the poor rural regions through their provision of goods and services (Barrow et al. 2016). In Africa, forests cover approximately 636.639.000 hectares, over 16% of the world's forest area and they are so important for cultural and socio-economic development and for the ecosystemic services (FAO 2020). The loss of forest in the world is estimated at 10,150,000 ha, of which 4,414,000 ha is recorded in Africa in 2020 (FAO 2020) against 4,096,000 ha in 2000 (FAO 2000). Africa is facing an unprecedented land degradation, coupled with climate change, and in Benin, the forest areas degraded yearly are estimated at 50.000 ha (FAO 2020). The significant biodiversity of Benin spread from south to north with various forest reserves covered approximatively 19% of the territory (FAO 2018). However, Benin is not considered as a forest country in West Africa (Ganglo and Maître 2003); despite that, it is still suffering a strong degradation of its forest (Imorou et al. 2019). Its classified forests cover 1.436.500 ha (FAO 2017). Unfortunately, a large part is destroying each year for agricultural and pastoral purposes and for the use of wood (FAO 2014). Consequently, ensuring its integrated management is essential for sustaining its services including provision to local populations of fuelwood, food and other non-timber forest products (Agbangla et al. 2015). The assessment of the degradation of the forest and theirs structures help to understand the past management of the trees and their dynamics and for the easy identification of the future types of management to be applied (Hitimana et al. 2004; Wulder et al. 2009; Nadkarni et al. 2008; Merino et al. 2007). Thus, an in-depth knowledge of the structural and ecological characteristics of forests is essential for the planning and sustainable management of forests. The tree density, the diameter structure, the height and the spatial distribution of the stand are important parameters to consider when characterizing a forest ecosystem (Herrero-Jáuregui et al. 2012; Agbangla et al. 2015). The spatial distribution of the forest indicates how individuals of the same species are distributed in the forest area, and provides information on the seed dispersal mode of the species as well as its site preferences (Agbangla et al. 2015). The density of a species at a given place is a function of its survival strategy, its ability to adapt to the ecological requirements of the environment, or to intentional enrichment in the past (Comita et al. 2007; Agbangla et al. 2015). Forest structural parameters have been extensively documented both in Benin and around the world. The studies of Pascal (2003), Aoudji et al. (2006), Agbangla et al. (2015), Yêhouénou-Tessi et al. (2012) and Kingbo et al. (2021) were based on the structural characteristics to relate ecological factors and the productivity of the forest or the different plant communities and also to map them. These studies enables scientists to provide decision-makers with analysis and decision-making tools for harvesting to exploit forests without destroying them while reconciling economic profitability and maintaining their diversity. Through all these studies, the key parameters of structure and spatial distributions are essential to the decision-making for the sustainable management of the forests over the world.

All these parameters have not yet been well studied or updated in the forest of Dogo-Kétou. The studies carried in the forest of Dogo-Kétou addressed a diversity of important scientific aspects but overlooked structural key parameters, which are decisive in the definition, and characterization of the forest stations for the sustainable management from a silvicultural point of view. Indeed, the studies of Codjia et al. (2009), Assongba et al. (2013), Sohou et al. (2014), Tchibozo et al. (2014), Tchibozo et al. (2014), Alohou et al. (2016) have developed various aspects of the forest of Dogo-Kétou as the factors contributing to the fragmentation of the classified sacred forest, the reliable database specific to local food resources in the regions, the distribution of the structural characterization of the populations of *Dialium guineense*, the level of fragmentation and vulnerability of the classified forest of Dogo-Kétou. There is a necessity to fill the gap related to characterizing the structure and ecology of the forest of Dogo-Kétou and the use of the phytosociological approach to know the different tree communities of this natural forest.

The phytosociological approach has been used by several studies focusing on structural characterization and definition of forest stations, which are essential for the future implementation of a good sustainable management plan of the forests. The phytosociological approach is reliable for investigating vegetation because it makes it possible to identify and characterize the forest stations, which are the basic units of a sustainable management of forests (Sokpon 1995; Ganglo 1999; Djègo 2006; Aoudji and Ganglo 2006; Aoudji et al. 2006; Tohngodo et al. 2006; Awokou et al. 2009).

To fill all this gap in the forest of Dogo-Kétou, the present study focused on the "Analysis of tree communities in a seasonally dry forest for guiding forest management decision in South Benin, West Africa". The main research questions that guided this research were as follow: what are the current tree communities in the forest of Dogo-Ketou and what are theirs structures? How are these tree communities renewed in this forest? The answers to these questions brought more information for the sustainable management of this classified forest. This study aimed globally to contribute to the sustainable management of Benin's forest ecosystems. More specifically it aimed i) to determine the tree communities of the forest of Dogo-Kétou; (ii) to characterize the structure and ecology of these forest communities and their characteristic species; (iii) and finally, to highlight the potential sylvicultural problems of the characteristic species of the tree communities while making proposals for the sustainable management of the forest of Dogo-Kétou.

2. Materiel and Methods

2.1. Study area

The classified forest of Dogo-Kétou, presented by Figure 1 below, is a large forest block formed by two large sectors. The sector of Kétou, located between 7° 23' 30''and 7° 33' 02'' North latitude, 02° 23' 30" and 02° 30' 30" East longitude, while the sector of Dogo is located between 7° 30' 40'' and 7° 41' North latitude, 02° 28' 3'' and 02° 4' 31'' East longitude. It has an area of 42.850 ha. This forest is under the hydrological influence of the river "Issanhoun" in the north; to the west by the river called "Ouémé" which serves as a reservoir for water leaving the forest zone; to the east and south by the deeply plateau notched flanks of the "Terre de barre" of Kétou.

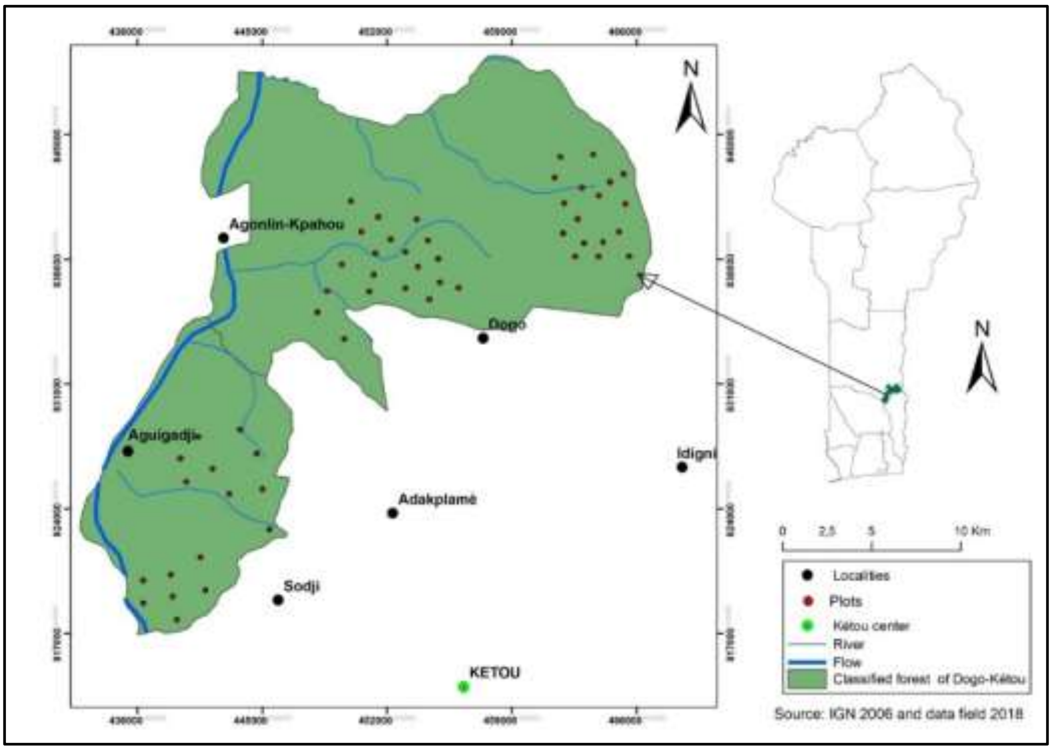

Figure 1. Location of the forest showing the data collection plots

2.2. Data collection

Fifty plots of one hectare each have been installed at a minimum distance of 50 m from the border of the nearest path to avoid border effects. The sampling plan was 200 m x 200 m square mesh, or one sampling point per four (4) hectares. This sampling area made it possible to integrate the maximum of biodiversity per plot. The plots of 100 m x 100 m were systematically established in the units of floristically homogeneous vegetation and five regeneration quadrats of 10 m x 10 m were installed in the four corners and in the center of each plot. Diameter at breast height (dbh ⩾ 10 cm) of tree individuals were measured. To understand the survival rate of young trees according to the stages of forest development, three regeneration classes were considered as defined by Feeley et al. (2007). It is about seedlings class: composed of individuals of dbh <10 mm; juvenile class: composed of individuals having: 10 mm < dbh < 50 mm, and small poles class: composed of individuals with dbh > 50 mm but < 100 mm.

2.3. Statistical analysis

2.3.1. Individualization of tree communities

The data matrix was submitted to a factorial analysis of the correspondences followed by the ascending hierarchical classification, which provided a dendrogram discriminating tree communities. The coefficient of similarity of Sörensen (1948) (Sonké 1998), made it possible to know whether two plots compared on the floristic level have a resemblance of tree communities; which makes it possible to map the space of the forest along the gradient of floristic similarity. The similarity threshold used is 50%, generally accepted (Ganglo et al. 1999; Ganglo 1999; Djègo 2006). For a K value greater than 50%, it can be concluded that there is a tree community between the two plots compared. The mathematical formula for this index is as follow:

$$\chi^2_{Obs} = n\,(b*c)2/(a + b)(c + d)(a + c)(b + d).$$

Where a is the number of species common to the two tree communities being compared, b and c are the numbers of species absent in one but present in the other. If $\chi^2_{obs} \geqslant \chi^2_{1-\alpha}$ (χ^2_{th} = 6,63, ddl = 1 at the probability threshold 0.01) we reject the hypothesis of independence of the floristically compared communities. Generally, the threshold chosen in statistics is 5 % to 1 % recommended but in the case of this study the threshold of 10% for the comparison of tree communities was retained (Sokpon 1995).

2.3.2. Identification of valuable species

The identification of valuable species was based on the determination of the Species Importance Value Index (SIVI). For Cottam and Curtis (1956), Species Importance Value Index (SIVI) was calculated for each species according to the formula:

IVIE = 100 * [(Ni/ƐN) + (Gi/ƐGi) + (Fi/ƐFi)]
With Ni = number of individuals of species i, Gi = basal area of species i, Fi = frequency of species i, RD is the dominance of each species, RF is the frequency of each species, RC being the recovery of each species. The SIVI of a species varies between 0 and 3. Species with SIVI close to 3 are ecologically important (Reitsma 1988).

2.3.3. Structural characterizations of forest, tree communities and characteristic species

2.3.3.1. Floristic indices of the forest and tree communities

The following floristic parameters were calculated for each plot before the average were found by tree community or for the whole forest:

- the specific richness (S).
- the Shannon Index (Shannon and Weaver 1963):

$H = -\sum_{i=1}^{s} \frac{ni}{n} \log_2 \frac{ni}{n}$ with ni = number of individuals of the species i; n = total number of trees inventoried in the plot.

- Equitability of Pielou: $Eq = \frac{H}{Hmax}$ with Hmax = $\log_2 s$ with Hmax is the Shannon theoretical maximum diversity index related to the stand; S is the specific richness.

2.3.3.2. Dendrometric parameters of the forest, tree Communities and characteristic species

- The density of each plot, community and for the forest was calculated with the formula $N = \frac{n}{s}$ where n is the total number of trees per 1 ha plot; s = area of the plot which is equivalent to 1 ha.
- The quadratic mean diameter (Dg) per plot, community and for the forest was calculated.

$Dg_p = \sqrt{\frac{1}{n}\sum_{i=1}^{n} di^2}$; with n the number of trees with dbh ≥ 10 cm inside the plot and di is the diameter in cm of tree i.

- The basal area (G, in m^2 / ha) at the reference level (1.3 m from the ground) was calculated for each plot, community and for the forest: $G = \frac{\pi \sum_{i=1}^{n} di^2}{4s} 10^{-4}$; di is the diameter (in m) of each tree i of the plot.

The analysis of the diversity of tree communities was done using the Shannon-Wienner diversity index (H) and Piélou equitability (E).

2.3.3.3. Diameter structures

The distributions of the diameter classes were carried out with an amplitude of 5 cm in the diameter classes.

2.3.3.4. Characterization of regeneration

The regeneration density of each quadrat and plots is calculated as follows:

$$N_r = \frac{1}{3}\sum_{i=1}^{3} d_{ri} \quad \text{with} \quad d_{ri} = \frac{n_i}{s_q}$$

Nr is the average regeneration density per plot expressed in plants per hectare. *dri* being the regeneration density in each of the five quadrats of each 100 m² plot i of the 1ha plot considered, nor the number of regenerations counted in each quadrat i, and sq the area of the quadrat in ha (sq = 0.01 ha).

2.3.4. Comparison of means

The tree communities were compared to the structural parameters calculated with the variance analysis test carried out in the software $R_{i386\ 3.5.1}$, when the parameters present normal data. In the case of parameters not following a normal distribution, the nonparametric Kruskal-Wallis test was performed. In all cases, when the probability associated with the test is less than 0.05, there is a significant difference between the two tree communities in comparison at the threshold of 5 %. For the relationship between tree communities and soil textures, we have probed the depth of the ground at three levels 10 cm, 20 cm and 30 cm, using holes with 0.5 m wide to 1 m long and 0.5 m depth to facilitate the identification of the type of soil at these three depths.

3. Results

3.1. Floristic diversity of the forest

The forest of Dogo-Kétou is not very diversified with a specific richness of the forest of 34 species of trees and revealed a difference going to 2 species from one plot to another. The calculated average Shannon index is 3.25 and confirms that the forest is poorly diversified but the species show a strong equitability between their different numbers because the Piélou Equitability hovers around 0.88, which indicates that the differences between the numbers of species are small.

3.2. Structural characteristic of the forest

The average density over the entire forest is 24 trees / ha with a variation of 0.24 which can reach 6 trees when leaving one plot for another. The trees are very small with a quadratic mean diameter of 22 cm. The calculated average basal area is very low per hectare, ie 1.01 m² / ha. These two size parameters indicate that the forest is full of very few trees of large diameters to the detriment of small trees, which are more numerous.

3.3. Identification and characterization of tree communities

The results of the factorial analysis of the correspondences and of the hierarchical classification carried out on the inventory made in the forest of Dogo-Kétou show three tree communities of plots according to their similarities (Figure 2). This analyze used more than 19 % of the information taken into account, to explain more than 50 % of the information contained in the contingency table of plots and tree species with their numbers subjected to this analysis.

The plots of tree communities are presented by management units in Table 3. The tree communities obtained are distributed according to the ecological conditions present in the inventoried Management Units.

Tree community 1 is made up of 9 plots, 4 of which are in the Management Unit (MU) of Efffêoutè, 2 in Dogo, 2 in Sodji and 1 in Adakplamè.

Tree community 2 is made up of 13 plots distributed among the Management Units, including 7 in Dogo, 3 in Adakplamè, 2 in Efffêoutè and 1 in Sodji.

Tree community 3 is made up of 28 plots installed in Efèoutè (4) and Adakplamè (8), Dogo (15) and Sodji (1).

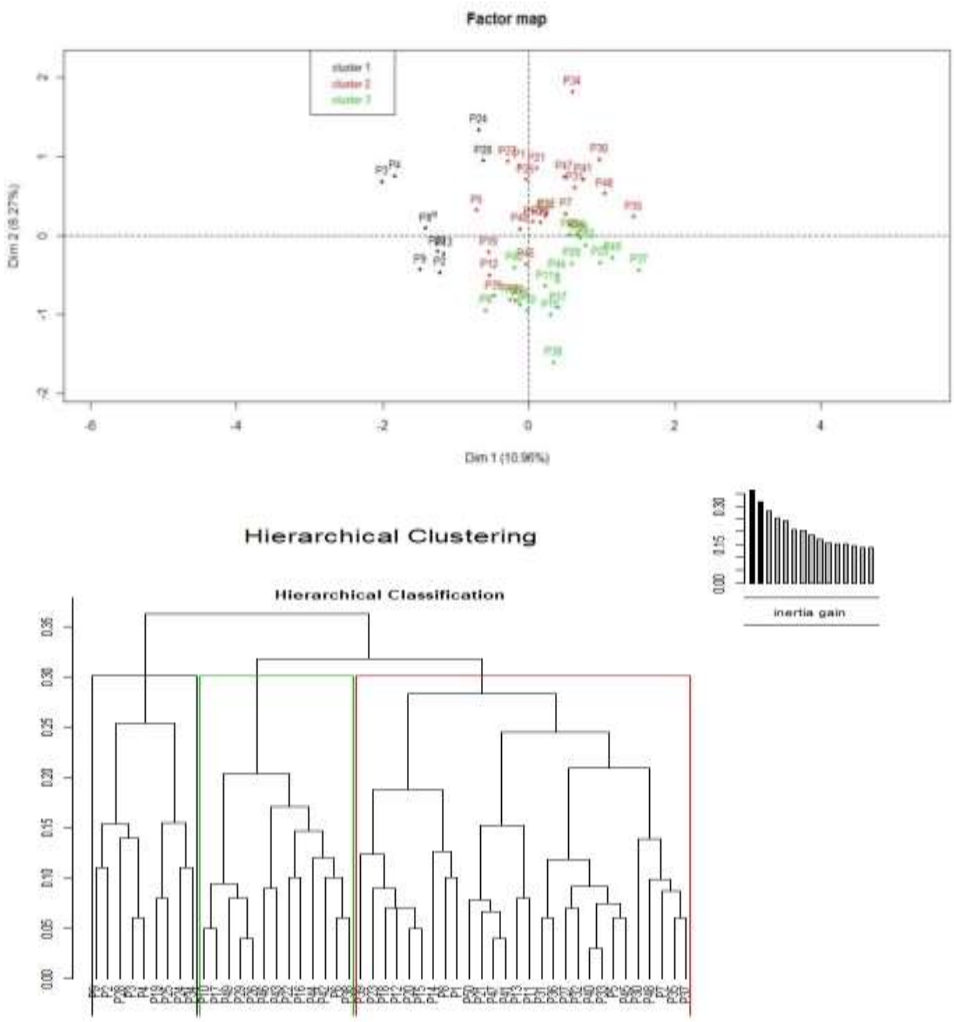

Figure 1. Factorial map and ascending hierarchical classification of tree communities.

The result of the values of the coefficient of similarity or the Sorensen index at the threshold of 50 % similarity, calculated between the tree communities showed that beyond 50%, the communities C1-C2; C1-C3; C2-C1; C2-C3; C3-C1; C3-C2 have been shown to have a certain community of tree species. This coefficient shows a certain overall similarity between the identified tree communities, but this overall similarity is not sufficient to homogenize the identified communities.

The test of χ^2 allowed to reveal the independence or not between the communities identified and the results. These probabilities were obtained on the basis of the 2 x 2 contingency table carried out between the tree communities two by two and their comparison with χ^2_{th} with 1 degree of freedom at the threshold of 0.1 whose value obtained is 6.63. The probabilities of χ^2 obtained being all is less than χ^2_{th} = 6.63 at 1 degree of freedom at the threshold of 0.1 show that the tree communities are independent of each other and can then constitute ecologically different units that can define the facies of the vegetation of trees in the forest of Dogo-Kétou.

χ^2(C1-C2)=2,940; χ^2(C1-C3)= 0,188 and χ^2(C2-C3)= 1,645

This means that the 3 tree communities or the subforests dominated by characteristic species are valid.

3.4. Choice of characteristic species of the communities

The choice of characteristic species of each tree community was based on the importance of the contribution of each species on the axes of the main components that define the communities and on the calculation of the value indices of ecological importance of each species. The analysis of this index reveals that community 1 comprises the plots dominated by the species *Pterocarpus erinaceus*, *Lannea barteri* and *Daniellia oliveri*; tree community 2 groups together the plots dominated by the species *Pterocarpus erinaceus*, *Pseudocedrela kotschyi*, *Anogeissus leiocarpa*; tree community 3 is dominated by species *Anogeissus leiocarpa*, *Daniellia oliveri*, *Vitellaria paradoxa*. These species characterize each of the three identified communities.

3.5. Structural and ecological characteristics of forest tree communities

3.5.1. Floristic parameters of communities

Table 1 presents the mean values of the floristic parameters of diversity calculated for each of the tree communities of the classified forest of Dogo-Kétou. Analysis of the table shows that the Shannon-Wiener diversity index (H) values obtained for communities are between 3 and 4.5 reflecting a relatively diverse communities. The values of the Equitability of Pielou Index (Eq) for these same communities are between 0.7 and 9, reflecting a high equitability between individuals within each community, which means that all species are well represented within the communities. The highest specific richness is observed in community 3 and the lowest is observed in community 2.

Table 1. Mean values of the floristic parameters of diversity

Communities	S	H	Eq
C1	34	4,07	0,80
C2	33	4,33	0,86
C3	37	4,12	0,79

3.5.2. Dendrometric parameters of species characteristic of tree communities

Table 2 presents the mean values of the dendrometric parameters of the tree communities and for their characteristic species. The dendrometric parameters of the tree communities in the forest, the parameters of density and basal area (N, G) of the communities do not show significant difference. The three communities are similar from the two dendrometric parameters. On the other hand for the quadratic mean diameter, the three communities present significant difference. Indeed the big trees are found in community 1 dominated by *Pterocarpus erinaceus*, *Lannea barteri* and *Daniellia oliveri*, which is observed on the basal area of this community which is the highest, despite its smaller density compared to the other communities. The average density of the communities is between 23 and 26 trees / ha. The basal area is between 0.9 m² / ha and 1.30 m² / ha, while the quadratic mean diameter is between 57 cm and 85 cm. The small sizes noted at the species level are reflected at the level of the tree communities, the Management Units and the forest.

For each of the characteristic species, the dendrometric parameters vary considerably from one group to another. The densities of these species vary between 2 and 6 trees / ha, which is relatively very low for characterizing the tree communities of the natural forest. The highest density value was found for *Pterocarpus erinaceus* in the first tree community that it characterizes with an average of 6 trees per hectare. The lowest density was recorded in community 2 with *Pseudocedrela kotschyi*. The average basal areas are generally low for each of the characteristic species. The trees with the highest basal area were recorded especially with the species *Anogeissus leiocarpa* and *Daniellia oliveri* in tree community 3 (0.26 m² / ha) which also characterize it. This community then presents more trees of these species than the other two communities. The quadratic mean diameter is obtained for *Daniellia oliveri* in communities 1 and 3 (23-24 cm). The low averages obtained for each characteristic species testify to the low density of the forest of Dogo-Kétou, which has more the aspect of a forest in reconstitution with the dominance of individuals of small diameter. *Vitellaria paradoxa* is a characteristic species in a subhumid zone in the southeast Benin whereas it is a tree of the dry and sub-dry zones. This testifies to an evolution of the ecological characteristics of the zone towards those of the sub-dry zones much more favorable to this kind of species that is more spread in the center and the north of the country covering the departments of Collines, Atacora, Donga, Borgou and Alibori.

Table 2. Dendrometric parameters of species of group values

Dendrometric parameters	N	δ	CV	g	δ	CV	Dg	δ	CV
C1	26,89		0,21	1,30		0,25	0,25		0,07
C2	25,46		0,28	0,91		0,60	0,20		0,21
C2	23,78		0,22	0,96		0,45	0,22		0,20
Shapiro Wilk	0,46			0,18			0.27		
ANOVA	0,37			0,11			0,04		
Welch	0.37			0,04			0,002		
Community 1									
Pterocarpus erinaceus	6,14	4,10	0,67	0,16	0,15	0,92	0,19	0,06	0,34
Daniellia oliveri	2,14	1,07	0,50	0,14	0,18	1,35	0,24	0,11	0,46
Lannea barteri	2,57	2,51	0,97	0,10	0,13	1,31	0,22	0,08	0,35
Community 2									

Pterocarpus erinaceus	3,09	2,51	0,81	0,09	0,09	1,01	0,19	0,07	0,37
Anogeissus leiocarpa	3,60	2,67	0,74	0,18	0,28	1,56	0,20	0,08	0,41
Pseudocedrela kotschyi	2,27	1,35	0,59	0,09	0,13	1,42	0,21	0,13	0,60
Community 3									
Anogeissus leiocarpa	5,48	3,42	0,62	0,26	0,36	1,38	0,20	0,10	0,47
Daniellia oliveri	4,74	3,33	0,70	0,26	0,32	1,23	0,23	0,09	0,41
Vitellaria paradoxa	3,00	1,84	0,61	0,11	0,24	2,13	0,18	0,09	0,48

NB : N = density per hectare; δ = standard deviation; CV = coefficient of variation; G = basal area in m² / ha, Dg = quadratic diameter in meters; ANOVA=variance analysis

3.5.3. Diameter structures of tree communities and their characteristic species

Figure 3 shows the diameter structure of the tree communities and for their characteristic species. It emerges from the analysis of the diameter structures of the tree communities that they globally present an appearance of a negative exponential structure with a dominance of individuals of small diameters. However, we note the low numbers at the level of the diameter classes [15-20 [and [20-25 [, which will have an impact on the evolution towards the upper classes. Individuals with a diameter greater than 45 cm have become very rare in the forest of Dogo-Kétou, which reflects a problem of overexploitation of mature trees of forest species, which already seems interesting for forest operators who do not hesitate to cut them. For the diameter structures of the characteristic species of the tree communities identified in the forest of Dogo-Kétou, each population of the species presents a various shape of diameter structures. Species as *Pterocarpus erinaceus* (C1 and C2), *Daniellia oliveri* (C1), *Pseudocedrela kotschyi* (C2), *Anogeissus leiocarpa* (C3), *Vitellaria paradoxa* (C3) exhibit a decreasing exponential structure with a dominance of small-diameter trees guaranteeing a good future if all the environmental conditions are favorable without human intervention. However, the lack of mature trees with big diameter beyond 30 or even 35 cm is also noted. Trees with diameter more than 60 cm are totally absent in the forest, which indicates a problem of overexploitation of mature tree.

However, the species *Lannea barteri* (C1), *Anogeissus leiocarpa* (C2) and *Daniellia oliveri* (C3) present a bell structure compared to that of the normal law or of the Gaussian curve marked by the dominance of trees with intermediate diameters. The effective of the young trees of the first classes are weak, indicating poor recruitment of these species. This weak recruitment of trees could be explained by human actions including overgrazing or vegetation fires to which this forest is prone.

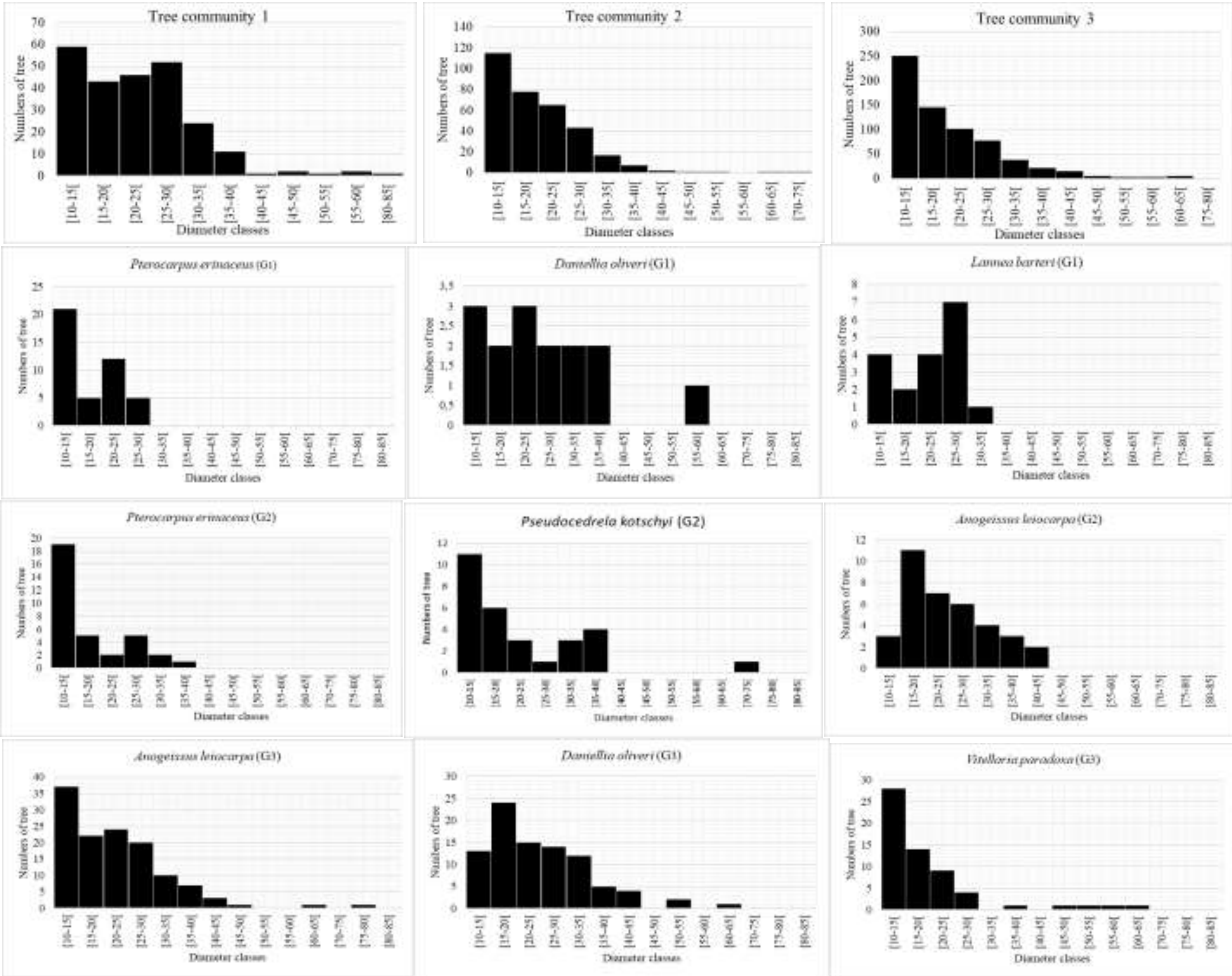

Figure 2. Diameter structures of the tree communities' and their characteristic species identified in Dogo-Kétou forest

3.5.4. Regeneration within tree communities

For the regeneration densities of the tree communities at the level of juveniles (10 < dbh < 50 mm) and the overall density of regenerations recorded (dbh < 10 cm), there is not a significant difference (P ⩾ 0.05) between the three communities presented in Table 3. In the class of young perch, there is a significant difference (P < 0.05) and community 1 is the one with the highest density. The densities are reduced with almost 40 % between the classes, which could be explained by the mortalities for various reasons.

Table 3. Densities of regeneration of the communities

Parameters	Class 2/juveniles		Class/young perch		Forest/overall regeneration	
	Mean	CV	Moy.	CV	Moy.	CV
C1	277,59	0,28	171,09	0,30	448,68	0,18
C2	255,75	0,36	111,74	0,22	367,49	0,28
C3	236,22	0,61	143,94	0,32	380,16	0,18
Shapiro test	0,009	-	0.5443	-	0.2455	-
Probabilities	0.33(A)	-	0.008 (A)	-	0.337 (A)	

NB: Class 2 or juveniles: 10 mm ⩽ dbh <50 mm; Class 3 or young poles: 50 mm⩽ dbh <100 mm; CV: Coefficient of variation; Class 1 : regenerations of seedlings are not presented because they have not been well identified in the inventoried quadrats.

3.5.5. Relationship between tree communities and soil textures

The textural characteristics of the soils of the different tree communities analyzed in the classified forest of Dogo-Kétou shows that the first two tree communities are characterized by the biotopes whose soils have a sandy appearance, stony in the surface layer (10 to 20 cm deep). Their soils contain a little deeper to 30 cm of clay and/or limestone. The third tree community is characterized by biotopes whose soils are generally hydromorphic. In some places, the community 3 has developed on soils rich in humus at the surface with a pronounced presence of clay in depth and the plant formations that develop there are a little more closed (dense forest or gallery forest).

4. Discussion

4.1. Determinism of tree communities

The study of tree communities is a fundamental source of basic data, so important for the conservation and sustainable management of natural ecosystems despite the fact that in some cases, the ecological interpretation of the communities identified may appear difficult (Bangirinama et al. 2010). Rainfall, hydromorphy, soil types, relief, drainage, vegetation structure and the degree of anthropization or disturbance of the forest are all determining factors explaining variations in the floristic composition and dendrometric parameters in the natural formations. Djègo (2006) and Djodjouwin (2011) worked in the regions with high rainfall such as southeast Benin and maintained that the distribution of plant communities is determined by the type of soil and on the same type of soil, plant communities may be different. For Djodjouwin (2011), the vertisols present in the forest of Lama (Benin) influence the difference observed in the values of the dendrometric parameters of enrichment plantations. Sokpon et al. (2006) showed that in the Sudanese region, rainfall and plant composition are important factors in the productivity of open forests in Benin. This really shows to what extent the factors influencing the establishment of the plant communities also influence the productivity of the forests.

The relief in the municipality of Dogo-Kétou is a low-altitude "bar land" erosion plateau (between 100 to 200 m) with more or less pronounced depressions (Tchibozo 2014). Two types of soil are found in this complex of forests (PAPF 2010). These are the soils on loose clay-sandy sediment of the continental terminal, the clay content of which increases with depth. The water retention capacity is low and the drainage perfect. The organic matter content can reach 5% under forest and less than 1 % under intensive crops. Tropical ferruginous soils are the second type of soil and occupy a small area. These soils are more or less concreted and shallower than ferralitic soils but have shallow horizons and usually have a sandy or sandy-clay texture with a clear predominance of kaolinite in the clay fraction of these soils. Very suitable for traditional food crops. The area is well watered because of the climate of southeastern Benin.

On the basis of the individualization of tree communities, the forest ecosystem of Dogo-Kétou presents a varied floristic physiognomy from the point of view of the main species that make up the tree communities in place even if from a pedological view there is only one little variation in soil type ranging from sandy to ferruginous in the surface horizons. Shaumba et al. (2017) also showed that the organization of tree communities in the dense forests of Uma in the Democratic Republic of Congo was linked to determining factors.

The communities of « *Pterocarpus erinaceus, Daniellia oliveri* and *Lannea barteri* », « *Pterocarpus erinaceus, Pseudocedrela kotschyi and Anogeissus leiocarpa* » and « *Anogeissus leiocarpa*, *Daniellia oliveri* and *Vitellaria paradoxa* » have been identified in open environments, dominated by savannas, which occupy a large part of the forest and all types of soils in presence.

This savannah occupies a large part of the forest and all types of soils present despite the fact that this forest is geographically located in a well-watered subequatorial zone characterized by the presence of dense forests. Indeed, according to Adomou (2005), the region of Dogo-Kétou is located in the Guinea-Congolese region and this region enjoys a humid tropical climate with four seasons. Sokpon (1995) presented South-East Benin as part of a region with particular climatic characteristics in the Dahomey-gap, with an annual average rainfall exceeding 1200 mm / year. This is why we meet in places dense forest, pockets of communities of trees dominated by species such as *Anogeissus leiocarpa*, *Pterocarpus erinaceus*, *Daniellia oliveri*, etc. belonging more to closed environments with an abundance of water as characterized by Sokpon et al. (2006).

4.2. Structural characteristics and sustainable management of the forest

The forest of Dogo-Kétou study made it possible to differentiate three tree communities, each characterized by the species "*Pterocarpus erinaceus*, *Daniellia oliveri* and *Lannea barteri*" at the level of the community 1, "*Pterocarpus erinaceus*, *Pseudocedrela kotschyi* and *Anogeissus leiocarpa*" at the level of community 2 and "*Anogeissus leiocarpa*, *Daniellia oliveri* and *Vitellaria paradoxa*" at the level of community 3. The comparison results between the tree communities showed that they have not a significant difference in overall from the point of view of the dendrometric parameters. Indeed the specific richness during this study is between 32 and 34 species within the communities and this richness varies between 10 and 11 species per hectare, with a dominance of five species in general including *Pterocarpus erinaceus, Daniellia oliveri, Anogeissus leiocarpa*, *Pseudocedrela kotschyi* and *Vitellaria paradoxa*. The Shannon index varies between 2.98 and 3.16 bits and the index of Equitability of Piélou is between 0.87 and 0.90. These values indicated a low diversity of trees in the forest of Dogo-Kétou but a high equitability between the individuals of the species. The values obtained for these indices are lower than those obtained by Adjakpa et al. (2011) in the forest of Sakété. The dendrometric parameters (average density, basal area and average diameter) of the tree communities are differentially appreciable. The communities identified appear to be globally identical from the point of view of dendrometric parameters. The average density varies between 23 and 26 trees/ha and the basal area between 0.91 m² / ha and 1.30 m² / ha. These values are much lower than those found by Sokpon et al. (2006) in the open forests of northern Benin where the average density was 279 trees / ha with a basal area around 14.1 m² / ha and those of Hounkpevi et al. (2011) who obtained an average density of 229 trees/ha with a basal area of 13.79 m² / ha. These parameters are even lower than those of Kingbo et al. (2021) who obtained in the forest of Pobè, 60 km away, an average density of 157 trees / ha and a basal area of 28.01 m² / ha.

These low values of density and basal area are explained on the one hand, by the state of regeneration of the forest that is dominated by small-diameter individuals (photo 1 and 2) and on the other hand, by the effects of increasingly human actions more frequent characterized by logging, carbonization and farming.

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Photo 1. Young trees of *Anogeissus leiocarpa* from community 3 in Adakplamè.
Source: Field work in the forest of Dogo-Kétou, 2018

Photo 2. Young stands of *Pterocarpus erinaceus* from community 1 in Dogo.
Source: Field work in the forest of Dogo-Kétou, 2018.

This results allowed to conclude that the forest of Dogo-Kétou is sufficiently degraded as indicated by Photo 3 than the forest of Itchèdè described by Awokou et al. (2009), the forests of Bonou and Itchèdè (Kakpo 2012), the forest of Lama (Gbêtoho et al. 2016) and the forest of Pobè (Kingbo et al. 2021).

Photo 3. Degraded area of a camp of Fulani herders in the development unit of d'Effè-outè.
Source: Field work in the forest of Dogo-Kétou, 2018.

In Burkina Faso, a Sahelian country, Sanon *et al*. (2015) obtained very high values in the islands of secondary forests in the southwest. For Hitimana *et al*. (2004) the ecology or history of the forests may explain the differences with the literature data.

Although the diameter structures present the communities whose future is assured by the presence of individuals of young diameters, these stands face a difficulty. The recruitment deficit was noted in the first diameter class [10; 20 cm[for species such as

Lannea barteri (C1), *Anogeissus leiocarpa* (C2) and *Daniellia oliveri* (C3); this is justified by the lack of mature seed individuals who can provide sufficient regeneration seeds in the forest. This confirms that the floristic composition and the structure of the tree communities of the forest of Dogo-Kétou reveal problems of regeneration of the characteristic species of the communities. These results are in line with the work of Enonzan (2010) and Tchibozo (2014) who noted a change in the occupation classes of the forest of Dogo-Kétou due to agricultural activities. Faced with this lack of seed potential, it is urgent that a search for seeds of species with high growth potential in the environment of the forest of Dogo-Kétou have to be carried out in order to produce these forest species in the nursery for the enrichment of this Forest. A development program could be based on the issue of renewing the forest of Dogo-Kétou with particular emphasis on characteristic species, taking into account aspects of raising awareness among neighboring populations on the conservation of forests and the production of these species in nursery. The species *Pterocarpus erinaceus*, *Daniellia oliveri*, *Anogeissus leiocarpa*, *Lannea barteri*, and *Vitellaria paradoxa* find an ecological optimum in the forest of Dogo-Kétou which allowed them to reach densities which made it possible to identify them as characteristic species of the different communities. The characterization of tree communities as carried out in the present study would not be sufficient to conserve the communities identified by their characteristic species. There is a need for modeling studies of the ecological niches of the characteristic species of the communities to bring more information's for the conservation of each tree community identified in this study. This, in order to influence the national policies in the conservation strategies of forest species and especially for production and the planting of native forest species such as those identified in this study.

5. Conclusion

This study was carried out in a natural forest exposed to anthropogenic disturbances. It documented the diversity of the tree communities of this ecosystem. Floristic parameters indicated moderate diversity for both large trees and regenerations. The characterization of tree communities as performed in this study would not be sufficient to conserve the communities present through the communities defined by their characteristic species. The identification of other probable habitats in the same environment or in other favorable zones of Benin or in West Africa, where the species of these communities could be introduced or reproduced naturally constitutes a challenge to be taken up by forthcoming studies. The determination of the ecological niche of the tree communities will bring a plus for the conservation of the characteristic species highlighted in this study and will make it possible to influence the national policies of in situ or ex situ conservation strategies of these forest species. The dendrometric parameters within the forest show a significant difference for the density but on the other hand no significant difference for the basal area and the quadratic diameter at the threshold of 5%. It appears that there is no significant difference between the tree communities, in terms of regeneration density. This showed that this forest is undergoing a full regeneration despite the various constraints it is facing. The diameter structures of the characteristic species of the communities showed that the forest is young and presents deficits in certain classes of larger diameters of certain species. Given the structure of tree species, it is essential and urgent to strengthen protection measures and management of the classified forest of Dogo-Kétou against illegal logging, poaching and vegetation fires. It is also urgent to find a new strategic plan for species conservation and resource management in order to guarantee better restoration of dense formations worthy of subhumid environments.

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