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Journal of Ecology and Natural Resources
ISSN: 2578-4994

Structural Characteristics of Niaouli Forests, Biodiversity, and Ethnobotanical Importance of the Valuable Species

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Research Article
Volume 7 Issue 4
Received Date: October 23, 2023
Published Date: November 24, 2023
DOI: 10.23880/jenr-16000357

Abstract

In Benin, forest resources are limited and are in the grip of alarming degradation. In southern Benin, the Niaouli forests (6°40’ to 6°45’ North Lat. and 2°05’ to 2°10’ East Long.) require special attention given their state of degradation leading to loss of biodiversity. In order to contribute to the sustainable management of the forests, our investigations focused on the characterization of the structure, floristic diversity, and forms of use of the valuable species. The data was collected by systematic sampling with rectangular meshes of 100 m × 200 m in square plots of one (01) ha each. In total, seven (07) plots were installed for the determination of dendrometric and biodiversity parameters. The regeneration of the species was counted in quadrats of 100 m^2 installed on a diagonal of each plot. Ethnobotanical surveys were carried out within local populations, on a sample of 188 people made of heads of peasant households or their representatives, carpenters, traditional healers, and loggers in order to identify valuable species and appraise their ethnobotanical importance. Four valuable species were identified. They were *Albizia zygia*, *Antiaris toxicaria*, *Ceiba pentandra*, and *Newbouldia laevis*. The diversity parameters showed that the forests of Niaouli are characterized by a low floristic diversity in comparison with the forest ecosystems of southern Benin. The main valuable species of the Niaouli forests were experiencing a regeneration problem likely to hinder their sustainability and sustainable use. *Albizia zygia*, *Antiaris toxicaria*, and *Ceiba pentandra* are used more in the form of wood respectively by 85 %, 50 %, and 75 % of respondents. *Newbouldia laevis* is used more in the form of an infusion by 33 %, fodder by 21 %, and wood by 21 % of respondents. Respondents cited 58 diseases treated with species from the Niaouli forests. Considering the results obtained, regular reforestation and the introduction of new adapted species must be carried out to increase the biodiversity and ecosystem services of the forests.

Keywords: Forest Ecosystem; Structural Characteristic; Biodiversity; Valuable Species; Niaouli; Benin; West Africa

Introduction

Forests ecosystems are extremely rich in plant and animal species that are sometimes little or badly known [1,2]. This species richness which characterizes especially some countries represents a fundamental basis for their development. On a global scale, forests currently cover an area of 4.06 billion ha corresponding to 31 % of the surface of the emerged land [3]. They play an essential role, thanks to the many ecosystem services they provide such as the production of wood and non-timber forest products (NTFPs), conservation of biodiversity, carbon storage, mitigation of the effects of climate change, water and soil protection, cultural and religious services [4-8].

In Benin, forests resources are limited. According to FAO [3], the forests of Benin cover an area of 3,135,000 ha. Those skinny forest resources are in the grip of alarming degradation [7,9-11] and subject to strong anthropogenic pressures, then disappearing at the rate of 50,000 ha/an [3]. The Southern Benin, characterized by a subequatorial climate regime, was quite conducive to the extension of dense semi-deciduous forests Akoègninou [12] which have however suffered from severe degradation, leaving only vegetation consisting of fields and thickets in which the original massifs are reduced to fragments of forest [7]. Thereby, it must be remembered that these bits of forest are undergoing more and more ecological alteration because of the impact of biotic and abiotic factors. Among these forest relics in Benin, Niaouli forests require a particular attention taking into account the forest exploitation they suffer from humans leading therefore to a loss of biodiversity especially that of valuable species. The expression valuable species comes from the fact that some species provide forest products and then they are more used than other species which are considered as secondary species [13].

Some previous research works have been carried out in different forest ecosystems in Benin and beyond. We can cite the description of the structure and ecology of commercial timber species reported by Agbangla [13] on Niaouli forests; description of the structure of *Anogeissus leiocarpa* stands in relation to anthropogenic pressure in Wari-Maro Forest Reserve in the center of Benin [6]; the structural and ecological characteristics of plant-communities in Itchèdè forest reserve in the plateau department in south Benin [9]; the description of the structure and ecology of *Diospyros mespiliformis* and *Dialium guineense* forest in the Massi reserve (Lama forest) in south Benin [7]; the phyto ecological assessment of plant communities in the swampy forest of Agonvè and related ecosystems in south Benin [14]; the typology, structural characteristics, and dynamics of fragile *Isoberlinia* spp. woodlands to inform their management in Togo [14]; the structural and ecological characteristics of *Antiaris toxicaria* and *Ceiba pentandra* communities in south Benin forests reported by Yêhouénou Tessi [15]; the ecology and structure of *Parkia biglobosa* parks highlighted in Donga department in North West Benin by Koura [16]; the characterization of the structure and ecology of tree communities in the forest of Pobè in Southeast Benin [17], etc. From the studies reported above, we can deduce that most of the previous research works didn't focus on Niaouli forests. In order to fill the knowledge gaps on those forests, our study investigated on their structural and ecological characteristics, biodiversity, and valuable species. The research questions that guided our investigation were as follows: (1) what are the characteristics of the structure and biodiversity of the Niaouli forests? (2) What are the main valuable species of the forests studied, their forms of use by local population and the related threats? Answering those questions will surely contribute to inform decision-making on the sustainable management of Niaouli forests.

Material and Methods

Study area

The total area of Niaouli forests is 120 ha [13]. They are located in the department of Atlantic, Allada municipality, and the district of Attogon (Figure 1), between latitudes 6°40' and 6°45' North, and longitudes 2°05' and 2°10' East. With respect to the topography of the study area, one of the forests is located on plateau while the second one is in lowland. The lowland forest is crossed by a tributary of the Couffo River, which represents the main source of water supply for the local population [13]. Along this river, it can be noticed the presence of certain hygrophilous species such as *Pentaclethra macrophylla* Benth, *Cola gigantea* A. Chev. var glabrescens Brenan & Keay, *Pycnanthus angolensis* Warb, *Entandrophragma angolense* (Welw.) C. DC. In the forest of plateau, grows a dense but degraded semi-deciduous forest whose central floristic core is composed of species such as *Antiaris toxicaria*, *Celtis mildbraedii* Engl., *Ceiba pentandra*, *Triplochiton scleroxylon* K. Schum, *Sterculia tragacantha* Lindl, *Lecaniodiscus cupanioides* Planch and many others. Phytogeographically speaking, this region belongs to the Guinea-Congolese regional transition area [18]. The average annual rainfall over the period from 1950 to 2009 is 1,144 mm. The rainfall regime is bimodal, with two rainy seasons of which the main one covers March to July and the second one lasts from September to October. The average daily temperature is about 28°C. The plateau area is characterized by a ferrallitic soil as opposed to the lowland where, hydromorphic soil is dominant [13]. Niaouli forests had also served as shelter for some war fugitives, which justifies the presence of *Dracaena arborea* Link species used at time to materialize tombs or sacred places. Thus, it can be inferred that it is a secondary degraded forest by human activities.

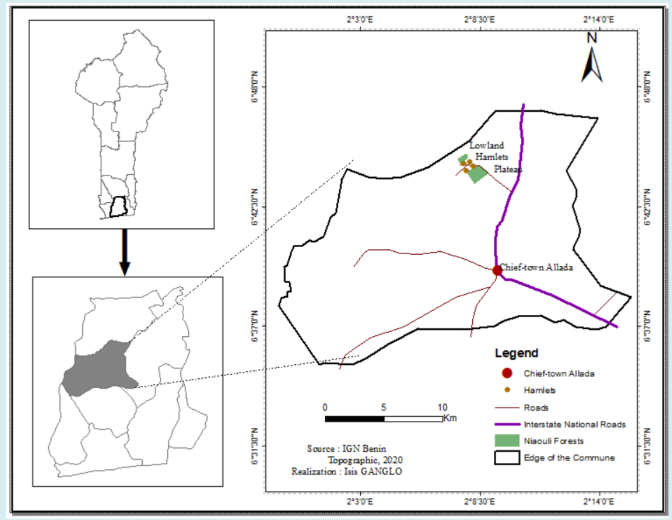

Figure 1: Geographical location of the studied forests in Benin.

Methods

Data collection

Forests inventory

A device of sample was installed and allow to collect data. The data was collected by systematic sampling with rectangular meshes of 100 m × 200 m in square plots of one (01) ha each. To avoid the border effect, each plot of 1 ha was installed at a minimum distance of 50 m from the border. In total, seven (07) plots of 1 ha were installed. The main data collected in each plot were: diameter at breast height (1.30 m) and the height of trees which are individuals of plant species with more than 10 cm of diameter at breast height [19]. They were respectively measured with π ribbons and Suunto clinometer. The Global Positioning System (GPS) was used to record the coordinates of each plot. To value the potential of regeneration in Niaouli forests especially for the valuable species, a count was made in diagonal quadrats of 100 m^2 (10 m * 10 m) installed in the 1 ha plots. Three regeneration classes were considered [15]:

- Seedling classes with circumference of C < 31.4 mm;
- Juvenile classes with circumference of 31.4 mm ≤ C < 157 mm;
- Young pole classes 157 mm ≤ C < 314 mm.

Identification of valuable species of Niaouli forests

The valuable species of a forest refers to a species that has an importance to the population taking into account the ecosystem services it provides and is thus submitted to some pressures due to its exploitation, leading to its possible disappearance from the environment. Thus, an ethnobotanical survey was carried out on surrounding populations living in nearby villages like Tanmè, Zoungoudo, Tokpa, Niaouli 1 and Lozounkpa. This allowed identifying the valuable species of Niaouli forests exploited by the populations. The most cited species and inventoried in the forests were considered as valuable species of Niaouli forests. The following formula was used Rea [20] and allowed to investigate 188 people:

$$n = \frac{t_p^2 * p(1-p) * N}{t_p^2 * p(1-p) + (N-1) * y^2}$$

n is the size of the sample; n = 188;
N is the size of the target population. N = 4506 [21];
P is the proportion of response expected from the population or real proportion. P = 0.5 [20];
tp is the quantile of the normal distribution;
y is the margin of sample error. y = 7% [20].

Data analysis

Description of the floristic diversity of Niaouli forests

The following diversity parameters were calculated for each plot and the average was computed by forest. There are:
The species richness [22];
Shannon Index [23,24]:

$$H' = -\sum_{i=1}^{s} \frac{N_i}{N} * \log_2\left(\frac{N_i}{N}\right)$$

Ni: number of individuals of the species i;
N: total number of individuals;
$\log_2$: basic logarithm 2.
Equitability of Pielou [25]

$$EQ = \frac{H'}{\log_2 S}$$

S: Total number of species
H': Shannon Index

Structural characteristic of Niaouli forests
Dendrometric parameters
The dendrometric parameters are mainly:
The basal area [19]

$$G = \sum \frac{\pi\left(\frac{d_i^2}{4}\right)}{s}$$

With d_i is the diameter at breast height level and s is the area of the plot in ha.

The density of population [19]

The density of each plot was calculated with the following formula:

$$Ni = \frac{ni}{s}$$

Where ni is the total number of trees per 1 ha plots and s the area.

The density of the forests was calculated as the mean value of the plot densities inventoried in each of them

The density of regeneration [13,17]

$$Nr = \frac{n_r}{s_q}$$

With n_r, the number of stems of the species considered in the quadrat and s_q the area of the quadrat of regeneration.

The number of regenerations by forest was calculated as the mean value of the number of regenerations in the quadrats inventoried in each of them

The quadratic mean diameter [19]

$$Dg = \sqrt{\frac{\sum_{i=1}^{n} di^2}{n}}$$

With n the number of trees with dbh ≥ 10 cm inside the plot and di is the diameter in cm of tree i.

The quadratic diameter of the forests was calculated as the mean value of the quadratic diameter of the plots inventoried in each of them

The height means of Lorey (H_L) [26]

$$H_L = \frac{\sum_{i=1}^{n} gi\, hi}{\sum_{i=1}^{n} gi}$$

With gi and hi the basal area and the total height of the tree i in each plot.

The height of the forests was calculated as the mean value of the height of the plots inventoried in each of them

The contribution to the basal area

$$Cs = 100\frac{G_p}{G}$$

With Gp the basal area of the trees of the species i and G the total basal area of the whole trees per plot.

The contribution to the basal area of a species per forest was calculated as the mean value of its contribution to the basal area per plots inventoried in each of the forest.

Diameter structure of the forests

All individuals inventoried were arranged by diameter classes of 5 cm of amplitude and then, tree densities by class of diameter were computed [18]. This allowed having histograms describing the diameter structure of the forest and their valuable species respectively.

Tests of mean comparison

Niaouli forests and their components were compared with respect to the structural and biodiversity parameters calculated, using an analysis of variance (ANOVA) and the nonparametric Kruskal-Wallis's test with the $R_{i386\_3.5.1}$ [27] software.

Forms of use of valuable species of Niaouli forests

The variables collected on the basis of ethnobotanical surveys were encoded in the Excel software to facilitate the calculation of citation frequencies. The formula considered is as follows [28]:

$$Fci = \frac{(n_i * 100)}{N}$$

With n_i the citation number of a variable i of a given parameter and N, the total number of citations of that parameter.

The parameters considered were the sex, age, ethnic group, educational level, marital status, categories of uses, organs used, forms of use, frequency of use, perceived abundance, harvesting method, selling market, species conservation strategy. Frequency histograms were performed to allow the interpretation of the results. The species, with high citation frequencies were considered as valuable species of Niaouli forests.

Index Value Importance (IVI) of the valuable species

The Index Value Importance (IVI) of the species is often used in tropical forest to describe the ecological importance of the species [29-31]. It varies form 0 (lack of dominance) to 300 (mono-dominance) [32,33].

IVI = Relative frequency + Relative density + Relative dominance for the species [2,32].

Where:

$$Relative\ frequency = \frac{Frequency\ of\ the\ species\ i}{Sum\ of\ the\ frequencies\ of\ all\ species} \times 100$$

$$Relative\ density = \frac{Total\ number\ of\ individuals\ of\ a\ species}{Total\ number\ of\ the\ individuals\ of\ all\ community\ species} \times 100$$

$$Relative\ dominance = \frac{Basal\ area\ of\ a\ species}{Total\ basal\ area} \times 100$$

Results

Structural characteristics of Niaouli forests

Dendrometric parameters

The dendrometric parameters of Niaouli forests are presented in Table 1. The variance analysis of these parameters (N, Dg, H_L, G) showed that there was no significant difference at 5 % of probability threshold between the two types of forest although the lowland forest has slightly higher dendrometric parameter values than the forest of plateau.

Forests	Density (N/ha)	Dg (cm)	H_L (m)	G (m^2/ha)
Forest of plateau	317 ± 58.48 a	26.8 ± 3.06 a	10.1 ± 1.78 a	16.53 ± 2.65 a
Lowland forest	333 ± 104.36 a	28.0 ± 2.66 a	11.1 ± 2.10 a	20.11 ± 5.94 a
P value	0.793	0.656	0.509	0.221

Table 1: Dendrometric parameters of Niaouli forests.

Diameter structure of the whole forests: The Figures 2 and 3 respectively show the diameter structures of the forest of plateau and the lowland forest. According to these figures, the diameter structures of the Niaouli forests showed an exponential negative pace where individuals of small diameters predominate. This diameter structure is characteristic of undisturbed natural forests. The diameter structure of the global forests rarely shows silvicultural problems of individual species. In order to appraise such problems to suggest management solutions, we present on Figures 4-7 the diameter structure of the valuable species identified in the forests.

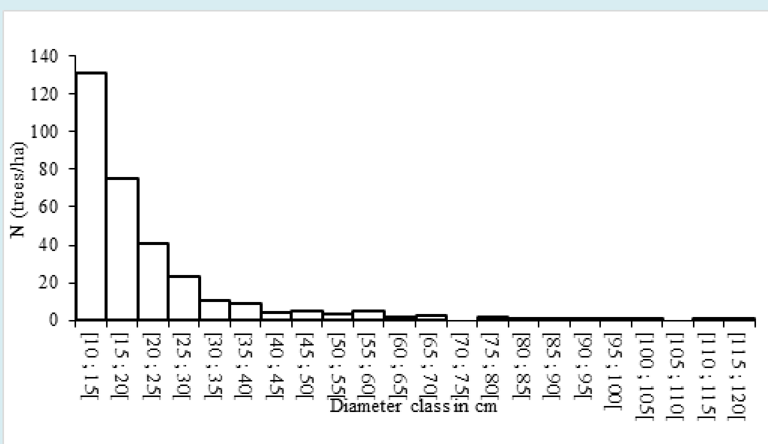

Figure 2: Diameter structure of the forest of plateau.

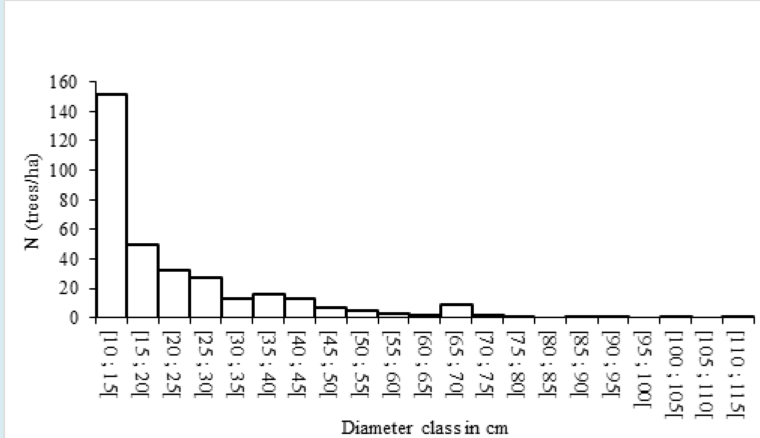

Figure 3: Diameter structure of the lowland forest.

Plant diversity of Niaouli forests

The plant biodiversity parameters of Niaouli forests are summarized in the Table 2. The analysis of variance of the species richness, Shannon index, and the equitability of Pielou of the Niaouli forests showed a significant difference at 5 % of probability threshold for the species richness and the Shannon index between the two types of forests. The lowland forest showed the highest species richness and Shannon index values compared to the forest of plateau. We deduced that; the lowland forest has higher species richness with better balance of species abundance distribution than the forest of plateau. The occurrence data we derived from the forest inventory were published on GBIF site at the following link (https://doi.org/10.15468/kvg37e)

Forests	Species richness (S)	Shannon index (H')	Equitability of Pielou (E)
Forest of plateau	12.4 ± 1.37 a	2.74 ± 0.25 a	0.54 ± 0.04 a
Lowland forest	18.5 ± 4.37 b	3.50 ± 0.45 b	0.60 ± 0.08 a
P value	0.01305	0.0054	0.158

N.B. For each parameter, the averages with the same letters are not significantly different at the 5% of probability threshold.

Table 2: Plant diversity parameters of the Niaouli forests.

Regeneration in Niaouli forests

Table 3 presents the evolution of the regeneration number across the developmental stages of the forests. It was noticed that in the forest of plateau, there was a decreasing trend of the density of regeneration following the evolutionary stages of the forest. Indeed, the seedlings were present in high number (12), the juveniles in number slightly low, and the young pole in lower number. Therefore, it is deduced that throughout the evolutionary stages of the forest, individuals of regeneration choke and die gradually. In the lowland forest however, there is a relatively stable situation across the developmental stages of the forest.

Regeneration classes/ Forests	Number of seedlings (dbh < 10 mm)	Number of juveniles (10 mm ≤ dbh < 50 mm)	Number of young poles (50 mm ≤ dbh < 100 mm)
Forest of plateau	11.6 ± 10.2 a	4.2 ± 1.7 a	2.1 ± 1 a
Lowland forest	2.4 ± 0.6 a	2.9 ± 0.6 a	3.1 ± 2.1 a
P value	0.647	0.784	0.539

Table 3: Evolution of the regeneration number across the developmental stages of the forests.

Identification and diameter structure of the valuable species of the forests

Identification of the valuable species of the forests

In total 79 plant species were used by the respondents. Among them, 44 were inventoried in the forests and therefore 35 were used by the respondents but were not inventoried in the forests. Twenty-four (24) other species were inventoried in the forests but the respondents did not mention them.

We present in Table 4, the frequency of the most cited species by respondents. We therefore deduced that, those four (04) species, are the valuable species of Niaouli forests.

According to the Index Value Importance (IVI), *Antiaris toxicaria* has the highest value of IVI (Table 4) compared to the other three species, followed by *Albizia zygia*; *Ceiba pentandra*, and *Newbouldia laevis*. All these species have an IVI value greater than 0 indicating their presence and dominance in the area.

Valuable species of Niaouli forests used by the respondents	Citation frequency (%)	Index Value Importance
Antiaris toxicaria	1.99	17.32
Albizia zygia	3.99	11.03
Ceiba pentandra	1.99	10.25
Newbouldia laevis	2.08	3.09

Table 4: Citation frequencies and Index Value Importance of the valuable species of Niaouli forests.

Diameter structure of the valuable species and lesson learnt: The diameter structures of the valuable species of Niaouli forests are presented on Figures 4-7. Analysis of the diameter structures of *Albizia zygia* and *Antiaris toxicaria* revealed the predominance of individuals of first diameter class [10,15]. It is then roughly an "inverted J" diameter distribution, which characterizes uneven aged and undisturbed stands; their sustainability is almost guaranteed by sufficient regeneration; we can infer that they are in appropriate site conditions. The diameter structure of *Ceiba pentandra* was rather irregular across diameter classes and let us infer irregular or sporadic fructification and regeneration with time; this diameter structure does not offer sufficient guarantee for the sustainability of the species in the forests; ecological conditions might not be so favorable for its long-term survival. Concerning *Newbouldia laevis,* it is represented by only one diameter class [10,15] and quite low density per ha; the species is therefore at risk of extinction and need pressing silvicultural care to increase its density through forest's enrichment and cultural follow-up operations like weeding, liana cutting, thinning of dominant species where canopy is closed etc.

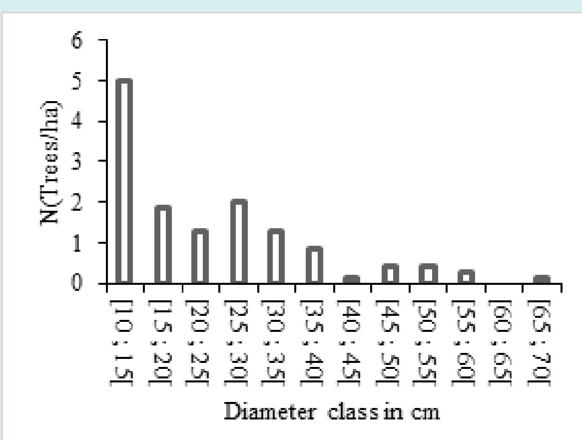

Figure 4: Diameter structure of *Albizia zygia*.

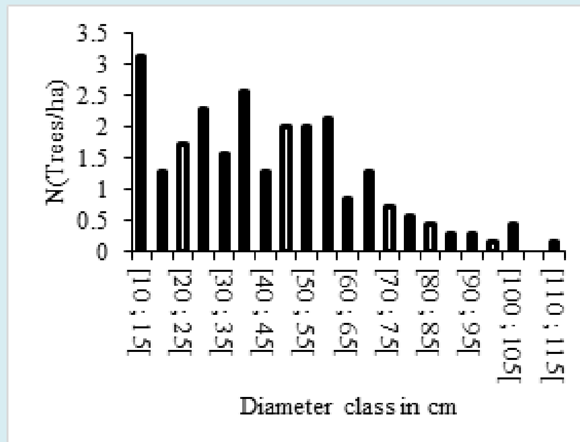

Figure 5: Diameter structure of *Antiaris toxicaria.*

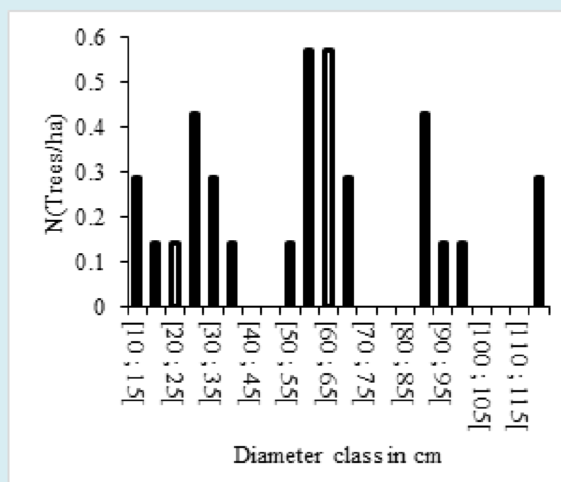

Figure 6: Diameter structure of *Ceiba pentandra.*

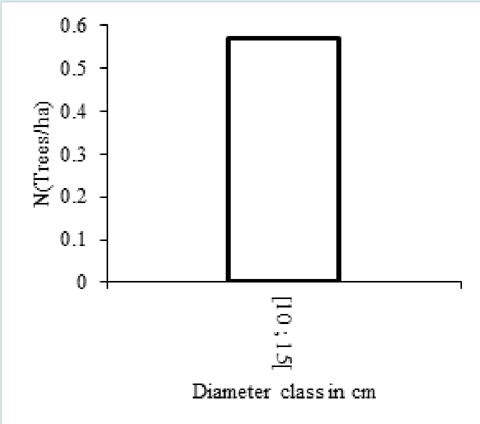

Figure 7: Diameter structure of *Newbouldia laevis.*

Use categories of plant species

The use category of a species refers to the specific objective of usage. It can be either medicinal or food. In this way, the identified valuable species are all used medically and also serve as wood (Figures 8-11). Apart from *Newbouldia laevis* the use as wood is the form of valorization for all species in comparison to other categories of uses. *Newbouldia laevis* is more used as fodder, compared to *Albizia zygia* and *Antiaris toxicaria*. *Ceiba pentandra* is the only one of the species which is not used as fodder by the respondents. For the use of wood, *Albizia zygia* comes first with 85 % of the citation frequency, followed by *Ceiba pentandra* (75 %). *Albizia zygia, Antiaris toxicaria,* and *Ceiba pentandra* are mainly used by carpenters to make tables, benches, chairs, beds etc. *Newbouldia laevis* is mainly used as energy wood.

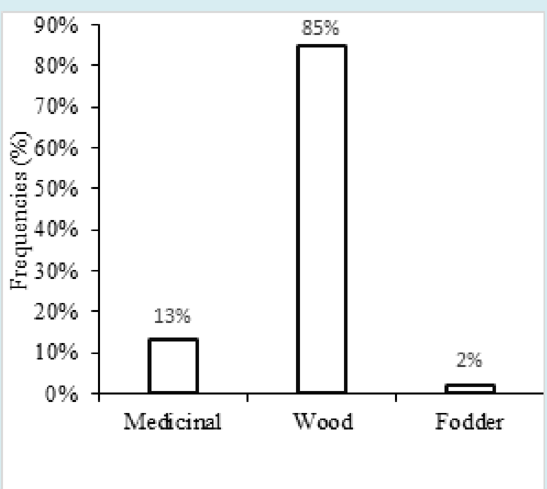

Figure 8: Use categories of *Albizia zygia.*

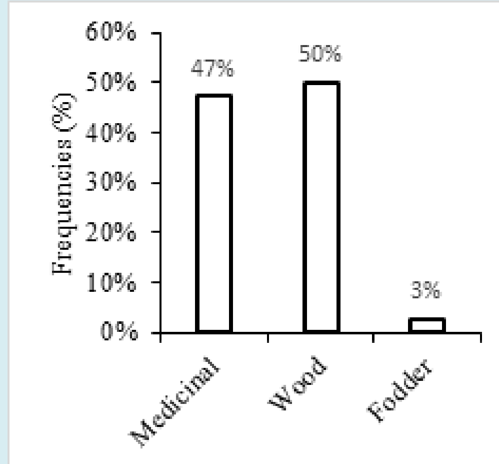

Figure 9: Use categories of *Antiaris toxicaria.*

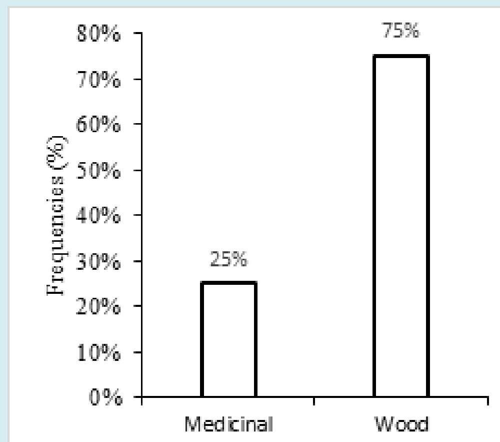

Figure 10: Use categories of *Ceiba pentandra.*

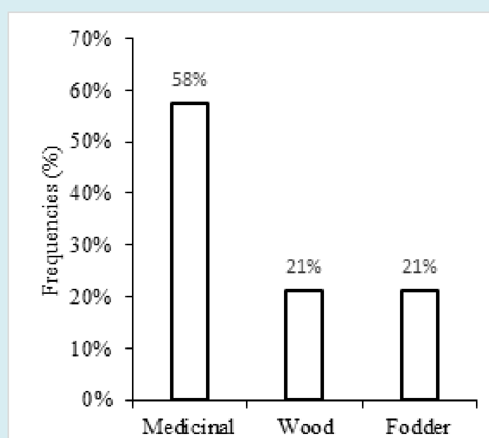

Figure 11: Use categories of *Newbouldia laevis.*

Use of valuable species in medicine

The identified valuable species of the Niaouli forests are used to treat mainly anemia, high blood pressure, wounds on the body, leprosy, diarrhea, bleeding in pregnant women, eczema, hemorrhoid, rheumatism, excessive thinness observed, ringworm, madness, envy, malaria (Table 5) and some of them have healing power *(Albizia zygia)*. All these diseases are treated with the leaves of the plants, bark, and the roots through decoction and crushing. The treatment of the bleeding is done mainly through crushing either the leaves of *Newbouldia laevis* or the leaves of *Ceiba pentandra.* By crushing, the sap of these leaves is extracted and consumed.

Treated diseases	Citation frequencies (%)	Valuable species			
		Albizia zygia	*Antiaris toxicaria*	*Ceiba pentandra*	*Newbouldia laevis*
Malaria	30.55	+	-	-	+
Bleeding in pregnant women	5.33	-	-	+	+
Anemia	5.04	-	-	-	+
Hemorrhoid	4.90	-	-	-	+
Wounds on the body	2.02	+	+	+	-
Leprosy	2.02	-	+	+	-
Eczema	1.44	-	+	-	-
Diarrhea	1.15	+	-	+	-
High blood pressure	1.01	-	-	+	+
Ringworm	0.14	+	-	-	-
Excessive thinness observed	0.14	-	-	+	-
Rheumatism	0.14	-	+	-	-

BN: (+) stands for use and (-) stands for non-use of the species.
Table 5: Use of valuable species in medicine.

Organs used and Harvesting Methods

The trunk is the most used organ for all valuable species apart from *Newbouldia laevis* for which the leaves are most used compared to the other valuable species (Figures 12-15). This species is also the only one for which the roots are exploited. The organs used are related to the medicinal services the species provides. The trunk of *Albizia zygia* has the highest frequency citation with respect to the importance of the wood use category followed by *Antiaris toxicaria* and *Ceiba pentandra.* For *Ceiba pentandra* not only the trunk is used but the branches are also exploited for wood energy.

As for the harvesting methods, the harvesting of the valuable species was essentially done by totally or partially cutting the organ to be used. One hundred percent of the respondents confirmed that for *Antiaris toxicaria*, *Ceiba pentandra,* and *Newbouldia laevis.* It is only for *Albizia zygia* that 2 % of the respondents mentioned as harvesting method, the removal of the whole plant, while 98 % use organ cutting method. However, it was noted that no matter the valuable species is, the majority of respondents found out that the harvesting methods they used were not destructive.

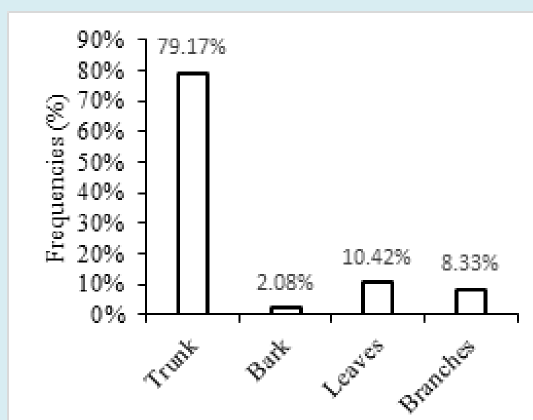

Figure 12: Organs used on *Albizia zygia.*

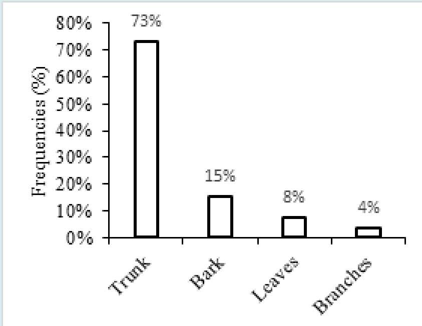

Figure 13: Organs used on *Antiaris toxicaria.*

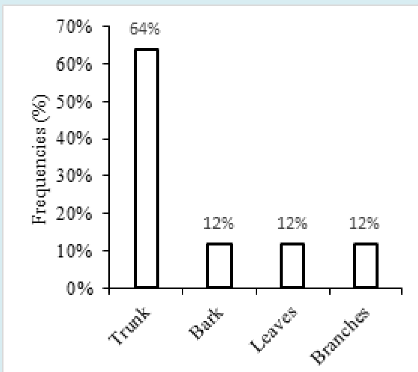

Figure 14: Organs used on *Ceiba pentandra*.

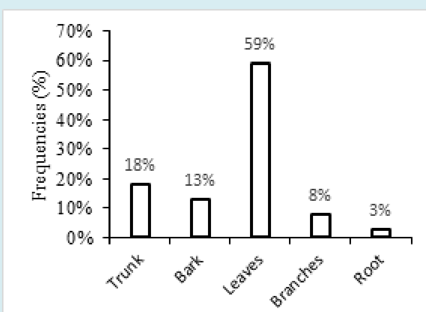

Figure 15: Organs used on *Newbouldia laevis*.

Species	Destructive method of harvesting (% of respondents)	Non-destructive method of harvesting (% of respondents)
Albizia zygia	17	83
Antiaris toxicaria	9	91
Ceiba pentandra	31	69
Newbouldia laevis	-	100

Table 6: Opinion of respondents with respect to harvesting methods of the organ of species.

We can note from the Table 6 above that most of the methods used in harvesting the organs of the species were not destructive.

Use forms of the species

The use form of a species refers to the particular transformation that an organ of the species undergoes before being used. For instance, we have use forms like infusion, decoction, crushing, etc. In this regard, *Albizia zygia, Antiaris toxicaria*, and *Newbouldia laevis* are more used in the form of infusion, according respectively to 50 %, 53 % and 58 % of the respondents (Figures 16-19). *Ceiba pentandra* is the only one that is more used in the form of decoction according to 60 % of the respondents (Figure 18).

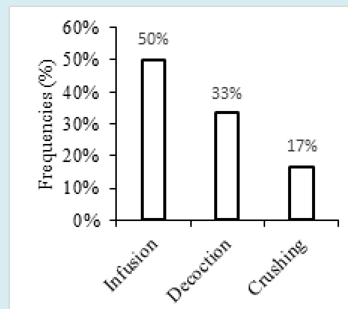

Figure 16: Use forms of *Albizia zygia*.

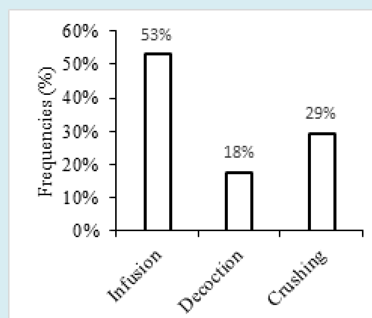

Figure 17: Use forms of *Antiaris toxicaria*.

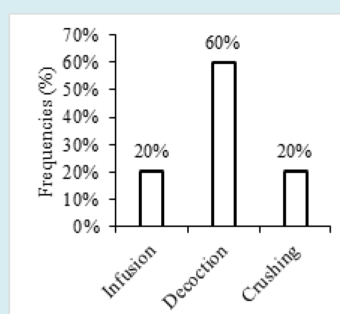

Figure 18: Use forms of *Ceiba pentandra*.

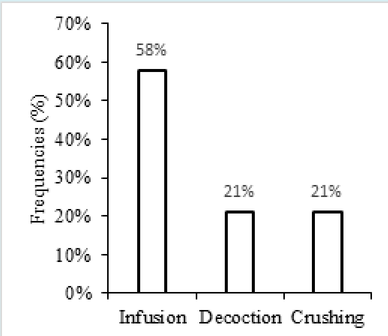

Figure 19: Use forms of *Newbouldia laevis.*

Discussion

Structural Characteristics, Plant Diversity, and Considerations on the Measures of Conservation of Niaouli Forests

The highest values of dendrometric parameters were obtained in the low land forest. This can be explained by the more favorable ecological conditions of the area, especially the humidity induced by the presence of the stream. There is then a microclimate which allows more continuous development of species and justifies the presence of species subservient to wetlands. According to Agbangla [34], the densities in Niaouli forests varied from 51 to 71 trees/ha with a basal area of 8.1 to 10.0 m^2/ha. Those results are low in comparison with those of our study where the forest' densities varied from 317 to 333 trees/ha with a basal area of 16.53 ± 2.65 to 20.11 ± 5.94 m^2/ha. The forests' densities of our study are higher than those obtained by Hounkpèvi [7] in the forest of *Diospyros mespiliformis* and *Dialium guineense* in Massi forest in Center Benin but lower than those reported by Froumsia [35] in Kalfou Forest Reserve of Cameroon despite the low rainfall noted and by De Lima [36] in a Brazilian tropical dry forest domain. The density (N/ha), the quadratic mean diameter Dg (cm) and the basal area G (m^2/ha) obtained in the forest of plateau (respectively N = 317 trees/ha; Dg = 26.8 cm; G = 16.53 m^2/ha) are also lower than those reported in the same type of forest (Itchèdè forest, South-East Benin) by Awokou [9]; indeed, the rainfall in South-East Benin is higher than what is recorded in the South Center Benin where Niaouli forests are located. Comparing to the work of Houéto [37] in Belléfoungou forest reserve located in the central west of Benin, the forest of plateau has higher dendrometric parameters. This can be explained by the rainfall patterns (bimodal in Niaouli forest versus unimodal in Belléfoungou forest in South-East Benin); furthermore, Niaouli forest grows on ferrallitic soils whereas Belléfoungou forest grows on ferruginous soils which are less favorable for deep roots soil exploration by plants. As for the plant diversity, the species richness (S) in Niaouli forests varied from 12.4 ± 1.37 to 18.5 ± 4.37 and the highest value was obtained in the low land forest. The Shannon index of the forest of plateau is (H') = 2.74 ± 0.25; this value is lower than the one found by da Silveira [38] in the Amazon basin (Brazil); indeed, although the Amazon Forest studied is degraded, Amazon forests in general remain the most diversified with respect to species richness and abundance of animals and plants. The lowland forest had a relatively high plant diversity with a mean value of Shannon index (H') = 3.50 ± 0.45 and a mean value of Equitability of Pielou (E) = 0.60 ± 0.08 implying that the site conditions were favorable for a more balanced abundance distribution than the forest of plateau. Those values are however lower than those found by Kingbo [17] in Pobè forest. The difference can be explained by the fact that, the Niaouli forests are more degraded than Pobè forest due to more care ensured to Pobè forest by its managers. A sustainable management of these forests would involve silvicultural operations aimed at reducing the density of high height trees where the canopy is closed in order to open it and facilitate the incidence of solar rays in the undergrowth to favor regeneration of species. The wood produced by these trees can be sold as a source of income for the Research Center. Also, we recommend proceeding to a regular reforestation and introduction of new species taking into account their ecology to increase the biodiversity and ecosystem services of the forests. For a sustainable management of the forests, we recommend to involve the local population in the management tasks so that they can derive some financial income and become more prone to forest protection.

Use categories, organs used, methods of harvesting, and threats to the biodiversity of the forests

The valuable species identified in Niaouli forests are *Albizia zygia*, *Antiaris toxicaria*, *Ceiba pentandra*, and *Newbouldia laevis.* Considering the valuable species list of Agbangla [33] two new species are added by our study. These are *Albizia zygia* and *Newbouldia laevis.* The forms of use of valuable species involved several organs in particular the trunk, bark, leaves, branches, and the roots. Their harvest is done by removal of the whole plant or by cutting the organ concerned. The harvesting method can therefore be destructive. It has been noted that the use of wood is the most widespread among the surrounding population. However, all species are used in medical domain and treat several diseases. Our results therefore support those reported in different studies elsewhere. Indeed, as Weniger [39] identified in Cameroon, *Albizia zygia* is used to treat malaria; in India, Elumalai [40] justified that *Ceiba pentandra* bark decoction has been used as a diuretic, aphrodisiac, and to treat headache, as well as type II diabetes; in Ivory Coast, Malan [39] identified *Albizia zygia* to treat rheumatism by applying the crushed leaves on the body, *Antiaris toxicaria* in the healing of hydrocephalus by bathing with bark decoction, *Ceiba pentandra* in the healing of diarrhea by making a decoction with the leaves or the bark and *Newbouldia laevis* in the healing of dysmenorrhea by making a decoction with the leaves and the bark; Adomou [41] identified healing anemia and hemorrhoid through the use of the barks, leaves and the roots of *Newbouldia laevis* in Southern Benin. As Adingni [42] justified through their work in the South East of Benin, the exploitation of the bark and the root in medical domain and the trunk for obtaining the wood, poses a threat to the survival and evolution of species, especially, *Albizia zygia* and *Antiaris toxicaria*. The diameter structures of the valuable species showed regeneration problem of *Ceiba pentandra* and even risk of extinction of *Newbouldia laevis*. It is important to take care in order to enrich these forests in valuable species so as to assure the survival and sustainability of the species. In Cameroon, Mapongmetsem [43] had identified *Ceiba pentandra* and *Albizia zygia* as the main local species useful for the conservation and the valorization of biodiversity in the agro-forests of the area. In Bia Tano Forest Reserve, Southern Ghana, Hammond [44-46], found that, *Antiaris toxicaria* has an important problem of regeneration when the area where it is located is disturbed, but in the absence of disturbance this species can easily regenerate. It would then be good to ensure the protection of these valuable species in Niaouli forests in order to guarantee their biodiversity.

Conclusion

This study was carried out in Niaouli forests, located in Southern Benin. The study enabled us to identity the valuable species of the forests and to characterize their structure. The dendrometric parameters were not significantly different at 5 % of probability threshold between the two forests. However, apart from the equitability of Pielou, the biodiversity parameters are significantly different at 5 % of probability level between the two forests. The results of this study led to conclude that some of the valuable species of Niaouli forests had a regeneration problem which does not guarantee their sustainability; Niaouli forests are characterized by a low floristic diversity in comparison to other forest ecosystems of Southern Benin and the use of wood of the valuable species is the most widespread among the local population. Considering the results obtained, it would be preferable to refer to silvicultural thinning aiming at decreasing the density of mature trees through opening the canopy where it is closed so that the regeneration of valuable species can be favored. The study of the structure, ecology, and the valuable species of the Niaouli forests should continue to yield results on other traits of the forests like their quantitative and qualitative dynamics to inform management decisions.

Acknowledgments

The authors tell their profound gratitude to the Global Biodiversity Information Facility (GBIF, www.gbif.org) and the European Union for their kind financial support to the research activities in the framework of the project BID-AF2020-083-USE.

Conflicts of Interest

The authors declare no conflict of interest.

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