Chapter

Phyto-Sociological Attributes, Ecosystem Services and Conservation Dynamics of Three Protected Forests in Tropical Rainforest Ecosystem of Nigeria

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Abstract

This study aimed at determining ecosystem services and conservation dynamics of three protected forests in Nigeria. Using simple sampling technique, 24 plots with 25 m^2 were established in these protected forests to facilitate data collection. A total of 370 individual trees per hectare, disproportionately distributed between 53 different species in 25 families, were encountered in Omo biosphere reserve (BR) while 381 stems in 63 species in 24 families in strict nature reserve (SNR) and Okomu national park (NP) recorded 352 individual stems, 59 species, and 25 families. The three protected forests had high tree species diversity index (Shannon-Wiener diversity index of 3.19 for Omo BR, 3.90 for Akure SNR, and 3.45 for Okomu NP). The values for basal area (36.63, 72.39, and 32.47 m^2), volume (427.08, 929.05, and 366.71 m^3), above-ground biomass (153.20, 316.73, and 353.92 ton), below-ground biomass (30.64, 63.35, and 190.04 ton), and total carbon stock (70.78, 91.92, and 212.35 ton) for Omo BR, Akure SNR, and Okomu NP, respectively. This study serves as baseline information for management of protected forests in Nigeria and it shows the potential of *in-situ* conservation for the dynamism of the ecosystem services.

Keywords: biodiversity, conservation, *Celtis zenkeri*, ecosystem services, *in-situ*, national park, protected forest

1. Introduction

Nigeria as one of the developing countries of the world has high population density and high biodiversity forest associated with tropical rainforest ecosystem. Nigeria as tropical rainforest is known for large diverse forest ecosystems with lots of *in-situ* conservation methods such as forest reserves (FR), strict nature reserves (SNR), biosphere reserves (BR), national parks (NP), and enrichment plantation (EP), they contribute to biodiversity reservoir of the world. Forest ecosystems in Nigeria are very important for biodiversity conservation, ecosystem functions, watershed protection, mitigation of climate change, economic sustainability, habitats for wild animals, and nutrition and enhancement of rural livelihoods [1]. The tropical rainforest is the most diverse of the terrestrial ecosystems, containing more flora and fauna species than any other biome, which are important source of biodiversity, food, and carbon storage [2]. Tropical rainforest has the ability to accommodate 70% of animal and plant species, which serves as a reservoir of biodiversity [1, 3]. Carbon sequestration, production of oxygen and Ozone layer protection are part of many services that the forest delivers as ecosystem services for the goods of the environment [4, 5].

Over 60% of the population residing in rural areas depend on forest and other biomass resources for fuel-wood and timber and non-timber forest products for their energy needs and livelihood. Forests are repository of the biodiversity, gene pool resources and sequester carbon dioxide, and they also provide a lot of other environmental services [1]. They play a vital role in sustaining the life of people which are crucial for food, water, forest resources and livelihood security. This is ensured through better management practices and sustainable utilization of forestlands. Forest vegetation covers protect watersheds, conserve species diversity, serve as habitat for wildlife, and contribute to good quality environment [6]. More than half of the world's species diversity can be found in the tropics according to a study by [7]. However, this critically important role of tropical forests is being threatened by deforestation. The effects of deforestation on the environment are numerous. There is overwhelming evidence and consensus that the high rate of tropical deforestation is one of the major causes of climate change [8, 9]. Deforestation contributes to climate change by reducing forest vegetation cover and increasing surface temperature. An estimated 20 to 25% of global emissions stem from deforestation, predominantly in the tropics [8]. Strategies to drastically reduce the rate of deforestation and restoration of degraded forests must be urgently developed in order to save the tropical forests and humans from the catastrophic effects of climate change. The forest is regulator of the micro and macro environment as carbon stock and carbon sequestration [5]. Furthermore, forest vegetation covers protect watersheds and species diversity, serves as biodiversity reservoir and conservation, habitat to wildlife and thus contributes to effective ecosystem functioning and good quality ecosystem. In addition, healthy forest vegetation cover plays important role in climate change mitigation by sequestering carbon dioxide from the atmosphere.

Tropical forests are predominantly located in developing countries and are often subject to activities such as logging and conversion to agriculture [10]. Nigerian rainforest ecosystems occupy 95,372 km^2 (9.7%) of the country's land mass. It is the most densely populated part of Nigeria and source of the bulk of the country's timber needs [11]. The protected forest is a specific term to denote forests with some amount of legal and constitutional protection in certain countries, besides being a generic term to denote forests where the habitat and resident species are legally accorded protection and are protected from any further depletion. Protected areas provide habitat for the country's endangered, rare and endemic plant and animal species. There are seven strict nature reserves, one biosphere reserve, 160 constituted forest reserves and six national parks in Nigeria. There are no known studies on the Phytosociological characteristics, ecosystem services and conservation dynamics of these protected forests. The method adopted by the government to promote ecosystem sustainability makes the forest play essential role in carbon sequestration and function effectively as climate change regulator. Thus, an increase in carbon sequestration can be achieved through conservation and effective management of these protected forests. This study essentially provides information on structure, species diversity, biomass, and carbon stock as ecosystem services and function to the environment. This, therefore, represents an important contribution to ecosystem-wide carbon cycle and amount of carbon dioxide that can be sequestered annually from the atmosphere by these protected forests.

2. Methodology

2.1 Study area

The research was conducted in three protected forests (Omo biosphere reserve (BR), Akure strict nature reserve (SNR) and Okomu national park (NP)), in May 2021, located in the southern part of Nigeria. Strict nature reserve (SNR) is prominent among the methods for *in-situ* conservation of biodiversity in Nigeria in particular and the world in general [1]. SNRs are created to protect representative samples of natural ecosystems for preservation of biodiversity and ecological processes, scientific study, environmental monitoring, education and the maintenance of genetic resources in a dynamic and evolutionary state [12]. Biosphere reserve (BR) is areas of terrestrial and coastal ecosystems promoting solutions to reconcile the conservation of biodiversity with its sustainable use. They are internationally recognized, nominated by national governments and remain under the sovereign jurisdiction of the states where they are located. An example of biosphere reserve in Nigeria is the Omo biosphere reserve (BR). The Omo biosphere reserve is located in Ijebu area of Ogun State, Southwest, Nigeria. Established in 1977, roughly 6000 people live within the biosphere reserve boundaries, which cover a total area of 130,600 hectares. There are several national parks established by the Federal Government (FG) of Nigeria to serve as tourist attraction centres and conservation of plants and animals. These national parks consist of diverse species of fauna and flora that contribute to the ecosystem development and conservation status. Nigeria national park service is the body that oversees and responsible for preserving, enhancing, protecting and managing vegetation and wild animals in the national parks of Nigeria. Nigeria national park service works closely with the Nigerian tourism development corporation in the handling and management of the national parks. These national parks cover a total land area of approximately 20,156 km^2, which is about 3% of Nigeria's total land area. Okomu national park covers a land area of 200 hectares in Edo State, about 60 km Northwest of Benin City, Nigeria. The area is bounded by latitudes 6.08° and 6.30° N and longitudes 5.01° and 5.27° E. The climate of the region is characterized by a double maximal year-round rainfall pattern with a mean annual rainfall of about 2200 mm, which peaks between May and October and a mean monthly temperature of 27°C. Tropical hardwood tree species in the area include *Celtis zenkeri, Triplochiton scleroxylon, Pycnanthus angolensis*, *Alstonia congoensis, Khaya ivorensis* (African mahogany) and *Lovoa trichilioides* (African walnut).

2.2 Method of data collection

These three (3) protected forests were selected (Omo BR, Akure SNR and Okomu NP) for this study. In each protected forest, biodiversity and tree growth data were collected from two lines transects of 1000 m each in length laid approximately at the centre of the protected forest [3, 6]. The two line transects were separated by a distance of at least 1000 m. Four temporary sample plots of 25 m × 25 m were laid at alternate sides along each transect at every 250 m interval. Thus, there were 4 sample plots per transect, 8 per protected forest and twenty-four (24) for this study. Within each plot, all living trees with Dbh ≥ 10 cm were identified, their Db, Dbh measured with girth tape and Dm, Dt and total heights measured with Spiegel Relaskop [1, 6].

2.3 Data analysis for species diversity

Species relative density (RD) used to determine species relative distribution was computed using:

$$RD = \left(\frac{\mathrm{ni}}{\mathrm{N}}\right) \times 100 \quad (1)$$

where: RD (%) = species relative density; n_i = number of individuals of species i and N = total number of all individual trees of all species in the entire forest reserve.

Species relative dominance (RDo) was estimated using:

$$RD_0 = \left(\frac{\sum Ba_i \times 100}{\sum Ba_n}\right) \quad (2)$$

where: Ba_i = basal area of all trees belonging to a particular species *i* and Ba_n = basal area of all individual trees.

Importance value index (IVI) of each species was computed with the relationship:

$$\mathrm{IVI} = \left(\frac{\mathrm{RD} + \mathrm{RD_0}}{2}\right) \quad (3)$$

Species diversity index (H′) was computed using the Shannon-Wiener diversity index below:

$$\mathrm{H}' = -\sum_{\mathrm{i=1}}^{\mathrm{s}} Pi\ In(Pi) \quad (4)$$

where: H′ = Shannon-Wiener diversity index; S = total number of species in the protected forest; p_i = proportion of S made up of the ith species and ln = natural logarithm.

Simpson Concentration index

$$\mathrm{D} = \sum\left(\frac{\mathrm{ni}}{\mathrm{Ni}}\right)^2 = \mathrm{D} = \frac{1}{\sum_{\mathrm{i=1}}^{\mathrm{s}} \mathrm{P_i}^2} \quad (5)$$

In the Simpson index, p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), Σ is still the sum of the calculations and (S) is the number of species.

Shannon's maximum diversity index was calculated using:

$$\mathrm{H_{Max}} = \mathrm{Ln}\ (\mathrm{S}) \quad (6)$$

Where: H_{max} = Shannon's maximum diversity index and S = total number of species in the protected forest.

Species evenness in each plot was determined using Shannon's equitability (E_H), which was obtained using:

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{s} P_i \text{Ln } P_i}{\text{Ln } (S)} \tag{7}$$

2.4 Forest conservation structure

The following computations were computed for forest structure analyses. The basal area of each tree in the protected forest was calculated using

$$BA = \frac{\pi D^2}{4} \tag{8}$$

Where: BA = Basal area (m^2), D = Diameter at breast height (cm) and л = pie (3.142). The total basal area for the plot was obtained by adding basal area of all trees in the forest reserve. Volume of individual trees was estimated using

$$V = \pi h \frac{Db^2 + 4(Dm^2) + Dt^2}{24} \tag{9}$$

where: V = Tree volume (m^3), π = 3.142, h = tree height (m) measurement and Db, Dm and Dt = tree cross-sectional area at the base, at the middle and top of merchantable height, respectively. The total volume for the forest reserve was obtained by adding all individual trees volume computed.

2.5 Biomass and carbon stock

In determining the total carbon (TC) stocks, estimation of AGB and BGB were computed. Biomass expansion factor (BEF) of 1.74 was used to estimate tree above-ground biomass for tropical rainforest [13], multiple by volume over bark (m^3/ha) and wood density (kg/m^3).

$$\text{Above} - \text{Ground Biomass (AGB)} = \text{BEF} \times \text{VOB} \times \text{WD} \tag{10}$$

Where, BEF = Biomass expansion factor; VOB = Volume over bark (m^3) and WD = Wood density (kg^{-2}). Wood density for tree species was acquired from Global Wood Density Database. Arithmetic mean of (0.60 gcm^3) for a tropical African forest was used for species that were not found in the database following [14]. The carbon stock of the protected forests was determined by a fraction of 50% of biomass.

$$AGC = AGB \times 0.5 \tag{11}$$

Thus, above-ground carbon (AGC) was calculated as a conversion factor of 0.5 multiplied by AGB.

$$BGB = AGB \times 0.2 \tag{12}$$

where below-ground biomass was computed as 20% of AGB following MacDicken [15]; IPCC [16], using a synthesis of global data and a conservative ratio shoot-to-root biomass of 5:1 [17].

$$TCS = AGC + BGC \tag{13}$$

The estimation of carbon content in BGC is the same as that of AGC Eq. 12. Total carbon storage (TCS ton ha^{-1}) stock was calculated by summing up the carbon stock of AGC and BGC following [18].

3. Results

3.1 Phytosociological characteristics, diversity and biomass estimation

The phytosociological characteristics, diversity and biomass estimation of these protected forests were analysed in this study (**Table 1**). The table indicates that a total of 370 individual trees per hectare, disproportionately distributed between 53

Growth characteristics and biodiversity indices	Protected forests		
	Omo Biosphere reserve	Akure Strict nature reserve	Okomu National park
Density ha^{-1}	370b	381a	352c
Family	25a	24a	25a
Mean Diameter (cm)	26.08b	35.61a	26.31b
Maximum Diameter (cm)	168.50c	251.50a	190.20b
Mean height (m)	14.15b	17.41a	15.59b
Basal Area (m^2) ha^{-1}	36.63b	72.39a	32.47c
Volume (m^3) ha^{-1}	427.08b	929.05a	366.71c
Species richness	81b	119a	76c
Species diversity	3.19c	3.90a	3.45b
Tree species	53c	63a	59b
Simpson_1-D	0.954b	0.951c	0.969a
Evenness_e^H/S	0.574b	0.571c	0.707a
Menhinick	3.768c	3.905b	3.933a
Margalef	10.42a	10.91a	10.71a
Equitability_J	0.863b	0.864b	0.915a
Above-ground biomass (ton) ha^{-1}	153.20c	316.73b	353.92a
Below-ground biomass (ton) ha^{-1}	30.64c	63.35b	190.04a
Total carbon storage (ton) ha^{-1}	70.78c	91.92b	212.35a

Values followed by similar letters at not significantly different ($p \leq 0.05$).

Table 1.
Growth characteristics, biodiversity indices and ecosystem services.

different species in 25 families, were encountered in Omo biosphere reserve while 381 stems in 63 species in 24 families and Okomu national park recorded 352 individual stems, 59 species and 25 families. There were significant differences in all the growth variables investigated in this study across the three protected forests (**Table 1**). The three protected forests had high tree species diversity index (Shannon-Wiener diversity index of 3.19 for Omo BR, 3.90 for Akure SNR and 3.45 for Okomu NP). The Simpson concentration index and species evenness are assessed for these protected forests as 0.954, 0.951 and 0.969 while 0.574, 0.571 and 0.707 for Omo BR, Akure SNR and Okomu NP, respectively. There were significant differences in all the biodiversity indices investigated in this study across the three protected forests (**Table 1**), indicating that diversity is dissimilar between the forests. The biological diversity indices of the protected forests compared favorably with other protected natural forests, sacred groves and other natural forest formations. The values for basal area (36.63, 72.39, and 32.47 m^2), volume (427.08, 929.05, and 366.71 m^3), above-ground biomass (153.20, 316.73, and 353.92 ton), below-ground biomass (30.64, 63.35, and 190.04 ton) and total carbon stock (70.78, 91.92, and 212.35 ton) for Omo BR, Akure SNR and Okomu NP, respectively. There were significant differences in all the biomass and carbon storage investigated in this study across the three protected forests (**Table 1**), indicating the carbon sequestration potentials of the forests.

3.2 Diameter distribution and canopy structure of the protected forests

The diameter distribution of trees in these protected forests followed inverted J distribution pattern common with tropical forest ecosystems (**Figure 1**). The figure reveals that the highest number of trees (205 stems/ha) was in the diameter class of less than 15 cm in Okomu NP followed by (168 and 108 stems/ha) Akure SNR and Omo BR Osogbo, respectively. The vertical structure of the selected protected forests is shown in **Figure 2**. The structures of these protected forests were determined by the canopy distribution of the forests, which was calculated based on the height distributions of the tree species. The figure reveals that the highest numbers of trees (111 stems/ha Akure SNR and 99 stems/ha Okomu NP) were in the middle canopy

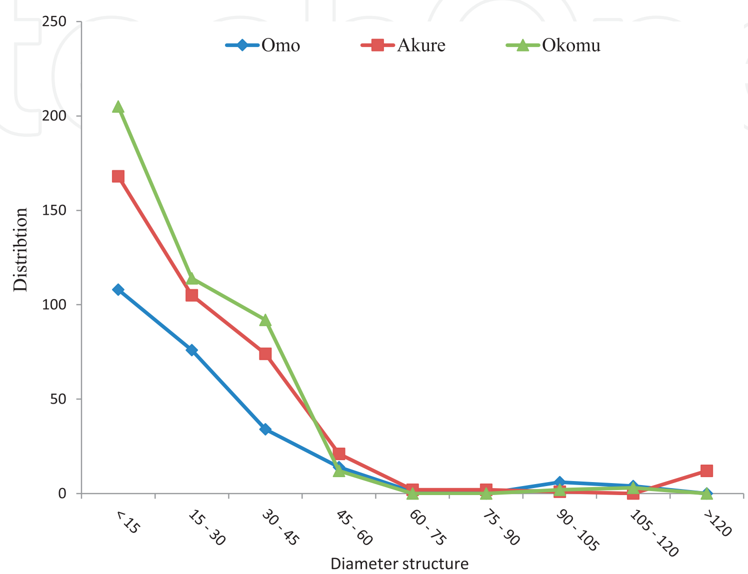

Figure 1.
Diameter distribution class for the protected forests.

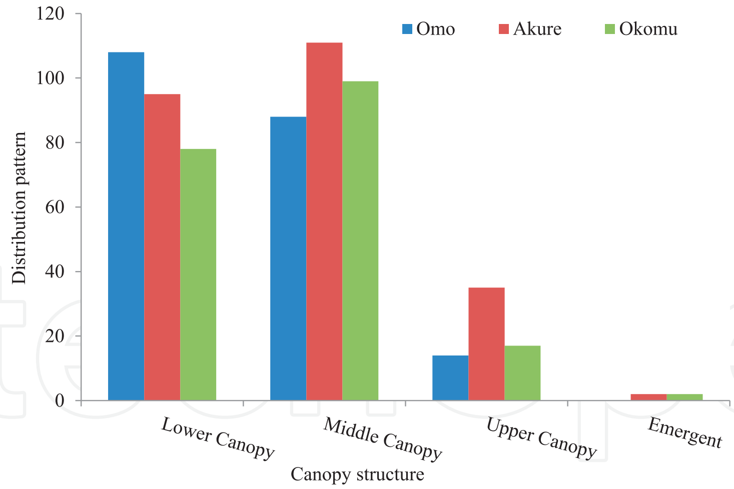

Figure 2.
Canopy structure based on height distribution for the protected forests.

structure of the forest followed by (108 stems/ha Omo BR) at the lower canopy structure of the forest.

4. Discussions

In these protected forests, individual tree density and species were recorded 370 (53) Omo BR, 381 (63) Akure SNR and 352 (59) Okomu NP. Similar tree compositions were reported in different researches across the tropical ecosystems, Onyekwelu *et al.* [6] reported 55, 73 and 78 for Osun Osogbo, Idanre hill and Ogun Onire sacred groves, respectively, in Nigeria, Baul *et al.* [19] reported 52 tree species in farm forests in Nepal, Chowdhury *et al.* [20] reported 55 tree species in village common forests of Khagrachari while Roy *et al.* [21] reported 62 species in the home gardens of Bangladesh [22]. The assessment of plant species revealed that all the encountered trees in the three protected forests were indigenous tropical hardwood species that are of economic value to humans and their environment. This is an indication that the three protected forests are repositories of many indigenous tropical hardwood tree species that are of high ecological, social and economic values. Forest habitats play an important role in the effective functioning of the forest ecosystem, and protected forests serve as *in-situ* conservation for rare plants being disturbed by anthropogenic activities [23]. This is crucial to the sustainable management and preservation of tree diversity resources. The tree species diversity and abundance of these protected forests as determined by the biodiversity indices indicated that these protected forests fulfilled the mandate of a biodiversity conservation strategy [24].

Biodiversity indices for these protected forests represent the diversity of floral compositions and their distribution in these forests. Tree species diversity and evenness indices found in this study are comparable to the study of Onyekwelu *et al.* [6], which reported that 3.19 (0.84), 3.25 (0.85) and 3.46 (0.86) for Osun Osogbo, Idanre hill and Ogun Onire sacred groves, respectively, in Nigeria. Lower Shannon-Wiener tree species diversity index of (1.80) was recorded in sacred grove of Igbo Olodumare, (1.23) was recorded for home gardens in Northern Bangladesh while (1.64) was recorded for protected forests of Bangladesh ([25, 26]), and (1.34) was recorded for collaborative forests in Nepal [27]. The Phytosociological attribute and floristic diversity of these selected protected forests were discovered to be comparable with other protected areas of tropical forest ecosystems of south-west, Nigeria [1]. The stand densities were also similar to those obtained for Garo hills, India [28], Borneo rainforest [29], Indonesian forest [30] and the Mexican tropical deciduous forest [31].

4.1 Biomass and Carbon stock estimation

Tropical forests are known to play an important role in regulating the global carbon cycle. The biomass of tropical forests plays a critical role in micro and macro absorption of carbon and carbon cycling of forest ecosystems [32]. However, tropical forest ecosystems particularly protected forests need to be adequately and regularly investigated for carbon stock accumulation. The total biomass of 183.83 kg ha^{-1}; 380.08 kg ha^{-1} and 543.96 kg ha^{-1} was recorded for Omo BR, Akure SNR and Okomu NP, respectively, which is lower than 164.82 ton ha^{-1} recorded for India forest and 156.73 ton $ha^{-1}$for Nigerian forest, respectively [4, 33]. The result of biomass in these protected forests is comparable with the studies of Wittmann *et al.* [32], which estimated 259.45 kg ha^{-1} for Southern Pantanal, Brazil. Agbelade and Adeagbo [5] estimated 617.85 kg ha^{-1} and 209.26 kg ha^{-1} for Akure SNR and Osun Osogbo sacred grove, respectively. The disparity in the values maybe a result of the different methods and equations adopted, this study uses BEF while other researchers used allometric equations. Carbon storage of forest biomass is an important attribute of a stable forest ecosystem and a key link in global carbon cycle. The total carbon stock estimated for these protected forests is 70.78 kg ha^{-1}, 91.92 kg ha^{-1} and 212.35 kg ha^{-1} for Omo BR, Akure SNR and Okomu NP, respectively, which is lower than 617.86 kg ha¯1 recorded for Akure strict nature reserve and 209.27 kg $ha^{-1}$for Osun Osogbo sacred grove [5]. Adekunle *et al.* [4]; IPCC [16] recorded 82.41 ton ha^{-1} for Indian forest and 78.29 kg ha^{-1} for Eda SNR, which can be compared with the result of this study. Tabue *et al.* [34] estimated 354.73 Mg ha^{-1} for Dja wildlife reserve in Cameroon. Munishi and Shear [35] reported over 300 Mg ha^{-1} carbon stock in Tanzanian Eastern forests. The above results indicated that protected forests would contribute significantly to carbon sequestration and climate change mitigation as long as the forest is adequately protected from deforestation and degradation. Thus, besides being a reservoir of biodiversity, protected forests also act as sink of atmospheric CO_2. The high biomass and carbon stock in this forest reserve is attributed to the effective conservation system that prevented the forest from degradation and deforestation as well as the federal government policy on National parks.

5. Conclusion

The use of protected forests is important for biodiversity and climate change mitigation. The scientific information provided by this research would further promote accurate estimation of the tree species diversity, stand volume and carbon stock in the Okomu protected forest. The results of the study indicated that there are many indigenous tropical tree species that are rare and in danger of extinction. There is strong evidence of active regeneration status, which indicates a good future for the Okomu protected forest. The study shows that the biodiversity-protected forests act as sink of atmospheric CO2 because of their high carbon stock and high biomass. The research revealed the abundance of relative dominant trees as well as their contributions to the preservation of the environment. This reference can be used to compare changes in carbon stocks over time. The current position of protected areas in terms of tree species abundance, evenness, carbon sequestration, productivity and structure shows the effectiveness of *in-situ* management. The forest has the potential to serve as a long-term carbon sink due to its good potential for carbon sequestration. To continue providing these ecosystem services and functions, the previous method that prevented the forest reserve from being degraded should be maintained and strengthened. According to the study, strict measures should be taken on identified protected areas so as to ensure their continuous impact on the environment.

Conflicts of interest

The manuscript was approved by the author. The author declares that there are no conflicts of interest or competing interests.

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