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*Research Article*

# Effects of canopy structure on the diversity and structure of tree species in omo biosphere reserve, Ogun state, Nigeria

**Ubaekwe RE[1*], Chima UD[2], Ekwugha EU[1], Okeke AN[1] and Onyekwere CM[3]**

[1]Department of Forestry and Wildlife Technology, Federal University of Technology, Owerri, Nigeria
[2]Department of Forestry and Wildlife Management, University of Port Harcourt, Nigeria
[3]Urban Tree Revival initiative, Nigeria.

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***Corresponding author**

Ubaekwe RE,
E-mail: ubaekwe.rosemary@futo.edu.ng

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**ABSTRACT**

This study assessed the effects of canopy structure on tree species diversity and forest structure in Omo Biosphere Reserve. Landsat imagery was used; supervised maximum likelihood classification was used to classify the reserve into two canopy structures (closed and open canopies). Random sampling technique was used to delineate 10 sample plots of 30m x 30m in each canopy type. Tree species with a diameter at breast height (Dbh) ≥10cm were enumerated in each sample plot. Shannon Weiner and Simpson's indices were used to assess the tree diversity, while diameter and height stratification were used to evaluate the forest structure. Shannon Weiner and Simpson's indices were 3.507 and 0.953, respectively, in open canopy structure (OCS) and 3.396 and 0.951, respectively, in closed canopy structure (CCS). Species richness and population were higher in OCS (64 and 575, respectively) than in CCS (56 and 531, respectively). *Milletia thonningii* and *Strombosia pustulata* were the dominant tree species in OCS and CCS, respectively. The mean Dbh and height in OCS were 40.09cm and 22.86 cm; and 50.21cm and 23.05cm in CCS, respectively. The basal area was 110.01$m^2$/ha in OCS and 207.97$m^2$/ha in CCS. The volume yield per hectare in OCS was 343.35$m^3$/ha and 842.49$m^3$/ha in CCS. The OCS was dominated by younger trees than the CCS. Canopy structure affects tree species richness, population, and diversity, as well as tree attributes.



## INTRODUCTION

Canopy structure is often referred to as the arrangement and density of branches, crowns, and leaves within the uppermost strata of a forest ecosystem. It covers a fraction of the ground surface area by the vertical projection of tree crowns. Canopy structure has a complex interplay with tree species diversity, composition, and overall forest structure (Ukonmaanaho *et al*., 2008). It directly and indirectly affects the biotic and abiotic environment of vegetation, especially the understory, by impacting factors such as temperature, humidity, light, and soil processes (Valladares *et al*., 2016). The canopy structure takes different forms and shapes, such as a closed canopy, an open canopy, and a multi-layered canopy. According to Ishii *et al*. (2013), a closed canopy structure is formed when the tree crowns are densely and closely packed, and the canopy can prevent about 95% of sunlight from reaching the forest floor. The vegetation under this form of tree canopy enjoys higher organic matter, soil moisture, humidity, wind protection, reduced temperature, and transpiration (Valladares *et al*., 2016; Kumar *et al*., 2020). However, the vegetation faces negative effects too, such as limited light availability, reduced photosynthesis, competition for nutrients, elevated incidence of phytophagous fungi and pests, and rainfall interception (Garkoti and Singh 1995; Valladares *et al*., 2016). In contrast, an open canopy structure is formed when the trees are sparsely populated, allowing more penetration of sunlight and rainfall into the forest floor. The vegetation under this canopy enjoys increased photosynthesis, a high rate of decomposition and nutrient cycling, and sometimes faces the direct impact of wind action (Valladares *et al*., 2016). In other words, canopy structure creates microclimatic variations in the ecosystem (Tonteri *et al*., 2016). The variations support the growth and development of a wider variety of tree species by providing niches for varying species with varying ecological requirements, thereby promoting the overall biodiversity within the ecosystem. For instance, the presence of open canopy structures, also known as canopy gaps, allow the growth and establishment of light-demanding species, while a closed canopy structure, also known as dense canopy cover, aids the growth and establishment of shade-tolerant species. More so, the intricacy of the canopy effects is linked to the nutrient cycling in the forest ecosystem. Barbie *et al*. (2008) documented that the leaves and branches, which are the components of the canopy, often act as a barrier, intercepting rainfall and light, thus reducing the direct input of water and light penetration. This affects the activities of the decomposers, like the fungi and bacteria, thereby affecting the rate of decomposition processes and nutrient cycling.

A biosphere reserve is one of the many methods of *in situ* conservation of biodiversity. It primarily consists of the transition zone, buffer zone, and core zone. The core zone is often referred to as a strict nature reserve (SNR). SNRs are areas with zero human disturbances, established purely to safeguard representative samples of natural ecosystems for the preservation of biodiversity and ecological processes, scientific study, environmental monitoring, education, and the maintenance of genetic resources in a dynamic and evolutionary state (Isichei, 1995). The tropical rainforest ecosystem, according to Anning *et al*. (2009), is one of the most diverse, complex, and species-rich ecosystems on the planet. However, the high rate of industrialization, human population explosion, urbanisation, poverty, land use, and land cover changes have resulted in the loss of biodiversity, forest degradation, forest fragmentation, and ecological instability in most forest reserves in Nigeria (Chima *et al*., 2009; Adekunle *et al*., 2014; Ubaekwe *et al*., 2022). These have serious negative impacts on ecosystem functioning, conservation and human survival. And once a stable ecosystem is disturbed or destroyed, it is ecologically and economically very difficult to repair and rehabilitate it (Jimoh *et al*., 2012). Other factors that also contribute to the loss of biodiversity, forest degradation, and ecological instability in Nigeria's nature reserves include declining manpower and capacity in the Forestry Department, inadequate forest patrol, the stoppage of the payment of annual royalty to rural communities, and outdated forestry laws and regulations (Adekunle *et al*., 2013). In other words, most of our forests in Nigeria have suffered damage as a result of anthropogenic and natural disturbances. These disturbances change the pattern of succession, successive composition, diversity, and canopy structure of forest ecosystems (Addo-Fordjour *et al*., 2009).

Canopy effects on species diversity, composition, and structure are often neglected despite the fact that canopy structure plays a vital role in shaping forest dynamics and ecological processes. This oversight can have momentous consequences for biodiversity conservation, ecosystem functioning, and sustainable forest management. Hence, this study aims to characterise the different canopy structures of Omo Biosphere Reserve and assess the canopy effects on tree diversity, composition, tree attributes, and the forest structure. This will offer insights on effective conservation strategies and sustainable forest management practices.

## MATERIALS AND METHODS

### Study Area

The research was conducted in the Strict Nature Reserve of Omo Biosphere Reserve. It is located between Latitudes 6° 57' 21" – 6° 58' 36"N and Longitudes 4° 19' 11" - 4° 40' 20"E, and total area coverage of 460 hectares in Ijebu East Local Government Area of Ogun State, south-western Nigeria (Figure 1). The Biosphere reserve was established and gazetted in 1977 (Okali and Ola-Adams 1987). The climate of the biosphere reserve is characterized by the mean annual rainfall of 1750mm, average relative humidity of 80% and temperature range of 32.15$^0$C to 21.40$^0$C (Ubaekwe, 2020).

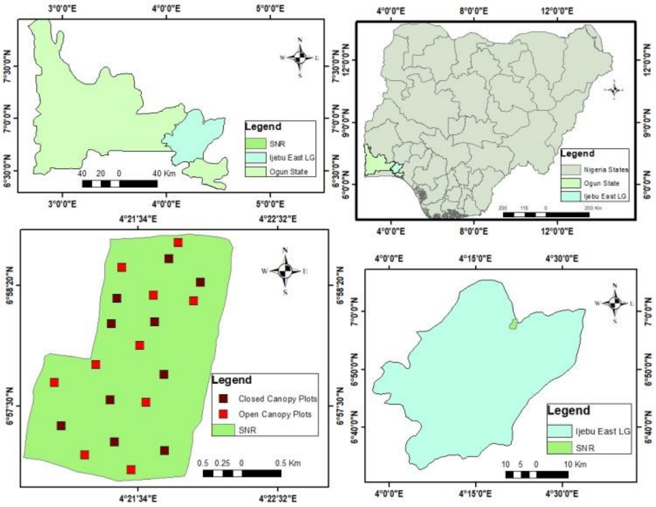

**Figure 1.** Map of the Study Area

### Data Collection

Landsat image of path (190) and row (055) was downloaded from the United Society of Geological Survey as secondary data, while random sampling technique was used to demarcate 10 sample plots of 30m x 30m each in open canopy and closed canopy structures. In each sample plot, tree identification and inventory process was restricted to trees with a diameter at breast height (dbh) greater than or equal to 10cm. The measurement of total tree height, defined as the vertical distance from the ground to the highest point (FAO, 2005), was achieved utilizing a Clinometer, while Dbh was measured using a diameter tape.

### Data Analysis

#### *Land Cover Classification*

The Landsat image was processed and geo-referenced to the World Geodetic System (WGS) 1984 ellipsoid using ground-based Coordinate Points (GCP) obtained from the site using GPS; then projected to the coordinate system of zone 31N in the Universal Transverse Mercator (UTM) system. False Color Composite (FCC) was created using bands 3, 4, and 5 for Landsat OLI/TIRS sensors (Abegunde & Adedeji, 2015).

The FCC was subjected to supervised classification using maximum likelihood classification technique in Arcgis. Extract by Mask tool was used in Arcmap environment to extract the shapefile of the study area, while raster calculator was used to calculate the area coverage of each land cover categories. Confusion Matrix was used to assess the accuracy of the land cover categorization, using training samples and ground-truth information as points of comparison.

### *Species Richness, Diversity and Structure*

The species richness for each of the canopy structures was evaluated by counting the number of trees enumerated, compiled and classified into family and species levels. The diversity of the tree species enumerated in the sampled plots were analysed in each canopy structure using Shannon-Weiner and Simpson's diversity indices as earlier used by (Adekunle *et al.*, 2014; Chima *et al.*, 2022 and Ubaekwe *et al.*, 2022). Species evenness and dominance was determined using Pielou's species evenness index (Pielou, 1966).

### *The Shannon-Weiner Diversity Index (H)*

$H = -\sum_{i=1}^{s} p_i \ln p_i$ ----------------------- Equation 1

Where: H = Shannon-Weiner diversity index, s = the aggregate number of species present within the community; $P_i$ = the fraction of s that is composed of the ith species; and "ln" = the natural logarithm.

The Pielou's species evenness index (EH) is a metric used to quantify the evenness of species distribution within a given ecological community.

$E_H = \frac{H}{lnS}$ ------------------------------- Equation 2

### *The Simpson's index of diversity*

$D = 1 - (\frac{\sum n(n-1)}{N(N-1)})$ --------------------- Equation 3

Where "**n**" represents the entire number of individuals within a specific species and "N" is the total amount of individuals of all the species itemized.

The basal area (BA) was calculated utilizing the following equation:

$BA = \frac{\pi d^2}{4}$ ----------------------- Equation 4

Where BA = basal area ($m^2$); $\pi$ = 3.143, d = diameter of the individual trees in meters.

### Volume estimation

V = BA x H ----------------------- Equation 5

Where: V = volume ($m^3$); BA = Basal Area ($m^2$), H = tree total height (m)

### *Forest Structure*

The measured tree Dbh and height were used to assess the vertical and horizontal arrangement of the trees in the reserve. All the trees enumerated were classified into different height and Dbh classes according to (Hall *et al.*, 2003).

## RESULTS

### Canopy Cover Classification and Area Coverage of each Canopy Structure

The result of the canopy cover classification of the reserve is shown in Figure 2. Closed canopy (dense vegetation), open canopy (sparse vegetation) and water body were the main land cover of the site. Areas of dark green, light green and blue colours represent areas of closed canopy, open canopy and water body respectively. The overall accuracy of the classification and the percentage Kappa coefficient were 0.94 and 91% respectively (Table 1). Table 2 shows the total area and percentage coverage of different land cover classes. Closed canopy structure covered the total area of 341ha (74.13%), open canopy structure covered 91ha (19.78%) while water body covered 28ha (6.09%).

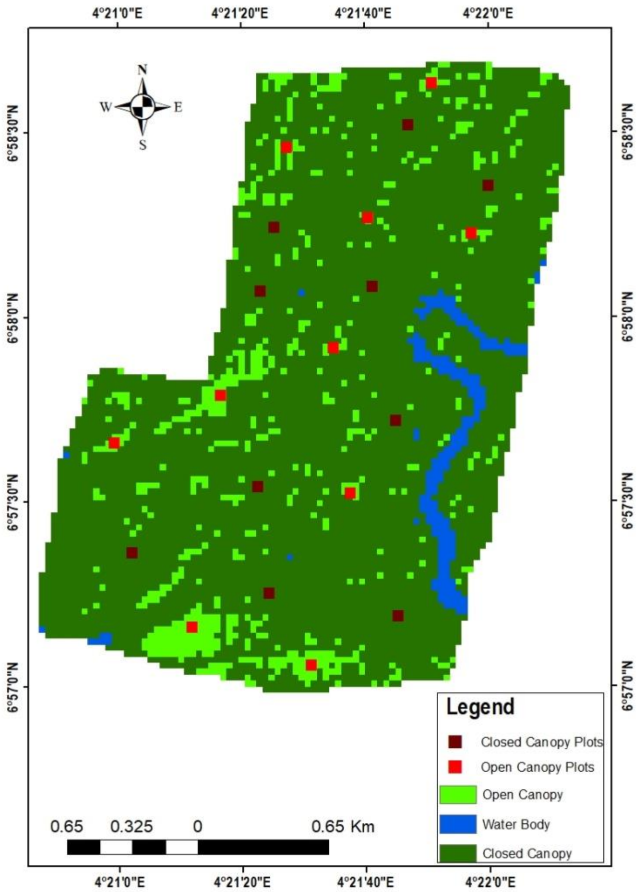


**Figure 2.** Land Cover Classification of the Strict Nature Reserve in Omo Biosphere Reserve

**Table 1.** Accuracy Report of the Land Cover Classification

| LULC Classes | Close Canopy | Open Canopy | Water | Ground points | Commission Error | User's Accuracy |
|---|---|---|---|---|---|---|
| Close Canopy | 48 | 1 | 2 | 51 | 0.06 | 0.94 |
| Open Canopy | 3 | 49 | 1 | 53 | 0.08 | 0.92 |
| Water | 0 | 2 | 47 | 49 | 0.04 | 0.96 |
| Total | 51 | 52 | 50 | 153 | | |
| Omission Error | 0.06 | 0.06 | 0.06 | | | |
| Producer's Accuracy | 0.94 | 0.94 | 0.94 | | | |
| Overall Accuracy | 0.94 | | | | | |
| p(r) | 0.33 | | | | | |
| **Kappa Coefficient** | **0.91** | | | | | |
| **Kappa Coefficient (%)** | **91** | | | | | |

**Table 2.** Area Coverage of Land Cover Classes

| LULC Classes | Area Coverage (ha) | Percentage Coverage |
|---|---|---|
| Dense Canopy (Close Canopy) | 341 | 74.13 |
| Open Canopy (Open Canopy) | 91 | 19.78 |
| Water body | 28 | 6.09 |
| **Total** | **460** | **100** |

### *Diversity Indices of Tree Species in Close and Open Canopy*

The species richness and diversity indices of tree species under the closed and open canopies are presented in Table 3. Fifty-six (56) and sixty-four (64) tree species were recorded in closed and open canopy structure respectively; while tree populations were 531 and 575 in closed and open canopy structure, respectively. Shannon-Wiener, Simpson and Margalef indices were 3.396, 0.951 and 8.765, respectively, for closed canopy structure; and 3.507, 0.953 and 9.914, respectively, for open canopy structure. The species dominance and evenness for closed canopy were 0.048 and 0.533 respectively; and 0.046 and 0.521, respectively, in open canopy structure.

**Table 3.** Diversity Indices of Tree Species in Closed and Open Canopy

| Diversity Indices | Closed Canopy | Open canopy |
|---|---|---|
| Taxa (Species) | 56 | 64 |
| Individuals | 531 | 575 |
| Shannon_H | 3.396 | 3.507 |
| Simpson_1-D | 0.951 | 0.953 |
| Margalef | 8.765 | 9.914 |
| Species Dominance_D | 0.048 | 0.046 |
| Species Evenness_e^H/S | 0.5330 | 0.5213 |

### *Tree Species Composition and Attributes in Open and Closed Canopy Structures*

Out of 575 trees enumerated in open canopy structure, *Milletia thonningii* (67) had the highest population, followed by *Xylopia villosa* (57), while 17 tree species including *Trichilia monadelpha* were represented by one tree each. Similarly, out of 531 trees in closed canopy structure, *Strombosia pustulata* (65) had the highest population, followed by *Diospyros dendo* (44), while 18 tree species including *Morus mesozygia* were represented by one tree each (Table 4).

*Mansonia altissima* (131.44cm) and *Ficus capensis* (10.23cm) had the highest and lowest mean DBH, respectively, in open canopy while *Piptadeniastrum africanum* (256.52cm) and *Erythrina suaveolens* (15.72cm) had the highest and lowest mean DBH, respectively, in closed canopy structure~~,~~ *Phyllanthus angolensis* (56.8m) and *Hildegardia barteri* (7.40m) had the highest and lowest mean height, respectively, in open canopy while *Ficus mucuso* (52.60m) and *Mallotus subulatus* (11.00m) had the highest and lowest mean height, respectively, in closed canopy structure. Similarly, *Mansonia altissima* (15.08cm/ha) and *Ficus capensis* (0.09cm/ha) had the highest and lowest mean basal area per hectare, respectively, in open canopy while *Piptadeniastrum africanum* (57.43cm/ha) and *Erythrina suaveolens* (0.22cm/ha) *had* the highest and lowest mean basal area per hectare, respectively, in closed canopy structure. *Bombax buonopozense* (594.44$m^3$/ha) *and Ficus capensis* (1.29 $m^3$/ha) had the highest and lowest mean volume per hectare, respectively, in open canopy while *Piptadeniastrum africanum* (2928.79$m^3$/ha) and *Bridelia micrantha* (3.47$m^3$/ha) had the highest and lowest mean volume per hectare, respectively, in closed canopy structure respectively.

**Table 4.** Tree Species Composition and Attributes in Open and Close Canopy Structures

| *TREE SPP* | Freq. Open | Freq. Close | Mean DBH(cm) Open | Mean DBH(cm) Close | Mean HT(m) Open | Mean Ht(m) Close | Mean BA/ha Open | Mean BA/ha Close | Mean V/ha Open | Mean V/ha Close |
|---|---|---|---|---|---|---|---|---|---|---|
| *Albizia zygia* | 2 | 1 | 26.10 | 18.52 | 13.75 | 19.30 | 0.61 | 0.30 | 8.52 | 5.78 |
| *Allanblackia floribunda* | | 1 | | 25.91 | | 19.20 | | 0.59 | | 11.25 |
| *Alstonia boonei* | 12 | 12 | 43.44 | 97.36 | 21.70 | 25.99 | 2.83 | 10.08 | 86.10 | 321.24 |
| *Aningeria robusta* | 6 | 9 | 36.23 | 35.82 | 15.48 | 15.44 | 1.28 | 1.28 | 20.86 | 22.15 |
| *Antiaris africana* | 1 | | 17.44 | | 26.50 | | 0.27 | | 7.03 | |
| *Baphia nitida* | 11 | 13 | 24.70 | 28.28 | 22.80 | 20.82 | 0.58 | 0.88 | 14.58 | 16.55 |
| *Berlinia grandiflora* | | 1 | | 50.92 | | 17.00 | | 2.26 | | 38.47 |
| *Blighia sapida* | 5 | 10 | 28.27 | 31.58 | 21.56 | 21.25 | 0.73 | 1.04 | 15.09 | 24.74 |
| *Bombax buonopozense* | 1 | | 128.58 | | 41.20 | | 14.43 | | 594.44 | |

| *TREE SPP* | Freq. Open | Freq. Close | Mean DBH(cm) Open | Mean DBH(cm) Close | Mean HT(m) Open | Mean Ht(m) Close | Mean BA/ha Open | Mean BA/ha Close | Mean V/ha Open | Mean V/ha Close |
|---|---|---|---|---|---|---|---|---|---|---|
| *Bosqueia angolensis* | 10 | 12 | 26.14 | 28.54 | 26.78 | 28.09 | 0.67 | 0.90 | 18.01 | 35.78 |
| *Brachystegia eurycoma* | 6 | 3 | 81.65 | 89.61 | 26.07 | 36.77 | 7.19 | 8.86 | 206.32 | 406.75 |
| *Brachystegia nigerica* | 1 | | 37.24 | | 24.00 | | 1.21 | | 29.04 | |
| *Bridelia micrantha* | 1 | 1 | 19.83 | 16.01 | 19.90 | 15.50 | 0.34 | 0.22 | 6.83 | 3.47 |
| *Carapa procera* | 2 | | 44.78 | | 28.50 | | 1.76 | | 50.82 | |
| *Buchholzia coriacea* | | 1 | | 58.88 | | 17.80 | | 3.03 | | 53.85 |
| *Ceiba pentandra* | 7 | 10 | 93.45 | 170.53 | 29.59 | 38.69 | 9.03 | 39.55 | 298.59 | 1975.82 |
| *Celtis mildbraedii* | 1 | | 54.90 | | 32.90 | | 2.63 | | 86.54 | |
| *Celtis zenkeri* | 13 | 5 | 54.10 | 39.08 | 26.78 | 15.50 | 4.09 | 1.44 | 167.45 | 22.55 |
| *Chrysophyllum prunifolium* | 1 | | 28.01 | | 20.00 | | 0.68 | | 13.69 | |
| *Cleistopholis patens* | 7 | | 33.85 | | 27.04 | | 1.10 | | 31.41 | |
| *Cola afzelii* | 1 | | 21.96 | | 14.00 | | 0.42 | | 5.89 | |
| *Cola gigantea* | 12 | 21 | 49.20 | 56.98 | 26.33 | 24.85 | 3.07 | 4.90 | 91.83 | 148.65 |
| *Cordia millenii* | 9 | 5 | 48.59 | 59.96 | 18.74 | 17.42 | 2.63 | 3.63 | 63.26 | 73.68 |
| *Dallium guinensis* | 3 | | 27.32 | | 27.27 | | 0.69 | | 20.36 | |
| *Daniella ogea* | 9 | 3 | 37.99 | 26.84 | 24.93 | 15.07 | 1.36 | 0.64 | 38.54 | 9.39 |
| *Diospyros dendo* | 31 | 44 | 30.36 | 30.24 | 27.24 | 25.77 | 1.24 | 1.42 | 49.59 | 59.25 |
| *Diospyros iturensis* | 35 | 5 | 26.23 | 17.73 | 14.91 | 17.08 | 0.93 | 0.29 | 18.44 | 4.92 |
| *Diospyros mespiliformis* | 2 | 6 | 24.41 | 34.42 | 21.25 | 33.60 | 0.52 | 1.08 | 11.08 | 36.14 |
| *Enantia chloranta* | 1 | | 14.61 | | 16.50 | | 0.19 | | 3.07 | |
| *Entandrophragma cylindricum* | 3 | 1 | 47.10 | 47.10 | 19.00 | 19.00 | 1.94 | 1.94 | 36.79 | 36.79 |
| *Entandrophragma utile* | 1 | 14 | 16.55 | 38.86 | 11.00 | 16.10 | 0.24 | 3.28 | 2.63 | 150.25 |
| *Erythrina suaveolens* | | 1 | | 15.72 | | 25.20 | 0.00 | 0.22 | 0.00 | 5.44 |
| *Fagara leprieuri* | 1 | 1 | 18.46 | 29.28 | 13.00 | 13.80 | 0.30 | 0.75 | 3.87 | 10.32 |
| *Ficus capensis* | 2 | | 10.23 | | 14.00 | | 0.09 | | 1.29 | |
| *Ficus exasperata* | 5 | | 81.91 | | 53.70 | | 6.68 | | 397.01 | |
| *Ficus mucuso* | | 2 | | 103.12 | | 52.60 | | 9.28 | | 488.12 |
| *Ficus thonningii* | | 1 | | 24.82 | | 13.00 | | 0.54 | | 6.99 |
| *Funtumia africana* | | 1 | | 18.91 | | 17.90 | | 0.31 | | 5.58 |
| *Funtumia elastica* | 26 | 19 | 27.98 | 27.68 | 22.87 | 21.91 | 0.90 | 0.72 | 28.21 | 15.08 |
| *Hexalobus crispiflorus* | 2 | | 24.28 | | 17.00 | | 0.68 | | 16.92 | |
| *Hildegardia barteri* | 2 | | 21.64 | | 7.40 | | 0.42 | | 3.20 | |
| *Hunteria umbellata* | 10 | 16 | 35.36 | 37.56 | 16.53 | 17.51 | 1.73 | 2.06 | 53.35 | 66.86 |
| *Irvingia gabonensis* | 2 | | 64.29 | | 28.50 | | 3.74 | | 110.11 | |
| *Khaya grandifoliola* | 17 | 36 | 86.83 | 63.86 | 26.46 | 23.50 | 8.61 | 4.80 | 282.39 | 144.54 |
| *Khaya senegalensis* | | 2 | | 76.86 | | 22.90 | | 5.25 | | 120.48 |
| *Lecaniodiscus cupanioides* | | 1 | | 45.35 | | 24.50 | | 1.80 | | 43.98 |
| *Mallotus subulatus* | | 1 | | 24.19 | | 11.00 | | 0.51 | | 5.62 |
| *Mansonia altissima* | 1 | | 131.44 | | 33.00 | | 15.08 | | 497.58 | |
| *Milicia excelsa* | 2 | 1 | 22.44 | 28.33 | 12.50 | 18.00 | 0.47 | 0.70 | 7.14 | 12.60 |
| *Milletia thonningii* | 67 | 33 | 28.73 | 25.16 | 14.24 | 14.27 | 0.90 | 0.72 | 14.79 | 12.76 |
| *Mitragyna stipulosa* | 1 | 1 | 16.52 | 36.66 | 24.20 | 19.50 | 0.24 | 1.17 | 5.76 | 22.88 |
| *Morus mesozygia* | 3 | 1 | 26.62 | 25.78 | 27.60 | 21.90 | 0.63 | 0.58 | 17.13 | 12.70 |
| *Musanga cecropioides* | 2 | | 28.55 | | 24.20 | | 0.72 | | 17.86 | |
| *Nauclea diderrichii* | 13 | 5 | 67.09 | 70.15 | 26.72 | 26.02 | 4.83 | 4.65 | 165.11 | 142.94 |
| *Nesogordonia papaverifera* | 15 | 14 | 34.29 | 39.34 | 19.85 | 20.52 | 1.45 | 1.52 | 29.66 | 30.97 |
| *Olax subscorpioidea* | 1 | 1 | 34.05 | 23.87 | 17.00 | 18.00 | 1.01 | 0.50 | 17.21 | 8.95 |
| *Parinari excelsa* | 5 | | 41.57 | | 20.20 | | 1.90 | | 48.26 | |
| *Phyllanthus angolensis* | 2 | | 75.59 | | 56.80 | | 5.01 | | 285.14 | |
| *Phyllanthus discoideus* | 9 | 5 | 36.59 | 48.71 | 23.74 | 28.72 | 1.40 | 2.76 | 39.76 | 101.37 |
| *phyllantus mullerianus* | 1 | 1 | 25.46 | 18.11 | 15.00 | 19.50 | 0.56 | 0.28 | 8.49 | 5.58 |
| *Piptadeniastrum africanum* | | 1 | | 256.52 | | 51.00 | | 57.43 | | 2928.79 |
| *pterygota macrocarpa* | 2 | 6 | 72.07 | 101.64 | 29.80 | 35.73 | 5.04 | 13.34 | 161.28 | 584.21 |
| *Pycnanthus angolensis* | 10 | 17 | 31.19 | 50.08 | 18.29 | 23.04 | 1.10 | 3.31 | 23.74 | 119.58 |
| *Ricinodendron heudelotii* | 16 | 14 | 45.15 | 66.15 | 19.69 | 25.51 | 2.36 | 5.17 | 64.88 | 177.66 |
| *Spondias mombin* | 1 | | 36.16 | | 23.50 | | 1.14 | | 26.81 | |
| *Sterculia rhinopetala* | 20 | 20 | 43.53 | 41.78 | 32.74 | 31.47 | 2.03 | 1.97 | 77.53 | 69.13 |
| *Sterculia tragacantha* | 13 | 22 | 38.30 | 42.28 | 21.35 | 19.40 | 1.92 | 2.20 | 60.63 | 65.96 |
| *Strombosia pustulata* | 47 | 65 | 26.74 | 24.62 | 15.79 | 15.08 | 0.72 | 0.58 | 13.01 | 9.42 |
| *Terminalia superba* | 17 | 16 | 58.84 | 155.75 | 20.66 | 39.11 | 4.96 | 29.06 | 178.68 | 1486.25 |
| *Treculia Africana* | | 2 | | 21.96 | | 13.85 | | 0.43 | | 5.89 |
| *Trichilia heudelotii* | 2 | 2 | 39.24 | 30.24 | 28.85 | 26.50 | 1.82 | 0.92 | 76.16 | 22.48 |
| *Trichilia monadelpha* | 1 | | 14.64 | | 18.00 | | 0.19 | | 3.37 | |
| *Trichilia prieureana* | 3 | 2 | 28.22 | 88.64 | 13.33 | 29.10 | 0.80 | 11.67 | 11.83 | 522.58 |
| *Uapaca togoensis* | | 1 | | 67.50 | | 29.90 | 0.00 | 3.98 | 0.00 | 118.90 |
| *Xylopia aethiopica* | 2 | 2 | 28.47 | 23.38 | 22.80 | 20.90 | 0.73 | 0.48 | 17.62 | 10.19 |
| *Xylopia villosa* | 57 | 39 | 17.09 | 17.09 | 11.50 | 11.18 | 0.29 | 0.28 | 3.86 | 3.60 |
| *Zantoxyllum zantoxynoides* | 1 | 1 | 23.30 | 37.87 | 26.20 | 28.40 | 0.48 | 1.25 | 12.41 | 35.55 |

### *Family distribution of tree species in Open and Close Canopy Structures*

The 64 and 56 tree species enumerated in open and closed canopy structures belong to 22 and 21 families, respectively. Fabaceae had the highest tree species composition in open (8) and closed (9) canopies, followed by Moraceae (6) and Meliaceae (6), respectively (Table 5). Out of 575 tree populations in open canopy, 109 trees belong to Fabaceae family, 69 trees belongs to Annonaceae family while Anacardiaceae and Phyllanthaceae had one tree population each. Out of 531 tree populations in closed canopy structure, Fabaceae family had the highest tree population (68), followed by Olacaceae (66), while Capparaceae, Clusiaceae and Phyllanthaceae had one tree population each. Meliaceae

(70.99cm) had the highest mean Dbh in open canopy structure, followed by Irvingiaceae (64.29cm), while Annonaceae (19.16cm) had the least mean Dbh. Similarly, in closed canopy structure, Combretaceae (155.75cm) had the highest Dbh, followed by Malvaceae (93.61cm) while Phyllanthaceae (16.01cm) had the least mean Dbh. Also, Moraceae (31.95m) and Annonaceae (13.64m) had the highest and lowest mean height,respectively, in open canopy structure, while Combretaceae (39.11m) and Annonaceae (11.66m) had the highest and lowest mean height, respectively, in closed canopy structure respectively.

**Table 5.** Family distribution of tree species in Open and Closed Canopy Structures

| FAMILY | Spp richness Open Canopy | Spp richness Close Canopy | Spp population Open Canopy | Spp population Close Canopy | Mean DBH(cm) Open Canopy | Mean DBH(cm) Close Canopy | Mean HT($m^3$) Open Canopy | Mean HT($m^3$) Close Canopy |
|---|---|---|---|---|---|---|---|---|
| Anacardiaceae | 1 | 0 | 1 | 0 | 36.16 | 0 | 23.50 | 0 |
| Annonaceae | 5 | 2 | 69 | 41 | 19.29 | 17.40 | 13.64 | 11.66 |
| Apocynaceae | 3 | 4 | 48 | 48 | 33.38 | 48.21 | 21.25 | 21.38 |
| Boraginaceae | 1 | 1 | 9 | 5 | 48.59 | 59.96 | 18.74 | 17.42 |
| Cannabaceae | 2 | 1 | 14 | 5 | 54.15 | 39.08 | 27.22 | 15.50 |
| Capparaceae | 0 | 1 | 0 | 1 | 0.00 | 58.88 | 0.00 | 17.80 |
| Chrysobalanaceae | 1 | 0 | 5 | 0 | 41.57 | 0.00 | 20.20 | 0.00 |
| Clusiaceae | 0 | 1 | 0 | 1 | 0.00 | 25.91 | 0.00 | 19.20 |
| Combretaceae | 1 | 1 | 17 | 16 | 58.84 | 155.75 | 20.66 | 39.11 |
| Ebenaceae | 3 | 3 | 68 | 55 | 28.06 | 29.56 | 20.72 | 25.83 |
| Euphorbiaceae | 4 | 5 | 28 | 22 | 43.87 | 58.15 | 23.48 | 25.51 |
| Fabaceae | 8 | 9 | 109 | 68 | 31.76 | 32.82 | 18.23 | 19.81 |
| Irvingiaceae | 1 | 0 | 2 | 0 | 64.29 | 0.00 | 28.50 | 0.00 |
| Malvaceae | 4 | 2 | 15 | 31 | 58.16 | 93.61 | 26.95 | 29.32 |
| Meliaceae | 8 | 6 | 36 | 57 | 70.99 | 57.57 | 24.93 | 21.88 |
| Moraceae | 6 | 5 | 15 | 7 | 41.95 | 47.01 | 31.95 | 26.54 |
| Myristicaceae | 1 | 1 | 10 | 17 | 31.19 | 50.08 | 18.29 | 23.04 |
| Olacaceae | 2 | 2 | 48 | 66 | 26.89 | 24.61 | 15.81 | 15.13 |
| Phyllanthaceae | 1 | 1 | 1 | 1 | 19.83 | 16.01 | 19.90 | 15.50 |
| Rubiaceae | 2 | 2 | 14 | 6 | 63.48 | 64.57 | 26.54 | 24.93 |
| Rutaceae | 2 | 2 | 2 | 2 | 20.88 | 33.58 | 19.60 | 21.10 |
| Sapindaceae | 1 | 2 | 5 | 11 | 28.27 | 32.83 | 21.56 | 21.55 |
| Sapotaceae | 2 | 1 | 7 | 9 | 35.06 | 35.82 | 16.13 | 15.44 |
| Sterculiaceae | 5 | 4 | 52 | 62 | 39.81 | 47.20 | 25.09 | 25.13 |
| **TOTAL** | **64** | **56** | **575** | **531** | | | | |

## Diameter and Height Distribution of Trees in Open and Closed Canopy Structure

The DBH class distribution of trees in open and closed canopy structure are shown in figures 3 and 4 below. In open canopy structure, tree populations decreased with an increase in Dbh class class of 10 – 20 cm had the highest tree population (163), followed by dbh class of 21-30 cm (159); while dbh classes 161 – 170, 181 – 190 and 221 – 230 cm had one tree population each. In closed canopy structure, Dbh distribution had an irregular trend; class of 21 - 30 cm had the highest tree population (163), followed by dbh class of 10 - 20 cm (130); while the dbh class of 171 – 180, 251 – 260, 301 – 310, 371 – 380 and 411 – 420 cm had one tree population each. The maximum Dbh class in open and close canopy structures were 221 – 230 cm and 411 – 420 cm, respectively.

The height class distribution of trees in open and closed canopy structures are shown in figures 5 and 6 below, both structures had a similar pattern of height distribution. In open canopy structure, height class of 11 - 20 m had the highest tree population (266), followed by height class of 21-30 m (163) while height class of 61 – 70 m had one tree population. Similarly, the highest tree population in closed canopy structure was found in height class of 11 – 20 m (250), followed by height class of 21-30 m (148), while height class of 91 – 100 m had each. The highest height classes of trees in open and closed canopy structures were 61 – 70 m and 91 – 100 m, respectively. More trees were observed in height classes between 1 – 30 m in open canopy than in closed canopy, while more trees were observed from height class 31 – 40 m and above, in closed canopy structure.

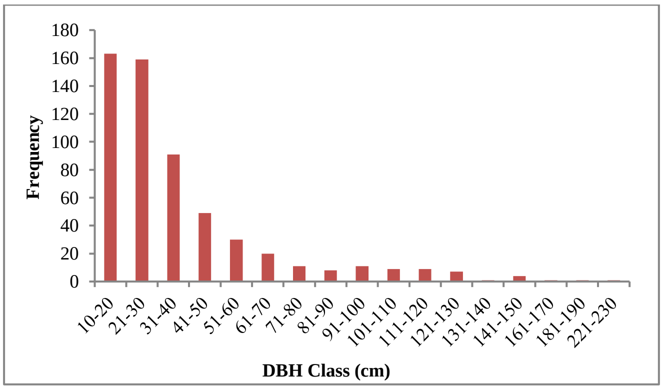


**Figure 3.** DBH distribution in Open Canopy Structure

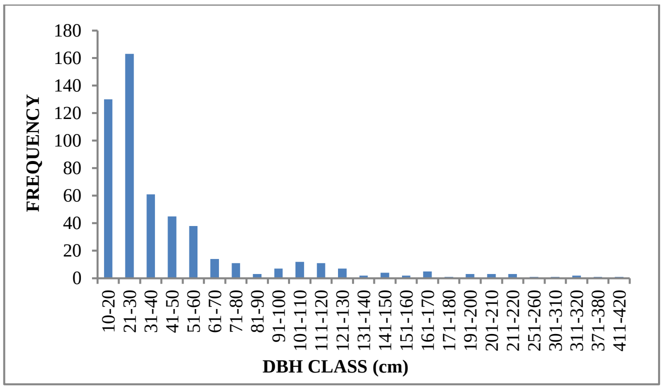


**Figure 4.** DBH distribution in Closed Canopy Structure

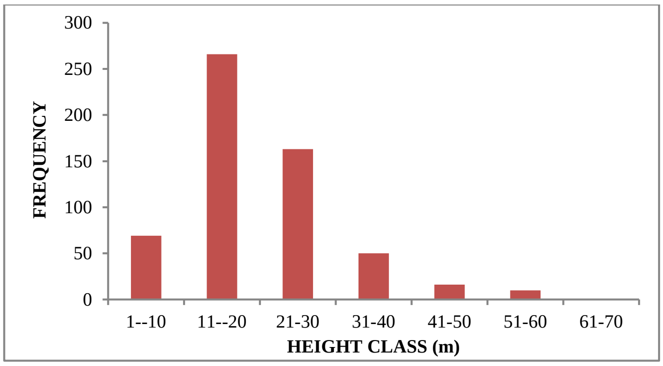


**Figure 5.** Height Class Distribution in Open Canopy Structure

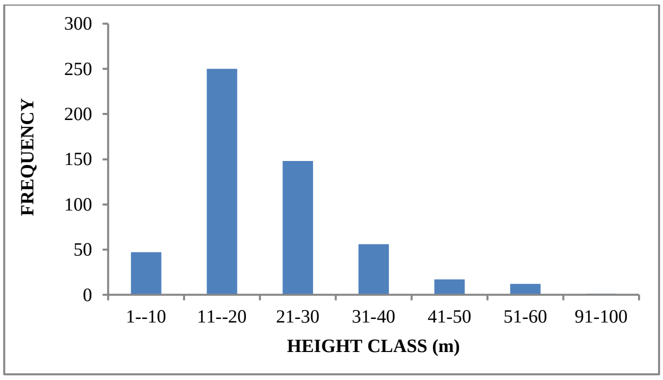


**Figure 6.** Height Class Distribution in Closed Canopy Structure

### *Summary of Tree Growth Variables in Open and Closed Canopy structures*

The summary of the tree growth variables in open and closed canopy structures are shown in Table 6. Average Dbh in open and closed canopies were 40.09 and 50.21, respectively. The maximum Dbh (cm) in open canopy was 222.79 (*Khaya grandifoliola*) and 413.75cm (*Ceiba pentandra*) in closed canopy structure. The average height (22.86m), maximum height (62.50m), basal area (110.01m$^2$/ha and volume (343.35m$^3$/ha) in open canopy structure were all less than the average height (23.05m), maximum height (92.00m), basal area (207.97m$^2$/ha and volume (842.49m$^3$/ha) in the close canopy structure; while only the minimum height (6.50m) in open canopy was higher than the minimum height (5.60m) in closed canopy.

**Table 6.** Summary of Tree Growth Variables in Open and Close Canopy structures

| VARIABLE | OPEN CANOPY | CLOSED CANOPY |
|---|---|---|
| Av. DBH (cm) | 40.09 | 50.21 |
| Max. Dbh (cm) | 222.79 | 413.75 |
| Tree sp. with max. Dbh | *Khaya grandifoliola* | *Ceiba pentandra* |
| Min. Dbh (cm) | 10.00 | 10.00 |
| Tree sp. with min. Dbh | *Pycnanthus angolensis* | *Xylopia villosa* |
| Av. Height (m) | 22.86 | 23.05 |
| Max. Height (m) | 62.50 | 92.00 |
| Min. Height (m) | 6.50 | 5.60 |
| Basal Area (m$^2$) / ha | 110.01 | 207.97 |
| Volume (m$^3$) / ha | 343.35 | 842.49 |

## DISCUSSION

### *Land Cover Classification and Area Coverage of each Land Cover of the SNR*

The land cover classification of the Strict Nature Reserve in Omo Biosphere Reserve revealed that the reserve is dominated by dense vegetation (closed canopy structure~~s~~), with traces of sparse vegetation (open canopy structure~~s~~) and water body. This could be linked to the fact that the reserve is a strict nature reserve under the management of UNESCO Man and the Biosphere Programme; hence, no anthropogenic activities are allowed in the reserve. Anthropogenic activities have been recognised globally as the major factors of habitat destruction and biodiversity decay (Chima and Ihuoma, 2014). Jimoh *et al.* (2012) and Ubaekwe *et al.* (2021), supported the assertion and specifically identified illegal logging, farming, industrialization, urbanization and access roads as the major factors that trigger dense vegetation destruction. Adekunle *et al.* (2014) added that inadequate forestry regulation and a declining workforce and capabilities in forestry agencies contribute also to loss of dense vegetations in developing countries. In other words, the above 70% coverage of dense vegetation (Closed canopy) in the reserve is an indication that the reserve is indeed a strict nature reserve, with little or no human disturbances. The result also highlighted the conservation and management success of the UNESCO Man and the Biosphere Programme. The over 70% coverage of the closed canopy structure~~s~~ could also be linked to the location of the reserve and the surrounding environment. It was observed that Omo Biosphere reserve is the core zone of Omo Forest Reserve, in other words, it is surrounded and protected by the buffer zone and the transition zone; and there was no access road that connects the reserve to the nearby community. The traces of sparse vegetation and water body in the reserve could be linked to more of natural factors than human factors. For instance, there were records of mature, tall and big trees that had naturally fallen to the ground due to factors such as thunderstorm and age, as observed during field data collection. The falling of these gigantic trees also affected the surrounding trees, leading to the creation of an open canopy structure in the affected areas.

### *Tree Species Composition, Diversity and Attributes in Open and Closed Canopy Structures*

The tree species that dominated the two canopy structures belong to the Moraceae, Meliaceae, Sterculiaceae and Fabaceae families while the rarest families are the

Bombaceae, Combretaceae and Chrysobalanaceae. This validates the report of Adekunle *et al*. (2014) and Adekunle *et al*. (2010), which recorded Sterculiaceae, Meliaceae, Moraceae and Ebenaceae as the dominant families in the tropical rainforest formation of Southwestern Nigeria. Meliaceae, Moraceae and Euphorbiaceae had also been recorded as the dominant families in the tropical rainforest of Doi Inthanon, Thailand by Kanzaki *et al*. (2004); the Xishuangbanna forest in southwest China by Lu *et al*. (2010) and the Andaman Giant evergreen forest in India by Rajkumar & Parthasarathy (2008). The low population (1) of several species in both canopy structures could be as a result of canopy effects. For instance, light demanding tree species would likely not survive under close canopy structure due to limited light availability, likewise shade tolerant tree species in open canopy structures. This would probably affect the population of the tree species. However, the representation of many tree species by few individuals is indicative of a highly heterogenous and diverse forest ecosystem.

The high diversity indices recorded in both structures indicates high tree species diversity. The diversity indices of the tree species in both structures were higher than the diversity of tree species (3.10) in Finima Nature Park, Bonny Island, Nigeria as reported by Ubaekwe *et al*. (2022); 2.20 – 2.65 diversity indices of Kodayar Forest Reserve in the West of Ghats, Southern India as reported by Sundaranpandian *and* Swamy (2000); and 3.31 diversity index of Kalakad Forest Reserve reported by Parthasarathy *et al*. (1999). However, the diversity indices recorded in both canopy structures are lower than the diversity index (3.79) of Oban Forest Reserve in Southeastern Nigeria reported by Jimoh *et al*. (2012) and the diversity index of 3.74 in SNR, Akure Forest Reserve Nigeria reported by Adekunle *et al*. (2013).

The diversity indices, species richness and tree population recorded in open canopy structure were comparably higher than what was recorded in the closed canopy structure. The same trend was reported by Kermavnar *et. al*. (2019), Singh *et al*. (2017) and Jimoh *et al*. (2012). This could be as a result of canopy effect; an open canopy structure gives more room for increased penetration of sunlight and rainfall to reach the forest floor, while high shading effects in closed canopy structure limits the amount of rainfall and sunlight reaching the forest floor. Dormann *et al*. (2020) reported that plant species richness and diversity increases with light availability; Pan and Guo, (2016) explained that adequate light availability influences seed germination, growth of seedlings and overall plant health; thus, encourages regeneration, species richness and diversity in open canopy structures of a forest ecosystem.

### *Diameter and Height Distribution of Trees in Open and Close Canopy Structures*

The floristic composition of the reserve is dominated by the understorey trees, and the diameter distribution exhibited an inverted J-shape curve. This is an indication of a stable ecosystem with a good regeneration potential. Similar findings were reported by Adekunle *et al*. (2010), Husch *et al*. (2003) and Ubaekwe *et al*. (2022). It was observed that open canopy structures were dominated by tree species with the lowest Dbh class (10–20 cm), unlike close canopy structures, which were dominated by a larger diameter class (21–30 cm), and the population of tree species in the middle stratum (11–20 m) was higher in open canopy structures than in closed canopy structures. This could be linked to different microclimatic conditions in both structures. The climatic conditions in open canopy structure encourage regeneration and fast growth of seedlings and saplings more than the conditions in closed canopy structures.

More so, the proportion of very big trees (Dbh > 100cm) in the closed canopy structure (11.11%) was far greater than the proportion of big trees (5.74%) in the open canopy structure. However, the proportion of big trees in both structures was greater than the 3.5% big trees recorded by Lu *et al*. (2010) in the tropical seasonal rainforests of Xishuangbanna, south-west China, and the 4.5% big trees recorded by Huang *et al*. (2003) in Tanzanian tropical forests. Similarly, the proportion of emergent trees (height > 40m) in the closed canopy structure (5.65%) was higher than the proportion of emergent trees in the open canopy structure (4.70%).

The variations in both Dbh and height in the two structures could be a result of competition for light, and variations in dominant tree species, age, and soil conditions. Rissanen *et al*. (2019) and Duursma *et al*. (2007) reported that trees in a closed canopy structure compete for access to sunlight due to limited light and thus tend to grow taller with expansive crowns in order to capture available light. Hence, there is a positive correlation between tree height and light interception capacity in closed canopy structures (Rijkers *et al*., 2000). It could also be as a result of age and maturity; Johnson *et al*. (2018) opined that older trees have had more time to grow and develop, thus developing larger diameters and heights when compared with younger trees, and older trees may have acclimatised; hence, having developed resilience and the ability to thrive in their environment. It could also be as a result of species composition as Hadi *et al*. (2009) and Jimoh *et al*. (2012) explained that various tree species have limited height and diameter they can naturally grow irrespective of environmental conditions. In other words, not all tree species have the ability to naturally grow tall and have large diameters. Consequently, the dominant tree species in the closed canopy structure might be tree species naturally characterised by tall heights and large diameters. More so, the horizontal and vertical structure of the reserve described a typical mature natural forest. Zheng *et al*. (2006) documented that the incidence of large trees in a forest ecosystem is a sign of a mature tropical rainforest. Saiter *et al*. (2011) added that a closed canopy structure and mature trees in various layers depict a mature phase of a natural forest.

The basal area per hectare obtained in both canopy structures were all higher than the basal area per hectare (54.64m$^2$/ha) recorded by Yang *et al*. (2008) in Mid-South Taiwan broadleaved rainforest; 47.8m$^2$/ha recorded in a riparian forest of Southern Pantanal (Wittmann *et al*., 2008); and 41.6m$^2$/ha recorded in Oban Division of Cross River National Park (Jimoh *et al*., 2012). However, the basal area per ha in the open canopy structure (110.01m$^2$/ha) was less than the 207.97m$^2$/ha recorded in the closed canopy structure of the reserve; and the 139.7m*2*/ha basal area recorded in the primary tropical forest of Indonesia (Kessler *et al*., 2005) but compared favourably with the 111.32m$^2$/ha basal area recorded in Okwangwo Forest, Cross River, Nigeria (Adeyemi *et al*., 2015). The high basal area in both structures is an indication of a well-stocked, stable, mature, and old-growth forest ecosystem and thus highlights conservation success. According to Alder and Abayomi (1994), a forest ecosystem with a high basal area per ha describes a well-stocked ecosystem. Jimoh *et al*. (2012) added that a forest ecosystem with a high basal area per hectare also describes a well-protected ecosystem with little or no human interference.

Tree volume is one of the basic parameters used to estimate the biomass and carbon accumulated within a forest ecosystem as well as measuring the productivity of the ecosystem. In this study, the volume per hectare recorded in the open canopy structure was lower when compared with the volume per hectare recorded in the closed canopy structure. In other words, the closed canopy structure of the reserve would have more biomass and carbon storage than the open canopy structure. The volume yield per hectare in both canopy structures were higher than the 145.22m$^3$/ha volume reported by Adekunle *et al.* (2013) in Akure Forest Reserve, Nigeria. The volume yield in the closed canopy structure was higher than 416m$^3$/ha recorded in the Italian Alps (Tonolli *et al.*, 2011) and 647.95m$^3$/ha recorded in Indian forests (Adekunle *et al.*, 2014). However, the volume yields in both canopies were less than the 971.09m$^3$/ha recorded in Eda Forest Reserve and the 1,866.9m$^3$/ha volume yield in Cross River National Park (Jimoh *et al.*, 2012). Different methods of volume yield estimation could contribute to the discrepancies in the results among other factors.

## CONCLUSION AND RECOMMENDATION

The study underscores the relevance of SNR as an *in situ* method in promoting species richness and diversity~~;~~ and safeguarding rare species and inhabitants under anthropogenic attack. The reserve is purely a strict nature reserve dominated by closed canopy structure; tall and mature trees with larger diameters. The tree species richness and diversity in the reserve were high when compared with other reserves in same tropical rainforest region. The dominant families in both canopies were mostly Moraceae, Meliaceae, Sterculiaceae and Fabaceae while the rarest families were the Bombaceae, Combretaceae and Chrysobalanaceae. *Milletia thonningii* and *Strombosia pustulata* were the dominant tree species in open and closed canopy structures respectively. Open canopy structure had more tree species richness, population and diversity while closed canopy structure had more emergent trees, with larger diameter and thus higher basal area and volume per hectare. The open canopy structure is dominated by the younger trees, thus the climatic conditions in open canopy structure support~~s~~ regeneration and early growth of trees more than the conditions in closed canopy structure. There were traces of species with very low populations with narrow range that could be vulnerable to extinction if not checked. Hence, the need to introduce conservation measures to avoid local extinction of such tree species.

## REFERENCES


Abegunde L and Adedeji O 2015: Impact of Land Use Change on Surface Temperature in Ibadan, Nigeria. *International Journal of Environmental and Ecological Engineering*, **9**, 235-241.

Addo-Fordjour P, Anning AK, Atakora EA and Agyei PS 2009: Diversity and distribution of climbing plants in a semi-deciduous rain forest, KNUST botanic garden, Ghana. *Int. J. Bot.*, 4,186-195.

Adekunle VA, Nair NK, Srivastava AK and Singh NK 2014: Volume yield, tree species diversity and carbon hoard in protected areas of two developing countries. *Forest Science and Technology*, **10**(2), 89-103. DOI: 10.1080/21580103.2013.860050

Adekunle VA, Olagoke A and Akindele S 2013: Tree species diversity and structure of a Nigerian strict nature reserve. *Tropical Ecology*, **54**(3), 275-289.

Adekunle VAJ, Olagoke AO and Ogundare LF 2010: Rate of timber production in a Tropical Rainforest Ecosystem of Southwest Nigeria and its implications on Sustainable Forest Management. *Journal of Forestry Research* **21**: 225–230.

Adeyemi AA, Ibe AE and Okedimma FC 2015: Tree structural and species diversities in Okwangwo forest, Cross River State, *Nigeria. Journal of Research In Forestry, Wildlife And Environment*, **7**(2): 30 - 41.

Alder D and Abayomi JO 1994: Assessment of data requirements for sustained yield calculations. A consultancy report prepared for the Nigerian Tropical Forest Action Plan, FORMECU. *Federal Department of Forestry, Ibadan, Nigeria*. 76.

Anning A, Akyeampong S, Addo-Fordjour P, Anti K, Kwarteng A and Tettey Y 2009: Floristic composition and vegetation structure of the KNUST Botanic Garden, Kumasi, Ghana. *Journal of Science and Technology* **28** (3):103-122.

Barbier S, Gosselin F, Balandier P 2008: Influence of tree species on understory vegetation diversity and mechanisms involved. A critical review for temperate and boreal forests. *For Ecol Manage* 254:1–15.

Chima UD, Qi D, Wu Z, Lan G and Chen L 2022: Diversity, Interspecific Interaction and Abundance of Undergrowth in Monocultures and Integrated Systems of Natural Rubber Plantation in Danzhou, Southern China. *Journal of Forest and Environmental Science*, **38**(2), 75-89.

Chima UD and Ihuma JO 2014: Natural Forest Conversion and Its Impact on Populations of Key Livelihood Tree Species in Omo Biosphere Reserve. *Nigeria. Journal of Research in Forestry, Wildlife and Environmental*, **6**(2), 1-12.

Chima UD, Ola-Adams BA, Adedire MO and Oyelowo OJ 2009: Impact of Land Use Changes on Soil Quality of A Biosphere Reserve in Southwestern Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, **1**(1), 111-122.

Dormann C, Bagnara M, Boch S, Hinderling J, Janeiro-Otero A, Schäfer D, Schall P and Hartig F 2020: Plant species richness increases with light availability, but not variability, in temperate forests understorey. *BMC Ecology*, **20**:43 https://doi.org/10.1186/s12898-020-00311-9

Duursma RA, M¨ akel¨ aA 2007: Summary models for light interception and light-use efficiency of non-homogeneous canopies. Tree Physiol. **27**(6), 859–870. https://doi. org/10.1093/treephys/27.6.859.

Garkoti SC, Singh SP 1997: Structure and functioning of herbaceous vegetation in high mountains of Central Himalaya. *Trop Ecol*. **38**: 153-156.

Food and Agricultural Organisation (FAO) 2005: Global Forest Resources Assessment. *FAO forestry paper 147*. Rome.

Hadi S, Ziegler T, Waltert M and Hodges JK 2009: Tree diversity and forest structure in Northern Siberut, Mentawai Islands, Indonesia. *Tropical Ecology* **50**(2):315-327.

Hall JB, Harris DJ, Medjibe V and Ashton PMS 2003: The effects of selective logging on forest structure and tree species composition in a central African Forest: implications for management of conservation areas. *Forest Ecology and management*, 183, 249–264.

Husch B, Charles IM and Thomas WB 2003: *Forest Mensuration*. New York: The Ronald Press Company. 410.

Isichei AO 1995: Omo biosphere reserve: current status, utilization of biological resources and sustainable management (Nigeria). *UNESCO South-South cooperation programme on Environmentally Sound Socio-Economic Development in the Humid Tropics*. Working paper 11:48.

Ishii H, Azuma W, Nabeshima E 2013: The need for a canopy perspective to understand the importance of phenotypic plasticity for promoting species coexistence and light-use complementarity in forest ecosystems. *Ecol. Res* 28: 191–198. https://doi.org/10.1007/s11284-012-1025-6.

Jimoh SO, Adesoye PO, Adeyemi AA and Ikyaagba ET 2012: Forest Structure Analysis in the Oban Division of Cross River National Park, Nigeria. *Journal of Agricultural Science and Technology* **2.5**: 510-518.

Kanzaki M, Hara M, Yamakura T, Ohkubo T, Tamyra MN, Sri-Ngernyuan GK, Sahunalu P, Teejuntuk S & Bunyavejchewin S 2004: Forest diversity and dynamism: findings from a large-scale plot network. pp. 474-481. *In*: E. C. Losos & E. G. Leigh (eds.) *The Diversity of Tropical Trees: Background.* Chicago University Press, Chicago.

Kermavnar J, Marinšek A, Eler K and Kutnar L 2019: Evaluating Short-Term Impacts of Forest Management and Microsite Conditions on Understory Vegetation in Temperate Fir-Beech Forests: Floristic, Ecological, and Trait-Based Perspective. *Forests*; **10**(10): 909. https://doi.org/10.3390/f10100909

Kessler M, Keber PJA, Gradstein SR, Bach K, Schmull M & Pitopand R 2005: Tree diversity in primary forest and different land use systems in Central Sulawesi, Indonesia. *Biodiversity and Conservation* **14**: 547-560.

Kumar M, Verma AK, Garkoti SC 2020: Lantana camara and Ageratina adenophora invasion alter the understory species composition and diversity of chir pine forest in central Himalaya, India. *Acta Oecologica*. https://doi.org/10.1016/j.actao.2020.103642.

Lü XT, Yin JX & Tang JW 2010: Structure, tree species diversity and composition of tropical seasonal rainforests in Xishuangbanna, south-west China. *Journal of Tropical Forest Science* **22**: 260-270.

Okali DUU and Ola Adams BA 1987: Tree population changes in treated rainforest at Omo Forest Reserve, South Western Nigeria. *Nig. Jour. Of Trop. Eco.*, **3**: 291: 313.

Pan J and Guo B 2016: Effects of Light Intensity on the Growth, Photosynthetic Characteristics, and Flavonoid Content of Epimedium pseudowushanense B.L.Guo. *Molecules*. 4; **21**(11):1475. doi: 10.3390/molecules21111475.

Parthasarathy N 1999: Tree diversity and distribution in undisturbed and human impacted sites of tropical wet evergreen forest in southern Western Ghats, India. *Biodiversity and Conservation* **8**:1365-1381.

Pielou EC 1966: The measurement of diversity in different types of biological collections. *J. Theor. Biol*.13:131–144. https://doi.org/10.1016/0022- 5193(66)90013-0.

Rajkumar M and Parthasarathy N 2008: Tree Diversity and Structure of Andaman Giant Evergreen Forests India. *Taiwania*, 53, 356–368.

Rijkers T, Pons TL & Bongers F 2000: The effect of tree height and light availability on photosynthetic leaf traits of four neotropical species differing in shade tolerance. *Functional Ecology*, **14**(1), 77-86. https://doi.org/10.1046/j.1365-2435.2000.00395.x

Rissanen K, Martin-Guay MO, Riopel-Bouvier AS and Paquette A 2019: Light interception in experimental forests affected by tree diversity and structural complexity of dominant canopy, *Agricultural and Forest Meteorology*, vol. **278**, 107655. https://doi.org/10.1016/j.agrformet.2019

Saiter FZ, Guilherme FAG, Thomaz LD & Wendt T 2011: Tree changes in a mature rainforest with high diversity and endemism on the Brazilian coast. Biodiversity Conservation **20**: 1929-1949.

Singh R, Sagar R, Srivastava P, Singh P and Singh J 2017: Herbaceous species diversity and soil attributes along a forest-savanna-grassland continuum in a dry tropical region. *Ecological Engineering*, 103, 226-235. ISSN 0925-8574, https://doi.org/10.1016/j.ecoleng.2017.04.020.

Sundarapandian SM and Swamy PS 2000: Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. *Journal Tropical Forest Science* **12**:104-123.

Tonolli S, Rodeghiero M, Gianelle D, Dalponte M, Bruzzone L and Vescovo L 2011. Mapping and modeling forest tree volume using forest inventory and airborne laser scanning. *European Journal of Forest Research*, **130**, 569-577.

Tonteri T, Salemaa M, Rautio P and Merila P 2016: Forest management regulates temporal change in the cover of boreal plant species. Forest Ecology and Management, 381:115-124.

Ubaekwe RE, Chima UD and Eguakun FS 2022: Spatio-Temporal Classification and Prediction of Land Use and Land Cover Change in Finima Nature Park Bonny Island, Nigeria *Journal of Geography, Environment and Earth Science International*. **26**(8): 40-53.

Ubaekwe RE, Chima UD and Okonkwo NO 2021: Geospatial Assessment of Land Use/Land Cover Change and its Impact on Forest Cover in Owerri, Imo State, Nigeria. *Nature Science*, 19(10), 30-38. ISSN1545-0740 (print); ISSN 2375-7167 (online). Available: http://www.sciencepub.net/nature .5

Ubaekwe R 2020: Carbon Stock and Storage Capacity of Tree Species in Strict Nature Reserve of Omo Biosphere Reserve, Ogun State, Nigeria. *Asian Journal of Environment and Ecology*, **13**(3): 26-36.

Ukonmaanaho L, Merilä P, Nöjd P and Nieminen T 2008: Litterfall production and nutrient return to the forest floor in Scots pine and Norway spruce stands in Finland. *Boreal Environment Research*. **13**. 67-91.

Valladares F, Laanisto L, Niinemets U, Zavala MA 2016: Shedding light on shade: ecological perspectives of understorey plant life. *Plant. Ecol. Divers*. **9** (3): 237-251 https://doi.org/10.1080/17550874.2016.1210262

Wittmann F, Zorzi BT, Tizianel FAT, Urquiza MVS, Faria RR, Sousa NM, Modena EDS, Gamarra RM and

Rosa ALM 2008: Tree Species Composition, Structure, and Aboveground Wood Biomass of a Riparian Forest of the Lower Miranda River, Southern Pantanal, Brazil. *Folia Geo-botany* **43**:397–411.

Yang KC, Lin JK, Hsieh CF, Huang CL, Chang YM, Kuan LH and Chiu ST 2008: Vegetation Pattern and Woody Species Composition of a Broad-Leaved Forest at the Upstream Basin of Nantzuhsienhsi in Mid-southern Taiwan. Taiwania. **53**: 325–337.

Zheng Z, Feng Z, Cao M, Li Z, Zhang J 2006: Forest Structure and Biomass of a Tropical Seasonal Rainforest in Xishuangbanna, Southwest China. *Biotropica* **38**: 318–327.