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Original Article

# Species diversity and abundance of anthropogenically disturbed areas of a Strict Nature Reserve in Ondo State, Nigeria

OPEN ACCESS

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**A B S T R A C T**

*This study evaluated the impacts of anthropogenic activities on tree species diversity and abundance. Tree species diversity and abundance of the degraded and undisturbed areas of the forest were assessed and compared. A total of 16 temporary, equal-sized plots (25m x 25m) were laid in both the degraded and undisturbed areas of the SNR using the systematic sampling technique. In each of the sampling plots, tree growth data were collected from all the living trees categorised as mature trees with Diameter at Breast Height (DBH) ≥ 10cm, saplings (DBH 1-9 cm), and seedlings (DBH ≤ 1.0cm). The trees were identified to species level and classified into families. In the overstory layer, 46 species from 18 families and 32 species from 15 families were encountered in the undisturbed and degraded areas, respectively. The sapling density per hectare was 91.8% more in the undisturbed area than what was recorded in the degraded area. The diameter distribution curve revealed a significant decline in tree density per hectare in the degraded area. The Jaccard similarity index between the degraded and undisturbed areas reveals that the overstory, sapling, and seedling layers were 42%, 27%, and 29% similar, respectively. The degraded area exhibited a significant loss of native tree species. The findings suggest that anthropogenic disturbances have significantly reduced tree species diversity and abundance in the degraded area. Hence, immediate conservation actions, including logging bans, agricultural restrictions, and enrichment planting, are essential to restore the degraded forest.*

K E Y W O R D S : *COVID-19 pandemic, Forest restoration, Hemp planting, Native species*

## INTRODUCTION

The world's forest covered approximately 50 percent of the earth's surface about eight thousand years ago, and has decreased from 32.5% to 30.8% in the last three decades (FAO and UNEP, 2020). Forest is one of the world's most valuable natural ecosystems and a natural habitat for wildlife worldwide (Wei *et al*., 2020). Our greatest asset to fight global warming is tropical forests because they cool the planet by more than a degree (WWF, 2023). Tropical forests are beginning to act as a carbon source, not a sink, under the pressures of a warming, drying and increasingly extreme climate (Zuidema *et al*., 2022). The widespread and increasing deforestation and degradation in the planet's three largest tropical forest basins, the Amazon, Congo and Southeast Asia, could deliver a global climate catastrophe (WWF, 2023). Forests are not only crucial for carbon sequestration but also for maintaining biodiversity, supporting food security,human health and livelihoods (Camara-Leret & Denney, 2019). The global tree search database in 2019 records over 60,000 species of trees, more than

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20,000 of which have been included in the IUCN Red List and over 8,000 of which are assessed as globally threatened (IUCN, 2019). Nonetheless, the rate at which tree species are disappearing differs from nation to nation and continent to continent.

Africa has 635 million hectares of forests, which account for 21.4 percent of its land area, which is equal to 16percentof the global forested area (Ahmed & Olaitan, 2023). Globally, Africa had the highest net loss of forest area in 2010–2020, with a loss of 3.94 million hectares per year (FAO & UNEP, 2020). Nigeria is among the countries in Africa with a high deforestation rate. Between 2000 and 2010, the rate of deforestation in Nigeria was 3.7%, which was third after Cameroon (9.3%) and Togo (5.1%) (Anonymous, 2010). Fasona *et al.* (2020) reported a 3.3% deforestation rate of primary forest between 1986 and 2016 and 10% between 2006 and 2016 in Southwest Nigeria. At this current rate deforestation, the primary forests in Southwestern Nigeria might be history in the next two decades if this menace is not given urgent attention.

From time immemorial, human beings intertwined with the forest and exclusively depended on it for shelter, clothing, food, medicine and aesthetic functions (Ahmed & Aliyu, 2019). Deforestation does not only result in the loss of plant species but also the permanent loss of their potential benefits to man. To date, only about 7% of tropical plants have been screened for chemical compounds that may prove useful in the development of pharmaceuticals, yet approximately 25% of modern-day prescription drugs are derived from such compounds (Onyekwelu & Lawal, 2018).

SNR2 is one of the two strict nature reserves in Southwestern Nigeria). This forest suffered unprecedented degradation from illegal loggers and Indian hemp (*Apocynum cannabinum*) planters in 2020, during the COVID-19 pandemic period. These miscreant elements took advantage of the lockdown to wreck huge havoc on this protected area. During the period, a large portion of the SNR was completely cleared for Indian hemp planting and loggers illegally cut down and carted away many big trees. In the process, several plant species were destroyed. This study evaluated the impact of the wanton destruction that took place in the SNR on tree species diversity and abundance by comparing the present status of the degraded and undisturbed areas of the forest.

## MATERIALS AND METHOD

### Study Area

This study was carried out in Strict Nature Reserve 2(SNR2) located within Akure Forest Reserve, Ondo State, Nigeria. The SNR lies between latitude 06.59718° N and longitude 004.49199º E in Akure Forest Reserve, Ondo State, Nigeria. It was constituted by the federal government of Nigeria in 1948 and the Forestry Research Institute of Nigeria (FRIN) was saddled with the responsibility of maintaining this forest. The forest covers an area of about 32 hectares (Adeduntan & Olusola, 2013). The area is gently undulating and lies on a general altitude of 229 m above sea level (Jones 1948). The climate is humid tropical with seasonal variation (Lawal & Adekunle 2013). The mean annual rainfall is about 4000 mm with double maxima in the months of July and September and a short relatively dry period in August. December through to February constitutes the major dry season (Ola-Adams & Hall, 1987). The monthly mean temperature is about 27◦C, a condition that is conducive to the development of tropical rainforest.

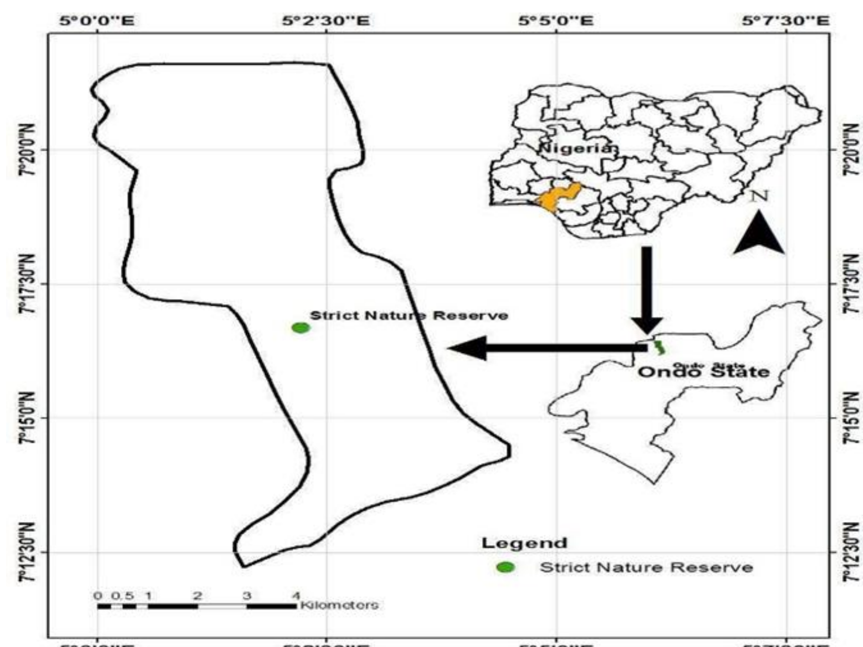


**Figure 1: Map of the Strict Nature Reserve**

**Method of Data Collection**

Systematic sampling technique was used for data collection. This entails the laying of two parallel transects of 1100 m with a distance of 500 m between them in the degraded and undisturbed portions of the SNR. Sample plots of 25 m × 25 m were laid in alternate direction along each transect at an interval of 250 m. A total of four plots were laid per transect and a total of eight sample plots in each of the selected forest classification. All living trees were categorized as mature trees (DBH≥ 10cm), saplings (DBH between 1 and 10cm) and seedlings (DBH< 1.0cm) according to Onyekwelu *et al*. (2022). In each plot, all three categories were identified, counted and recorded. Possible effort was made not to omit any tree in a sample plot. This is because any species omitted would indicate the absence of such species in the ecosystem.

**Data Analysis**

**Stand basal area estimation**

The basal area of all trees in the sample plots in the selected study area was calculated using the formula:

$$BA = \frac{\pi D^2}{4} \qquad (1)$$

Where BA = Basal area ($m^2$), D = Diameter at breast height (cm) and π = Pie (3.142).

The total basal area for each of the sample plots was obtained by the sum of the BA of all trees in the plot.

Basal area per hectare was obtained by multiplying mean basal area per plot with the number of 25×25m plots in a hectare (16).

**Tree species classification and biodiversity indices**

All the trees were classified into species and families. Several biodiversity indices were used for comparing the abundance and diversity of the tree, sampling and wildling species as done by Saiter*et al.* (2011) and Adekunle *et al.* (2013). The indices are:

(i) The relative density of the species was computed as:

$$RD = \frac{n_i}{N} \times 100 \qquad (2)$$

Where: RD = species relative density, $n_i$ = number of individual of species I, N = total number of all individual trees of all species in the entire community.

(ii) Species relative frequency (RF) was computed as:

$$RF = \frac{\text{Frequency of a species}}{\text{Sum frequencies of all species}} \text{ x } 100 \qquad (3)$$

(iii) Species relative dominance ($RD_O$ (%)) was computed using the equation:

$$RD_O = \frac{\sum Ba_i \times 100}{\sum Ba_n} \qquad (4)$$

Where: $Ba_i$ = basal area of individual tree belonging to species I, $Ba_n$ = stand basal area

ImportanceValue Index (IVI) or coverage index (CI) for each species was computed as:

$$IVI = \frac{RD + \text{RF} + \text{RDo}}{3} \qquad (5)$$

(v) Family Importance Value (FIV)

The Family Importance Value (FIV) was used to understand a family's share in the tree community. FIV is defined as the sum of its relative dominance (RDm), its relative density (RD) and its relative frequency (RF), which is

Calculated as follows:

$$RD_m = \frac{\text{Total basal area for a family}}{\text{Total basal area for all families}} X\ 100 \quad (6)$$

$$RD = \frac{\text{Number of individual of a family}}{\text{total number of all individual}} X\ 100 \quad (7)$$

$$RF = \frac{\text{Frequency of a family}}{\text{sum frequencies of all families}} X\ 100 \quad (8)$$

Thus,

Family Importance Value = RDm + RD + RF (9)

(vi) Species evenness in each site was determined using Shannon's equitability ($E_H$) (eqn. 10):

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{S} P_i \, ln(P_i)}{ln(S)} \qquad (10)$$

(vii) Margalef's index was calculated using the equation 11:

$$D = \frac{S-1}{ln\, N} \qquad (11)$$

Where: S = number of species; N = number of individuals

(viii) Simpson's index

$$D = 1 - \sum \left(\frac{n_i}{N}\right)^2 \qquad (12)$$

Where: $n_i$ = number of individual of species I; N = total number of all tree species in the entire community

(ix) Species diversity index was calculated using the Shannon-Weiner diversity index (Kent and Coker, 1992):

$$H' = -\sum_{i=1}^{S} p_i \, ln(\, p_i) \qquad (13)$$

Where; H' = Shannon-Weiner diversity index, S = Total number of species in the community, $P_i$ = Proportion of S made up of the $i^{th}$ species,ln = natural logarithm

(x) Shannon's maximum diversity index was calculated using the relationship:

$$H_{max} = \ln(S) \quad (14)$$

Where; $H_{max}$ = Shannon's maximum diversity

(xi) Mangalef's index was calculated using the equation below:

$$D = \frac{S-1}{\ln N} \quad (15)$$

Where; S = number of species, N = number of individuals

(xii) Menhinick's Index (D) of species richness was computed as:

$$D = \frac{S}{\sqrt{N}} \quad (16)$$

Where: D: Menhinick's index, S: Number of species, N: Number of individuals

Two similarity indices were used to assess species presence or absence between different paired forest portions according to Hammond and Pokory (2020).

(xiii) Sorensen's coefficient similarity index (SCSI) was computed according to.

$$SCSI = \frac{2M}{2M+N} \quad (17)$$

(xiv) Jaccard coefficient similarity index (JCSI)

$$JCSI = \frac{M}{M+N} \quad (18)$$

M is the number of species matches within the comparison pair and N is the sum number of species frequencies at forest areas in a column with a presence in just one row of species frequency.

## RESULTS AND DISCUSSION

### Results

In the degraded area of the SNR, *Pterigota macrocarpa* had the highest density per hectare (28), followed by *Sterculia rhinopetala* (24) and *Cola gigantean* (22). *Cola gigantean* had the highest basal area and species importance ((3.31m$^2$, 13.47), followed by *Sterculia rhinopetala* (2.25m$^2$, 11.97). While *Triplochiton scleroxylon* ranked third in terms of basal area per hectare (3.97m$^2$), *Pterygota macrocarpa* rated third in terms of species important value (10.45) as presented in Table 1. In the undisturbed area of SNR, *Mansonia altissima* (76) had the highest density per hectare, followed by *Celtis zenkeri* (62) and *Nesogordonia paverifera* (30). More so, basal area per hectare was in this order *Entandrophragma angolense* (12.87m$^2$) >*Triplochiton scleroxylon* (9.08m$^2$) *sterculiarhinopetala* (7.96m$^2$) >*Mansoniaaltisima* (4.99m$^2$) respectively. In addition, *Mansonia altisima* had the highest species important value (9.79) in the undisturbed area of the SNR. This was followed by *Triplochiton scleroxylon* (8.34), *Entandrophragma angolense* (8.32), *Sterculia rhinopetala* (8.08) and *Celtis zenkerii* (7.98) as shown in Table 2.

The family importance value for trees in the degraded and undisturbed areas of the study area is presented in Tables3 and 4 respectively. There were more families in the undisturbed forest area (18) than in the degraded area (15). In this study, sterculiaceae had the highest number of species in both degraded (8) and undisturbed (11) portions of the forest. The family sterculiaceae had the same important value in both locations of the forest. In the degraded area, FIV was in the order: euphorbiaceae (10.02) >meliaceae (8.35) >sapotaceae (7.49)>sapindaceae (1.82). In the undisturbed area of the forest, sterculiaceae andmeliaceae had the highest and second highest FIV (25.72, 15.34). This was followed by ulmaceae (8.33) and annonaceae (5.64). The family Verbenaceae had the least FIV (1.23) in theundisturbed area of the forest, as presented in Table 4.

The diameter of trees found in the undisturbed and degraded areas of the forest ranged from 10.5cm to 175cm and 11.0cm to 119.2cm respectively (Fig. 2). In both selected locations of the forest for this study, the majority of trees were in the lower diameter class. The number of trees in the subsequent higher diameter classes decreased as the tree diameter increased. The diameter distribution curve obtained for the two contrasting areas followed the usual inverted J-shaped curve typical of tropical natural forest ecosystem. The number of trees decreased with an increase in tree diameter.

The phytosociological characteristics and biodiversity indices for the overstory and understory species are presented in Table 5. Tree density per hectare in the degraded area and undisturbed area of the forest were 194 and 468 respectively. In addition, the sapling density per hectare in the undisturbed area was 1480 and 122 in the degraded area; the seedling density was 318 in the degraded area and 1840 in the undisturbed area of the forest.

Although tree mean diameter was reported to be higher in the degraded area of the forest (38.23), other growth characteristics were comparatively greater in the undisturbed area of the forest, as presented in Table 5. A total of 46 tree species belonging to 18 families and 32 species belonging to 15 families were found in the undisturbed and degraded areas, respectively. The Shannon-Wiener diversity index was 3.17 in the undisturbed area of the forest and 3.06 in the degraded area. The Margalef index was higher in the undisturbed area (8.25) than the degraded portion (5.89). The Simpson index recorded for the two areas of the forest was 0.93. The Menhinick index further revealed a higher species richness in the undisturbed area of the forest (3.01) than the degraded area (2.30). The Shannon's equitability index of abundance of the different species was higher in the degraded area (0.88) than in the undisturbed area (0.83) of the forest. The species evenness was 0.52 for the undisturbed and 0.67 for the degraded.

**Table 1: Density/ha and species importance value indices (IVI) for tree species in the degraded portion of SNR2**

| S/N | Species | Density/Ha | BA($m^2$) | RD | RF | RDo | IVI |
|---|---|---|---|---|---|---|---|
| **1** | *Alstonia boonei* | 6 | 0.34 | 3.09 | 4.35 | 1.11 | 2.85 |
| **2** | *Amphimas pterocapoides* | 2 | 0.27 | 1.03 | 1.45 | 0.90 | 1.13 |
| **3** | *Antiaris toxicaria* | 2 | 0.07 | 1.03 | 1.45 | 0.23 | 0.90 |
| **4** | *Blighia sapida* | 2 | 0.06 | 1.03 | 1.45 | 0.21 | 0.90 |
| **5** | *Buchholzia coriacea* | 2 | 0.04 | 1.03 | 1.45 | 0.12 | 0.87 |
| **6** | *Celtis mildbraedii* | 6 | 0.37 | 3.09 | 4.35 | 1.22 | 2.89 |
| **7** | *Celtis zenkeri* | 6 | 0.51 | 3.09 | 4.35 | 1.69 | 3.04 |
| **8** | *Chrysophyllum albidum* | 2 | 0.57 | 1.03 | 1.45 | 1.87 | 1.45 |
| **9** | *Cleistopholis patens* | 4 | 0.51 | 2.06 | 2.90 | 1.69 | 2.22 |
| **10** | *Cola gigantean* | 22 | 6.61 | 11.34 | 7.25 | 21.82 | 13.47 |
| **11** | *Cola hispida* | 4 | 0.08 | 2.06 | 2.90 | 0.27 | 1.74 |
| **12** | *Cordia millenii* | 8 | 0.62 | 4.12 | 2.90 | 2.03 | 3.02 |
| **13** | *Drypetes floribunda* | 4 | 0.36 | 2.06 | 2.90 | 1.17 | 2.05 |
| **14** | *Hura crepitans* | 6 | 0.20 | 3.09 | 4.35 | 0.67 | 2.70 |
| **15** | *Khaya grandifoliola* | 4 | 1.91 | 2.06 | 2.90 | 6.31 | 3.76 |
| **16** | *Malacantha alnifolia* | 10 | 0.99 | 5.15 | 5.80 | 3.25 | 4.74 |
| **17** | *Mansonia altissima* | 10 | 1.45 | 5.15 | 5.80 | 4.80 | 5.25 |
| **18** | *Margaritaria discoidea* | 2 | 0.23 | 1.03 | 1.45 | 0.76 | 1.08 |
| **19** | *Musanga cecropioides* | 2 | 0.03 | 1.03 | 1.45 | 0.10 | 0.86 |
| **20** | *Nesogordonia papaverifera* | 4 | 0.92 | 2.06 | 1.45 | 3.05 | 2.19 |
| **21** | *Pterocarpus mildbraedii* | 2 | 0.04 | 1.03 | 1.45 | 0.14 | 0.87 |
| **22** | *Pterygota macrocarpa* | 28 | 2.49 | 14.43 | 8.70 | 8.23 | 10.45 |
| **23** | *Pycnanthus angolensis* | 2 | 0.30 | 1.03 | 1.45 | 1.00 | 1.16 |
| **24** | *Ricinodendron heudelotii* | 4 | 0.49 | 2.06 | 1.45 | 1.62 | 1.71 |
| **25** | *Spathodea campanulata* | 2 | 0.03 | 1.03 | 1.45 | 0.11 | 0.86 |
| **26** | *Sterculia oblonga* | 2 | 0.08 | 1.03 | 1.45 | 0.26 | 0.91 |
| **27** | *Sterculia rhinopetala* | 24 | 4.50 | 12.37 | 8.70 | 14.84 | 11.97 |
| **28** | *Terminalia superb* | 4 | 1.28 | 2.06 | 2.90 | 4.21 | 3.06 |
| **29** | *Trichilia monadelpha* | 2 | 0.12 | 1.03 | 1.45 | 0.39 | 0.96 |
| **30** | *Trichilia welwitschii* | 2 | 0.03 | 1.03 | 1.45 | 0.09 | 0.86 |
| **31** | *Trilepisium madagascariense* | 6 | 0.84 | 3.09 | 2.90 | 2.78 | 2.92 |
| **32** | *Triplochiton scleroxylon* | 8 | 3.97 | 4.12 | 4.35 | 13.10 | 7.19 |
| **Total** | | 194 | 30.31 | 100 | 100 | 100 | 100 |

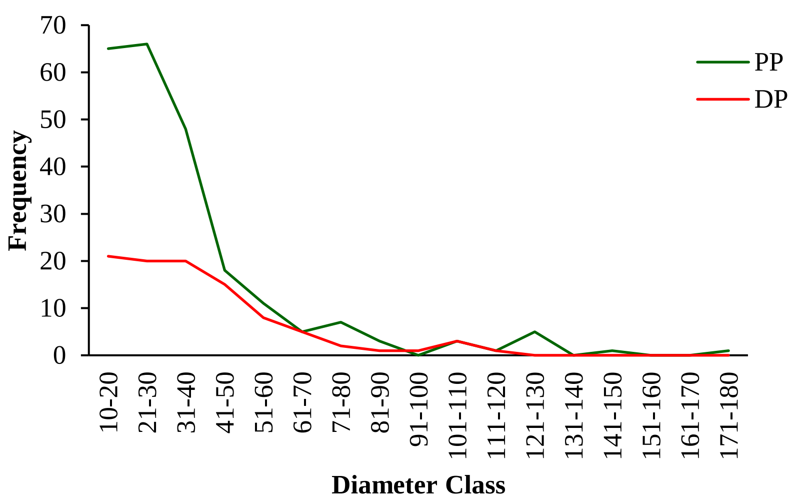


**Figure 2: Diameter distribution of trees in the undisturbed portion (pp) and degraded portion (Dp) of the study area.**

**Table 2: Density/ha and species important value indices (IVI) for tree species in the undisturbed portion of SNR2**

| S/N | Species | Freq/ha | BA ($m^2$) | RF | RD | RDo | IVI |
|---|---|---|---|---|---|---|---|
| 1 | *Amphimaspterocarpoides* | 2 | 0.20 | 0.85 | 0.43 | 0.29 | 0.52 |
| 2 | *Anonidiummannii* | 28 | 2.87 | 3.39 | 5.98 | 4.13 | 4.50 |
| 3 | *Buchholzia coriacea* | 2 | 0.16 | 0.85 | 0.43 | 0.22 | 0.50 |
| 4 | *Celtis mildbraedii* | 12 | 1.45 | 5.93 | 2.56 | 2.10 | 3.53 |
| 5 | *Celtis philippensis* | 8 | 0.79 | 1.69 | 1.71 | 1.14 | 1.52 |
| 6 | *Celtis zenkeri* | 62 | 3.31 | 5.93 | 13.25 | 4.77 | 7.98 |
| 7 | *Chrysophyllum albidum* | 10 | 1.96 | 2.54 | 2.14 | 2.83 | 2.50 |
| 8 | *Chrysophyllumperpulchrum* | 6 | 0.44 | 2.54 | 1.28 | 0.64 | 1.49 |
| 9 | *Cleistopholis patens* | 2 | 1.71 | 0.85 | 0.43 | 2.46 | 1.25 |
| 10 | *Cola acuminate* | 2 | 0.03 | 0.85 | 0.43 | 0.05 | 0.44 |
| 11 | *Cola gigantean* | 16 | 1.76 | 3.39 | 3.42 | 2.34 | 3.05 |
| 12 | *Cola millenii* | 8 | 0.24 | 1.69 | 1.71 | 0.35 | 1.25 |
| 13 | *Cola nitida* | 2 | 0.04 | 0.85 | 0.43 | 0.06 | 0.44 |
| 14 | *Cordia millenii* | 2 | 2.27 | 0.85 | 0.43 | 3.27 | 1.51 |
| 15 | *Cordia platythyrsa* | 2 | 0.37 | 0.85 | 0.43 | 0.54 | 0.60 |
| 16 | *Desplatsiasubericarpa* | 6 | 2.09 | 3.39 | 1.28 | 3.02 | 2.56 |
| 17 | *Diospyros dendo* | 2 | 0.02 | 0.85 | 0.43 | 0.04 | 0.44 |
| 18 | *Diospyros zenkeri* | 2 | 0.03 | 0.85 | 0.43 | 0.05 | 0.44 |
| 19 | *Discoglypremnacaloneura* | 8 | 2.00 | 1.69 | 1.71 | 2.89 | 2.10 |
| 20 | *Entandrophragmaangolense* | 14 | 12.87 | 3.39 | 2.99 | 18.57 | 8.32 |
| 21 | *Entandrophragmacylindricum* | 2 | 0.02 | 1.69 | 0.43 | 0.03 | 0.72 |
| 22 | *Entandrophragma utile* | 4 | 0.72 | 1.69 | 0.85 | 1.03 | 1.19 |
| 23 | *Funtumia elastic* | 18 | 0.83 | 5.08 | 3.85 | 1.20 | 3.38 |
| 24 | *Hannoaklaineana* | 4 | 0.20 | 1.69 | 0.85 | 0.29 | 0.95 |
| 25 | *Khaya grandifoliola* | 10 | 1.13 | 1.69 | 2.14 | 1.63 | 1.82 |
| 26 | *Malacanthaalnifolia* | 8 | 0.13 | 1.69 | 1.71 | 0.19 | 1.20 |
| 27 | *Mansoniaaltissima* | 76 | 4.99 | 5.93 | 16.24 | 7.20 | 9.79 |
| 28 | *Milicia excels* | 2 | 0.03 | 0.85 | 0.43 | 0.05 | 0.44 |
| 29 | *Musangacecropioides* | 4 | 0.27 | 0.85 | 0.85 | 0.39 | 0.70 |
| 30 | *Nesogordoniapapaverifera* | 30 | 2.30 | 4.24 | 6.41 | 3.32 | 4.66 |
| 31 | *Piptadenatriunafricanum* | 2 | 0.24 | 0.85 | 0.43 | 0.35 | 0.54 |
| 32 | *Pterocarpus osun* | 2 | 0.11 | 0.85 | 0.43 | 0.16 | 0.48 |
| 33 | *Pterygota macrocarpa* | 2 | 0.05 | 1.69 | 0.43 | 0.07 | 0.73 |
| 34 | *Pycnanthusangolensis* | 6 | 0.31 | 2.54 | 1.28 | 0.45 | 1.42 |
| 35 | *Ricinodendronheudelotii* | 2 | 1.04 | 1.69 | 0.43 | 1.49 | 1.21 |
| 36 | *Sterculia oblonga* | 2 | 0.04 | 0.85 | 0.43 | 0.05 | 0.44 |
| 37 | *Sterculia rhinopetala* | 28 | 7.96 | 6.78 | 5.98 | 11.49 | 8.08 |
| 38 | *Strombosiagrandifolia* | 4 | 0.25 | 1.69 | 0.85 | 0.36 | 0.97 |
| 39 | *Strombosiapustulata* | 4 | 0.07 | 0.85 | 0.85 | 0.10 | 0.60 |
| 40 | *Terminalia superb* | 4 | 2.42 | 1.69 | 0.85 | 3.50 | 2.02 |
| 41 | *Trichiliagrandifolia* | 10 | 0.31 | 1.69 | 2.14 | 0.44 | 1.42 |
| 42 | *Trichiliamonadelpha* | 2 | 0.05 | 0.85 | 0.43 | 0.07 | 0.45 |
| 43 | *Trichiliawelwitschii* | 2 | 0.04 | 0.85 | 0.43 | 0.06 | 0.44 |
| 44 | *Trilepisiummadagascariense* | 14 | 2.20 | 1.69 | 2.99 | 3.17 | 2.62 |
| 45 | *Triplochiton scleroxylon* | 28 | 9.08 | 5.93 | 5.98 | 13.10 | 8.34 |
| 46 | *Vitex doniana* | 2 | 0.02 | 0.85 | 0.43 | 0.04 | 0.44 |
| **Total** | | 468 | 69.44 | 100 | 100 | 100 | 100 |

**Table 3: Family value index (FVI) for over story species in the degraded portion the SNR2**

| S/N | Family | BA/Ha | Density /Ha | No of spp | RF (%) | RD (%) | RDo (%) | FIV (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | Annonaceae | 0.27 | 2 | 1 | 4.44 | 3.13 | 0.90 | 2.82 |
| 2 | Apacynaceae | 0.34 | 2 | 1 | 6.67 | 3.13 | 1.11 | 3.63 |
| 3 | Bignoniaceae | 0.03 | 2 | 1 | 6.67 | 3.13 | 0.11 | 3.30 |
| 4 | Boraginaceae | 0.62 | 2 | 1 | 2.22 | 3.13 | 2.03 | 2.46 |
| 5 | Capparaceae | 0.51 | 2 | 1 | 4.44 | 3.13 | 1.69 | 3.09 |
| 6 | Combretaceae | 1.28 | 2 | 1 | 2.22 | 3.13 | 4.21 | 3.19 |
| 7 | Euphorbiaceae | 1.28 | 8 | 5 | 13.33 | 12.50 | 4.23 | 10.02 |
| 8 | Leguminosae | 0.11 | 4 | 1 | 2.22 | 6.25 | 0.37 | 2.95 |
| 9 | Meliaceae | 2.06 | 6 | 3 | 8.89 | 9.38 | 6.79 | 8.35 |
| 10 | Moraceae | 0.94 | 6 | 3 | 6.67 | 9.38 | 3.09 | 6.38 |
| 11 | Myristicaceae | 0.30 | 2 | 1 | 2.22 | 3.13 | 1.00 | 2.12 |
| 12 | Sapindaceae | 0.04 | 2 | 1 | 2.22 | 3.13 | 0.12 | 1.82 |
| 13 | Sapotaceae | 1.54 | 4 | 2 | 11.11 | 6.25 | 5.12 | 7.49 |
| 14 | Sterculiaceae | 20.11 | 16 | 8 | 17.78 | 25.00 | 66.36 | 36.38 |
| 15 | Ulmaceae | 0.88 | 4 | 2 | 8.89 | 6.25 | 2.90 | 6.01 |
| **Total** | | 30.31 | 64 | 32 | 100 | 100 | 100 | 100 |

**Table 4: Family value index (FVI) for over story species in the undisturbed portion the SNR2**

| S/N | Family | BA/ha | Density/ Ha | No of spp | RF | RD | RDo | FIV |
|---|---|---|---|---|---|---|---|---|
| **1** | Annonaceae | 4.57 | 4 | 2 | 5.97 | 4.35 | 6.60 | 5.64 |
| **2** | Apocynaceae | 0.83 | 2 | 1 | 8.96 | 2.17 | 1.20 | 4.11 |
| **3** | Boraginaceae | 0.37 | 2 | 1 | 2.99 | 2.17 | 0.54 | 1.90 |
| **4** | Capparaceae | 0.16 | 2 | 1 | 2.99 | 2.17 | 0.22 | 1.79 |
| **5** | Combretaceae | 2.42 | 2 | 1 | 4.48 | 2.17 | 3.50 | 3.38 |
| **6** | Ebenaceae | 0.06 | 4 | 2 | 2.99 | 4.35 | 0.08 | 2.47 |
| **7** | Euphorbiaceae | 3.04 | 4 | 2 | 7.46 | 4.35 | 4.38 | 5.40 |
| **8** | Leguminosae | 0.31 | 4 | 2 | 1.49 | 4.35 | 0.45 | 2.10 |
| **9** | Meliaceae | 15.14 | 14 | 7 | 8.96 | 15.22 | 21.84 | 15.34 |
| **10** | Moraceae | 2.50 | 6 | 3 | 5.97 | 6.52 | 3.60 | 5.37 |
| **11** | Myristicaceae | 0.31 | 2 | 1 | 7.46 | 2.17 | 0.45 | 3.36 |
| **12** | Olacaceae | 0.32 | 4 | 2 | 2.99 | 4.35 | 0.47 | 2.60 |
| **13** | Sapotaceae | 2.54 | 6 | 3 | 5.97 | 6.52 | 3.66 | 5.38 |
| **14** | Simaroubaceae | 0.44 | 4 | 2 | 1.49 | 4.35 | 0.64 | 2.16 |
| **15** | Sterculiaceae | 28.76 | 22 | 11 | 11.94 | 23.91 | 41.30 | 25.72 |
| **16** | Tiliaceae | 2.09 | 2 | 1 | 5.97 | 2.17 | 3.02 | 3.72 |
| **17** | Ulmaceae | 5.55 | 6 | 3 | 10.45 | 6.52 | 8.01 | 8.33 |
| **18** | Verbenaceae | 0.03 | 2 | 1 | 1.49 | 2.17 | 0.04 | 1.23 |
| Total | | 69.44 | 92 | 46 | 100 | 100 | 100 | 100 |

In the sapling layer of this forest, a total of 54 and 36 species belonging to 21 families each were found in the undisturbed and degraded areas respectively (Table 5). Contrary to the results on diversity and abundance obtained for the overstory layer, high values were recorded for all the diversity indices in the degraded area of the sapling layer. In the seedling layer, a total of 41 species in 20 families and 26 species in 13 families were found in the undisturbed and degraded areas of this forest, respectively.

In the seedlings layer of the forest, the Shonnon-Wiener index was 3.13 for the undisturbed area and 2.59 for the degraded area. The Margalef indices were 5.86 and 4.93 in the undisturbed and degraded areas, respectively. In the same vein, Shonnon's equitability index and evenness were 0.84 and 0.56 in the undisturbed and 0.79 and 0.51 in the degraded areas, respectively. However, the Menhinick index revealed higher species richness in the degraded area (2.06) than the undisturbed area (1.35) of the forest.

**Table 5: Summary of Stand growth characteristics and biodiversity indices for the overstory and understory layers of two contrasting forest areas.**

| Growth Characteristics and Biodiversity indices | Forest Class | |
|---|---|---|
| | **Undisturbed** | **Degraded** |
| Stand Growth Characteristics | | |
| Density/ha | 468 | 194 |
| Mean Diameter (cm) | 35.10 | 38.23 |
| Maximum Diameter (cm) | 175.00 | 119.20 |
| Mean height (m) | 21.50 | 20.54 |
| Basal Area ($m^2ha^{-1}$) | 69.44 | 30.31 |
| | | |
| Biodiversity indices for mature trees | | |
| Family richness | 18 | 15 |
| Number of tree species | 46 | 32 |
| Shannon-Wiener diversity index | 3.17 | 3.06 |
| Margalef index | 8.25 | 5.89 |
| Simpson index (Simpson_1-D) | 0.93 | 0.93 |
| Shannon's equitability index | 0.83 | 0.88 |
| Evenness_e^H/S | 0.52 | 0.67 |
| Menhinick | 3.01 | 2.30 |
| Sorensen's Coefficient Similarity Index | 0.59 | |
| Jaccard Coefficient Similarity Index | 0.42 | |
| | | |
| Understory Layer (Saplings) | | |
| Density/ha | 1480 | 122 |
| | | |
| Biodiversity indices | | |
| Family richness | 21 | 21 |
| Number of tree species | 54 | 36 |
| Shannon-Wiener diversity index | 3.32 | 3.38 |
| Margalef index | 8.02 | 8.51 |
| Simpson index (Simpson_1-D) | 0.95 | 0.96 |
| Shannon's equitability index | 0.83 | 0.94 |
| Evenness_e^H/S | 0.51 | 0.81 |
| Menhinick | 1.99 | 4.61 |
| Sorensen's Coefficient Similarity Index (SCSI) | 0.42 | |
| Jaccard Coefficient Similarity Index (JCSI) | 0.27 | |
| | | |
| Understory Layer (seedlings) | | |
| Density/ha | 1840 | 318 |
| | | |
| Biodiversity indices | | |
| Family richness | 20 | 13 |
| Number of tree species | 41 | 26 |
| Shannon-Wiener diversity index | 3.13 | 2.59 |
| Margalef index | 5.86 | 4.93 |
| Simpson index (Simpson_1-D) | 0.94 | 0.88 |
| Shannon's equitability index | 0.84 | 0.79 |
| Evenness_e^H/S | 0.56 | 0.51 |
| Menhinick | 1.35 | 2.06 |
| Sorensen's Coefficient Similarity Index | 0.45 | |
| Jaccard Coefficient Similarity Index | 0.29 | |

The Sorenson coefficient similarity index (SCSI) and Jaccard coefficient similarity index (JCSI) for comparing the two selected areas of the forest are also presented in Table 6. The Sorenson similarity index revealed that the overstory species of the two areas of the forest were 59% similar while the Jaccard coefficient similarity index indicated that they were 42% similar. The sapling layers of the two contrasting areas of the forest shared few similar species as indicated by the results of the SCSI (42%) and JCSI (27%). For the seedling layer, the Jaccard index indicated a 29% mutually similar species while the Sorenson's similarity index revealed a 45% similar species.

**Discussion**

The transitioning of forested land to agricultural and barren land is a gradual process. When the disturbance rate in forest ecosystems is greater than the process of natural regeneration, the results are general reduction in forest quality, (forest degradation) and a progressive decrease in forest area (deforestation). Deforestation and forest degradation as a result of anthropogenic activities are more catastrophic than what could be imagined. Olayinka *et al*. (2018) reported that anthropogenic activities, such as illegal logging, have decimated Eda Forest Reserve in Ekiti State. The resulting impact on rural poverty is alarming, as it threatens the livelihoods of rural and forest-dependent communities. Deforestation has been linked to environmental degradation (Tanveer *et al.,* 2024). Carbon emissions from deforestation increase greenhouse gases in the atmosphere, contributing to global warming. The consequences transcend national borders, affecting the global population (Sule *et al.*, 2024).

In this study, the density per hectare of most of the economic, highly valued timber species such as *Mansoniaaltissima*, *Celtis zenkeri*and *Khaya grandifoliola* had reduced significantly in the degraded area of the forest. For instance, while *Mansoniaaltissima* had 76 trees per hectare in the undisturbed area, only 10 trees per hectare were encountered in the degraded area. Similarly, *Celtis zenkeri* had 62 trees per hectare in the undisturbed area but 6 trees per hectare were recorded for the same species in the degraded area. This reduction could be attributed to selective logging by the illegal loggers during covid 19 pandemic. Cazzolla-Gatti *et al*. (2017) described selective harvesting as the periodic removal of valuable timber trees of a specified minimum felling diameter. Selective logging has been reported to negatively impact the structure, composition, and functioning of the forest ecosystem, thus flagged as an agent of forest degradation (Gaui *et al*., 2019). Sterculiacaea had the highest basal area per hectare and family important value in both the undisturbed and the anthropogenically degraded forests.

Similarly, Tree density per hectare for the overstory layer in the degraded (194/ha) was less than the value for the undisturbed areas (468). The reduction in number of individual trees per hectare in the degraded area was also evident in the diameter distribution curve of the two areas of the forest. The basal area per hectare was significantly higher in the undisturbed area ($69.44m^2$) than in the degraded area ($30.31m^2$). Lower basal area in the degraded area of this forest could be attributed to the destruction orchestrated by the hemp planters and illegal loggers. This clearly indicated that the degraded area had lost over 50% of what its quality and tree quantity. Lawal & Adekunle (2013) recorded 61.12 $m^2$basal area per hectare for this SNR2 in 2013, which is lower than what is recorded in this study. The observed increase in basal area after a decade indicated a growing and healthy natural forest. The little increase could be as a result of the typical slow grow rate of tropical indigenous hardwood species (Lawal & Bakare, 2020). Among the mature trees, *Mansoniaaltisima* had the highest species importance value (9.79) in the undisturbed area and the family sterculiaceae had the highest FIV in both areas of the forest. These findings are in congruence with the researches of Lawal & Adekunle (2013) and Omomoh *et al.* (2019) who also reported *Mansoniaaltissima as the species* with the highest species importance value (IVI) and Sterculiaceae with the highest family importance value (FIV) in Queen's plot, Akure forest reserve.

All the biodiversity indices obtained for mature trees were higher in the undisturbed area than in the degraded area. This was as a result of the massive illegal harvesting and clear felling for the cultivation of *Cannabis sativa*~~,~~.Many trees were harvested illegally, cut down and burnt to create the room for growing *Cannabis sativa* during covid-19 pandemic. The impacts of uncontrolled logging and several other human activities in tropical rainforest ecosystems on biodiversity conservation, residual trees and seedlings, and the environment were reported by Adekunle & Olagoke (2010) and Adekunle *et al*. (2010). The tree density, number of species and Shannon-Wiener diversity index obtained for the mature trees of the undisturbed area were higher than what was reported for some sacred groves in Southwest Nigeria. Shannon–Wiener diversity indices of 1.8 and 3.46, number of species of 32 and 58 and tree density of 309 and 417/ha were recorded for some sacred groves in southwest Nigeria (Onyekwelu *et al*., 2021). However, tree density per hectare was comparably higher in all the sacred groves than what was recorded in the mature tree layer of the degraded area of SNR2 (194 individual/ha). Out of the total number of sacred groves investigated by Onyekwelu *et al*. (2021), 75% of them had higher number of species and Shannon-Wiener diversity indices than the mature tree layer of the degraded area of this forest.

Although the number of species recoded in the sapling layer of the undisturbed area was higher than the number recorded in the degraded area, all other diversity and species richness indices were higher in the degraded area. These findings agreed with the work of Onyekwelu *et al*. (2021), who revealed that the Shannon–Wiener diversity index (1.8–3.46 (overstory); 2.65–3.55 (understory)) and tree density (309–417 individuals/ha (overstory); 775–1445 individuals/ha (understory)) were higher at the understories than the overstories. Johnston (2019) reported a significantly higher Shannon diversity index in the understory of hardwood forests compared to the overstory. The higher species diversity and richness in the sapling layer of the degraded area indicated the potential of this area to recover from degradation overtime and return to its original status if anthropogenic activities are completely abated. The sustainability of this forest is less threatened due to the presence of saplings that can replace the mature trees that were cleared felled during Indian hemp cultivation and those extracted illegally.

Generally, the number of seedlings was higher than the number of saplings and overstory species in undisturbed and degraded areas of SNR2. This result is in agreement with the findings of Onyekwelu & Olusola (2014) and Johnston (2019). Almost all the diversity indices and the abundance recorded for the seedlings were higher in the undisturbed area than the degraded area of this forest. The differences were due to the anthropogenic activities in the degraded area. Polycyclic and high-intensity logging are expected to result in more damage to the residual forest and consequently, reduced seedling regeneration. Sukhbaatar *et al.* (2019) opined that high-intensity of logging tend to limit regeneration by reducing the overall seedling numbers. However, the ability of the forest ecosystem to recover depends on the time lag after logging disturbances (Butarbutar *et al*., 2019).

Moreover, the higher dissimilarity at the sapling layer between the degraded and undisturbed areas reported in this study could be attributed to the severity of damage done by the illegal loggers. According to Lindenmayer & Laurance (2017), loggers target larger trees carrying a greater proportion of total seed output in the forest ecosystem. Regeneration will be initiated when the seeds fall on the soil and if such seeds are viable and soil conditions are favourable (Damptey *et al.*, 2021).

## CONCLUSION AND RECOMMENDATION

Anthropogenic activities in protected areas are discovered to be is catastrophic and the impacts could cause irreparable damage to the forest ecosystem. The inverse J-shaped diameter distribution curves of the two contrasting forest areas investigated in this study were as expected of a typical natural forest and, the number of individual trees under each diameter class was higher in the undisturbed area. The tree density per hectare, number of species, species richness, and diversity indices were comparably lower in the degraded area of the SNR2. In addition, the Jaccard coefficient similarity index between the degraded and undisturbed areas indicated the level of similarity in species diversity and abundance. It became clear from the findings of this study that the degraded area of this forest had lost its original status. Hence, efforts should be put in place by all the tiers of the government and all other stakeholders to avert further encroachment on this protected area. Therefore, total ban on logging activities and prohibition of clear felling of the forest for agricultural practices are recommended. Enrichment planting of the degraded area is also recommended as an urgent restoration measure.

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**Authors' Contributions**

AL & VAJA conceived the research ideas and designed methodology for the project; AL, VAJA & OJA collected the research data; AL analysed the data; AL & VAJA led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

**Ethical Statement**

Not applicable

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