IMPACT OF NATURE-BASED CONSERVATION MEASURES ON FLORA SITY AND PRODUCTIVITY IN TROPICAL RAINFOREST ECOSYSTEM OF NIGERIA

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Abstract
Nigeria is endowed with rich forest ecosystems, which have been subjected to severe threats. To prevent complete loss of the forests, several conservation measures were adopted such as Strict Nature Reserve (SNR) and Sacred Groves (SG). Currently, information on the impact forest conservation measures on biodiversity is scanty. We assessed tree species diversity of two primary forests (Omo-SNR and Akure-SNR), two SGs (Idanre Hills and Ogun-Onire) and two degraded forests (Eda and OA3 forest reserves) in rainforest ecosystem of south-western Nigeria. Data were collected from 48 (8 per site) 800m^2 temporary sample plots, systematically laid along two transects of 1000m per site. Tree species richness followed the order: Akure-SNR (63) > Ogun-Onire (62) > OA3 (56) > Omo-SNR (53) > Eda (45) > Idanre Hills (43). Shannon-Wiener diversity index was high in all sites, with OA3 forest having the highest value (3.68) and Idanre Hills SG having the lowest value (3.14). Species distributions among the sites were even (range: 0.83–0.93). Degraded forests had low mean dbh compared with primary forests and SGs. Degradation had a significant negative effect on forest productivity. This was evident from the lower basal area and volume production in degraded forests (7.09–15.40 m^{2}ha^{-1}; 58.00–138.53 m^{3}ha^{-1}) compared to primary forests (32.47–72.39 m^{2}ha^{-1}; 366.71–929.05 m^{3}ha^{-1}) and SGs (32.99–42.59 m^{2}ha^{-1}; 273.21–398.46 m^{2}ha^{-1}). The poor results from degraded forest could be attributed to degradation activities. These findings suggest that natural conservation measures can protect biodiversity in rainforest ecosystem. More efforts should be made to prevent further degradation and encroachment into primary forests and SGs.

Keywords: *Forest conservation, Flora diversity, Strict Nature Reserve, Sacred Grove, Degraded forest, Tropical rainforest*

Introduction

The threats posed by global climate change and biodiversity loss provide evidence that nature is under assault and in crisis. Scientists (e.g. Steffen et al. 2015) warn that the earth is approaching dangerous tipping points in our planetary system. What this means in practical terms is that many systemic changes may be difficult, costly, or impossible to reverse (Barber et al., 2020). The forest is top on the chart of ecosystems under severe threat. Over 40% of the world's land is now agricultural or urban land, with ecosystem processes deliberately redirected from natural to anthropogenic pathways (Barber et al., 2020). FAO (2015) opined that by 2010, about 37.7% and 31.6% of global forestland would have been converted to agricultural land and other land-use types, respectively while only 30.7% would be under forest cover.

For years, remorseless destruction of forests has been going on. Of all the factors associated with forest loss, deforestation, forest degradation and fragmentation are most notable (Onyekwelu, 2017). With a reported decrease in global forest area of 1.8 billion hectare within the past 5,000 years, FAO (2016) indicated that the current global forest area is only about 50% of what it was some 5,000 years ago. There are evidences that deforestation is not abating, forest decline will continue, though the rate of decline is decreasing, especially in developed countries. The 2015 global forest resources assessment indicated that global forest area declined by about 129 million ha (3.1%) between 1990 and 2015 (FAO, 2015). Forest fragmentation is reaching critical thresholds, with 70% of forests now less than 1 km from a forest edge (Haddad et al. 2015) and natural ecosystems fragmented into some 600,000 pieces (Ibisch et al. 2017). Currently, forest loss is most prevalent in the tropical regions of the world. Despite increased awareness of the key roles tropical forests play in solving the most urgent global environment and development challenges, the rate of tropical deforestation remains alarmingly high. Much of the forest loss is associated with population growth and demand of forestland for farming, grazing and other land-use forms, unsustainable levels of exploitation of forest resources, etc (Onyekwelu, 2017).

The need for action against the growing threat to forests is urgent. More than ever, there is need for nature to address the intertwined challenges of ecosystem destruction and biodiversity loss. For example, Onyekwelu (2017) postulated that if the estimated annual deforestation rate of 350,000– 400,000 ha in Nigeria is sustained, the country may become completely forestless within the next three decades. Nature-based solutions (NbS) is among the various approaches developed to address the menace of ecosystem destruction. IUCN defined nature-based solutions as "actions to protect, sustainably manage, and restore natural or modified ecosystems,that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". Thus, nature-based measures encompass a broad range of actions that protect, restore, or sustainably manage ecosystems (including natural, semi-natural, or created) to provide benefits (Cohen-Shacham et al., 2016). There are many many variants of NbS (e.g. ecosystem-based adaptation, natural infrastructure, forest and landscape restoration, natural climate solutions, etc (Cohen-Shacham et al., 2016). However, no matter the variant, the protection and strengthening of the ecological integrity of natural ecosystems must lie at the core of each. Barber et al. (2020) opined that although nature-based measures need to be applied across a diversity of ecosystems, the single most important intervention to deliver synergistic climate and biodiversity outcomes on land is the protection of primary forests. The closer ecosystems are kept to natural patterns of biodiversity distribution and abundance, the higher the stability and quality of the ecosystem services they provide (Barber et al., 2020). In this study, we examined the impact of nature-based conservation measures on flora diversity and productivity in tropical rainforest ecosystem of south-western Nigeria.

Methodology

This study was carried out in sacred groves, primary forests and degraded forests from the rainforest ecosystem within the south-western region of Nigeria (Figure 1). The ecological zones within the south-western region of Nigeria include: mangrove, tropical rainforest and derived savanna. Annual rainfall in this region could range from between 1400 mm to over 3000 mm while mean temperature varies between 21ºC and 34ºC. Rainy season occurs between the months of April and November while dry season lasts from December to March. Soils are predominantly ferruginous tropical, typical of the variety found in intensively weathered areas of basement complex formations in the rainforest ecosystem of south-western Nigeria (Onyekwelu *et al.* 2008).

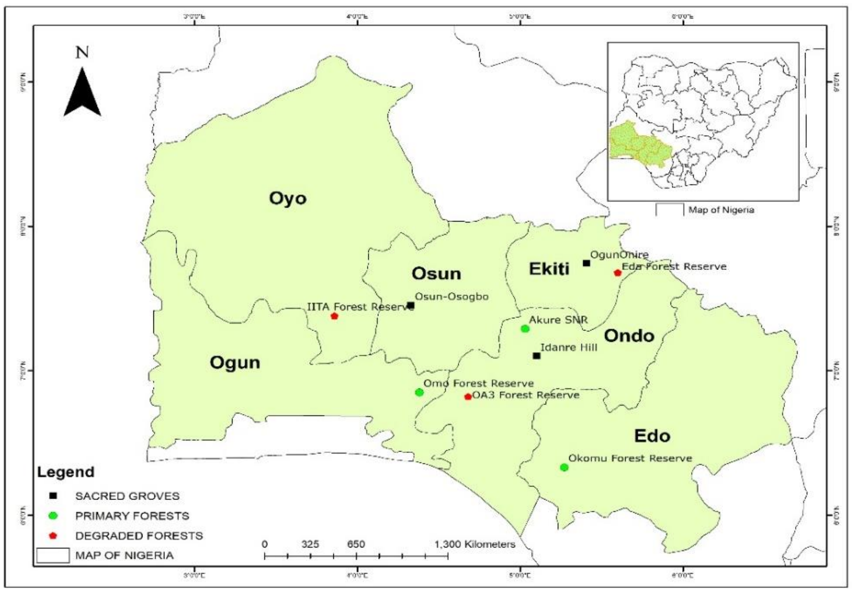

Figure 1: Map of south-western region of Nigeria showing the locations of the study sites

The three forest types involved in this study, which are under different management systems, are sacred groves (Idanre Hills and Ogun-Onire) primary forests (Akure and Omo Strict Nature Reserves (SNR)) and degraded forests (OA3 and Eda forest reserves). Akure-SNR is located in Akure forest reserve between latitude 7°16′ and 7°18′N and longitude 5°9′ and 5°11′E. It covers a land area of 69.93 km^2 and has been under strict conservation since 1936. Omo-SNR, located within Omo forest reserve, lies between latitude 6º 35' to 7º 05'N and longitude 4º 19' to 4º 40'E. It has been under strict conservation since 1949, it has a core and buffer zones of 460 and 14,200 ha, respectively (Onyekwelu *et al*. 2008). Idanre Hills sacred grove, located in Idanre, Ondo State Nigeria, has awesome natural landscapes and high plains with spectacular valleys interspersed with inselbergs of about 3,000 ft above sea level. It covers an area of 48 ha. Ogun-Onire sacred grove is located in Ire-Ekiti, in Ekiti State, Nigeria. It covers an area of 10 ha. Both sacred groves are protected using laws, taboos and strict religious restrictions. Eda forest reserve is located in Ekiti state, which lies on latitude 7º 23' and 7º 46' N and longitude 4º 45' to 5º 47' E. It occupies an area of about 200 km^2 on an elevation of 526 m above sea level. The OA3 forest is found within Oluwa forest reserve in Odigbo local government area of Ondo state. It lies within longitude 6° 55'N to 7°20'N and latitude 4°32'E to 3°45'E and covers a total area of 678.06 km^2.

Method of Data Collection

In this study, two primary forests (Omo-SNR and Akure-SNR), two sacred groves (Idanre Hill and Ogun-Onire) and two degraded forests (Eda and OA3 forest reserves) in tropical rainforest ecosystem of Nigeria were purposefully selected based on prominence/significance, accessibility and permission to conduct inventory. Two line transects of 1000 m each in length, separated by a distance of at least 1000 m were laid approximately at the middle of each site. Temporary sample plots of 40 m × 20 m were laid on alternate sides along each transect at every 250 m interval, giving a total of 4 plots per transect, 8 per site and 48 for this study. Within each sample plot, all trees with Dbh ≥ 10cm were identified and their diameter at breast height, diameters at the base, middle, top as well as total heights were measured. The scientific names of all trees and their authorities were confirmed using Trees of Nigeria (Keay, 1989).

Data computation and analyses

Basal Area Estimation

The basal area of all trees in each sample plot was calculated using equation 1:

$$BA = \frac{\pi D^2}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn 1)}$$

Where BA = Basal Area (m^2), D = Diameter at Breast Height (cm) and π = Pie (3.142).

The total basal area for each sample plots was obtained as the sum of the basal areas of all trees in the plot. Basal area per hectare was obtained by first computing the mean plot basal area and then multiplying the mean plot basal area by 12.5 (i.e. number of 40 m x 20 m plots in an hectare)

Volume Estimation

Volume of individual trees was estimated using Newton's tree volume equation (eqn 2):

$$V = \pi h \frac{Db^2 + (Dm^2) + Dt^2}{24} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn 2)}$$

Where V is tree volume (m^3), Db, Dm and Dt are diameters (m) at the base, middle and top of each tree, and *h* is total tree height (m).

The total volume for each sample plots was obtained by summing the volumes of all trees in the plot. Volume per hectare was obtained by first computing the mean plot total volume and secondly by multiplying the mean plot total volume by 12.5, being the number of 40 m x 20 m plots in one hectare.

The following biodiversity indices were computed:

(i) Species diversity index was calculated using the Shannon-Wiener diversity index (eqn. 3):

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn. 3)}$$

Where: H' = Shannon-Wiener diversity index; P_i = proportion of S made up of the i^{th} species, ln = natural logarithm

(ii) Species evenness in each site was determined using Shannon's equitability (E_H)(eqn. 4):

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{S} P_i \ln(P_i)}{\ln(S)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn. 4)}$$

(iii) Margalef's index was calculated using the equation 5:

$$D = \frac{S-1}{\ln N} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(eqn. 5)}$$

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

(iv) Simpson's index

$$D = 1 - \sum \left(\frac{n_i}{N} \right)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

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

Results

The basal area production of the ten most dominant tree species in each of the study sites are presented in Table 1. With respect to basal area, no single tree species was found to be dominant across all the sites (Table 1). The most sites-wide basal area dominant tree species are: *Celtis zenkerii* (four sites); *Alstonia boonei, Cola gigantea, Sterculia rhinopetala* and *Cordia milenii* (three sites). Basal area production varied from site to site and from species to species within the same site. In Akure-SNR, *Entandrophragma cylindricum* had the highest basal area production (5.69 m^2) while *Cola gigantea* recorded the highest basal area production (4.41 m^2) in Omo-SNR. The tree species with the high basal area production in Ogun-Onire grove are *Celtis zenkerii* (5.46 m^2) and *Pterigota macrocarpa* (2.93 m^2). In Idanre Hill sacred groves, *Ceiba pentandra* (5.99 m^2) and *Alstonia boonei* (4.00m^2) had high basal area production. Basal area production of tree species in the degraded forests was relatively small compared to the values obtained for tree species in the primary forests and sacred groves. For example, *Celtis zenkerii* had the highest basal area production of 0.69 m^2 in OA3 forest, which is much lower than the 5.46 m^2 basal area production of the same species in Ogun-Onire grove (Table 1). *Spondias mombin* had basal area of 0.41 m^2 in Eda forest reserve.

Table 1: Basal Area (m^2) production of the ten most dominant tree species in the study sites

		Primary Forests		Sacred Groves		Degraded Forests	
S/N	Tree Species	Akure-SNR	Omo-SNR	Ogun-Onire	Idanre Hills	OA3 Forest	Eda Forest
1	*Ceiba pentandra*	-	-	-	5.99	-	-
2	*Entandrophragma cylindricum*	5.69	-	-	-	-	-
3	*Terminalia superba*	5.53	4.13	-	-	-	-
4	*Celtis zenkerii*	2.17	-	5.46		0.69	0.25
5	*Brachystegia nigerica*	4.97	-	-	-	-	0.20
6	*Triplochiton schleroxylon*	4.68		0.95	-	-	-
7	*Cola gigantean*	-	4.41	2.56	3.09	-	-
8	*Alstonia boonei*	-	0.63	-	4.00	0.36	-
9	*Entandrophragma angolense*	3.54	-	-	-	-	-
10	*Pterigota macrocarpa*	-	-	2.93	-	-	-
11	*Chrysophylum purpuchrum*	2.70	-	-	-	-	-
12	*Sterculia rhinopetala*	2.23	2.51	-	-	-	0.20
13	*Cassia siemen*	-	-	-	2.50	-	-
14	*Antiaris africana*	-	-	-	2.40	-	-
15	*Morus mesozygia*	-	-	2.23	-	-	-
16	*Mansonia altisima*	2.11	-	-	-	0.18	-
17	*Celtis mildbreadii*	2.05	1.47		-	-	-
18	*Blighia sapida*	-		1.88	-	-	-
19	*Baphia nitida*	-	1.29		-	-	-
20	*Anopysis kleniana*	-	-	1.14	-	-	-
21	*Trilepson madagascariensis*	-	-	1.18	-	-	0.33
22	*Ficus sycomorus*	-	-	1.18	-	-	-
23	*Funtumia elastica*	-	-	-	1.11	0.23	-
24	*Ricinodendrum heudelotii*	-	1.08	-	-	-	-
25	*Cordia plathutysa*	-	0.99	-	-	-	-
26	*Ficus mucuso*	-	-	-	0.90	-	-
27	*Cordia milenii*	-	-	0.89	-	0.22	0.16
28	*Milicia excels*	-	-	-	0.87	-	-
29	*Monodora myristica*	-	-	-	0.63	-	-
30	*Berlinia grandifolia*	-	-	-	0.61	-	-
31	*Pycnanthus angolensis*	-	0.59	-	-	-	-
32	*Microdesmis puberula*	-	0.47	-	-	-	-
33	*Spondias mombin*	-	-	-	-		0.41
34	*Draceana maginata*	-	-	-	-	0.35	
35	*Magariteria discoidea*	-	-	-	-	-	0.32
36	*Trichilia welwitschii*	-	-	-	-	-	0.28
37	*Macaranga barterii*	-	-	-	-	0.19	
38	*Cola acuminata*	-	-	-	-	-	0.18
39	*Entandrophragma utili*	-	-	-	-	-	0.17
40	*Trichilia monadelpha*	-	-	-	-	0.16	-

The volume production of the ten most dominant tree species in the study sites are presented in Table 2. With respect to volume production, *Entandrophragma cylindricum* had the highest volume production of 101.42 m^3 production in In Akure-SNR (range:

19.74 - 101.42 m^3) while *Terminalia superba* recorded the highest volume production of 53.31 m^3 in Omo-SNR (range: 8.47 - 53.31 m^3). *Ceiba pentandra* and *Celtis zenkerii* had the highest volume production of 62.99 m^3 and 47.33 m^3 at Idanre Hill (range: 4.36 - 62.99 m^3) and Ogun-Onire (range: 5.37 - 47.33 m^3) sacred groves, respectively, which were lower than those of the high volume producing tree species in primary forests (Table 2). Volume production of tree species in the three forest types followed similar trend with basal area production. Trees in the degraded forests exhibited lower volume production compared to those of trees in the primary forests and sacred groves. For example, while the highest tree volume production in primary forest and sacred grove were 101.42 m^3 and 62.99 m^3, respectively, the highest volume production of trees in the degraded forest was only 5.92 m^3 (Table 2). *Ricinodendrum heudelotii* had the highest volume production of 5.92m^2 in OA3 forest while *Magariteria discoidea* produced the highest volme of 0.27m^3 in Eda forest reserve.

Table 2: Volume (m^3) production of the ten most dominant tree species in the study sites

		Primary forests		Sacred groves		Degraded forests	
S/N	Tree Species	Akure-SNR	Omo-SNR	Ogun-Onire	Idanre Hills	OA3 Forest	Eda Forest
1	*Entandrophragma cylindricum*	101.42	-	-	-	-	-
2	*Triplochiton schleroxylon*	79.57	-	7.47	-	-	-
3	*Brachystegia nigerica*	74.17	-	-	-	-	1.56
4	*Terminalia superba*	72.37	53.31	-	-	-	-
5	*Ceiba pentandra*	-	-	-	62.99	-	-
6	*Cola gigantean*	-	52.89	22.97	24.36	-	-
7	*Celtis zenkerii*	25.69	-	47.33	-	5.26	1.63
8	*Alstonia boonei*	-	8.47	-	38.96	2.52	1.37
9	*Sterculia rhinopetala*	23.37	31.63	-	-	-	1.98
10	*Cassia siemen*	-	-	-	30.57	-	-
11	*Entandrophragma angolensis*	30.32	-	-	-	-	-
12	*Morus mesozygia*	-	-	27.65	-	-	-
13	*Pterigota macrocarpa*	-	-	27.47	-	-	-
14	*Mansonia altisima*	25.60	-	-	-	1.23	
15	*Chrysophylum purpuchrum*	23.93	-	-	-	-	-
16	*Cordia plathutysa*	-	23.11	-	-	-	-
17	*Antiaris africana*	-	-	-	21.52	-	-
18	*Celtis mildbreadii*	19.74	15.05	-	-	1.07	-
19	*Milicia excelsa*	-	-	-	13.05	-	-
20	*Blighia sapida*	-	-	11.47	-	-	-
21	*Ricinodendrum heudelotii*	-	11.15		-	5.92	-
22	*Cordia milenii*	-	10.39	5.37	-	2.98	-
23	*Ficus sycomorus*	-	-	9.73	-	-	-
24	*Funtumia elastica*	-	-	-	9.47	1.40	-
25	*Pycnanthus angolensis*	-	9.25	-	-	-	-
26	*Baphia nitida*	-	8.64	-	-	-	-
27	*Ficus mucuso*	-	-	-	7.77	-	-
28	*Trilepson madagascariensis*	-	-	7.46	-	-	2.71
29	*Anopysis kleniana*	-	-	7.28	-	-	-
30	*Magariteria discoidea*	-	-	-	-	-	5.65
31	*Albizia zygia*	-	-	-	4.46	-	-
32	*Berlinia grandifolia*	-	-	-	4.36	-	-
33	*Monodora myristica*	-	-	-	-	-	-
34	*Spondias mombin*	-	-	-	-	-	2.83
35	*Musanga cecropioides*	-	-	-	-	2.59	-
36	*Draceana maginata*	-	-	-	-	2.13	-
37	*Trichilia welwitschii*	-	-	-	-	-	1.86
38	*Cola acuminate*	-	-	-	-	-	1.36
39	*Entandrophragma utili*	-	-	-	-	-	1.30
40	*Sterculia tricagantha*	-	-	-	-	1.27	-

Tree dbh distribution in the primary forests, degraded forests and sacred groves followed the inverse-J pattern typical of natural tropical rainforest ecosystem (Figure 2a-c). Majority of the trees in the six sites fell within 10–20 cm dbh class, followed by 20–30 cm class. Only few trees in the primary forest and sacred grove sites had dbh above 100 cm (Figure 2a & b), which is contrary to the degraded forest sites where the largest trees fell within the dbh class of 40–50 cm (Figure 2c). The highest stand density across the six sites was recorded in the lowest dbh class of 10–20 cm, making this class the highest contributor of stand density to total density for each site. Stand density consistently decreased with increase in dbh (Figure 2a-c).

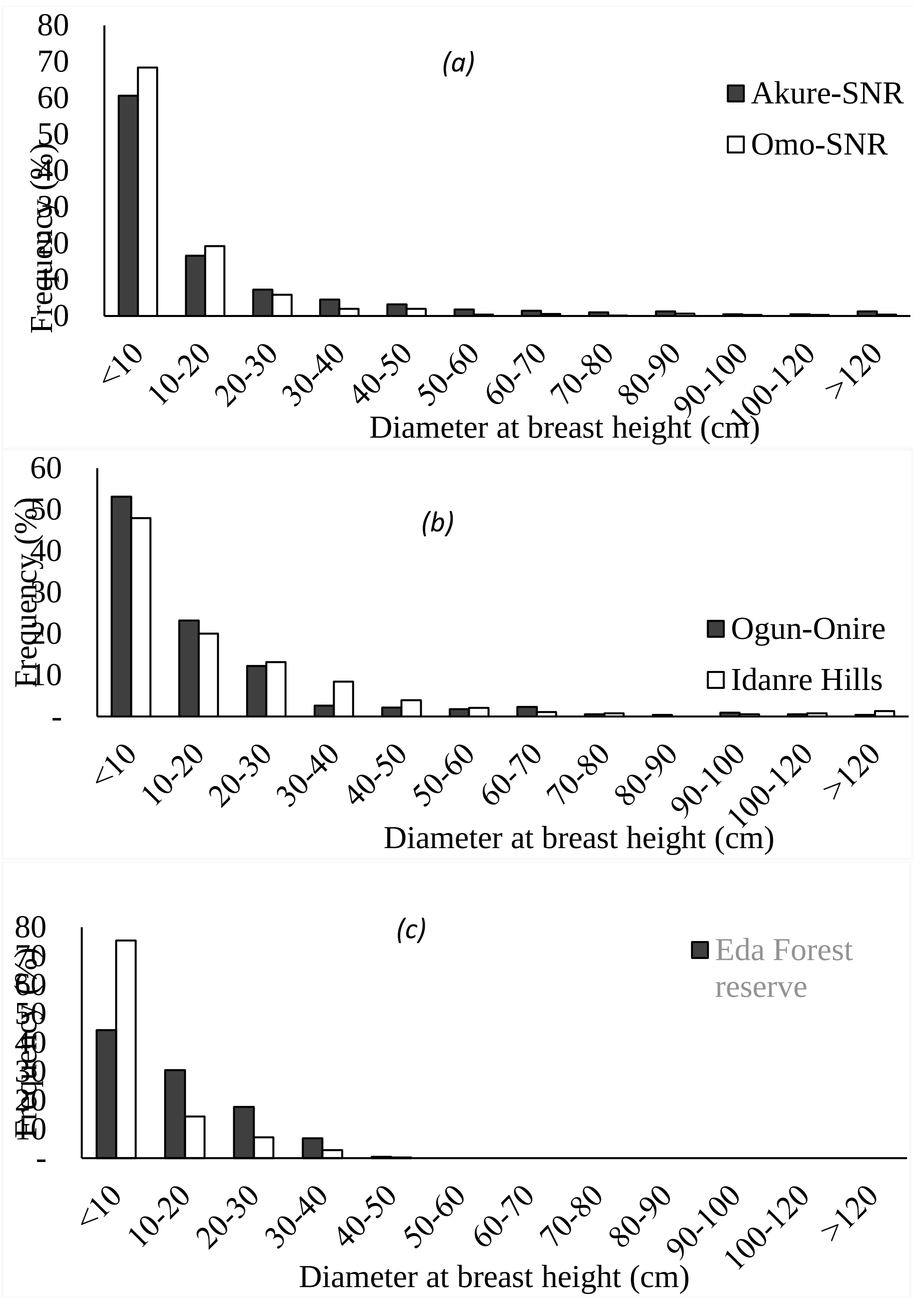

Figure 2: Tree diameter distribution in (a) primary forest, (b) sacred grove and (c) degraded forest sites in south-western Nigeria

The summaries of biodiversity indices and tree growth variables in the study sites are presented on Table 3. Family richness varied from 15 to 25 with Omo SNR having the highest and Eda forest reserve having the lowest. Tree species richness followed the order:

Akure-SNR (63) > Ogun-Onire sacred grove (62) > OA3 forest reserve (56) > Omo-SNR (53) > Eda forest reserve (45) > Idanre Hill sacred grove (43). There were significant differences in species diversity index, with OA3 forest reserve having the highest Shannon-Wiener diversity index (3.68) and Idanre Hills sacred grove having the lowest value (3.25). Species distributions among the sites were even (range: 0.85 to 0.93). Degraded forests had lower mean dbh (20.7cm to 23.9cm) compared with primary forests (26.1cm to 35.6cm) and sacred groves (24.4cm to 31.9cm). Trees in degraded forests (range: 10.22 m - 10.36 m) were generally shorter than those in primary forests (range: 14.15 m - 17.41 m) and sacred groves (range: 13.50 m - 13.73 m) as revealed by their mean heights. Also, basal area and volume per hectare were much higher in the primary forests and sacred groves compared to degraded forests (Table 3). There were more individual trees per hectare in primary forest sites (range: 372 - 381) and sacred grove sites (309 - 413) than in the degraded forest sites (177 - 234).

Table 3: Summary of biodiversity indices and tree growth variables in the study sites

Biodiversity indices	Primary Forest		Sacred groves		Degraded Forest	
	Akure SNR	Omo SNR	Idanre Hills	Ogun-Onire	Eda forest	OA3 forest
Number of Families	24	25	19	24	15	24
Number of Species	63	53	43	62	45	56
Number of Trees Ha^{-1}	381	372	309	413	177	234
Shannon-Wiener Diversity Index	3.57	3.43	3.25	3.50	3.53	3.68
Species Evenness	0.86	0.86	0.86	0.85	0.93	0.91
Simpson Concentration (λ)	0.95	0.95	0.94	0.95	0.96	0.97
Species Richness (Margalef Index)	11.28	9.50	7.94	10.13	9.31	10.98
Mean Dbh (cm)	35.61	26.10	31.92	28.04	21.09	20.69
Dominant Dbh (cm)	251.5	168.5	185.00	131.50	42.30	57.50
Mean height (m)	17.41	14.15	13.50	13.73	10.68	10.22
Dominant height (m)	54.60	28.80	24.80	23.2	11.20	15.5
Basal Area (m^2ha^{-1})	72.39	36.63	42.59	41.11	7.09	9.38
Volume (m^3ha^{-1})	929.05	427.08	398.46	337.39	58.00	64.78

Discussion

Globally, tropical forests directly affect the livelihoods of over 1.35 billion people (FAO, 2014), store about 247 Gigatons of carbon (Saatchi *et al.,* 2011) and harbor over half of the world's terrestrial biodiversity (Onyekwelu *et al*., 2018; Gibson *et al*., 2011). In many countries, intact tropical forests have disappeared completely (Potapov *et al.*, 2017) while many are under different stages of degradation. In Nigeria, tropical rainforest is fast disappearing as a result of steady increase in anthropogenic activities that degrade the forest, coupled with the increase in the demand for forest lands and products. To guarantee a stable environment and ensure sustainable ecosystem services provision from Nigerian tropical rainforest to the people, conservation of the ecosystem is necessary.

Biodiversity indices are usually generated to bring the floristic diversity and abundance in different habitats to similar scale for comparison, which is important in studying the effectiveness of conservation measures (Onyekwelu, 2021). Species diversity and richness are among the important indices used to characterize biodiversity conservation status of forest ecosystems. Shannon-Wiener diversity index (H') is widely used to investigate community diversity indices because it takes both richness and evenness into account and because species abundances are standardised to proportions (Kent and Coker, 1992). Studies have shown that the number of tree species in tropical rainforests is far higher than in any other forest ecosystem, except in a situation where deforestation and forest encroachment have eaten deep into tropical forests. For example, between 100 and 300 tree species per hectare are found in rainforests (especially in south America and southeast Asia (Richards, 1996)), a value that is much higher than that the number of species found in temperate forests (Onyekwelu *et al*., 2008). Nwoboshi (1982) opined that the number of trees per hectare could be as high as 400 in very rich rainforests. The low number of tree species (i.e. 43 - 63) reported for the three forest types in this study compared to the general range for tropical rainforests (100 - 400), may be an indication that Nigerian tropical rainforest ecosystems are species-poor, which is collaborated by past studies that which reported a range of 32 to 79 species (Lowe, 1997; Adekunle, 2006; Adekunle and Olagoke, 2008; Onyekwelu *el al.,* 2008; Onyekwelu and Olusola, 2014; Onyekwelu *et al*. (2021). The high Shannon-Wiener diversity index for the primary forests and sacred groves in this study (3.25 - 3.57), which is consistent with reports for similar sites in Nigeria (Adekunle and Olagoke, 2008; Onyekwelu *et al*., 2008; Onyekwelu and Olusola, 2014), is attributed to their mature and fairly undisturbed forest canopy, which supports rich and diverse plant and animal species. The diversity index for the sacred groves (3.25 - 3.63) is similar to the values (2.86–3.96) reported for sacred groves in India and Nigeria (Rao *et al*., 2011; Onyekwelu and Olusola, 2014) but higher than the range of 1.2 – 1.4 reported by Mgumia and Oba (2003) for sacred groves in Tanzania.

The primary forests in this study (Akure-SNR and Omo-SNR) have been under strict conservation since 1936 and 1949 (Isichei, 1995; Onyekwelu *et al*., 2008). There is no recorded evidence of timber exploitation in both forests within living memory. Similarly, the two sacred groves in this study have been under strict conservation since they were constituted. Tree felling, farming and other forest degradation activities are forbidden in the sacred groves. The primary forests and sacred groves are not under any form of conventional management method, they are managed by nature. The degraded forests in this study (OA3 and Eda forest reserves) have experienced repeated exploitation and degradation activities in recent times to the extent that they have been classified as highly degraded forests.

The primary forests and sacred groves in this study are considered nature-based conservation measures because of their protection and ecological integrity and because they are kept closer to natural patterns of biodiversity distribution and abundance (Barber *et al*., 2020). The better growth parameters of the primary forests in this study compared to the degraded forests, coupled with their good biodiversity indices, could be attributed to the effectiveness of nature-based conservation strategy. The concept of sacred grove is also an effective nature-based conservation strategy due to their comparably higher tree growth parameters and slightly better biodiversity indices than the degraded forests. The poor growth parameters of the degraded forests is expected, given their long history of degradation and almost uncontrolled nature of logging as well as high volume of timber removed from them. Degradation had negative effect on productivity in the degraded forests as evidenced by the much lower basal area and volume production in degraded forests (7.09–9.38 m^2ha^{-1}; 58.00–64.78 m^3ha^{-1}) compared to primary forests (36.63–72.39 m^2ha^{-1}; 427.08–929.05 m^3ha^{-1}) and sacred groves (41.11–42.59 m^2ha^{-1}; 337.39–398.46 m^3ha^{-1}). Another evidence of the effect of degradation is the absence of large trees in the degraded forests as revealed by results on Table 3 and Figure 2).

Conclusion

This study reveals the positive impact of nature-based conservation strategies on flora diversity and productivity. We discovered that the growth parameters and tree species diversity indices were higher in the primary forests and sacred groves than in the degraded forests. These findings suggest that nature-based conservation measures can protect flora diversity in the rainforest ecosystem. Therefore, more effort towards preventing further forest degradation and encroachment into primary forests and sacred groves is recommended.

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