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CONSERVATION POTENTIALS, TREE SPECIES DIVERSITY, DISTRIBUTION AND STRUCTURE OF SACRED GROVES IN SOUTH-WESTERN NIGERIA

Onyekwelu JC[1], Agbelade AD[2, *], Tolorunju MS[1], Lawal A[1], Stimm B[3] & Mosandl R[3]

[1]*Department of Forestry and Wood Technology, Federal University of Technology, P.M.B. 704, Akure, Nigeria*
[2]*Department of Forest Resources and Wildlife Management, Ekiti State University, P.M.B. 5363, Ado Ekiti, Nigeria*
[3]*Chair of Silviculture, Technical University of Munich, Hans-Carl-von-Carlowitz-Platz 2 D-85354 Freising, Germany*

**aladesanmi.agbelade@eksu.edu.ng*

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Though sacred groves were not originally established for biodiversity conservation purposes, they have contributed largely to biodiversity conservation. The distribution of sacred groves in south-western Nigeria was investigated and examined for biodiversity conservation potentials. Four sacred groves (Osun-Osogbo, Igbo-Olodumare, Idanre hills and Ogun-Onire) were selected for this study. Data were collected from 32 temporary sample plots of 20 m x 40 m. Nineteen sacred groves were identified across south-western Nigeria. A total of 37 families were enumerated within the four groves, with 32, 26, 22 and 22 families occurring in Ogun-Onire, Idanre Hills, Osun-Osogbo and Igbo-Olodumare, respectively. A pooled total of 141 tree species (41 to 85 per grove) were encountered in the four sacred groves, with Ogun-Onire having a significantly higher number of species than the other groves. Tree density ranged from 1427 to 4825 ha^{-1}. Shannon-Wiener diversity index (2.63 to 3.55) was significantly different in the four groves, with Igbo-Olodumare and Ogun-Onire having the lowest and highest values, respectively. When compared to the biodiversity indices of some tropical rainforests, the results indicated that sacred groves have high potentials for biodiversity conservation and thus could serve as reservoir of biodiversity.

Keywords: Anthropogenic influences, biodiversity indices, conservation measures, traditional method, tropical rainforest, regeneration potentials

INTRODUCTION

Biodiversity is an essential component of the forest for a healthy ecosystem. The rates of deforestation and forest degradation must be drastically reduced or halted and the forests conserved, if this important ecosystem is to be maintained. Currently, there are dire needs for appropriate restoration and forest conservation measures given the threats faced by the forest ecosystem. It has been postulated that conventional forest conservation methods have not been very effective in conserving biodiversity in many tropical forests because they have often pitted humans against nature by restricting the rights and livelihoods of communities (Le Saout et al. 2013, Onyekwelu 2017).

Before the advent of conventional forest conservation methods, several communities in Africa and Asia had traditional methods of conserving both plant and animal species in their habitats. Recently, traditional methods of conserving biodiversity gained the attention of scientists, partly due to the large-scale deforestation, degradation, encroachment and the conversion of forestland into agricultural land in tropical regions. The sacred grove system, which is the most widely practised traditional forest conservation measures, has gained prominence in recent times (Pradhan et al. 2019, Onyekwelu 2021). Biocultural and indigenous approaches to the conservation of biodiversity through sacred groves are becoming important, increasingly recognised and valued (Pradhan et al. 2019). Sacred groves are conserved for the worship of traditional deities, the practice of spiritual beliefs and religious rituals, cultural tenets and festivals of importance for sustenance of the cultural heritage of indigenous people. Sacred groves are tracts of virgin forests that harbour rich biodiversity. They are repositories of rare and endemic species and remnants of primary forests that are protected by the local people based on taboos, culture and religious beliefs (Khan et al. 2008, Onyekwelu 2021).

Usually, indigenous communities attach reverence to sacred groves, hence they are poised to protect their sanctity and components for their deities and religious purposes, and thus prevent them from desecration and destruction. Aura, fear, myths, taboos and rules are usually attached to sacred groves and are used to protect their forest from encroachments. Although sacred groves were not created for biodiversity conservation purposes, they have, over the years, contributed largely to biodiversity conservation (Onyekwelu 2021). Today, they are noted to be the reservoir of native biodiversity, refuge for endemic and endangered species and to represent biodiversity hotspots (Myers et al. 2000, Onyekwelu & Olusola 2014). This may be attributed to the customary practices that govern sacred groves which may have conserve elements of biodiversity that are often lost from forests subject to exploitation. Sacred groves are ecologically and genetically very important since they house rare and endangered flora and fauna species (Myers et al. 2000, Onyekwelu 2021).

Today, the ecological importance of sacred groves as a complementary biodiversity conservation method with associated environmental benefits is widely recognised. The practice of sacred groves is still prevalent and relevant in many parts of south-western Nigeria. Sacred groves adorn almost every village in south-western Nigeria, which explains why they are seen as symbols of identity for most of the Yoruba people in Nigeria (Adeyanju 2020). However, they are faced with myriads of challenges that are threatening their continued existence (Onyekwelu 2021). Despite their prominence in the culture of indigenous people of Nigeria, sacred groves have not been widely studied, and documentation of their locations and distributions do not exist. Thus, a survey of the sacred groves in south-western Nigeria was undertaken in an attempt to map their distributions, investigate the sacred groves structure and the tree species diversity, as well as their contributions to biodiversity conservation.

MATERIAL AND METHODS

The study area

This study was conducted in the south-western region of Nigeria (Figure 1). The region lies between longitude 2º 31′ and 6º 00′ E and latitude 6º 21′ and 8º 37′ N. It is dominated by tropical rainforest ecosystem, but has some derived savannah, as well as mangrove and swamp forest. The climate is tropical, with high mean annual temperature (21–34 ºC) and well-distributed high annual rainfall (1400 mm–4000 mm). Rainfall begins in April and ends in November while dry season occurs from December to March. Soils are predominantly ferruginous, typical of the variety found in intensively weathered areas of basement complex formations within the rainforest zone of south-western Nigeria (Onyekwelu et al. 2008).

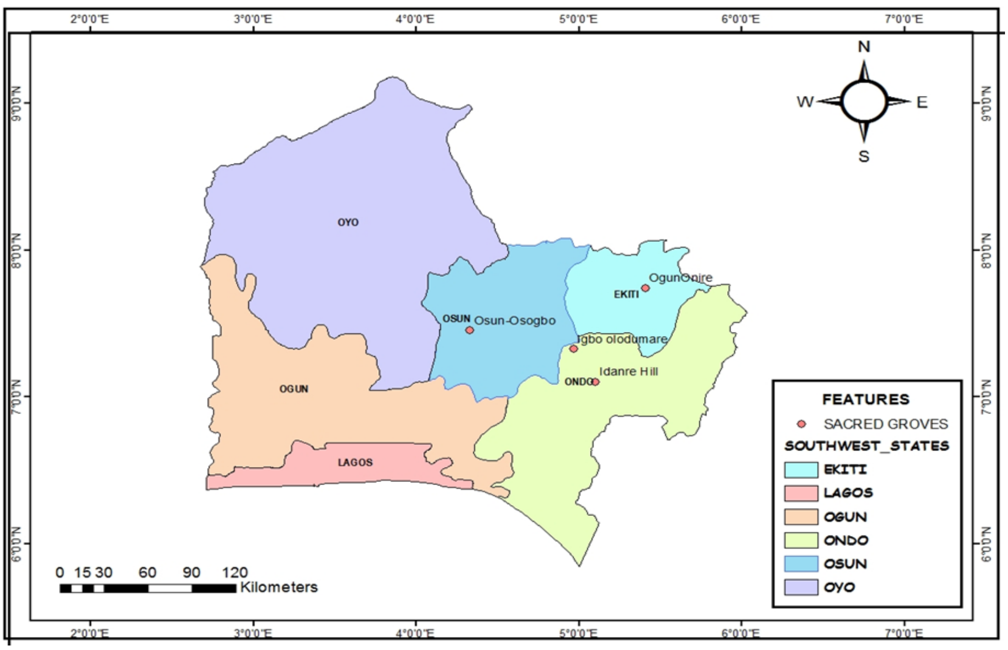

Figure 1 Map of south-western Nigeria with sacred groves locations

Data collection

The six states in south-western Nigeria were surveyed for sacred groves. The visitation to identified groves was based on available information. Sometimes, people were reluctant to provide information on sacred groves for fear of the gods or taboos. All identified sacred groves were visited and their GPS points taken. In addition, accessibility to and within a sacred grove was discussed with the custodian of the grove for granting permission to undertake inventory. Out of the identified sacred groves, four were selected for vegetation assessment, i.e., Osun-Osogbo (Osun State), Ogun-Onire (Ekiti State), Idanre Hills and Igbo-Olodumare (Ondo State) (Figure 1). Though the selection of groves was based on prominence/significance and accessibility, it was ensured that those selected were not located in a similar section of south-western Nigeria. Two line transects of 1000 m each in length were laid approximately at the centre of each selected grove, with the transects separated from the other by at least 1000 m distance. Four temporary sample plots, 40 m × 20 m were laid at alternate sides along each transect at an interval of 250 m, resulting in 4 plots per transect, 8 per sacred grove and a total of 32 for this study. In each plot, all living trees with dbh ≥ 10 cm were identified and their diameters at the base (Db), breast height (Dbh), middle (Dm) and top (Dt), as well as total heights, were measured. Tree sapling enumeration was carried out within a 10 m × 10 m subplot laid at the centre of each 40 m × 20 m plot. All saplings (dbh > 1.0 cm, but < 10 cm) were identified and their dbh measured. For seedling enumeration (dbh < 1.0 cm), a quadrant of 5 m × 5 m was laid within each subplot. Seedling species were identified and their frequency recorded.

Data computation and analyses

Tree basal area of each tree was calculated using equation 1:

$$BA = \frac{лD^2}{4} \quad (1)$$

where BA = basal area (m²), D = diameter at breast height (cm) and л = pie (3.142). Total plot basal area was obtained as the summation of the basal areas of all trees within the plot. Basal area per hectare was computed as the product of mean plot basal area and the number of 40 m x 20 m plots per hectare.

Volume of individual trees was estimated using equation 2:

$$V = лh \frac{Db^2 + 4(Dm^2) + Dt^2}{24} \quad (2)$$

where V = volume (m³), π = 3.142, h = tree height (m), Db, Dm and Dt = tree diameters at the base, middle and top of the tree, respectively. Plot volume was calculated as the summation of the volumes of all trees within the plot. Volume per hectare was obtained as the product of mean plot volume and the number of 40 m x 20 m sample plots in one hectare.

Species relative density (RD), used to determine species relative distribution, was computed using equation 3:

$$RD = \left(\frac{n_i}{N}\right) x\ 100 \quad (3)$$

where RD (%) = species relative density, n_i = number of individuals of species i, N = total number of all individual trees.

Species relative dominance (RD_o) was estimated with equation 4:

$$RD_0 = \left(\frac{\Sigma Ba_i\ x\ 100}{\Sigma Ba_n}\right) \quad (4)$$

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

Importance value index (IVI) of each species was computed with the relationship (equation 5):

$$IVI = \left(\frac{RD + RD_0}{2}\right) \quad (5)$$

Species diversity index (H') was computed using the Shannon-Wiener diversity index (equation 6):

$$H' = \Sigma_{i=1}^{5} Pi\ In(P_i) \quad (6)$$

where H' = Shannon-Wiener diversity index, S = total number of species in the forest reserve,

p_i = proportion of S made up of the i^{th} species, ln = natural logarithm.

Simpson Concentration index was computed using equation 7:

$$D = \Sigma\left(\frac{n_i}{N_i}\right)\hat{}2 = D = \frac{1}{\sum_{i=1}^{5} P_i^2} \quad (7)$$

Margalef's index of species richness (M) was estimated with equation 8:

$$M = \left(\frac{S - 1}{Ln\ N}\right) \quad (8)$$

where S is the number of species, N is the number of individuals.

Shannon's maximum diversity index was calculated using equation 9:

$$H_{Max} = Ln\ (S) \quad (9)$$

where H_{max} = Shannon's maximum diversity index, S = total number of species in the sacred grove.

Species evenness was determined using Shannon's equitability (E_H), which was obtained using equation 10:

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{5} P_i Ln\ P_i}{Ln\ (S)} \quad (10)$$

Sorensen's species similarity index between two sacred forests was calculated using equation 11:

$$SI = \left(\frac{2c}{a + b}\right) \quad (11)$$

where c = number of species in sites a and b, a and b = number of species at sites 1 and 2, respectively.

One-way analysis of variance was used to test for significant differences between the biodiversity indices and growth parameters of the four sacred groves. Significant treatment means were separated using Fisher's least square difference.

RESULTS

Distribution of sacred groves in south-western Nigeria

Nineteen sacred groves were encountered in five states in south-western Nigeria. Obtaining information about sacred forests was difficult as people were unwilling to give information for reasons of fear or taboo. A good number of the groves were found in Ekiti, Osun and Ondo States. Generally, the sacred groves are small in size (> 1 ha to 122 ha) and the largest being Osun-Osogbo with a core and buffer zones of 75 and 47 ha, respectively. All the sacred groves are protected by local laws, customs, taboos and are dedicated to deities. Access into each sacred grove is highly regulated, where access is preceded by permission from the responsible authorities. In some sections of the groves, access is prohibited except by priests to perform rituals. The administration systems of the sacred groves are developed and complex. Some are community sites (e.g. Ogun-Onire) and some are state sites (e.g. Idanre Hills and Igbo-Olodumare), while others are national monuments and/or UNESCO World Heritage sites (e.g. Osun-Osogbo). All the sacred groves have rich cultural history and have existed for hundreds of years. Some of the groves have become popular tourist attraction centres with thousands of visitors every year (e.g. Osun-Osogbo and Idanre Hills).

Biodiversity indices

Cumulative tree density (seedlings, saplings and canopy trees) in the sacred groves ranged from 1427 to 4825 ha^{-1}, with Ogun-Onire having significantly highest density (4825 ha^{-1}) and Igbo-Olodumare having significantly lowest density (1427 ha^{-1}) (Table 1). There was no significant difference in tree density between Idanre Hills and Ogun-Onire groves. A total of 37 families were enumerated in the four groves, distributed into 32, 22, 22 and 26 families for Ogun-Onire, Osun-Osogbo, Igbo-Olodumare and Idanre Hills groves, respectively (Table 1). Family richness was statistically similar in Igbo-Olodumare and Osun-Osogbo, which were significantly lower than those of Idanre Hills and Ogun-Onire groves. A pooled total of 141 tree species was encountered in the four sacred groves. Species richness differed significantly between the groves. Ogun-Onire had

85 species, which was significantly higher than those of the other sacred groves, while Igbo-Olodumare had significantly lowest species richness (Table 1). Species richness at Osun-Osogbo and Idanre Hills were not significantly different. Shannon-Wiener diversity index (H') (2.63–3.55) followed the order Ogun-Onire > Idanre Hills > Osun-Osogbo Igbo-Olodumare, with Igbo-Olodumare having the lowest diversity index. Margalef index (5.64–10.02) followed the order Ogun-Onire > Osun-Osogbo > Idanre Hills > Igbo-Olodumare and differed significantly. Species evenness at the groves ranged from 0.71 to 0.80 and differed significantly. Tree species at Idanre Hills and Ogun-Onire groves were more evenly distributed compared to those encountered at Osun-Osogbo and Igbo-Olodumare groves.

Fabaceae and Moraceae were the two most important families across the sacred groves, and Sterculiaceae was the most important family in three groves (Table 2). The three most important families in each grove were Osun-Osogbo: Fabaceae (32.91%), Moraceae (12.97%) and Sterculiaceae (8.22%); Igbo-Olodumare: Sterculiaceae (44.08%), Fabaceae (9.72%) and Euphorbiaceae (8.42%); Idanre Hills: Fabaceae (28.54%), Apocynaceae (14.93%) and Moraceae (13.34%) and Ogun-Onire: Sterculiaceae (14.77%), Moraceae (14.25%) and Ulmaceae (11.33%). In most cases, the dominant tree species also doubled as the important ones. Though the sacred groves presented high species richness, only few species dominated each site. For example, three dominant species at each grove [Osun-Osogbo: *Brachystegia eurycoma* (19.94%), *Angylocalyx oligophyllus* (19.0), *Ceiba pentandra* (10.93%), Igbo-Olodumare: *Hildegardia barteri* (63.46%), *Sterculia tragacantha* (7.09%), *Ricinodendrum heudelotii* (4.21%), Idanre Hills: *Holarrhena floribunda* (21.93%), *Antiaris africana* (14.39%), *Morus mesozygia* (12.52%) and Ogun-Onire: *Blighia sapida* (20.96%), *Celtis zenkerii* (12.15%) and *Diospyros dendo* (11.24%)] dominated 49.87%, 74.21%, 48.84% and 43.02% of their sites, respectively (Table 3). Species similarity indexes were as follows, Idanre Hills and Osun-Osogbo: 47.2%, Idanre Hills and Ogun-Onire: 45.5%, Ogun-Onire and Osun-Osogbo: 40.4%, Igbo-Olodumare and Ogun-Onire: 40.0%, Igbo-Olodumare and Osun-Osogbo: 38.5% and Igbo-Olodumare and Idanre Hills: 37.3%, indicating that species similarity across the four groves was fairly the same.

Growth characteristics

The maximum dbh of individual trees was 185, 150.80, 131.50 and 105 cm for Idanre Hills, Osun-Osogbo, Ogun-Onire and Igbo-Olodumare sacred groves, respectively. Mean dbh varied from 24.4 to 31.9 cm and was highest at Idanre Hills and lowest in Ogun-Onire, while mean tree height was highest at Ogun-Onire (13.7 m)

Table 1 Biodiversity indices and growth structure for the sacred groves

Biodiversity indices and growth variables	Sacred groves			
	Osun Osogbo	Igbo Olodumare	Idanre Hills	Ogun Onire
Number of species	65^{b}	41^{c}	60^{b}	85^{a}
Number of families	22^{c}	22^{c}	26^{b}	32^{a}
Number of trees ha^{-1}	3078^{b}	1427^{c}	4633^{a}	4825^{a}
Shannon-Wiener's index H'	2.98^{c}	2.63^{c}	3.17^{b}	3.55^{a}
Shannon-Wiener's evenness	0.71^{b}	0.71^{b}	0.77^{a}	0.80^{a}
Shannon maximum diversity index	4.17^{b}	3.71^{c}	4.09^{b}	4.44^{a}
Simpson concentration (λ)	0.09^{b}	0.13^{a}	0.07^{b}	0.05^{b}
Species richness (Margalef index)	8.09^{b}	5.64^{c}	7.11^{b}	10.02^{a}
Basal area ($m^2 ha^{-1}$)	32.69^{c}	51.83^{a}	44.85^{b}	40.70^{b}
Volume (m^3ha^{-1})	270.83^{c}	302.74^{b}	389.52^{a}	319.57^{b}
Mean dbh (cm)	24.39^{c}	31.68^{a}	31.89^{a}	28.00^{b}
Mean height(m)	9.76^{c}	11.95^{b}	13.50^{a}	13.74^{a}
Maximum dbh (cm)	150.80^{b}	105.00^{c}	185.00^{a}	131.50^{c}
Maximum height (m)	26.80^{b}	32.50^{a}	30.80^{a}	32.50^{a}

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

Table 2 Family importance value index (FIV) for 7 important families in (a) Osun-Osogbo, (b) Igbo-Olodumare, (c) Idanre Hills and (d) Ogun-Onire sacred groves

Family	Basal area ha^{-1}	Volume ha^{-1}	RD (%)	RD_o (%)	FIV (%)
(a) Osun-Osogbo sacred grove					
Fabaceae	0.54	130.13	23.91	41.9	32.91
Moraceae	0.07	59.21	6.52	19.43	12.97
Sterculiaceae	0.02	19.35	6.52	9.92	8.22
Apocynaceae	0.61	15.13	4.35	6.52	5.43
Rubiaceae	0.25	4.03	8.7	2.41	5.55
Ulmaceae	0.03	15.93	2.17	6.55	4.36
Euphorbiaceae	0.25	7.21	4.35	3.94	4.14
(b) Igbo-Olodumare sacred grove					
Sterculiaceae	36.27	186.92	18.18	69.99	44.08
Fabaceae	2.22	15.30	15.15	4.29	9.72
Euphorbiaceae	4.02	24.39	9.09	7.76	8.42
Moraceae	2.87	35.49	6.06	5.54	5.80
Meliaceae	0.70	3.91	6.06	1.36	3.71
Sapindaceae	0.43	4.19	6.06	0.84	3.45
Anacardiacae	1.17	6.30	3.03	2.26	2.65
(c) Idanre Hills sacred grove					
Fabaceae	17.45	168.18	18.18	38.9	28.54
Apocynaceae	9.31	78.22	9.09	20.76	14.93
Moraceae	6.87	67.80	11.36	15.31	13.34
Malvaceae	5.40	43.97	9.09	12.04	10.57
Meliaceae	0.29	1.75	11.36	0.65	6.01
Leguminosae	1.04	7.48	4.55	2.32	3.43
(d) Ogun-Onire sacred grove					
Sterculiaceae	7.19	58.10	11.86	17.67	14.77
Moraceae	7.46	70.22	10.17	18.33	14.25
Ulmaceae	8.53	70.78	1.69	20.96	11.33
Malvaceae	5.87	46.58	5.08	14.43	9.76
Fabaceae	1.49	10.37	15.25	3.66	9.45
Sapindaceae	2.99	17.88	3.39	7.34	5.36
Meliaceae	0.93	5.95	6.78	2.28	4.53

RD = species relative density, RD_o = species relative dominance, FVI = family importance value index

and lowest at Osun-Osogbo (9.76 m). Basal area was highest at Igbo-Olodumare grove (51.83 m^2 ha^{-1}) followed by Idanre Hills (44.85 m^2 ha^{-1}), Ogun-Onire (40.7 m^2 ha^{-1}) and Osun-Osogbo grove (32.69 m^2 ha^{-1}). Idanre Hills recorded the highest stand volume (389.52 m^3 ha^{-1}) followed by Ogun-Onire (319.57 m^3 ha^{-1}), Igbo-Olodumare (302.74 m^3 ha^{-1}) and Osun-Osogbo grove (270.83 m^3 ha^{-1}). There were significant differences ($p < 0.05$) in all the tree growth characteristics investigated (Table 1). Except for mean dbh and stand basal area, the best growth characteristics were obtained at Ogun-Onire and Idanre sacred groves while the poorest were obtained at Osun-Osogbo grove (Table 1).

Tree dbh distribution followed inverse J-shape (Figure 2). As the tree dbh increased, the number of trees decreased, and vice-versa. The majority of the trees in the four groves fell within the dbh range of 0–30 cm, followed by 30–45 cm class, and only a few trees were encountered within the dbh class above 60 cm (Figure 2). Trees with high numbers were found within the height class of 0–10 m and 10–20 m (Figure 3). Only very few trees had heights that were higher than 20 m.

Table 3 Tree species diversity indices for seven most dominant species in (a) Osun-Osogbo, (b) Igbo-Olodumare, (c) Idanre Hills and (d) Ogun-Onire sacred groves

Family	Species	Density ha^{-1}	Mean Dbh (cm)	Mean Ht (m)	Mean BA (m^2)	Mean Vol (m^3)	RD (%)	RD_o (%)	IVI (%)
(a) Osun-Osogbo sacred grove									
Fabaceae	*Brachystegia eurycoma*	27	41.96	13.96	0.25	2.56	6.37	19.94	13.16
Fabaceae	*Angylocalyx oligophyllus*	16	17.05	9.65	0.02	0.16	3.75	19.00	11.37
Fabaceae	*Ceiba pentandra*	5	92.6	18.83	0.76	7.02	1.12	10.93	6.02
Ulmaceae	*Celtis zenkeri*	20	32.98	12.74	0.11	0.78	4.87	6.55	5.71
Apocynaceae	*Funtumia elastic*	30	26.75	10.54	0.07	0.51	7.12	6.41	6.76
Sterculiaceae	*Cola hispida*	70	17.47	7.38	0.03	0.14	16.85	5.77	11.31
Fabaceae	*Dialium guineense*	45	17.56	9.46	0.03	0.18	10.86	3.72	7.29
(b) Igbo-Olodumare sacred grove									
Sterculiaceae	*Hildegardia barteri*	253	33.22	11.35	0.13	0.67	62.04	63.46	62.75
Sterculiaceae	*Sterculia tragacantha*	23	20.72	10.29	0.06	0.28	5.74	7.09	6.42
Euphorbiaceae	*Ricinodendrum heudelotii*	17	44.78	13.86	0.21	1.29	4.21	4.21	4.21
Anacardiacae	*Spondias mombin*	14	26.09	10.38	0.08	0.45	3.45	2.93	3.19
Apocynaceae	*Funtumia elastic*	13	19.70	11.98	0.05	0.25	3.06	2.84	2.95
Fabaceae	*Ceiba pentandra*	11	41.00	14.76	0.20	1.22	2.68	2.61	2.65
Cannabaceae	*Celtis mildbraedii*	9	22.93	14.00	0.08	0.50	2.30	2.26	2.28
(c) Idanre Hills sacred grove									
Apocynaceae	*Holarrhena floribunda*	4.69	109.9	21.57	1.52	12.99	7.63	21.93	14.78
Moraceae	*Antiaris africana*	9.38	97.97	22.77	1.00	10.5	6.8	14.39	10.6
Moraceae	*Morus mesozygia*	1.56	105.2	30.8	0.87	13.05	7.31	12.52	9.92
Fabaceae	*Ceiba pentandra*	9.38	65.4	17.03	0.4	3.59	4.54	5.77	5.15
Malvaceae	*Pterygota macrocarpa*	1.56	63.5	16.8	0.32	2.07	4.41	4.56	4.49
Fabaceae	*Pterocarpus mildbraedii*	3.13	60.95	17.75	0.31	2.11	4.23	4.51	4.37
Meliaceae	*Entandrophragma cylindricum*	1.56	49.60	14.80	0.19	0.99	3.44	2.78	3.11
(d) Ogun-Onire sacred grove									
Sapindaceae	*Blighia sapida*	6	65.28	13.68	0.47	2.82	1.53	20.96	11.25
Ebenaceae	*Diospyros dendo*	2	10	5.3	0.01	0.01	0.38	11.24	5.81
Fabaceae	*Albizia zygia*	5	12.9	9.6	0.01	0.06	1.15	9.82	5.48
Malvaceae	*Bombax buonopozense*	2	15.5	10.1	0.02	0.1	0.38	8.58	4.48
Fabaceae	*Millettia thonningii*	11	23.14	14.21	0.02	0.07	2.68	7.22	4.95
Sterculiaceae	*Pterygota macrocarpa*	36	33.7	15.5	0.02	0.15	8.81	1.62	4.42
Ulmaceae	*Celtis zenkerii*	67	32.23	15.53	0.13	1.05	16.48	12.15	8.31

Dbh = diameter at breast height, Ht = height, BA = basal area, Vol = volume, RD = species relative density, RD_o = species relative dominance, IVI = importance value index

DISCUSSION

Distribution and status of sacred groves in south-western Nigeria

Sacred groves exist in many countries in the world, but are more common in Asian and African countries (Bhagwat & Rutte 2006). Globally, India has the highest number of sacred natural sites, i.e., 100,000–150,000 sites (Malhotra et al. 2001). The 19 sacred groves of south-western Nigeria, reported in this study, is low considering previous published reports. Borokini (2016) opined that almost all south-eastern and south-western Nigerian communities have at least one sacred natural site, while Adeyanju (2020) observed that sacred groves are symbols of identity for most Yoruba people in south-western Nigeria.

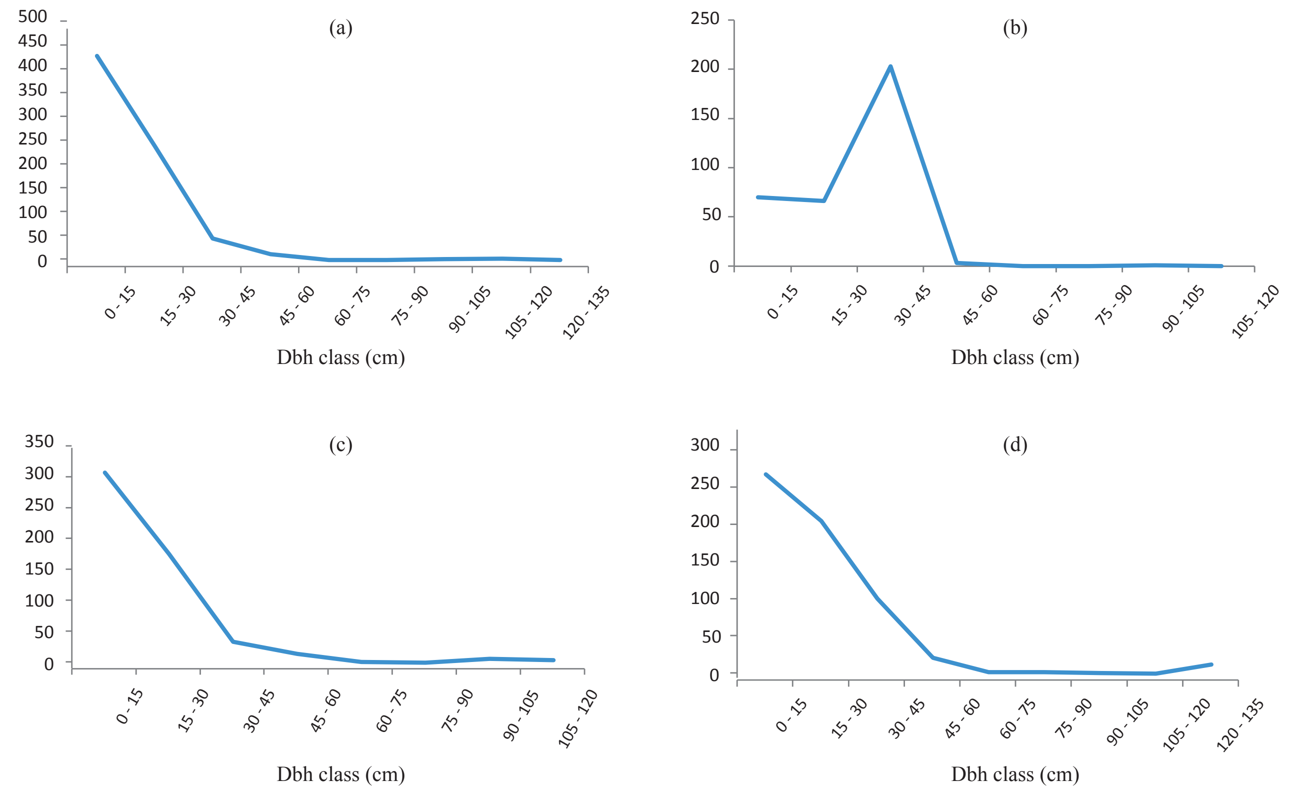

Figure 2 Diameter distribution (cm) in (a) Osun Osogbo, (b) Igbo Olodumare, (c) Idanre hills and (d) Ogun Onire sacred groves

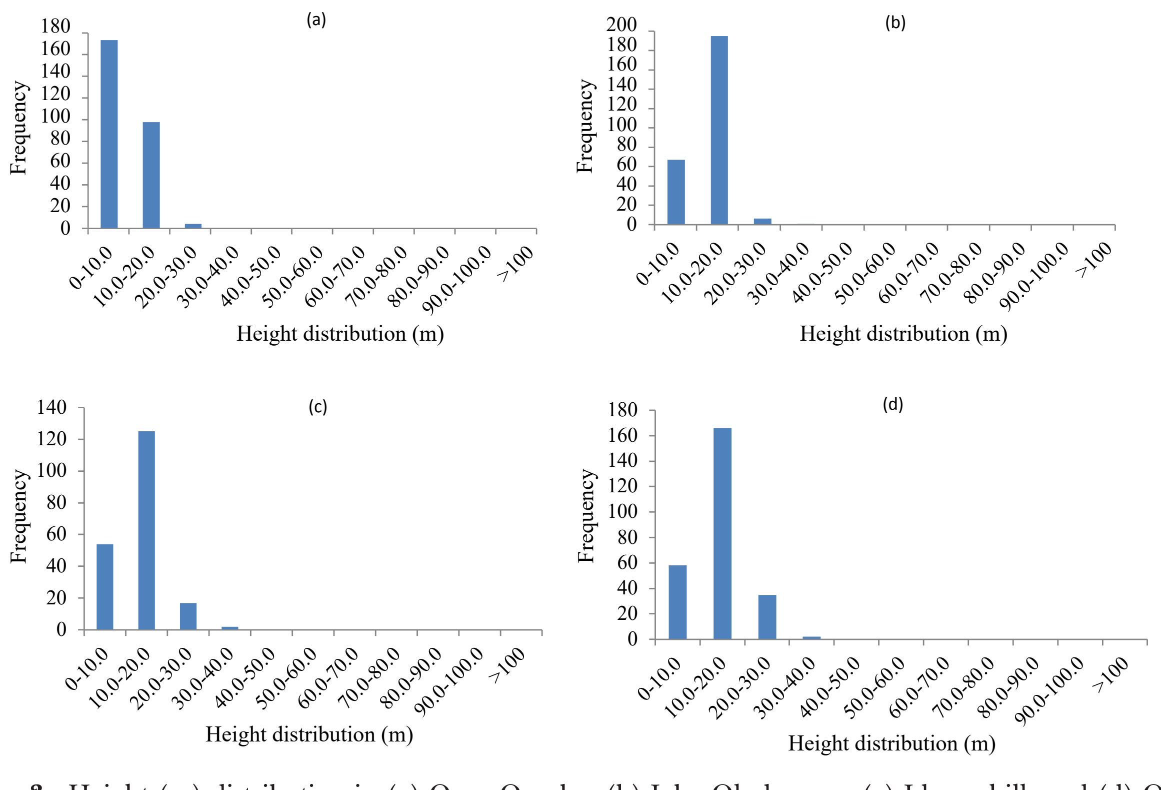

Figure 3 Height (m) distribution in (a) Osun Osogbo, (b) Igbo Olodumare, (c) Idanre hills and (d) Ogun Onire scared groves

Up to 3,000 sacred groves have been identified in Ghana (Boadi et al. 2017). It should be noted that this study only covered sacred forests (defined as patches of intact natural forests dedicated for deity worship or cultural festival), and thus other forms of sacred natural sites (burial/coronation sites, sacred rock, etc.) were excluded. In addition, the low number of groves in this study is attributed to time constraint, secrecy attached to sacred groves and fear of deityies or taboos, which constrained the people from giving information. Thus, it was postulated that there may be far more sacred groves in south-western Nigeria than that have been reported. The current list of findings serve as a baseline and should be updated as more groves are identified.

The importance of sacred groves as a biodiversity conservation tool is their widespread distribution. Most sacred groves are relatively small in size, however, the cumulative area they occupy in a region could be large upon summing up. Osun-Osogbo is the largest known sacred grove in Nigeria with a total area of 122 ha (core area of 75 ha and buffer zone of 47 ha) (Onyekwelu & Olusola 2014). Thus, sacred groves in Nigeria are small in size compared with their counterparts in some parts of the world. Khan et al. (2008) reported large sacred groves of up to 26,326 ha. Encroachment was observed to be minimal in the sacred groves, which can be attributed to the effectiveness of the taboos, local laws, customs and regulations used in their management, in addition to the prohibition or highly regulated access (Borokini 2016, Adeyanju 2020). Due to respect and fear of the taboos and deities, people usually keep away from the sacred groves, and thus refrain from felling trees within the site (Onyekwelu & Olusola 2014).

Tree growth and yield characteristics

Tree density in the sacred groves was found to be higher than the range of 406 to 671 ha^{-1} reported for some primary and degraded tropical natural forests in Nigeria (Onyekwelu et al. 2008, Lawal & Adekunle 2013, Adekunle et al. 2014). The higher stand density in the study is attributed to the inclusion of seedlings and saplings in the estimation. The previous studies only included overstory trees (dbh > 10 cm) in their estimations. Stand volume of the groves (270.83 to 389.52 m ha^{-1}) were similar to the 387 m ha^{-1} for Akure Strict Nature Reserve (SNR), Nigeria, 287.49 m ha^{-1} for Eda forest reserve, Nigeria and 312 m ha^{-1} for Southern Pantanal, Brazil (Wittmann et al. 2008, Adekunle et al. 2013, Adekunle et al. 2014). Thus, sacred groves have the potentials for high volume production, and by implication high biomass and carbon sequestration, thus making them good carbon sinks. The distribution of tree diameters indicate how well the forest is regenerating by using the resources of the site. The inverse-J tree dbh distribution in this study is typical of natural tropical forests and an indication of good regeneration status and a healthy forest ecosystem (Onyekwelu & Olusola 2014, Sundarapandian & Subbiah 2015). The tree height distribution graphs revealed that a high proportion of trees were within the height class of 10–20 m, with only a few trees within 30–40 m height class, which collaborates the findings of Adekunle et al. (2013).

Biodiversity indices and conservation status of the sacred groves

Biodiversity indices are estimated to bring the floristic diversities and abundance of different habitats to a similar scale for comparison. High Shannon-Wiener diversity index (H′) values imply high species richness of such ecosystem. The H′ of the four sacred groves (2.63 to 3.55) was similar to values of natural rainforests in south-western, Nigeria (2.82 to 3.66) (Onyekwelu et al. 2008, Adekunle et al. 2013, Onyekwelu & Olusola 2014). The high H′ (3.17 to 3.55) of Idanre Hills and Ogun-Onire groves compared favourably with the values reported for some primary forests in Nigeria (3.31–3.74) (Onyekwelu et al. 2008, Adekunle et al. 2013)). Igbo-Olodumare and Osun-Osogbo sacred groves had similar H′ values which either corresponded to, or higher than, those of some degraded forests in Nigeria (Onyekwelu et al. 2008). The H′s of this study were similar to the range of 2.94–3.96 of sacred groves in south-eastern Ghats, India but higher than values obtained for sacred groves in Tamil Nadu Indian (1.69–2.33) and Tanzania (1.2–1.4) (Mgumia & Oba 2003, Sundarapandian & Subbiah 2015). The H_{max} values of this study (3.71–4.44) were higher than those of some previous studies (1.80–3.46) (Onyekwelu & Olusola 2014, Agbelade & Ojo 2020). These H_{max} values implied that most of the species encountered in the sites do not have equal area abundance. Species richness is one of the most widely used indices for measuring the biodiversity of an ecosystem. The numbers of species encountered in Igbo-Olodumare, Idanre Hills and Osun-Osogbo groves (41–65) were within the range reported for degraded and primary rainforests and sacred groves in Nigeria (Lowe 1997, Onyekwelu & Olusola 2014, Aigbe & Nchor 2021), however the value obtained for Ogun-Onire grove (85) was higher. Similarly, Boadi et al. (2017) reported higher species in Jachie sacred grove than in Nkrabea forest reserve in Ghana. This strengthens the belief that sacred groves are important for in-situ biodiversity conservation, ecosystem functioning and are repository of many indigenous tree species, including rare and endangered species (Colding & Folke 1997, Onyekwelu 2021).

Compared to the other sacred groves, in this study, Igbo-Olodumare had the lowest Margalef index. The distribution of few tree species per hectare is mostly responsible for the poor tree species richness in most Nigerian forest ecosystems. Ogun-Onire and Idanre Hills had similar species evenness values (0.77 and 0.80), which were significantly higher than the values (0.71 and 0.71) for Osun-Osogbo and Igbo-Olodumare groves. Thus, tree species are more similarly distributed in Idanre Hills and Ogun-Onire groves compared to the others. Adekunle et al. (2013) and Lawal and Adekunle (2013) obtained similar species evenness values (0.82–0.87) for some natural forests in Nigeria, while higher evenness value of 0.91 was reported for a national park and forest reserve (Aigbe & Nchor 2021). Onyekwelu et al. (2008) and Agbelade & Ojo (2020) reported a lower evenness value of 0.45 to 0.66 for some natural forests in south-western Nigeria. Adekunle et al. (2014) presented lower species evenness values of 0.56 to 0.76 for Murtiya, Balcha and Nishangara forests in Katarnia Ghat Wildlife Sanctuary, India. The generally low species similarity between pairs of sacred groves in this study may be due to the rarity of some species, genetic and site differences. The dominance of Igbo-Olodumare by *Hildegardia barteri* could explain its low species similarity with other sacred groves in this study. Connell and Lowman (1989) affirmed that a forest with 50–80% of its canopy covered by only a few species is considered a low diversity forest. IUCN (2004) opined that a species is considered endangered if the reduction of its population size is greater than 80% over the last ten years, and extinct if at least 20% within the next 20 years.

The high diversity indices in this study were an indication of the potentials of sacred groves as a biodiversity conservation measure. The good biodiversity conservation status of the sacred groves can be attributed to the strict traditional method of conservation and the prohibition/restriction of anthropogenic activities within the groves. Religious beliefs and taboos were central to the protection of sacred groves in India, which led to increase in tree species diversity (Khan et al. 2008, Sundarapandian & Subbiah 2015). The good conservation status of most sacred groves in this study is attributed to the fact that indigenous communities consider the groves as the home of deities, place of worship and cultural site and festivals, and consequently refrained from destroying them, which is similar to the situation in Tanzania (Adeyanju 2020, Onyekwelu 2021, Mgumia & Oba 2003). In a previous study, Onyekwelu and Olusola (2014) attributed the low species diversity in Igbo-Olodumare grove to its "low sacredness" since only 5% of community dwellers consider the grove as the home of deity and place of worship, which may have led to encroachments. The low diversity index of Igbo-Olodumare sacred grove can also be attributed to its rockiness and its surprising dominance by a few tree species e.g. *Hildegardia barteri* (RD_o and IVI of 63.46% and 62.75%, respectively) (Onyekwelu & Olusola 2014). The slight reductions in biodiversity indices of Osun-Osogbo compared to an earlier study may be connected with some emerging practices at the grove (Onyekwelu & Olusola 2014). Due to the high influx of people into Osun-Osogbo grove during the annual Osun and other festivals, understory species are sometimes trampled upon (Adeyanju 2020). Oftentimes, rituals and sacrifices may involve ground clearing and ground fires by the priests and visiting devotees. All these may adversely affect tree density, especially the density of understory trees, thereby impacting negatively on natural regeneration and species richness. This may explain the lower number of families, tree density and Shannon-Wiener's diversity index in Osun-Osogbo grove, compared to Idanre Hills and Ogun-Onire that have fewer festivals and lower number of tourist visits.

Table 4 supports the widely held opinion that the sacred grove system promotes biodiversity conservation. This is evident in this study where the biodiversity indices of the four sacred groves were either comparable or better than the biodiversity indices of natural forests in Nigeria and India. Apart from Akure SNR, Nigeria, which consistently had

Table 4 Comparison of biodiversity indices of sacred forests in this study with published results of tropical forests

Forest type		State of forest	Biodiversity indices					Tree growth variables			Source
			No. of families	No. of species	H′	Species richness	Species evenness	Density per ha	Mean Dbh	Mean BA	
Sacred groves	Osun-Osogbo	Intact	22	65	2.98	8.09	0.71	3078	24.39	32.69	Current study
	Igbo-Olodumare	Encroached	22	41	2.63	5.64	0.71	1427	31.68	51.83	
	Idanre Hills	Intact	26	60	3.17	7.11	0.77	4633	31.89	44.85	
	Ogun-Onire	Intact	32	85	3.55	10.02	0.80	4825	28.00	40.70	
Natural forests	Eda Forest Reserve	Degraded	17	28	2.58	5.71	0.45	301	40.65	40.68	Agbelade & Ojo (2020)
	Murtiya Forest	NA	20	23	2.37	4.27	0.76	172	34.37	71.73	Adekunle et al. (2014)
	Balcha Forest	NA	10	11	1.35	2.19	0.56	96	32.19	58.46	
	Nishangara Forest	NA	12	13	1.73	2.44	0.67	136	31.46	56.33	
	Akure Enrichment Forest	Enriched	21	42	3.25	7.58	0.87	446	23.26	35.20	Lawal & Adekunle (2013)
	Akure Degraded Forest	Degraded	11	18	2.74	5.00	0.95	60	13.80	0.95	
	Akure Strict Nature Reserve	Primary	31	95	3.74	64.72	0.82	387	22.68	22.54	Adekunle et al. 2013
	Queen Forest	Primary	27	51	3.31	5.16	0.66	671	27.30	85.40	Onyekwelu et al. (2008)
	Oluwa Forest	Degraded	24	45	3.12	5.04	0.60	513	22.50	35.90	
	Elephant Forest	Degraded	22	31	2.82	4.98	0.57	508	21.60	29.40	

Dbh = diameter at breast height, H′ = Shannon-Wiener's index, BA = basal area better biodiversity indices than other sacred groves, the other natural forests had lower biodiversity indices than most of the sacred groves. Table 4 also revealed that primary forests had biodiversity indices that were higher or comparable with those of the sacred groves. Except for Igbo-Olodumare, other sacred groves had higher biodiversity indices than degraded forests (Table 4). Thus, sacred groves have high potentials for biodiversity conservation and could serve as reservoirs of biodiversity.

CONCLUSIONS

The sacred grove system is an effective species conservation measure. The high biodiversity indices of the groves are attributed to the effectiveness of the laws and taboos guiding them, thus curtailing anthropogenic influences. Sacred groves harbour comparable or higher species richness and diversity than primary and degraded forests. Tree dbh distributions in the groves indicated that they have good regeneration potentials. The biodiversity conservation gains of the sacred groves should be incorporated into state forest conservation programmes. This could be achieved through participatory community-based forest management systems. *In-situ* conservation should be encouraged through assisted regeneration and by strengthening the traditional laws and regulations guiding the sacred groves. Cultural values and indigenous knowledge should be incorporated into the policy framework of conservation.

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