Understory Species Diversity, Regeneration and Recruitment Potential of Sacred Groves in South West Nigeria

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Abstract

Background

Global species extinction rates due to forest conversions are increasing. Ecologists, conservationists and governments have adopted various conservation methods. Sacred grove is one conservation option that has gained attention in recent time. We assessed understory species diversity, regeneration and recruitment potentials of four sacred groves in southwestern Nigeria. Overstory tree species were inventoried in eight 800m^2 temporary sample plots, systematically laid along two transects of 1000m each. Understory tree species were assessed in 100m^2 plots for saplings and 25m^2 plots for seedlings in all sample plots.

Results

Shannon-Wiener diversity index (1.8-3.46 (overstory); 2.65-3.55 (understory)), number of species (32-58 (overstory); 39-78 (understory)) and tree density (309-417 individuals/ha (overstory); 775-1445 individuals/ha (understory)) were comparable and/or higher at the understories than the overstories. Dbh distribution curves showed highest stand density at the lowest class (10–20 cm) and decreased with increasing dbh, indicating good regeneration status and healthy ecosystem. Regeneration was considered good and fair, because in most cases, number of seedlings > saplings > overstory trees or number of seedlings > saplings ≤ overstory trees. The good regeneration status was further confirmed by the good species recruitment in the understory. Some tree species were found to be unique to some sacred groves while some species that were absent in protected forests existed in the groves. The presence of these unique tree species indicated the potential of sacred groves in conserving important tree species. The high regeneration could be attributed to strict access restrictions in the groves, and the taboos and myths feared by the people. However, the high influx of people into sacred groves for festivals and rituals, which results in trampling and burning of seedlings, is a threat to the diversity, regeneration and recruitment potentials of the groves.

Conclusion

High regeneration and recruitment status maintained in all the sacred groves in this study were achieved using taboos, cultural and traditional methods. These methods could be incorporated in managing forest reserves in Southwestern Nigeria.

Keywords: Ecological indicators, natural regeneration, biodiversity conservation, ecosystem services

Introduction

Biodiversity is essential for the wellbeing of the ecosystem but the escalating extinction crisis shows that the diversity of nature can no longer support the current pressure that humanity exerts on the forest (Shushma *et al.*, 2015). High density and diversity of species in rainforests have attracted incessant disturbance of the ecosystem through high harvesting pressure (both legal and illegal) (Onyekwelu *et al.*, 2008). Species extinction rate is increasing, reaching up to 1,000 times or more than the natural rate because of habitat destruction, land conversion for agriculture and development, climate change, pollution and the spread of invasive species (Shushma *et al.*, 2015). Consequently, ecologists, conservationists and governments have recommended and adopted various conventional and traditional conservation methods. One of the methods that have gained attention in the recent past is the use of traditional practices in protecting and managing biodiversity, among which the sacred grove system is prominent (Daye and Healey, 2015). In Nigeria and elsewhere, sacred groves have been observed to play important role in biodiversity conservation (Bhagwat and Rutte, 2006; Khan *et al.*, 2008; Kokou *et al*., 2008; Onyekwelu and Olusola, 2014). Many studies have assessed the forest population, structure and biodiversity conservation potentials of the overstory layers of sacred groves in Nigeria (Onyekwelu and Olusola 2014; Salami and Akinyele, 2018; Ikyaagba *et al*., 2019). However, studies on understory tree species diversity in sacred groves are rare while no known study has assessed the regeneration and recruitment potentials of sacred groves in Nigeria.

The forest understory is an integral component of the forest ecosystems, thus it demands as much attention as the overstory. Ecologically, understory tree species play a fundamental role in diversity, structure, and functioning of forest ecosystems (Svenning, 2000). They support a large fraction of total community floristic diversity and provide habitats and food for many kinds of animals (Tchouto *et al.*, 2006). The forest understory plays a central role in the dynamics of forest ecosystems by influencing long-term successional patterns and contributing to forest nutrient cycles (Chastain *et al.*, 2006). It has been suggested that the forest understory may show different patterns of species diversity than the overstory due to different responses to light level, nutrient availability, and temperature (Svenning, 2000) and could be as species-rich as the forest overstory (Tchouto *et al.*, 2006) or even richer.

Sacred groves have been noted to harbour many commercially important and highly valuable tree species, they are religio-culturally and socio-economically important to their communities, hence their sustainability is key to their host communities (Onyekwelu and Olusola, 2014; Adeyanju, 2020). But today, they are confronted with anthropogenic infringement and hence the task of finding suitable strategies to enhance regeneration and species recruitment. Regeneration is a biological process which involves asexual and sexual reproduction, dispersal and establishment (Barness, 1997), successful regeneration and vigorous height growth lead to recruitment. In silviculture, recruitment is a process by which trees move from one size class to another (Helms, 1998) or by which young trees overgrow certain threshold values of height or diameter (Lexerod and Eid, 2005). Greene *et al.* (1999) listed the factors that could influence the density and composition of seedlings in forest ecosystems to include: site conditions, seed rain and seed banks, light conditions, competition, intra- and inter-species relations.

Regeneration of forest trees is essential for conservation and maintenance of biodiversity in forest ecosystems as well as for forest management. The knowledge of plant regeneration status helps in developing management options and setting priorities. Limited tree regeneration is a major threat to forest sustainability. The satisfactory natural regeneration behaviour of the forests depends on population structure characterized by the production and germination of seed, establishment of seedlings and saplings in the forest (Khumbongmayum *et al*., 2006). Complete absence of tree seedlings and saplings in a forest indicates poor regeneration, while presence of sufficient number of seedlings indicate successful regeneration (Saxena and Singh 1984). Despite the biodiversity conservation merits of sacred groves and the importance of regenerates in sustaining and maintaining biodiversity, studies on tree species regeneration status in Nigerian sacred groves are are lacking. Therefore, an attempt was made in this study to fill this knowledge gap. Consequently, this study investigated the understory tree species diversity, regeneration and recruitment potential of sacred groves in southwestern Nigeria.

Methodology

The study was carried out in southwestern region of Nigeria made up of six federal states of Lagos, Ogun, Oyo, Osun, Ekiti and Ondo. The region lies between longitude 2^{0} 31' and 6^{0} 00' East and Latitude 6^{0} 21' and 8^{0} 37'N with land area of 77,818 km^{2} (Agboola, 1979). A high percentage of the region lies within the tropical rainforest zone of Nigeria. Annual rainfall ranges between 1400 mm and 4000 mm while mean temperature varies between 21 - 34ºC. Rainfalls occur within the months of April to 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 zone of southwestern Nigeria (Onyekwelu *et al.*, 2008).

Method of Data Collection

Out of the sacred groves in southwestern Nigeria, four (Osun-Osogbo, Igbo-Olodumare, Idanre Hills and Ogun-Onire) were purposefully selected based on prominence/significance, accessibility and permission to conduct inventory. The selected groves covered three (Ekiti, Ondo and Osun) of the six southwestern states. Two line transects of 1000m each in length, separated by a distance of at least 1000m were laid approximately at the middle of each sacred grove. Temporary sample plots of 40m × 20m were laid on alternate sides along each transect at every 250m interval, giving 4 plots per transect, 8 per sacred grove and 32 for the study. Within each sample plot, all living trees with Dbh ≥ 10cm were identified and their Dbh and total heights measured. For tree sapling enumeration, a 10m × 10m sub-plot was laid at the middle of each plot. All saplings (Dbh >1.0 cm but < 10cm) were identified and their dbh measured. A 5m × 5m quadrant was laid within each sub-plot for seedlings (Dbh < 1.0cm) enumeration. Frequencies of identified seedling species were recorded.

Data computation and analysis

The following biodiversity indices were computed:

(i) **Species relative density** was computed as

$$RD = \frac{n_i}{N} \times 100 \quad \text{(eqn. 1)}$$

Where: RD (%) = species relative density; ni = number of individuals of species i; N = total number of all tree species in the entire community

(ii) **Species relative dominance (RDo (%))** was computed for overstory trees and saplings using equation 2.

$$RD_O = \frac{\sum Ba_i \times 100}{\sum Ba_n} \quad \text{(eqn. 2)}$$

Where**:** Ba_i = Basal area of individual tree belonging to species i; Ba_n = Stand basal area

(iii) **Importance Value Index (IVI)**: This was obtained using equation 3.

$$IVI = \frac{RD + RD_O}{2} \quad \text{(eqn. 3)}$$

(iv) **Sorensen's species similarity index** between two sites was calculated using equation 4:

$$SI = \left(\frac{2C}{a+b}\right) \text{X}100 \quad \text{(eqn. 4)}$$

Where: C = number of species at sites a and b; a, b = number of species at sites a and b.

(v) **Species diversity index** was calculated using the Shannon-Wiener diversity index (eqn. 5):

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i) \quad \text{...(eqn. 5)}$$

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

(vi) **Shannon's maximum diversity index** was calculated using eqn. 6:

$H_{max} = \ln(S)$ …………………………..…………………………………………. (eqn. 6)

Where: H_{max} = Shannon's maximum diversity; S = Total number of species in the community.

(vii) **Species evenness** in each site was determined using Shannon's equitability (E_H)(eqn. 7):

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{S} P_i \ln(P_i)}{\ln(S)} \quad \text{....................................(eqn. 7)}$$

(viii) **Margalef's index** was calculated using the eqn. 8:

$$D = \frac{S-1}{\ln N} \quad \text{...(eqn. 8)}$$

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

The five most dominant tree species in each sacred grove were selected for regeneration assessment. Regeneration status was determined based on population sizes of seedlings, saplings (Bhuyan *et al.* 2003; Khumbongmayum *et al.*, 2006) and overstory trees. Good regeneration:,seedlings > saplings > overstory trees; fair regeneration: seedlings > or ≤ saplings ≤ adults; poor regeneration:,the species survives only in sapling stage, but no seedlings (saplings may be <, > or = adults); if a species is present only at adult stage it is considered as not regenerating (Khumbongmayum *et al.*, 2006). Species is considered as 'new' (recruitment) if the species has no adults and saplings but only seedlings. In this study, a species was considered unique to a sacred grove if found only in that sacred grove in this study. Also, a species was considered endemic if it is only found in a sacred grove and never been reported in any forest site in Southwestern Nigeria based on the information at our disposal.

Results

The overstories and understories of the sacred groves in this study were dominated by few tree species. Results of species relative dominance revealed that seven tree species occupied between 66.06% and 85.69% of the overstories and 60.81% and 92.56% of the undertories of the sacred groves (Tables 1 to 4). As few as 2 to 3 tree species could occupy over 50% of the sacred groves. *Hidergardia barterii* alone occupied 65.09% of the overstory of Igbo-Olodumare (Table 2), making it the most dominant species across the sacred groves in this study. At the understory layer, *Napoleona imperialis* was the most dominant species, occupying 33.65% of the understory of Idanre Hills grove (Table 1). No single species was dominant in all the four sacred groves (both overstories and understories). *Ceiba pentandra* and *Funtumia elastica* were dominant in the overstories of three of the four sacred groves. In most cases, the dominant tree species in the overstory layer were not the dominant species in the understory of specific sacred grove, the only except being *Sterculia tragacantha* and *Cola hispida* which were dominant in the overstory and understory of Igbo-Olodumare and Osun-Osogbo sacred groves, respectively (Tables 2 and 4). The dominant tree species also doubled as the important species as a result of their high IVI (Table 1 to 4).

Number of tree families in the overstory and understory layers of the various sacred groves varied from 19 to 29 and 15 to 25, respectively (Table 5). The understory of the sacred groves had higher species richness (39 to 78) than the overstory layer (32 to 62), a situation that was observed across all sacred grove (Table 5). Similarly, tree density at the understory layer (775 to

1445 ha^{-1}) was much higher (85.5% to 367.6%) compared to the density at the overstory layers (309 to 417 ha^{-1}) of the sacred groves (Table 5). Shannon-Wiener diversity index ranged from 1.8 to 3.46 at the overstory layer of the sacred groves and 2.65 to 3.55 at the understory (sapling) layer.

Table 1: Important value index (IVI) for seven most important species in Idanre Hill sacred grove

S/N	Overstory				Understory			
	Species	**RD (%)**	**RDo (%)**	**IVI (%)**	**Species**	**RD (%)**	**RDo (%)**	**IVI (%)**
1	*Ceiba pentandra*	3.03	21.98	12.51	*Napoleona imperialis*	14.91	33.65	24.28
2	*Cassia siamen*	15.15	9.18	12.17	*Alcormanis difformis*	14.04	26.14	20.09
3	*Cola gigantean*	7.58	11.33	9.45	*Combretum racemosum*	8.77	5.86	7.32
4	*Alstonia boonei*	1.52	14.66	8.09	*Lecaniodiscus cupanioides*	5.26	5.93	5.60
5	*Antiaris africana*	3.03	8.81	5.92	*Albizia zygia*	3.51	3.53	3.52
6	*Funtumia elastic*	5.05	4.08	4.57	*Dialum guinensis*	2.63	4.36	3.49
7	*Berlinia grandiflora*	6.57	2.24	4.40	*Baphia nitida*	2.63	3.34	2.99

Table 2: Important values index (IVI) for seven most important species in Igbo-Olodumare sacred grove

	Overstory				Understory			
S/N	**Species**	**RD (%)**	**RDo (%)**	**IVI (%)**	**Species**	**RD (%)**	**RDo (%)**	**IVI (%)**
1	*Hidergardia barterii*	62.07	65.09	63.58	*Spondias pinnata*	22.78	29.44	26.11
2	*Ricinodendron heudelotii*	4.21	7.45	5.83	*Combretum racemosum*	13.92	17.48	15.70
3	*Sterculia tragacantha*	5.75	2.13	3.94	*Hidergadia barterii*	8.86	20.93	14.89
4	*Ceiba pentandra*	2.68	4.13	3.41	*Sterculia tragacantha*	7.59	12.45	10.02
5	*Funtumia elastic*	3.07	1.17	2.12	*Trichilia welwitschii*	6.33	7.58	6.96
6	*Spondias mombin*	3.45	2.31	2.88	*Cissus araloides*	5.06	3.13	4.09
7	*Ficus sycomorus*	0.38	3.41	1.90	*Olax subscorpioidea*	6.33	1.55	3.94

Table 3: Important values index (IVI) for even most important species in Ogun-Onire sacred grove

S/N	Overstory				Understory			
	Species	**RD (%)**	**RDo (%)**	**IVI (%)**	**Species**	**RD (%)**	**RDo (%)**	**IVI (%)**
1	*Celtis zenkerii*	16.29	20.75	18.52	*Lecaniodiscus cupanioides*	8.403	12.41	10.41
2	*Pterigota macrocarpa*	8.71	11.13	9.92	*Napoleona imperialis*	5.042	13.05	9.05
3	*Cola gigantean*	7.58	9.72	8.65	*Monodora angolensis*	6.723	8.47	7.60
4	*Morus mesozygia*	4.55	8.49	6.52	*Alchornea laxiflora*	5.882	7.65	6.77
5	*Trilepisium madagascariensis*	4.55	4.48	4.51	*Montandra guineensis*	5.882	6.42	6.15
6	*Blighia sapida*	1.52	7.15	4.33	*Antiaris africana*	4.202	6.22	5.21
7	*Anopysis klaineana*	3.41	4.34	3.87	*Strombosia pustulata*	3.361	6.59	4.97

Table 4: Important values index (IVI) for even most important species in Osun-Osogbo sacred grove

S/N	Overstory				Understory			
	Species	**RD (%)**	**RDo (%)**	**IVI (%)**	**Species**	**RD (%)**	**RDo (%)**	**IVI (%)**
1	*Brachystegia euricoma*	6.30	19.76	13.03	*Cola hispida*	10.26	26.00	18.13
2	*Antiaris africana*	3.70	18.82	11.26	*Baphia nitida*	8.97	23.14	16.06
3	*Cola hispida*	16.67	5.71	11.19	*Combretum racemosum*	7.69	8.83	8.26
4	*Dialum guinensis*	10.74	3.69	7.21	*Montandra guinensis*	5.77	7.63	6.70
5	*Funtumia elastic*	7.04	6.35	6.69	*Napoleona imperialis*	5.13	7.68	6.40
6	*Ceiba pentandra*	1.11	10.82	5.97	*Lecaniodiscus cupanioides*	5.13	3.79	4.46
7	*Celtis zenkerii*	4.81	6.49	5.65	*Diospyros zenkerii*	5.77	2.46	4.11

Table 5: Summary of understory and overstory biodiversity indices of the sacred groves

Biodiversity indices	Sacred groves			
	Osun-Osogbo	Igbo-Olodumare	Idanre Hills	Ogun-Onire
Overstory Layer				
Number of Families	27	19	26	29
Number of Species	50	31	43	62
Number of Trees Ha^{-1}	417	408	309	408
Shannon-Wiener Diversity Index	3.19	1.8	3.25	3.46
Species Evenness	0.84	0.52	0.86	0.85
Simpson Concentration (λ)	0.07	0.4	0.06	0.05
Species Richness (Margalef Index)	8.05	5.57	7.94	10.24
Understory Layer				
Number of Families	17	15	20	25
Number of Species	55	39	73	78
Number of Understory Ha^{-1}	775	835	1445	903
Shannon-Wiener Diversity Index	3.55	2.65	3.26	3.51
Species Evenness	0.63	0.36	0.36	0.43
Simpson Concentration	0.96	0.90	0.92	0.95
Species Richness (Margalef Index)	8.12	5.65	9.90	11.31

Species similarity between pairs of sacred groves varied from 57.69% to 82.35% in the overstory and 24.66% to 75.47% in the understory (Table 6). Species similarity between pairs of groves was higher in the overstory than the understory. In the Overstory, species similarity was highest between Idanre Hills and Osun-Osogbo (82.35%) and lowest between Igbo-Olodumare and Osun-Osogbo (57.69%). In the understory layer, the highest similarity index was between Ogun-Onire and Osun-Osogbo (75.47%) while the lowest value was between Igbo-Olodumare and Ogun-Onire (24.66%).

Table 6: Species Similarity

Sorenses Similarity Index	Overstory (%)	Understory (%)
Idanre Hill and Igbo Olodumare	66.67	31.03
Idanre Hill and Ogun-Onire	79.31	65.45
Idanre Hill and Osun-Ososgbo	82.35	50.00
Igbo-Olodumare and Ogun-Onire	72.73	24.66
Igbo-Olodumare and Osun-Osogbo	57.69	40.00
Ogun-Onire and Osun-Osogbo	80.00	75.47

In all the sacred groves, tree dbh distribution followed inverse-J shape (Figure 1). Majority of the trees in the four groves fell within 10cm - 20cm dbh class, followed by 20cm - 30cm class; only few trees were above 100cm (Figure 1). The highest stand density across the four groves 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 grove. Stand density consistently decreased with increase in dbh (Figure 1).

Species regeneration status was studied using the 5 dominant species in each grove. Except *Dialum guinensis* and *Funtumia elastica* whose regeneration was poor because they were not found at seedling stage, other species in Osun-Osogbo recorded higher number of seedlings followed by saplings and overstory trees (Figure 2), indicating that the species had good regeneration status. In Igbo-Olodumare grove, three of the five dominant tree species had good to fair regeneration while *Funtumia elastica* and *Ceiba pentandra* displayed poor regeneration status (Figure 3). The regeneration of *Ceiba pentandra*, *Alstonia boonei* and *Cassia siamen* at Idanre Hills were considered poor due to the absence of seedlings of the species and the lower density of saplings compared to overstory trees (Figure 4). The other two species had good regeneration. Figure 5 presented a picture of poor regeneration status at Ogun-Onire grove. Out of five dominant species, three species were not represented at seedling stage and had lower density of saplings compared to overstory trees. The regeneration of *Trilepson madagascariensis* and *Pterygota macrocarpa* was fair. Figure 6 revealed that Ogun-Onire grove had the highest recruitment potential, followed by Osun-Osogbo. Both Igbo-Olodumare and Idanre Hills groves displayed low recruitment potential. Tree species that occurred at only one site were regarded as unique to that site and denoted with "+". Tree species common to at least two sacred groves were denoted with "o". Results on Table 7 revealed that among the four sacred groves, Ogun-

Onire grove had the highest number of unique species (24), which was followed by Osun-Osogbo grove with a total of 14 unique species (Table 7). Both Igbo-Olodumare and Idanre Hills sacred groves had 9 unique species each. Tree species endemic in the sacred groves are presented on Table 8. For example, *Hildegardia barterii, Piptadeniastrum africanum* and *Irvigia smithii* were the tree species found only in Igbo-Olodumare. *Angylocarlyx oligophyllus* was found only in Osun-Osogbo. *Anopyxis klaineana, Tetrapleura tetraptera, Draceana arborea, Lovoa trichilioides, Lannea welwitschii and Drypetes gossweileri* were tree species found only in Ogun-Onire grove.

Discussion

The understory, which comprises a major component of plant diversity, contributes to the structural complexity of forests and is important in the dynamics and functioning of the forest ecosystem (Royo and Carson, 2005; Su *et al.*, 2019). Where the understory is species poor, the sustainability of the forest is threatened, since there may not be enough seedlings to replace the overstory trees when they die or are removed. The absence of or poor seedling or sapling population may imply lack of or poor regeneration or temporal cessation in recruitment. Except at Igbo-Olodumare, the Shannon–Wiener diversity indices at the understories of sacred groves (Osun-Osogbo, Idanre Hills and Ogun-Onire) in this study were generally similar to those of their respective overstories. This implies that species diversity in the understories and overstories of three groves are similar. The diversity indices of our sacred groves are higher or similar than what were reported for some primary forests, degraded forests and sacred groves in Nigeria (Lawal and Adekunle, 2013; Onyekwelu and Olusola, 2014). The higher diversity index at the understory of Igbo-Olodumare grove than its overstory is an indication of higher species diversity at its understory. Johnston (2019) reported a significantly higher Shannon diversity index in the understory of hardwood forests in northern Michigan and Wisconsin, USA compared to the overstory.

The future community structure and regeneration status of a species could be predicted from the relative proportion of understory species in the total populations of various species in the forest (Khumbongmayum *et al.*, 2006). The higher number of species at the understory layers (range: 39 -78) compared to the overstory layers (range: 32 - 62) of our sacred groves is an indication of the contribution of the understory to biodiversity conservation and a confirmation that the understory of sacred groves could be more species rich than the overstory layer. Our results imply that tree regeneration in the four sacred groves is healthy, which is similar to the view expressed by Khumbongmayum *et al*. (2006). The sacred groves in our study had higher number of understory species compared to what was reported by Onyekwelu and Olusola (2014). Similarly, Khumbongmayum *et al*. (2006) reported higher understory species (seedlings and sapling) than overstory trees in four sacred groves in Manipur, India. Higher number of understory species was also reported by Johnston (2019) for hardwood forests of northern Michigan and Wisconsin, USA. Another indication of good regeneration in our sacred groves is the much higher tree density in the understory layer than the overstory layer, which is in consonance with some published results (Khumbongmayum *et al*., 2006; Onyekwelu and Olusola, 2014; Johnston (2019). Density of regenerating medicinal plants in sacred groves of central western Ghats, India were almost twice that of forest reserves (Boraiah *et al*., 2003).

In most cases, the number of seedlings was higher than number of saplings and overstory species in our sacred groves. Ballabha *et al*. (2013) opined that regeneration is considered good if the number of seedlings > number saplings > number of overstory trees; fair if the number of seedlings > number saplings ≤ number of overstory trees; which were the situations in our groves. The differences in the densities of seedlings, saplings and overstory trees among the four sacred groves in this study may be due to the interactive influences of an array of biotic and abiotic factors, especially anthropogenic factors and natural phenomena. Studies have shown that anthropogenic activities is increasing in sacred groves in Nigeria (Onyekwelu and Olusola, 2014; Adeyanju, 2020).

Currently, the Nigerian forest ecosystems are faced with lots of challenges. Illegal logging, urbanization and clearance of forests for agriculture had negatively impacted on the extent of the forests and the population of valuable tree species. Some Nigerian forest reserves have undergone various degrees of degradation from both illegal and legal loggers, which has led to reduction in species richness (Aruofor, 2001; Onyekwelu *et al.*, 2008; Olayinka *et al.*, 2018). Recent studies (Onyekwelu and Olusola, 2014; Adeyanju, 2020) have revealed that sacred groves are gradually being encroached upon. Species regeneration is usually negatively affected by forest degradation. Therefore, forestry professionals are confronted with the task of finding the best approach to enhance regeneration of valuable tree species.

Tree species regeneration depends on the maturity and diameter structure of their population (Bhuyan *et al.* 2003). Characteristics of the forest floor, micro-environmental conditions under the forest canopy and anthropogenic activities influence tree regeneration. Tree diameter distribution is an indication of how well the forest is regenerating and is making use of site resources (Rao *et al.,* 1990). The tree dbh distribution curves of the sacred groves in this study followed the inverse-J shape typical of natural tropical rainforests (Onyekwelu *et al*., 2008) and some sacred groves (Khumbongmayum *et al*., 2006; Onyekwelu and Olusola, 2014; Sarkar and

Devi, 2014). Inverse-J dbh distribution is an indication of good regeneration status and healthy forest ecosystem (Sarkar and Devi, 2014). It suggests an evolving or expanding population, climax or stable type of population in forest ecosystem, indicating that the forest harbours a growing population (Mishra *et al.*, 2005; Sahu *et al*., 2012). We share similar opinion with Khumbongmayum *et al*. (2006) that the presence of established seedlings of dominant species is an indication of their excellent recruitment which also suggests that the prevailing environmental conditions of the study site are favourable for their establishment stage. The high recruitment recorded in the sacred groves may be attributed to disposal by birds and other animals that bring new seeds or fruits to the groves. In addition, the high recruitment could be attributed to disposal by worshipers, visitors and tourists to the groves.

Conservation and maintenance of biodiversity in natural forest ecosystem can only be guaranteed through regeneration. Our observation is that the overall tree regeneration status in our sacred groves is satisfactory showing “good” and “fair” regeneration, though few tree species fell under “poor” and “not” regenerating status. Successful regeneration of a tree species depends on its ability to produce large number of seedlings and the ability of seedlings and saplings to survive and grow, situations that were evident in our sacred groves. The good species regeneration recorded in the sacred groves could be attributed to high level of access restrictions imposed by their managements (chief priests, community leaders, etc). For instance, nobody dared enter Ogun-Onire grove without the permission of the chief priest as the grove is believed to be sacred and the habitation of the gods. Also, there are taboos and myths that are feared by the people, which prevents their entrance into the groves. With these restrictions, anthropogenic activities that could destroy seedlings are reduced thereby enhancing regeneration and recruitment potentials. However, some of these appear to be changing or could change given some recent developments in sacred grove management in Nigeria. Activities (rituals, initiations, festivals, and other ceremonies) in Nigerian sacred groves have increased in recent times, which has led to an alarming high influx of people into the groves. It is estimated that between 130,000 and 150,000 people visit Osun-Osogbo grove for annual festival celebration (Aleshinloye. and Maruyama, 2015; Adeyanju, 2020). Due to this high influx of people, seedlings and saplings are sometimes trampled upon and their survival is affected. Oftentimes, ritual rites and sacrifices may involve ground clearing and ground fires by priests and devotees. Since individual species in young stages are more vulnerable to any kind of environmental stress and anthropogenic disturbance, sapling and seedling densities in the sacred groves are adversely affected, thereby negatively influencing species regeneration and recruitment. In addition, lot of seeds in the soil seed bank could be destroyed during ground clearing or burning, which could affect their germination and result in limited or no regeneration.

Sacred groves could serve as reservoir for preserving unique and endangered tree species. In this study, some tree species were discovered to exist only in one sacred grove. For instance, *Hildegardia barteri* was endemic to Igbo-Olodumare, *Lovoa trichilioides* was unique to Ogun-Onire sacred grove. No known study has reported the presence of any of these species in any forest reserves in Southwestern Nigeria. Also, some tree species that are not found in protected forests in Nigeria (e.g. Akure forest reserve, Queen's plot, Omo forest reserve) (Lawal and Adekunle, 2013, Salami and Akinyele, 2018, Omomoh *et al.,* 2019) were encountered in some of the sacred groves. The presence of these unique tree species directly or indirectly contributes to the welfare and stability of the local environment. The prevalence of the unique species clearly indicates the potential of sacred groves for conservation of important tree species. Onyekwelu and Olusola (2014) reported that about 32% of the species encountered in Osun-Osogbo and

Igbo-Olodumare sacred groves are among the tree species classified as endangered by FORMECU (1998).

Conclusion and recommendation

Sacred groves could harbour high regeneration and promote tree species conservation, especially in forest understory layer. Osun-Osogbo, Idanre Hills, Igbo-Olodumare and Ogun-Onire sacred groves harboured some unique and important tree species. High regeneration and recruitment status maintained in all the sacred groves in this study were achieved using taboos, cultural and traditional methods. These methods could be incorporated in managing forest reserves in Southwestern Nigeria. Also, conservative efforts should be made to avert the extinction of endemic species in the sacred groves.

List of Abbreviations

Dbh – Diameter at breast height

RD – Relative Density

n_i – number of individual of species

N – Total number of all tree species in the entire community

RD_0 – Relative Dominance

Ba_i – Basal area of individual tree belonging to a species

Ba_n – Stand basal area

IVI – Important Value Index

SI – Similarity Index

H' – Shannon-Wiener diversity index

S – Total number of species in the community

E_H – Species evenness

D – Marhalef's index

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

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Footnotes

Tree Diversity in Sacred Groves

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Table 7: Unique tree species in the study area

S/N	Name of Species	Osun-Osogbo	Igbo-Olodumare	Idanre Hills	Ogun-Oonire
1	*Afzelia africana*	−	−	−	+
2	*Albizia ferruginea*	o	o	o	o
3	*Albizia lebbeck*	o	−	−	o
4	*Albizia zygia*	o	−	o	o
5	*Alchornea laxiflora*	−	−	−	+
6	*Alchornia cordifolia*	−	−	+	−
7	*Alstonia boonei*	−	−	o	o
8	*Amphiman pterocarpoides*	−	+	−	−
9	*Angylocalyx oligophyllus*	+	−	−	−
10	*Anopyxis klaineana*	−	−	−	+
11	*Anthocleista djalonensis*	−	−	+	−
12	*Anthonotha macrophylla*	−	−	−	+
13	*Antiaris africana*	o	−	o	−
14	*Baphia nitida*	o	−	o	−
15	*Berlinia grandiflora*	−	−	o	o
16	*Blighia sapida*	o	o	o	o
17	*Bombas buonopozense*	−	−	−	+
18	*Brachystegia eurycoma*	+	−	−	−
19	*Brachystegia kennedyi*	−	−	−	+
20	*Brachystegia nigerica*	o	o	−	−
21	*Canarium schweinfurthii*	−	−	−	+
22	*Cassia siamen*	−	−	+	−
23	*Ceiba pentandra*	o	o	o	o
24	*Celtis mildbraedii*	o	o	−	o
25	*Celtis philippensis*	−	−	−	+
26	*Celtis zenkerii*	o	o	−	o
27	*Chrysophyllum albidum*	−	−	o	o
28	*Cleistopholis patens*	−	+	−	−
29	*Cola acuminata*	−	−	−	+
30	*Cola gigantea*	−	−	o	o
31	*Cola hispida*	o	o	o	o

32	*Cola millenii*	o	o	−	o
33	*Cordia millenii*	−	+	−	−
34	*Dialium guineense*	o	−	o	−
35	*Diospyros dendo*	−	o	o	o
36	*Diospyros mobutensis*	o	−	−	o
37	*Discoglypremna caloneura*	+	−	−	−
38	*Distemonanthus benthamianus*	o	−	o	−
39	*Dracaena arborea*	−	−	−	+
40	*Dracaena marginata*	o	−	o	−
41	*Drypetes gossweileri*	−	−	−	+
42	*Drypetes oblongifolia*	+	−	−	−
43	*Entandrophragma angolense*	−	−	−	+
44	*Entandrophragma cylindricum*	−	−	+	−
45	*Ficus sycomorus*	−	+	−	−
46	*Ficus exasperate*	−	o	o	o
47	*Ficus mucoso*	o	−	o	o
48	*Funtumia elastica*	o	o	o	o
49	*Gliricidia sepium*	+	−	−	−
50	*Gmelina arborea*	+	−	−	−
51	*Hanoa cleniana*	+	−	−	−
52	*Hildegardia barteri*	−	+	−	−
53	*Holarrhena floribunda*	−	−	+	−
54	*Hunteria Umbellata*	−	−	−	+
55	*Irvingia smithii*	−	+	−	−
56	*Ixora guinensis*	+	−	−	−
57	*Khaya grandifoliola*	−	o	o	o
58	*Lannea welwitschii(Hiern)*	−	−	−	+
59	*Lecaniodiscus cupanioides*	o	o	−	o
60	*Lovoa trichilioides*	−	−	−	+
61	*Malachanta alnifolia*	−	−	−	+
62	*Mallotus oppositifolius*	−	−	−	+
63	*Manilkara obovata*	o	−	o	−
64	*Mansonia altissima*	−	+	−	−
65	*Margaritaria discoidea*	o	o	o	o
66	*Massularia acuminate*	+	−	−	−
67	*Melachanta alnifolia*	+	−	−	−
68	*Milicia excels*	−	o	o	o
69	*Milletia thonningii*	o	−	o	o
70	*Monodora myristica*	o	−	o	−
71	*Monodora tenuifolia*	−	−	−	+

72	*Morinda lucida*	−	−	+	−
73	*Morus mesozygia*	−	−	o	o
74	*Myrianthus arboreus*	−	−	−	+
75	*Napoleonaea imperialis*	+	−	−	−
76	*Newbouldia laevis*	o	−	o	−
77	*Piptadeniastrum africanum*	−	+	−	−
78	*Pterocarpus mildbraedii*	−	−	+	−
79	*Pterygota macrocarpa*	−	o	o	o
80	*Pycnanthus angolensis*	−	−	−	+
81	*Rauvolfia vomitoria*	−	−	+	−
82	*Ricinodendron heudelotii*	o	o	−	o
83	*Rothmannia longiflora*	o	o	−	−
84	*Rothmannia whitfieldii*	+	−	−	−
85	*Spathodea campanulata*	o	−	−	o
86	*Spondias mombin*	−	o	o	−
87	*Spondias pinnata*	o	−	o	o
88	*Sterculia oblonga*	o	o	o	o
89	*Sterculia rhinopetala*	−	−	−	+
90	*Sterculia tragacantha*	−	o	o	−
91	*Strombosia fasae*	+	−	−	−
92	*Strombosia pustulata*	−	−	−	+
93	*Tabernaemontana coronaria*	+	−	−	−
94	*Terminalia superba*	−	−	o	o
95	*Tetrapleura tetraptera*	−	−	−	+
96	*Trema orientalis*	−	−	+	−
97	*Trichilia monadelpha*	o	−	o	−
98	*Trichilia welwitschii*	o	o	o	o
99	*Trilepisium madagascariense*	o	−	−	o
100	*Triplochiton scleroxylon*	o	−	−	o
101	*Voacanga africana*	−	−	−	+
102	*Zanthoxylum zanthozaloides*	−	+	−	−

Note: + a unique species, o species common to sites and – species not found in the site.