

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

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

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12
13 **Abstract**

14 ***Background***

15 Global species extinction rates due to forest conversions are increasing. Ecologists,
16 conservationists and governments have adopted various conservation methods. Sacred grove is
17 one conservation option that has gained attention in recent time. We assessed understory species
18 diversity, regeneration and recruitment potentials of four sacred groves in southwestern Nigeria.
19 Overstory tree species were inventoried in eight 800m² temporary sample plots, systematically
20 laid along two transects of 1000m each. Understory tree species were assessed in 100m² plots for
21 saplings and 25m² plots for seedlings in all sample plots.

22 ***Results***

23 Shannon-Wiener diversity index (1.8-3.46 (overstory); 2.65-3.55 (understory)), number of
24 species (32-58 (overstory); 39-78 (understory)) and tree density (309-417 individuals/ha
25 (overstory); 775-1445 individuals/ha (understory)) were comparable and/or higher at the
26 understories than the overstories. Dbh distribution curves showed highest stand density at the
27 lowest class (10–20 cm) and decreased with increasing dbh, indicating good regeneration status
28 and healthy ecosystem. Regeneration was considered good and fair, because in most cases,

29 number of seedlings > saplings > overstory trees or number of seedlings > saplings ≤ overstory
30 trees. The good regeneration status was further confirmed by the good species recruitment in the
31 understory. Some tree species were found to be unique to some sacred groves while some species
32 that were absent in protected forests existed in the groves. The presence of these unique tree
33 species indicated the potential of sacred groves in conserving important tree species. The high
34 regeneration could be attributed to strict access restrictions in the groves, and the taboos and
35 myths feared by the people. However, the high influx of people into sacred groves for festivals
36 and rituals, which results in trampling and burning of seedlings, is a threat to the diversity,
37 regeneration and recruitment potentials of the groves.

38 ***Conclusion***

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

42 **Keywords:** Ecological indicators, natural regeneration, biodiversity conservation, ecosystem
43 services

44 **Introduction**

45 Biodiversity is essential for the wellbeing of the ecosystem but the escalating extinction crisis
46 shows that the diversity of nature can no longer support the current pressure that humanity exerts
47 on the forest (Shushma *et al.*, 2015). High density and diversity of species in rainforests have
48 attracted incessant disturbance of the ecosystem through high harvesting pressure (both legal and
49 illegal) (Onyekwelu *et al.*, 2008). Species extinction rate is increasing, reaching up to 1,000
50 times or more than the natural rate because of habitat destruction, land conversion for agriculture
51 and development, climate change, pollution and the spread of invasive species (Shushma *et al.*,

52 2015). Consequently, ecologists, conservationists and governments have recommended and
53 adopted various conventional and traditional conservation methods. One of the methods that
54 have gained attention in the recent past is the use of traditional practices in protecting and
55 managing biodiversity, among which the sacred grove system is prominent (Daye and Healey,
56 2015). In Nigeria and elsewhere, sacred groves have been observed to play important role in
57 biodiversity conservation (Bhagwat and Rutte, 2006; Khan *et al.*, 2008; Kokou *et al.*, 2008;
58 Onyekwelu and Olusola, 2014). Many studies have assessed the forest population, structure and
59 biodiversity conservation potentials of the overstory layers of sacred groves in Nigeria
60 (Onyekwelu and Olusola 2014; Salami and Akinyele, 2018; Ikyagba *et al.*, 2019). However,
61 studies on understory tree species diversity in sacred groves are rare while no known study has
62 assessed the regeneration and recruitment potentials of sacred groves in Nigeria.

63

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

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

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

97 gap. Consequently, this study investigated the understory tree species diversity, regeneration and
98 recruitment potential of sacred groves in southwestern Nigeria.

99 **Methodology**

100 The study was carried out in southwestern region of Nigeria made up of six federal states of
101 Lagos, Ogun, Oyo, Osun, Ekiti and Ondo. The region lies between longitude $2^{\circ} 31'$ and $6^{\circ} 00'$
102 East and Latitude $6^{\circ} 21'$ and $8^{\circ} 37'N$ with land area of 77,818 km² (Agboola, 1979). A high
103 percentage of the region lies within the tropical rainforest zone of Nigeria. Annual rainfall ranges
104 between 1400 mm and 4000 mm while mean temperature varies between 21 - 34°C. Rainfalls
105 occur within the months of April to November while dry season lasts from December to March.
106 Soils are predominantly ferruginous tropical, typical of the variety found in intensively
107 weathered areas of basement complex formations in the rainforest zone of southwestern Nigeria
108 (Onyekwelu *et al.*, 2008).

109 ***Method of Data Collection***

110 Out of the sacred groves in southwestern Nigeria, four (Osun-Osogbo, Igbo-Olodumare, Idanre
111 Hills and Ogun-Onire) were purposefully selected based on prominence/significance,
112 accessibility and permission to conduct inventory. The selected groves covered three (Ekiti,
113 Ondo and Osun) of the six southwestern states. Two line transects of 1000m each in length,
114 separated by a distance of at least 1000m were laid approximately at the middle of each sacred
115 grove. Temporary sample plots of 40m × 20m were laid on alternate sides along each transect at
116 every 250m interval, giving 4 plots per transect, 8 per sacred grove and 32 for the study. Within
117 each sample plot, all living trees with Dbh \geq 10cm were identified and their Dbh and total
118 heights measured. For tree sapling enumeration, a 10m × 10m sub-plot was laid at the middle of

119 each plot. All saplings (Dbh >1.0 cm but < 10cm) were identified and their dbh measured. A 5m
 120 × 5m quadrant was laid within each sub-plot for seedlings (Dbh < 1.0cm) enumeration.
 121 Frequencies of identified seedling species were recorded.

122
 123 **Data computation and analysis**

124
 125 The following biodiversity indices were computed:

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

127
$$RD = \frac{n_i}{N} \times 100 \dots\dots\dots (eqn. 1)$$

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

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

132
$$RD_o = \frac{\sum Ba_i \times 100}{\sum Ba_n} \dots\dots\dots (eqn. 2)$$

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

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

135
$$IVI = \frac{RD + RD_o}{2} \dots\dots\dots$$

136 (eqn. 3)

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

138
$$SI = \left(\frac{2C}{a + b} \right) \times 100 \dots\dots\dots (eqn. 4)$$

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

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

141
$$H' = -\sum_{i=1}^S p_i \ln(p_i) \dots \dots \dots \text{(eqn. 5)}$$

142 Where: H' = Shannon-Wiener diversity index; P_i = proportion of S made up of the ith species, ln
 143 = natural logarithm

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

145
$$H_{\max} = \ln(S) \dots \dots \dots \text{(eqn. 6)}$$

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

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

148
$$E_H = \frac{H'}{H_{\max}} = \frac{\sum_{i=1}^S P_i \ln(P_i)}{\ln(S)} \dots \dots \dots \text{(eqn. 7)}$$

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

150
$$D = \frac{S-1}{\ln N} \dots \dots \dots \text{(eqn. 8)}$$

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

152 The five most dominant tree species in each sacred grove were selected for regeneration
 153 assessment. Regeneration status was determined based on population sizes of seedlings, saplings
 154 (Bhuyan *et al.* 2003; Khumbongmayum *et al.*, 2006) and overstory trees. Good
 155 regeneration:,seedlings > saplings > overstory trees; fair regeneration: seedlings > or ≤ saplings
 156 ≤ adults; poor regeneration:,the species survives only in sapling stage, but no seedlings (saplings
 157 may be <, > or = adults); if a species is present only at adult stage it is considered as not
 158 regenerating (Khumbongmayum *et al.*, 2006). Species is considered as 'new' (recruitment) if the
 159 species has no adults and saplings but only seedlings. In this study, a species was considered
 160 unique to a sacred grove if found only in that sacred grove in this study. Also, a species was

161 considered endemic if it is only found in a sacred grove and never been reported in any forest site
162 in Southwestern Nigeria based on the information at our disposal.

163 **Results**

164 The overstories and understories of the sacred groves in this study were dominated by few tree
165 species. Results of species relative dominance revealed that seven tree species occupied between
166 66.06% and 85.69% of the overstories and 60.81% and 92.56% of the undertories of the sacred
167 groves (Tables 1 to 4). As few as 2 to 3 tree species could occupy over 50% of the sacred groves.
168 *Hidergardia barterii* alone occupied 65.09% of the overstory of Igbo-Olodumare (Table 2),
169 making it the most dominant species across the sacred groves in this study. At the understory
170 layer, *Napoleona imperialis* was the most dominant species, occupying 33.65% of the understory
171 of Idanre Hills grove (Table 1). No single species was dominant in all the four sacred groves
172 (both overstories and understories). *Ceiba pentandra* and *Funtumia elastica* were dominant in
173 the overstories of three of the four sacred groves. In most cases, the dominant tree species in the
174 overstory layer were not the dominant species in the understory of specific sacred grove, the only
175 except being *Sterculia tragacantha* and *Cola hispida* which were dominant in the overstory and
176 understory of Igbo-Olodumare and Osun-Osogbo sacred groves, respectively (Tables 2 and 4).
177 The dominant tree species also doubled as the important species as a result of their high IVI
178 (Table 1 to 4).

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

183 1445 ha⁻¹) was much higher (85.5% to 367.6%) compared to the density at the overstory layers
 184 (309 to 417 ha⁻¹) of the sacred groves (Table 5). Shannon-Wiener diversity index ranged from
 185 1.8 to 3.46 at the overstory layer of the sacred groves and 2.65 to 3.55 at the understory (sapling)
 186 layer.

187
 188 **Table 1: Important value index (IVI) for seven most important species in Idanre Hill**
 189 **sacred grove**

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

190

191

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

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

194

195

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

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

198

199

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

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

202 **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

203
 204 Species similarity between pairs of sacred groves varied from 57.69% to 82.35% in the overstory
 205 and 24.66% to 75.47% in the understory (Table 6). Species similarity between pairs of groves
 206 was higher in the overstory than the understory. In the Overstory, species similarity was highest
 207 between Idanre Hills and Osun-Osogbo (82.35%) and lowest between Igbo-Olodumare and
 208 Osun-Osogbo (57.69%). In the understory layer, the highest similarity index was between Ogun-
 209 Onire and Osun-Osogbo (75.47%) while the lowest value was between Igbo-Olodumare and
 210 Ogun-Onire (24.66%).

211 **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-Osogbo	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

212 In all the sacred groves, tree dbh distribution followed inverse-J shape (Figure 1). Majority of the
213 trees in the four groves fell within 10cm - 20cm dbh class, followed by 20cm - 30cm class; only
214 few trees were above 100cm (Figure 1). The highest stand density across the four groves was
215 recorded in the lowest dbh class of 10–20 cm, making this class the highest contributor of stand
216 density to total density for each grove. Stand density consistently decreased with increase in dbh
217 (Figure 1).

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

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

243 **Discussion**

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

258 index in the understory of hardwood forests in northern Michigan and Wisconsin, USA
259 compared to the overstory.

260 The future community structure and regeneration status of a species could be predicted from the
261 relative proportion of understory species in the total populations of various species in the forest
262 (Khumbongmayum *et al.*, 2006). The higher number of species at the understory layers (range:
263 39 -78) compared to the overstory layers (range: 32 - 62) of our sacred groves is an indication of
264 the contribution of the understory to biodiversity conservation and a confirmation that the
265 understory of sacred groves could be more species rich than the overstory layer. Our results
266 imply that tree regeneration in the four sacred groves is healthy, which is similar to the view
267 expressed by Khumbongmayum *et al.* (2006). The sacred groves in our study had higher number
268 of understory species compared to what was reported by Onyekwelu and Olusola (2014).
269 Similarly, Khumbongmayum *et al.* (2006) reported higher understory species (seedlings and
270 sapling) than overstory trees in four sacred groves in Manipur, India. Higher number of
271 understory species was also reported by Johnston (2019) for hardwood forests of northern
272 Michigan and Wisconsin, USA. Another indication of good regeneration in our sacred groves is
273 the much higher tree density in the understory layer than the overstory layer, which is in
274 consonance with some published results (Khumbongmayum *et al.*, 2006; Onyekwelu and
275 Olusola, 2014; Johnston (2019). Density of regenerating medicinal plants in sacred groves of
276 central western Ghats, India were almost twice that of forest reserves (Boraiah *et al.*, 2003).

277 In most cases, the number of seedlings was higher than number of saplings and overstory species
278 in our sacred groves. Ballabha *et al.* (2013) opined that regeneration is considered good if the
279 number of seedlings > number saplings > number of overstory trees; fair if the number of

280 seedlings > number saplings \leq number of overstory trees; which were the situations in our
281 groves. The differences in the densities of seedlings, saplings and overstory trees among the four
282 sacred groves in this study may be due to the interactive influences of an array of biotic and
283 abiotic factors, especially anthropogenic factors and natural phenomena. Studies have shown that
284 anthropogenic activities is increasing in sacred groves in Nigeria (Onyekwelu and Olusola, 2014;
285 Adeyanju, 2020).

286
287 Currently, the Nigerian forest ecosystems are faced with lots of challenges. Illegal logging,
288 urbanization and clearance of forests for agriculture had negatively impacted on the extent of the
289 forests and the population of valuable tree species. Some Nigerian forest reserves have
290 undergone various degrees of degradation from both illegal and legal loggers, which has led to
291 reduction in species richness (Aruofor, 2001; Onyekwelu *et al.*, 2008; Olayinka *et al.*, 2018).
292 Recent studies (Onyekwelu and Olusola, 2014; Adeyanju, 2020) have revealed that sacred
293 groves are gradually being encroached upon. Species regeneration is usually negatively affected
294 by forest degradation. Therefore, forestry professionals are confronted with the task of finding
295 the best approach to enhance regeneration of valuable tree species.

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

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

313 Conservation and maintenance of biodiversity in natural forest ecosystem can only be guaranteed
314 through regeneration. Our observation is that the overall tree regeneration status in our sacred
315 groves is satisfactory showing “good” and “fair” regeneration, though few tree species fell under
316 “poor” and “not” regenerating status. Successful regeneration of a tree species depends on its
317 ability to produce large number of seedlings and the ability of seedlings and saplings to survive
318 and grow, situations that were evident in our sacred groves. The good species regeneration
319 recorded in the sacred groves could be attributed to high level of access restrictions imposed by
320 their managements (chief priests, community leaders, etc). For instance, nobody dared enter
321 Ogun-Onire grove without the permission of the chief priest as the grove is believed to be sacred
322 and the habitation of the gods. Also, there are taboos and myths that are feared by the people,
323 which prevents their entrance into the groves. With these restrictions, anthropogenic activities
324 that could destroy seedlings are reduced thereby enhancing regeneration and recruitment
325 potentials. However, some of these appear to be changing or could change given some recent

326 developments in sacred grove management in Nigeria. Activities (rituals, initiations, festivals,
327 and other ceremonies) in Nigerian sacred groves have increased in recent times, which has led to
328 an alarming high influx of people into the groves. It is estimated that between 130,000 and
329 150,000 people visit Osun-Osogbo grove for annual festival celebration (Aleshinloye. and
330 Maruyama, 2015; Adeyanju, 2020). Due to this high influx of people, seedlings and saplings are
331 sometimes trampled upon and their survival is affected. Oftentimes, ritual rites and sacrifices
332 may involve ground clearing and ground fires by priests and devotees. Since individual species
333 in young stages are more vulnerable to any kind of environmental stress and anthropogenic
334 disturbance, sapling and seedling densities in the sacred groves are adversely affected, thereby
335 negatively influencing species regeneration and recruitment. In addition, lot of seeds in the soil
336 seed bank could be destroyed during ground clearing or burning, which could affect their
337 germination and result in limited or no regeneration.

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

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

351 **Conclusion and recommendation**

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

359

360 **List of Abbreviations**

361 Dbh – Diameter at breast height

362 RD – Relative Density

363 n_i – number of individual of species

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

365 RD_0 – Relative Dominance

366 Ba_i – Basal area of individual tree belonging to a species

367 Ba_n – Stand basal area

368 IVI – Important Value Index

369 SI – Similarity Index

370 H' – Shannon-Wiener diversity index

371 S – Total number of species in the community

372 E_H – Species evenness

373 D – Marhalef's index

374

375 **Declarations**

376 *Ethics approval and consent to participate*

377 Not applicable

378

379 *Consent for publication*

380 Not applicable

381

382 *Availability of data and material*

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

385

386 *Competing interests*

387 The authors declare that they have no competing interests

388

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418

419 **Footnotes**

420 *Tree Diversity in Sacred Groves*

421

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510

511 **Table 7: Unique tree species in the study area**

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

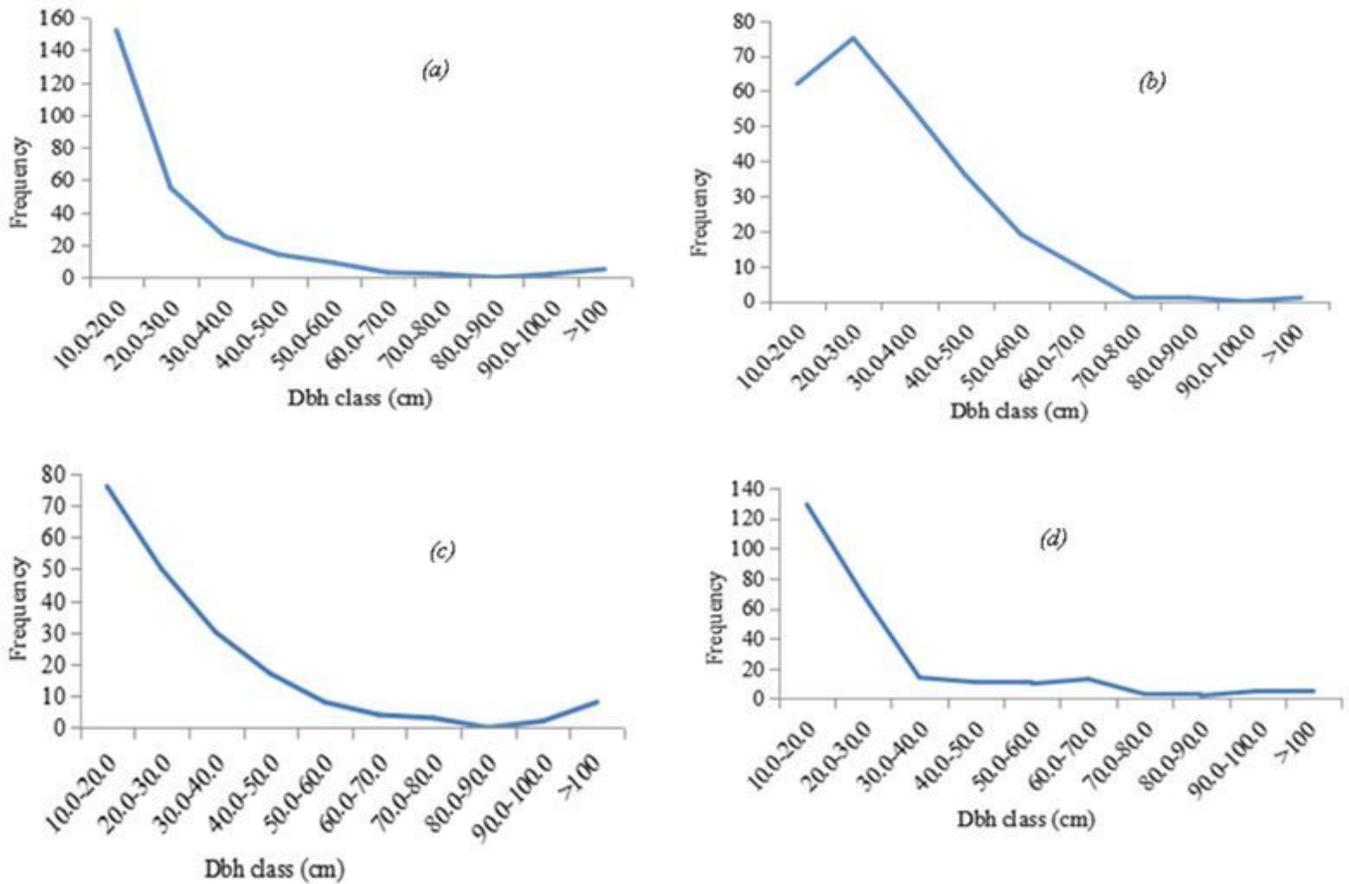
32	<i>Cola millenii</i>	0	0	-	0
33	<i>Cordia millenii</i>	-	+	-	-
34	<i>Dialium guineense</i>	0	-	0	-
35	<i>Diospyros dendo</i>	-	0	0	0
36	<i>Diospyros mobutensis</i>	0	-	-	0
37	<i>Discoglyprena caloneura</i>	+	-	-	-
	<i>Distemonanthus</i>	0	-	0	-
38	<i>benthamianus</i>				
39	<i>Dracaena arborea</i>	-	-	-	+
40	<i>Dracaena marginata</i>	0	-	0	-
41	<i>Drypetes gossweileri</i>	-	-	-	+
42	<i>Drypetes oblongifolia</i>	+	-	-	-
43	<i>Entandrophragma angolense</i>	-	-	-	+
	<i>Entandrophragma</i>	-	-	+	-
44	<i>cylindricum</i>				
45	<i>Ficus sycomorus</i>	-	+	-	-
46	<i>Ficus exasperate</i>	-	0	0	0
47	<i>Ficus mucoso</i>	0	-	0	0
48	<i>Funtumia elastica</i>	0	0	0	0
49	<i>Gliricidia sepium</i>	+	-	-	-
50	<i>Gmelina arborea</i>	+	-	-	-
51	<i>Hanoa cleniana</i>	+	-	-	-
52	<i>Hildegardia barteri</i>	-	+	-	-
53	<i>Holarrhena floribunda</i>	-	-	+	-
54	<i>Hunteria Umbellata</i>	-	-	-	+
55	<i>Irvingia smithii</i>	-	+	-	-
56	<i>Ixora guinensis</i>	+	-	-	-
57	<i>Khaya grandifoliola</i>	-	0	0	0
58	<i>Lannea welwitschii(Hiern)</i>	-	-	-	+
59	<i>Lecaniodiscus cupanioides</i>	0	0	-	0
60	<i>Lovoa trichilioides</i>	-	-	-	+
61	<i>Malachanta alnifolia</i>	-	-	-	+
62	<i>Mallotus oppositifolius</i>	-	-	-	+
63	<i>Manilkara obovata</i>	0	-	0	-
64	<i>Mansonia altissima</i>	-	+	-	-
65	<i>Margaritaria discoidea</i>	0	0	0	0
66	<i>Massularia acuminata</i>	+	-	-	-
67	<i>Melachanta alnifolia</i>	+	-	-	-
68	<i>Milicia excels</i>	-	0	0	0
69	<i>Milletia thonningii</i>	0	-	0	0
70	<i>Monodora myristica</i>	0	-	0	-
71	<i>Monodora tenuifolia</i>	-	-	-	+

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

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

513

Figures



Key: (a) Osun Osogbo, (b) Igbo Olodumare, (c) Idanre hills and (d) Ogun Onire

Figure 1

Tree diameter distribution in the selected sacred groves

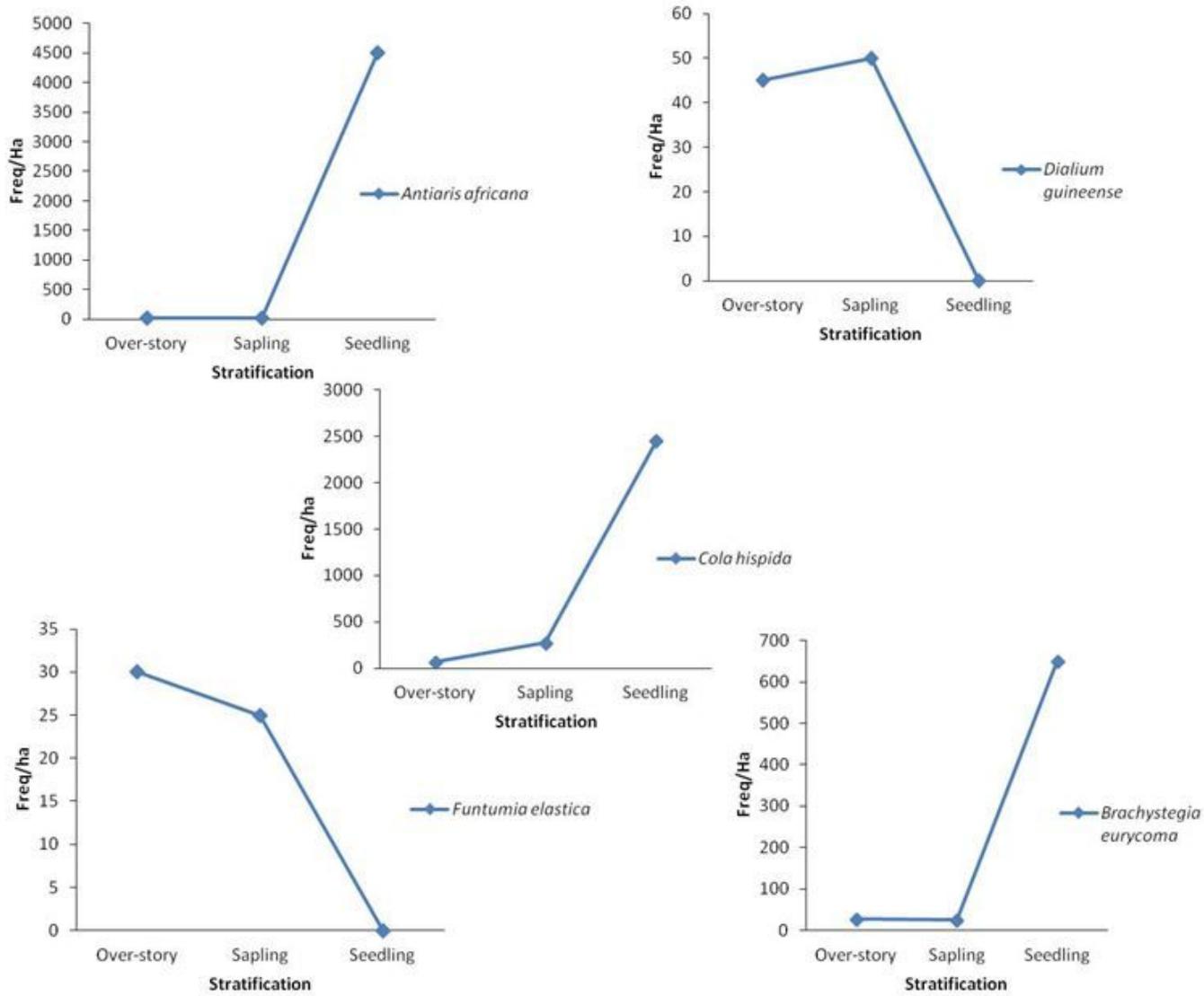


Figure 2

Regeneration status of five (5) most dominant species in the Osun-Osogbo sacred grove

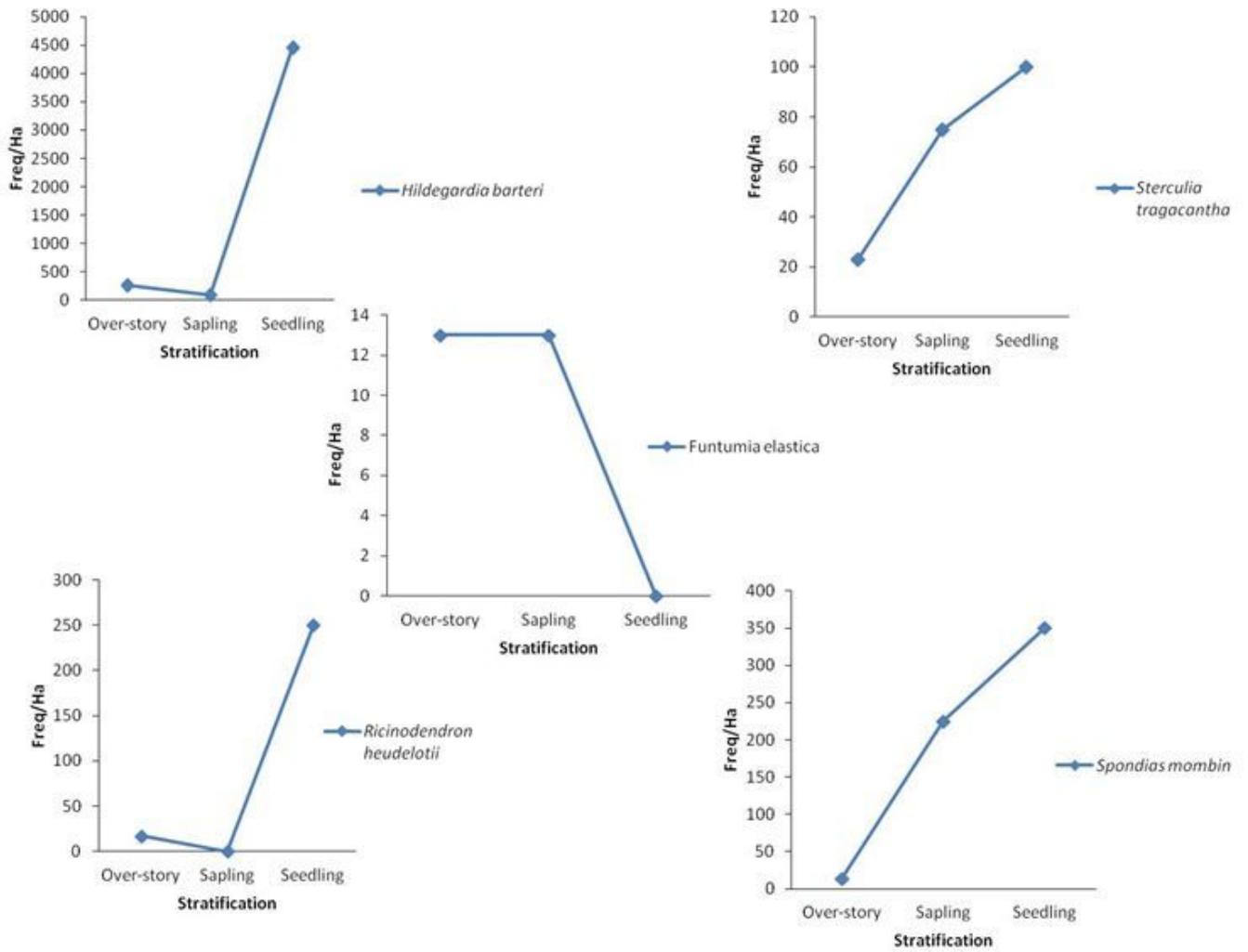


Figure 3

Regeneration status of five (5) most dominant species in Igbo-Olodumare sacred grove

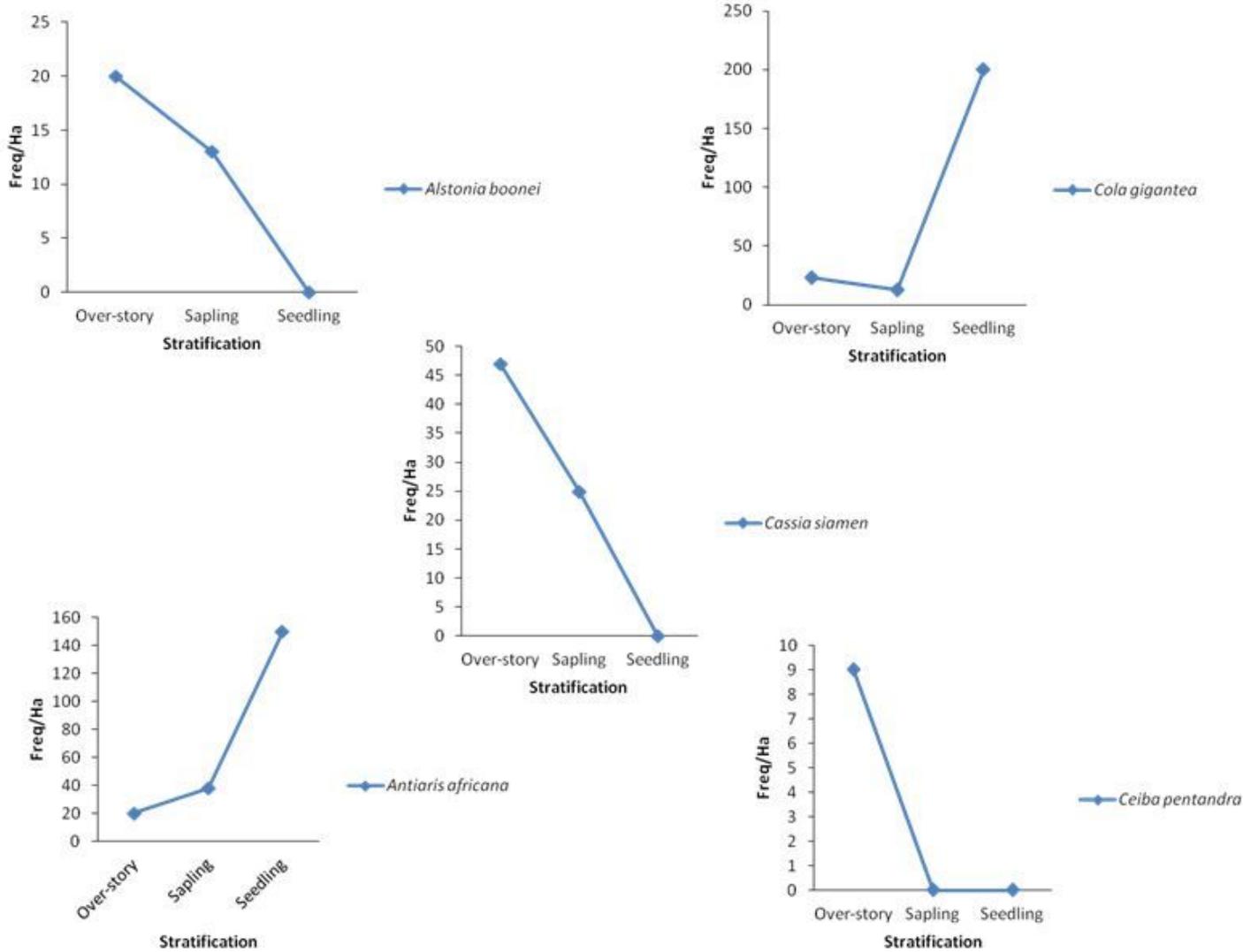


Figure 4

Regeneration status of five (5) most dominant species in Idandre Hills sacred grove

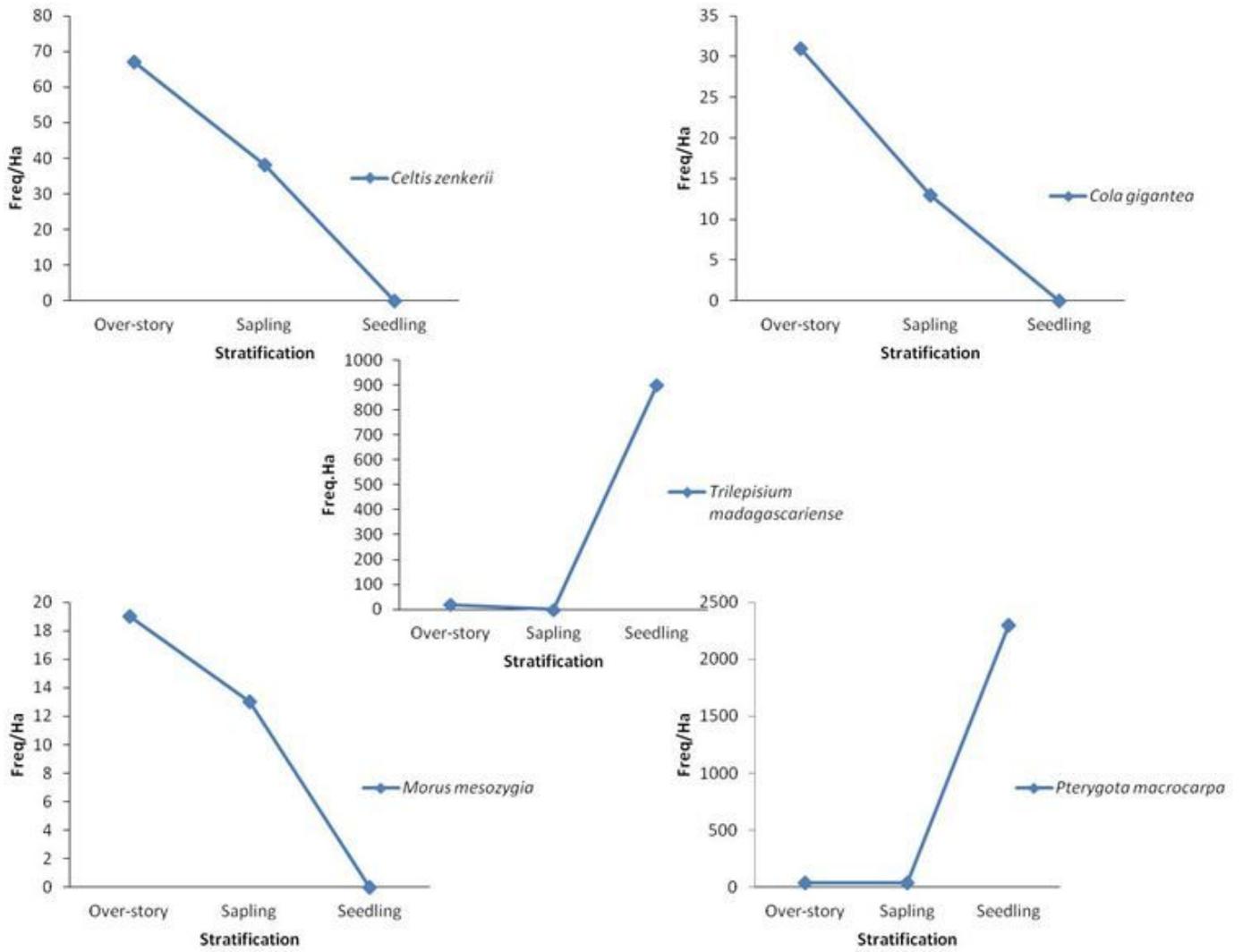


Figure 5

Regeneration status of five (5) most dominant species in Ogun-Onire sacred grove

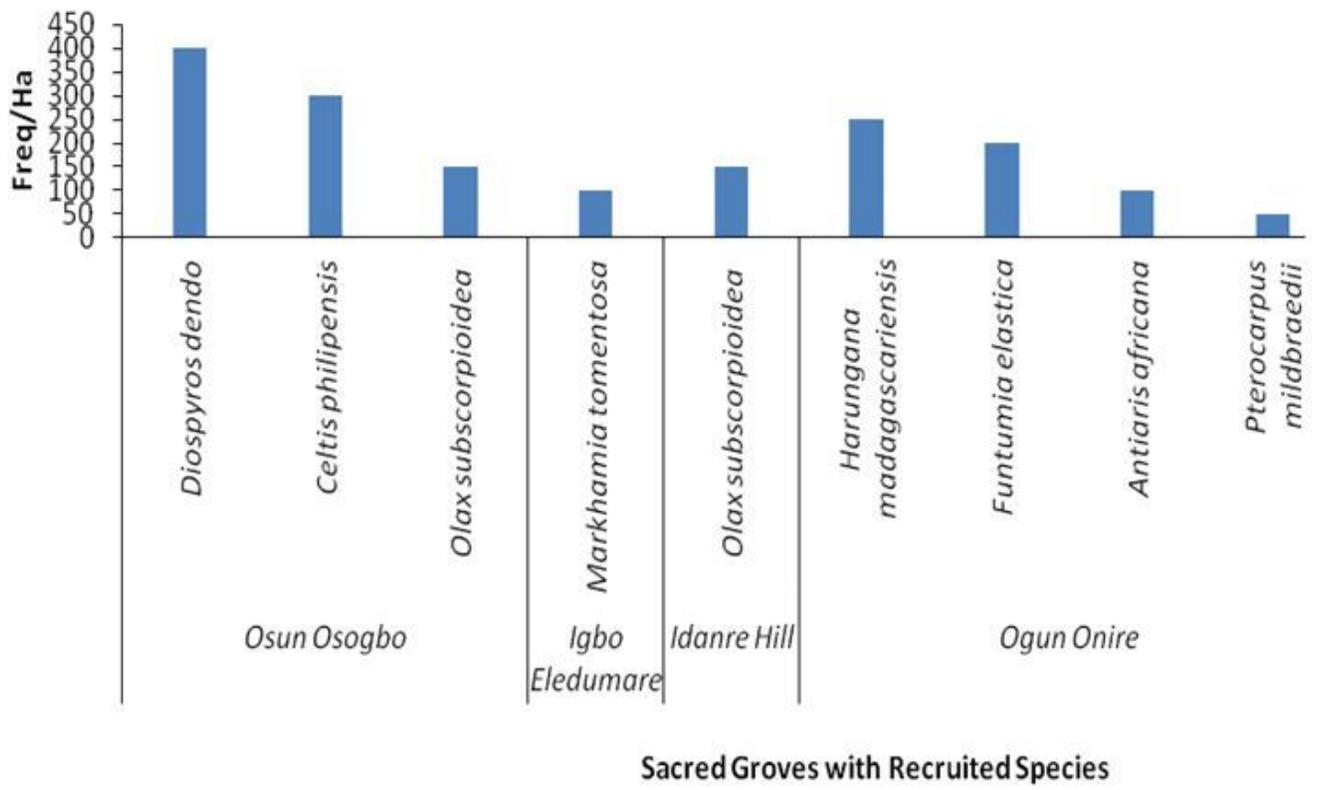


Figure 6

Recruitment potential of sacred groves in SW Nigeria