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Volume Yield, tree species diversity and Carbon storage of sacred groves in Southwestern, Nigeria

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Abstract

Recently, the role of sacred groves in biodiversity conservation and provision of ecosystem goods and services has been a subjected to scientific investigation. In this study, data were collected from four sacred groves (Osun-Osogbo, Igbo-Olodumare, Idanre Hills and Ogun-Onire) in southwestern, Nigeria to investigate their volume yield, tree species diversity, biomass and carbon storage potentials. Data were collected from 32 sample plots of 20 m x 40 m, established across the four sacred groves. In each plot, all woody plants with dbh ≥10cm were identified and their growth variables (dbh and height) measured. Non-destructive allometric equation method was adopted for the estimation of volume, biomass and carbon stock production. The number of families and tree species encountered in the groves (understory and overstory layers) ranged from 22 to 32 and 41 to 85, respectively. The four groves had high Shannon-Wiener diversity index (2.63 - 3.55). They had high volume yield (244.99 m^3ha^{-1} to 343.08 m^3ha^{-1}), biomass production (87.8 t ha^{-1} to 231.86 t ha^{-1}) and carbon stock (43.9 t ha^{-1} to 115.9 t ha^{-1}), with potentials for continuous growth as evidenced by the presence of young trees in the lower canopy. Thus, besides being good biodiversity conservation method, sacred groves act as sink of atmospheric CO_2 considering their high biomass and carbon accumulation. The use and protection of sacred groves by indigenous people has enhanced tree species diversity, improved carbon sequestration and production of other forests ecosystem goods and services, thereby mitigating climate change and its effects.

Keywords: Biomass, Climate change, Carbon stock, Carbon sequestration, sacred forest and Traditional methods.

Introduction

The forest vegetation cover is an important component used by nature to regulate global and local climate, thereby reducing the impact of global warning and climate change. It provides tangible (goods) and intangible (services) benefits that protect the ecosystem to deliver its maximum potentials. Carbon sequestration, production of oxygen and ozone layer protection are part of many services that the forest delivers as ecosystem services for the goods of the environment. Furthermore, forest vegetation cover protect watersheds, species diversity, serve as biodiversity reservoir and conservation, habitat for wildlife and thus contribute to effective ecosystem functioning and good quality ecosystem. Healthy forest vegetation cover play important role in climate change mitigation by sequestering carbon dioxide from the atmosphere.

Carbon sequestration has been identified as one of the inexpensive strategies to ameliorate climate change. The contribution of tropical forests to carbon sequestration is enormous (Oades, 1988; Bryan et al. 2010). Tropical forests are known to be crucial to global carbon sink, removing carbon from the atmosphere and storing it in trees, mitigating climate change incidences and harsh environmental conditions (Agbelade and Adeagbo 2020). It is estimated that about 1.6 billion tons of carbon are stored by tropical forests (Lasco et al. 2000; Myers, 2000). However, this critically important role of tropical forests is being threatened by deforestation. There is overwhelming evidence that the high rate of tropical deforestation is one of the major causes of climate change (Archana, 2013; Lawrence and Vandecar, 2014).

Deforestation contributes to climate change by reducing forest vegetation cover and increasing surface temperature. About 20 to 25% of global emissions stem from deforestation, predominantly in the tropics (Archana, 2013). Strategies to drastically reduce the rate of deforestation and restoration of degraded forests must be urgently developed in order to save the tropical forests. Apart from natural forests, other forest types have ability to contribute to climate change mitigation through their carbon sequestration efficiency, among which is sacred grove. Sacred groves represents biodiversity hotspots, refuge for endangered species, they are important for implementation of article 8(j) of the Conservation of Biological Diversity, which stresses the use of traditional wisdom and practices for conservation and sustainable use of biodiversity (Myers et al. 2000). The sacred grove system promotes ecosystem sustainability, plays essential role in carbon sequestration and functions effectively as climate change regulator. Thus, increase in carbon sequestration can be achieved through conservation and effective management of groves. In this study, we investigated tree species diversity, productivity and carbon storage in four sacred groves in southwestern, Nigeria.

Methodology

The Study Area

This study was conducted in sacred groves located in southwestern region of Nigeria (longitude 2º31′ and 6º00′ E and latitude 6º21′ and 8º 37′ N). The region is dominated by tropical rainforest, with some derived savanna and mangrove/swamp ecosystems. The climate is tropical, it is characterized by high mean annual temperature (21 - 34ºC) and annual rainfall (1400 mm - 4000 mm). The rainy season begins in March and ends November while dry season occurs between December and March. Soils are predominantly ferruginous, typical of the variety found in intensively weathered areas of basement complex formations in the rainforest zone of south-western Nigeria (Onyekwelu et al. 2008).

Method of Data Collection

The four (4) sacred groves selected for this study are: Osun-Osogbo, Ogun-Onire, Idanre Hills and Igbo-Olodumare. In each grove, biodiversity and tree growth data were collected from two lines transects of 1000 m long, laid approximately at the centre of the grove and separated by a distance of at least 1000 m. Four temporary sample plots of 40 m × 20 m were laid at alternate sides along each transect at every 250 m interval. Thus, there were 4 sample plots per transect, 8 per sacred grove and 32 for this study. Within each plot, all living trees with Dbh ≥ 10 cm were identified and their Dbh and total heights measured.

Data computation and analyses

Data from the four groves were analyzed for the following biodiversity indices and forest structure: species diversity index, species evenness, importance value index (IVI), species similarity index, basal area and volume. Data computation and analyses were conducted following the procedures outlined by Onyekwelu et al. (2008), Onyekwelu and Olusola (2014).

Estimation of Biomass and Carbon stock

The Above Ground Biomass (AGB) of trees was estimated using equation 2 (Brown 1997, Ketterings et al. 2001). Equation 1 is more accurate in estimating AGB of forests than other allometric equations (Chave et al. 2014), which explains its wide-scale adoption by scientists in determining the carbon storage of tropical forests (Adekunle et al. 2014, Chave et al., 2005, 2014, Agbelade and Adeagbo, 2020).

$$AGB = 34.47 - 8.067(D) + 0.6589(D)^2 \qquad \text{(Eq. 1)}$$

Where: AGB = Above-ground Biomass per tree (kg) and D = dbh (cm)

Below-ground biomass (BGB) of each tree was estimated by multiplying AGB by a factor of 0.2 (Brown 1997; Ketterings et al. 2001; Chave et al. 2014). Biomass per plot was obtained by adding the biomass of individual trees within each sample plot. Biomass was then extrapolated to hectare by computing mean plot biomass and then multiplies it by the number of 40 m × 20 m sample plots in one hectare.

The amount of carbon stock (CS) in each tree and sacred grove was calculated using the Macdicken (1997) formula (CS = (AGB + BGB) x 0.49). The coefficient of 0.49 is the conversion factor of biomass to carbon stock. The total carbon stock (TCS) was obtained as the summation of aboveground and belowground carbon stocks. One-way analysis of variance (ANOVA) was used to test for significant differences between diversity indices, biomass and other parameters of the sacred groves. Means found to differ significantly were separated using Fisher's least square difference.

Results

The number of tree species encountered in the sacred groves (understory and overstory layers) ranged from 41 to 85 while between 22 and 32 tree families were identified (Table 1). Shannon-Wiener diversity index varied from 2.63 to 3.55. There were significant differences in all the biodiversity indices across the four sacred groves (Table 1), indicating that diversity is dissimilar between the groves. Ogun-Onire had significantly higher biodiversity indices compared to any of the other sacred groves. In most cases, Igbo-Olodumare had the significantly lowest biodiversity indices while for most of the indices, Idanre Hills and Osun-Osogbo groves were statistically similar (Table 1). The three species found to be most important (i.e. high IVI) in the floristic compositions of the sacred groves were: *Brachystegia eurycoma, Angylocalyx oligophyllus* and *Cola hispida* (Osun-Osogbo); *Blighia sapida*, *Celtis zenkerii* and *Diospyros dendo* (Ogun-Onire); *Hildegardia barteri*, *Sterculia tragacantha* and *Ricinodendrum heudelotii* (Igbo-Olodumare); and *Ceiba pentandra, Cassia siamen* and C*ola gigantea* (Idanre Hills).

Tree density (consisting of seedlings, saplings and canopy trees) in the four groves ranged from 1427 to 2825 ha^{-1}, with Ogun-Onire having the significantly highest density (2825 ha^{-1}) which is statistically similar to the density at Idanre Hills and Igbo-Olodumare having the significantly lowest tree density (1427 ha^{-1}) (Table 1). Majority of the trees in the four groves were small (dbh range: 0 cm – 30 cm), only few trees had large dbh. Stand growth characteristics differed significantly between the sacred groves (Table 1). Maximum tree dbh ranged from 105 cm to 185 cm and significantly highest at Idanre Hills sacred grove. Mean stand tree dbh ranged from 24.4 cm to 31.9 cm while mean height varied from 9.8 to 13.7 cm. The highest stand volume production (343.08 m^3ha^{-1}) was recorded at Idanre Hills grove while the lowest volume production was obtained at Osun-Osogbo (244.99 m^3ha^{-1}). The diameter distribution graph of individual trees in sacred forests (Figure 1) shows an inverse J-shaped pattern common with tropical natural forests. In all the sacred grove, most of the trees were found in the lower diameter class.

Table 1: Summary of biodiversity indices, stand growth characteristics, biomass and carbon stock accumulation for sacred groves in southwestern Nigeria

	Sacred Groves			
Biodiversity Indices and Growth variables	Osun-Osogbo	Igbo-Olodumare	Idanre Hills	Ogun-Onire
Number of Families	22c	22c	26b	32a
Number of Species	65b	41c	60b	85a
Shannon-Wiener's Index (H’)	2.98c	2.63c	3.17b	3.55a
Shannon Maximum Diversity Index	4.17b	3.71c	4.09b	4.44a
Species Richness (Margalef index)	8.09b	5.64c	7.11b	10.02a
Shannon-Wiener's Evenness	0.71b	0.71b	0.77a	0.80a
Shannon Maximum Diversity Index	4.17b	3.71c	4.09b	4.44a
Mean Dbh (cm)	24.40c	31.70a	31.90a	28.0b
Mean Height (m)	9.80c	12.00b	13.50a	13.70a
Maximum Dbh (cm)	150.8b	105.0c	185.0a	131.5c
Maximum height (m)	26.8	32.5	30.8	28.3
Total Density (ha^{-1}) (overstory and understory (saplings and seedlings)) trees	1878b	1427c	2633a	2825a
Density (ha^{-1}) of overstory trees only	423a	409b	311c	413b
Mean stand volume (m^3ha^{-1})	244.99c	260.77b	343.08a	260.70b
Mean stand total biomass (t ha^{-1})	154.91b	87.8c	231.86a	178.09b
Mean stand total carbon stock (t ha^{-1})	77.5c	43.9b	115.9a	84.2b

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

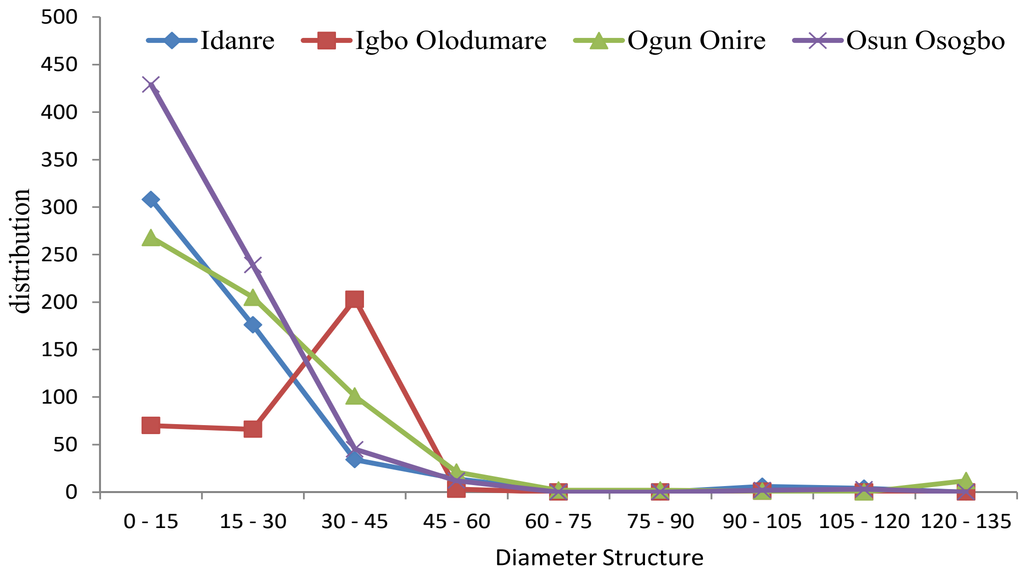

Figure 1 Diameter Structures of the Four Sacred groves

Few tree species accounted for the biomass and carbon contents in each sacred grove. Table 2 indicated that five tree species accounted for 31.2% to 76.8% of the total biomass and carbon contents of the sacred grove. The biomass production of the five tree species ranged from 2.8 t ha^{-1} - 25.59 t ha^{-1}; 3.96 t ha^{-1} - 10.32 t ha^{-1}; 7.57 t ha^{-1} - 51.16 t ha^{-1} and 7.64 t ha^{-1} - 12.97 t ha^{-1} at Osun-Osogbo, Igbo-Olodumare, Idanre Hills and Ogun-Onire sacred groves, respectively (Table 2). The mean stand total biomass production was significantly different in all the sacred groves, with Idanre Hills having the significantly highest total biomass (231.86 t ha^{-1}) and Igbo-Olodumare having the significantly lowest value (87.8 t ha^{-1})(Table 1). The mean stand total carbon, which ranged from 43.9 t ha^{-1} to 115.9 t ha^{-1}, followed similar trend as stand biomass production (Table 1).

Table 2: Five tree species with the high biomass (t) and carbon stock (t) in the sacred groves

Name of species	Freq	AGB	BGB	TB	AGC	BGC	TC	% of total
Osun-Osogbo sacred grove								
Ceiba pentandra	3	21.33	4.27	25.59	10.66	2.13	12.80	
Brachystegia euricoma	17	17.83	3.57	21.39	8.91	1.78	10.70	
Antiaris africana	10	11.08	2.22	13.30	5.54	1.11	6.65	67.2
Rothmania whitfieldii	7	2.92	0.58	3.50	1.46	0.29	1.75	
Hanoa cleniana	1	2.37	0.47	2.84	1.18	0.24	1.42	
Igbo-Olodumare sacred grove								
Ceiba pentandra	7	8.60	1.72	10.32	4.30	0.86	5.16	
Ficus Spp	1	7.68	1.54	9.22	3.84	0.77	4.61	
Ricinodendrum heudelotii	11	4.03	0.81	4.83	2.01	0.40	2.42	57.9
Hildegardia barteri	162	3.52	0.70	4.23	1.76	0.35	2.11	
Piptadeniastrum africanum	1	3.30	0.66	3.96	1.65	0.33	1.98	
Idanre Hills sacred grove								
Ceiba pentandra	6	42.63	8.53	51.16	21.32	4.26	25.58	
Antiaris africana	6	23.01	4.60	27.61	11.50	2.30	13.80	
Alstonia bonnei	3	17.43	3.49	20.92	8.72	1.74	10.46	76.8
Milicia excelsa	1	13.63	2.73	16.36	6.82	1.36	8.18	
Ficus mucuso	3	6.31	1.26	7.57	3.15	0.63	3.79	
Ogun-Onire sacred grove								
Blighia sapida	4	10.81	2.16	12.97	5.41	1.08	6.49	
Diospyros mobutensis	2	10.36	2.07	12.43	5.18	1.04	6.22	
Ficus sycoprorus	1	8.46	1.69	10.16	4.23	0.85	5.08	31.2
Triplochiton scleroxylon	3	7.80	1.56	9.36	3.90	0.78	4.68	
Pterygota macrocarpa	23	6.367	1.27	7.64	3.18	0.64	3.82	

AGB, BGB, TB, AGC, BGC and TC are Aboveground biomass, Below ground biomass, total biomass, Above ground carbon, below ground carbon and Total carbon, respectively

Discussion

Results of tree species assessment revealed that all the encountered trees in the four selected sacred forests were indigenous tropical hardwood species. Thus, the four sacred forests investigated are repositories of indigenous tropical hardwood tree species that are of high ecological, social and economic values. Our results give ample evidence to postulate that our sacred groves serves as *in-situ* conservation of indigenous tree species, which may include endangered, rare and endemic species, which is also the position of other research workers (Colding and Folke, 1997; Onyekwelu and Olusola, 2014, Boadi et al. 2017, Onyekwelu 2021). The tree species diversity and abundance of these sacred forests as determined by the biodiversity indices indicated that these sacred sites are fulfilling the mandate of biodiversity conservation strategy (UNEP-WCMC 2008). The floristic diversity of our sacred groves compares favourably with those of protected natural tropical forests ecosystems of southwestern Nigeria (Adekunle et al. 2013, Onyekwelu and Olusola 2014, Agbelade and Ojo 2020). The stand densities were also similar to those obtained for Garo hills, India (Kumar et al. 2006), Borneo rainforest (Small et al. 2004), Indonesian forest (Kessler et al. 2005) and the Mexican tropical deciduous forest (Duran et al. 2006).

The higher volume per hectare recorded for Idanre hill could be as a result of the presence of higher number of large diameter trees than the other sacred forests. The variation in tree volume across these sacred forests could be attributed to the differences in effective nature of conservation, sizes of trees in the forest areas, management regimes, etc and the variation in climatic conditions (Banda et al. 2006, Munishi et al. 2011). The Above-Ground Biomass (AGB) of tropical forests plays critical role in micro and macro absorption of carbon and carbon cycling of forest ecosystem. Carbon dioxide absorption from the atmosphere and processing of the carbon dioxide into biomass are done effectively by the plants and stored as biomass into plant physiological system (Ramachandran et al. 2007). The total biomass and carbon stocks of our sacred groves, especiall Ogun-Onire and Idanre Hills, as well as some published results (Waikhom et al. 2018), Dar et al. 2019, Devi et al. 2021) are indications that sacred groves contribute immensely to carbon sequestration and climate change mitigation. There is consensus in these literature that sacred groves have potentials for high biomass and carbon stock accumulation, which is equally our observation from the results of the present study. The implication of the our results is that sacred groves would contribute significantly to carbon sequestration and climate change mitigation if the cumulative areas they cover are taken into consideration. Thus, besides being a reservoir of biodiversity, sacred grove also act as sink of atmospheric CO_2. The high biomass and carbon stock in the sacred groves is attributed to the traditional conservation system that prevented or minimised degradation or the outright destruction of the forest as well as the old age of the sacred groves

Conclusion and Recommendations

The high rate of forest land encroachment, forest degradation and deforestation is a threat to biodiversity conservation and climate change mitigation in Nigeria. Sacred groves are veritable tools for biodiversity conservation and climate change mitigation. The status of these sacred groves in terms of biodiversity conservation, volume production, biomass and carbon stock revealed the efficacy of traditional methods of *in-situ* conservation. Our sacred groves have good potential for carbon sequestration, which calls for immediate attention and their further conservation to serve as long-term carbon sink. Besides being a good biodiversity conservation mechanism, sacred groves also act as sink of atmospheric CO_2 considering their high biomass and carbon stock accumulation. It is recommended that the traditional laws, culture and taboos guiding these sacred groves should be strengthened, sacred groves should be demarcated as parts of protected areas, especially in Nigeria.

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