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Tree species diversity and soil status of two natural forest ecosystems in lowland humid tropical rainforest region of Nigeria

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Abstract

The species rich tropical rainforests have been under intense pressure to satisfy demands for timber and non-timber products, the long term effect being degradation in terms of quality and quantity of the forest ecosystem. Tree species diversity and soil properties were investigated for a primary (Queen's) and two degraded (Elephant and Oluwa) tropical rainforests in Nigeria. Queen's forest has not been logged within living memory while Oluwa and Elephant forests were last logged in early 1970s and 1990s, respectively. Differences in soil physical and chemical properties of the three sites could not be attributed to the effect of forest degradation since there was no discernable pattern in soil properties of primary and degraded forests. A total of 31 families were encountered in all three sites (26, 24 and 22 in Queen's, Oluwa and Elephant forests, respectively). Queen's forest had the highest number of tree species (51), followed by Oluwa (45) and lastly by Elephant forest (31). About one third of all tree species identified in Queen's, Oluwa and Elephant forests were among the endangered tree species in Nigeria, a situation that calls urgent conservation measures. Species diversity index, species richness and species evenness followed the order: Queen's forest > Oluwa > Elephant forest, indicating that species diversity, species richness and species evenness in the three sites depended on the state of the forest, with diversity decreasing as the level of forest degradation increases. The similarity of species diversity of the once highly degraded Oluwa forest to that of Queen's forest shows that lowland tropical rainforests have the ability of returning to their original "species rich" situation even after significant degradation, , provided the forest is left undisturbed for a considerable period of time.

Introduction

One of the well-known characteristics of tropical rainforests is the large number of species in them. Though accounting for only 7% of earth's dry surface area, rainforests accommodate 70% of animal and plant species in world ecosystems. Between 100 and 300 tree species ha^{-1} are found in rainforests. This high species diversity is partly responsible for the intense pressure under which rainforests are subjected, the long-term effect being forest degradation and deforestation. Unlike deforestation, forest degradation does not involve land-use change. Forest degradation is usually accompanied by species extinction, reduction in biodiversity, decrease in primary productivity, etc. About ten million hectares of rainforests are degraded annually. About 200,000 ha of rainforest in Cameroon are degraded annually, with over 40 tree and wildlife species being threatened with extinction (WRM, 1999).

The Nigerian rainforest ecosystems occupies only 9.7% of the country's land mass of 983,213 km^2 but it is the most densely populated and source of the bulk of Nigeria's timber. The acceptance of Nigerian timber species in the international market in the early 20th century, coupled with rising domestic demand, lead to the situation where exploitations became unregulated and timber removed on a massive scale, a process that led to serious forest degradation and has left less than 5% of the country's rainforest ecosystems as undisturbed. Following centuries of degradation, many rainforests are severely threatened and persist as forest fragments. Consequently, there is a growing interest in quantifying habitat characteristics like forest structure, floristic composition and species richness in primary and degraded forests (Gillespie *et al.* 2004). This study investigates tree species diversity and soil properties of primary and degraded rainforest ecosystems in southwestern Nigeria.

Methods

The study was conducted in Queen's and Elephant forests in Omo forest reserve (latitude 6^o 35′-7^o 05′N & longitude 4^o 05′-4^o 40′E) and Oluwa forests in Oluwa forest reserve (latitude 6°55'–7° 20'N & longitude 3°45'–4° 32'E). Both reserves were heavily exploited during the past 50 years, except for few inaccessible parts. By early

1970s, Oluwa and Omo were already degraded and designated for industrial plantation. Queen's forest was constituted a Strict Nature Reserve in 1949 and Biosphere Reserve in 1977, with no evidence of timber exploitation. Elephant forest was heavily exploited in the past but the establishment of Elephant project in 1992 resulted to significant reduction in exploitation. In Oluwa, the natural forest has not been exploited since the early 1970s.

Annual rainfall in both reserves (March to November) ranges from 1,700 to 2,200mm. Annual temperature and average daily relative humidity in Oluwa and Omo is 26°C and 80%, respectively. Average elevation is 100 m in Oluwa and 123m in Omo. Soils are classified as Alfisol, are well-drained, mature, red, stony and gravely in the upper parts of the sequence. The texture of topsoil in both reserves is mainly sandy loam.

Data were collected from 24 temporary sample plots of 20 x 20m, laid systematically in the sites. Within each plot, trees with dbh ≥ 10 cm were identified and their dbh measured. Soil sample collection and enumeration of regeneration were conducted within a 6 x 6m sub-plot, laid at the centre of each sample plot. Three soils samples (at 2m intervals) were collected from each plot 0–15, 15–30, 30–45 and 45–60cm depths. Soils from similar depths in each plot were mixed and composite samples collected. Samples for bulk density were collected from 0 -15cm only.

Soil samples were air-dried and ground in a Wiley mill to pass through a 2mm sieve. Particle size was determined by hydrometer method, with sodium hexameta-phosphate as dispersing agent. Core cylinder samples were dried at 105°C for two days and bulk density calculated as the ratio of oven-dry weight of soil to cylinder volume. Soil pH was determined with digital pH meter in 1:2 soil/water solution. Organic matter was estimated by Walkley and Black (1934). Extract for available P was prepared with ammonium fluoride and P determined by molybdenum-blue method. Total N was determined by micro Kjeldahl method. Soil samples were leached with 1N ammonium acetate solution (pH=7.0) and exchangeable Ca and Mg determined by atomic absorption spectrophotometer while exchangeable Na and K by digital flame photometry. Species relative density was given by:

$$RD = (\mathrm{ni}/\mathrm{N})\ x\ 100 \qquad (1)$$

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

Species relative dominance (RDo (%)) was computed using equation (2):

$$RDo = \frac{(\sum \mathrm{Ba}_i x 100)}{\sum \mathrm{Ba}_n} \qquad (2)$$

Ba_i = basal area of individual trees belonging to species *i*; Ba_n = stand basal area

The relationship, RD + RDo/2, gave the importance value (IV) for each species. Species diversity index was calculated using Shannon-Wiener diversity index (Kent & Coker, 1992).

$$H' = -\sum_{i=1}^{s} p_i \ln(p_i) \qquad (3)$$

H' = Shannon-Wiener diversity index; S = total number of species in the community; p_i = proportion of *S* made up of the *i*th species; ln = natural logarithm.

Shannon's maximum diversity index was calculated using equation (4):

$$H_{\max} = \ln(S) \qquad (4)$$

Species evenness in each community was determined using Shannon's equitability (E_H):

$$E_H = \frac{\mathrm{H'}}{\mathrm{H}_{\max}} = \frac{\sum_{i=1}^{s} \mathrm{p_i} \ln(p_i)}{\ln(\mathrm{S})} \qquad (5)$$

Sorensen's species similarity index between two sites was calculated using equation (6):

$$SI = \left(\frac{2C}{a+b}\right) * 100 \qquad (6)$$

C = number of species in sites *a* & *b*; *a* & *b* = number of species at sites *a* & *b*

Test of significance for soil nutrients, density, species diversity and richness, dbh, volume and basal area among the three sites was undertaken by one way analysis of variance using SPSS 13.0 for Windows. Means found to differ significantly were separated using Fishers' Least Square Difference.

Results and Discussion

Bulk density at 0–15cm depth varied from 1.32 to 1.43 gcm^{-3} in the three sites and were not significantly different ($p<0.05$). While sand content decreased with increase in depth, clay and silt content followed an opposite trend. Differences in silt contents of the sites at similar depth were not significant. Sand content differed significantly ($p>0.05$) at 0–15cm only while clay content differed significantly up to 30cm depth. Except Na, the concentration of all nutrients decreased with increase in depth. The soils of the sites are slightly acidic, with acidity increasing with increase in depth. pH of the sites did not differ significantly up to 30cm depth but beyond this depth, Oluwa soil had significantly higher pH than other sites. Organic matter ranged from 1.53 to 3.72%, decreased with increasing depth and did not differ significantly among the three sites. Available P and exchangeable Na were significantly higher in Queen's and Elephant forests than in Oluwa while exchangeable K was significantly higher in Oluwa than in Queen's and Elephant forests. Exchangeable Mg, Ca and total N were not significantly different across the three sites. When rainforest soils are exposed by deforestation or degradation, the consequences could include soil structure degradation, impaired soil nutrients, soil compaction, *etc*, especially when the land is converted to agricultural land (Lemenih *et al.* 2005). However, it appears that soil nutrient pool is not seriously degraded as long as the site remains under forest cover as indicated by our results. The difference in soil nutrients of the three sites may not be the result of forest degradation since there was no discernable pattern between soil properties of primary and degraded forests. For example, the soil properties of Elephant forest (degraded) was similar to that of Queen's forest (primary) while that of Oluwa forest (degraded) was better in few soil attributes (*e.g.* K) than Queen's forests. It is likely that the observed differences in some soil attributes could be inherent in the two forest reserves (Oluwa and Omo), probably in their parent materials, etc. However, long term research is needed to validate these results.

Thirty-one (31) families (27, 24 and 22 in Queen's, Oluwa and Elephant forests, respectively (Tab. 1)) were encountered in all three sites. Families with high number of species include Euphorbiaceae, Sterculiaceae, Meliaceae, Mimosoideae and Apocynaceae. Seventy-six tree species (51 in Queen's forest; 45 in Oluwa forest and 31 in Elephant forest) were identified in the three sites. Number of species in Queen's and Oluwa forests were significantly higher than that in Elephant forest (Tab. 1). The Nigerian rainforest is dominated by members of Sterculiaceae, *Moraceae*, *Ulmaceae*, *Meliaceae* families (Isichei, 1995), which agrees with our findings. In addition members of Apocynaceae and Euphorbiaceae families and species like *Diospyros* spp, *Napoleonaea* spp and *Strombosia pustulata* are important part of the floristic composition of the study sites. When compared to some rainforests around the world, the three sites investigated could be considered to be species poor. Number of tree species ha^{-1} could be as high as 400 in very rich rainforests (Nwoboshi, 1982). Tropical rainforests in South America and Southeast Asia harbour 200–300 species ha^{-1} (Richards 1996). Fifty-four seedling species (29, 28 and 24 in Oluwa, Queen's and Elephant forests, respectively), distributed among 21 families, were encountered. The seedling species in each site were similar to those of the tree category. However, seedling species like *Daneillia ogea, Mansonia altissima, Mallotus oppositifolius, Piptadeniastrum africanum,* and *Moringa oleifera* were not represented in the tree category, indicating that they might be among the future members of the study communities. Regeneration of *Draceana* spp and *Diospyros* spp was high in all sites. However, regeneration of *Funtumia elastica, Daneillia ogea* and *Hunteria umbellate* was high at Oluwa forest only, those of *Napoleonaea vogelii and Moringa oleifera* were high at Queen's forest only while that of *Napoleonaea* spp and *Desplatsia spp* were considerable at Elephant forest.

Based on FORMECU (1999) classification, 16 (31%), 15 (33%) and 8 (26%) species in Queen's, Oluwa and Elephant forests, respectively are among endangered tree species in Nigerian forests (Tab. 1). Bearing in mind that only 58 (10.4%) of the 560 tree species in Nigerian forests are endangered (FORMECU, 1999), this result suggests that a high number of trees in Nigeria's rainforest are currently endangered. This is to be expected given the long history of logging and the high volume of timber removed from this ecosystem. The occurrence of a significantly higher number of endangered species in primary (Queen's) forest than in degraded (Elephant) forest could imply the effectiveness of conservation in protecting endangered species from going into extinction.

Table 5: Summary of the results of various analyses conducted for the three study sites

Study sites	Density (trees ha^{-1})	No. of families	No. of species	No. of endangered species	Mean Dbh (cm)	Basal area (m^2ha^{-1})	volume (m^3ha^{-1})	H'	H_{max}	E_H	D
Oluwa forest	513b	24	45a	15	22.5a	35.9a	350.6a	3.12	5.04	0.60	1.92
Queen's Forest	671a	27	51a	16	27.3b	85.4b	1015.4b	3.31	5.16	0.66	1.85
Elephant Forest	508b	22	31b	8	21.6a	29.4a	262.7a	2.82	4.98	0.57	2.16

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

Relative density (RD) varied from 0.5–16.3%, 0.7–17.0% and 0.7–18.5% in Queen's, Oluwa and Elephant forests, respectively. Species with high RD in all sites are: *Diospyros mespiliformis*, *Strombosia pustulata*, *Drypetes paxii, Napoleonaea spp, Celtis zenkeri, Sterculia rhinopetala* and *Cola millenii*. Relative dominance (RDo) ranged from 0.05–25.9%, 0.11–14.3% and 0.11–14.6% in Queen's Oluwa and Elephant forest, respectively. Tree species like *Diospyros mespiliformis, Khaya ivorensis* and *Napoleonaea* spp have the highest importance value (IV) in Oluwa, Queen's and Elephant forests, respectively. More than one species shared dominance in primary and degraded forests. Species similarity index were 634% (Queen's and Elephant), 58.3% (Queen's and Oluwa) and 47.4% (Oluwa and Elephant) and revealed that tree species in Queen's and Elephant forests are more similar than any other site combinations. Shannon-Wiener diversity index (H') and Shannon's maximum diversity index (H_{max}) followed the order Queen's > Oluwa > Elephant forest (Tab. 1) and lies within the general limit of 1.5 to 3.5 (Kent & Coker, 1992). The trend of H' for the three sites suggest that species diversity decreases as the level of forest degradation increases, which is consistent with results in literature (Nath *et al.* 2005). H' for the study sites are lower than their maximum diversity indices, indicating that all species in the sites do not have equal area abundance. Diversity index would be maximum if all species had equal area abundance. The H' of 3.34–3.66 for some rainforest sites in Nigeria (Adekunle, 2004) is similar to that of Queen's and Oluwa forests but higher than that of Elephant.

The results of Shannon's equitability (E_H) revealed that species evenness in the three communities are similar, which is collaborated by the difference between H' and H_{max} for each site pair (Tab. 1). Species evenness is a measure of the relative abundance of species that make up the richness of an area, with evenness being maximum

(E_H=1) when all species have similar population size; the higher the value of E_H, the more even the species in their distribution (Kent & Coker, 1992). The components of species diversity that determine the expression of species traits include species richness, evenness, composition, interactions among species, etc, with species richness being the most widely used index of biodiversity. Our results indicate that Queen's and Oluwa forest have similar species richness, which is superior to that of Elephant forest, implying that species richness decreased as the intensity of forest degradation increases. In rainforests in India, tree species richness decreased with increase in intensity of forest disturbance (Nath *et al.* 2005). Since uncontrolled and unsustainable logging could reduce species richness, the significantly lower species richness in Elephant forest could be the result of repeated timber logging. Species richness in Queen's and Oluwa forests is comparable with that of some rainforest sites in Nigeria (Adekunle, 2004).

Though Elephant forest has remained under forest cover, its composition and biological functions appear to have been compromised due to degradation. This is because it is the poorest of the three sites. The current status of Elephant forest could be attributed to repeated logging activities, since it is the most logged of the three sites. The general trend is that unlogged forests contain more species, are more diverse and even than logged ones. Logging in lowland swamp forest in Costa Rica was reported to reduce richness by 14 species (Webb and Peralta).

Bearing in mind that Oluwa forest was once highly degraded, its comparable results with that of Queen's forest (primary) is an indication that rainforests possess the ability to recover from degradation and returning to their original "species rich" situation, even after significant degradation. However, this necessitates that all forms of degradation activities must cease or controlled as was the case in Oluwa forest, which was neither logged nor encroached upon for over three decades. A tropical dry forest in Puerto Rico recorded a relatively rapid recovery when left undisturbed for 13 years (Murphy *et al.,* 1995). The potentials of degraded Oluwa forest to recover from degradation calls for a re-consideration of the current practice in Nigeria in which degraded forests are converted to monoculture forest plantations. The urgent need for conservation measures is further underscored by the endangered status of a high percentage of tree species in the study forests. Since frequency of logging impacts greatly on biodiversity, the frequency of logging operations in Nigeria's rainforests must be reduced and subsequent logging operations planned on sustained yield basis. There should be strict enforcement of export prohibition of roundwood and semi-finished timber products by Government of Nigeria, prohibition of exploitation of endangered species, etc.

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