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# FOREST STRUCTURE ANALYSIS OF AKOPI FOREST IN BENUE STATE, NIGERIA

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## ABSTRACT

***This study analyzed the structure of Akopi forest to facilitate its sustainable management. Data was collected from seven 0.25 ha sample plots in the forest stand using the systematic line plot sampling design. All trees in the sample plots with stem diameter at breast height of ≥ 5 cm were identified and measurements taken for stand structural attributes which include tree stem diameter at breast height (DBH), total tree height (THT), tree crown diameter (CD) and tree crown height (CH). Forest structure was analyzed based on tree density (tress/ha), size class distributions and diversity indices (Shanon-Weiner index, Pielou evenness idex and mean structural diversity index). The results of the analysis produced low Shanon-Weiner index values (1.185 to 1.521) for all the structural attributes indicating low structural diversity. Pielou evenness (0.661 to 0.761) for all structural attributes and the Mean structural diversity (1.354) for the forest stand also revealed low structural diversity. The results of this study suggest Akopi forest is undergoing deforestation. Sustainable management measures that will enhance structural diversity should be considered and implemented.***

**Keywords:** structural diversity, diversity indices, forest structure, tree size distribution, forest density.

## INTRODUCTION

Forests play a significant role in the socio-economic well being of rural and urban communities, as well as ecological benefits. Tropical forests consist of diverse plant species which serve as habitats to diverse fauna. Some of these habitats are being degraded and some converted to other land uses. Global Forest Resources Assessment has shown declining areas of natural forests, particularly in Africa (Sloan and Sayer, 2015). Local communities in Africa are heavily dependent on forests for fuel wood as a source of household energy (Clancy, 2008; Bailis *et al.*, 2015; Sassen *et al.*, 2015); and selective logging of trees for fuel wood alters the structure of a forest. The manner in which tree size attributes vary and are distributed within a forest stand defines the structure of the forest. High forest structural diversity is associated with stands where there are multiple tree sizes (Buongiorno *et al.*, 1994). Forest structure is the result of both natural processes and human disturbance. The specific structure of a forest is formed through the processes of seed dispersal, regeneration, growth and mortality (Harper 1977). Studies have demonstrated that the structure of a forest can be an important indicator of biodiversity and productivity (Kimming, 1997; Shimatani, 2001; Vogeler *et al.*, 2014; Bohn and Huth, 2017; Horak *et al.*, 2019; LaRue *et al.*, 2019), therefore its assessment has become important in many forest ecological studies.

Different methods have been used to assess forest structure. Forest structure can be simply assessed by the frequency distributions of tree attributes such as tree stem diameter, tree basal area and tree height, or by the stem density per hectare (Cummings *et al.*, 2002; Ostertag *et al.*, 2014; Djomo, 2015; Clark *et al.*, 2019). Diversity indices such as the Shannon-Weiner index (Shannon and Weiner 1949), Gini index (Gini, 1921), Margalef index (Margalef, 1958), the McIntosh index (McIntosh, 1967), and Simpson's index (Simpson, 1949) have been used to assess forest structural diversity in previous studies (Staudhammer and LeMay, 2001; Barbeito *et al.*, 2009; Wang *et al.*, 2011; Ercanli & Kahriman 2015; Ercanli, 2018). These indices incorporate single or combined tree attributes to obtain an index value that is used to describe the structural diversity of a forest stand.

McElhinny *et al.* (2005) provides a review of indices used to assess forest structural diversity, which they categorized into three types of index framework: "(1) indices based on the cumulative score of attributes; (2) indices based on the average score of groups of attributes; and (3) indices based on the interaction of attributes. Their review identified a variety of different indices with no single index preferred over the others. Hui *et al*. (2019) also provides a review of methods for quantitative analysis of forest structure.

Stand structure analysis provides an insight into the regeneration, growth and productivity status of a forest stand. For any rational sustainable forest management decision, there is need for current quantitative information on the forest of interest. The Akopi forest provides ecological and socio-economic services to surrounding rural settlements. With effective sustainable management, Akopi forest can offer multidimensional opportunities for socioeconomic development. Therefore, this study was carried out to analyze the structure of Akopi forest with a view to provide a framework to facilitate effective sustainable management interventions for the forest.

## MATERIALS AND METHODS

### Study Area

The Akopi forest is located in Guma Local Government Area in Benue State, Nigeria. The Akopi forest lies between 8°42.9′E, 8°44.4′E and 7°54.9′N, 7°55.0′N (Figure 1). The forest covers approximately 260 ha of land. The forest is not a designated forest reserve by the State Government, and is managed by the local community. The climate of the area is tropical savanna, and has two seasons (dry and wet seasons). The wet season extends between April to October, and the dry season between November to March. The Akopi forest consists of about 18 tree species, and the most abundant species are *Anogeissus leiocarpa*, *Pseudocedrela kotschyi* and *Mitragyna inermis* (Yager *et al*., 2019).

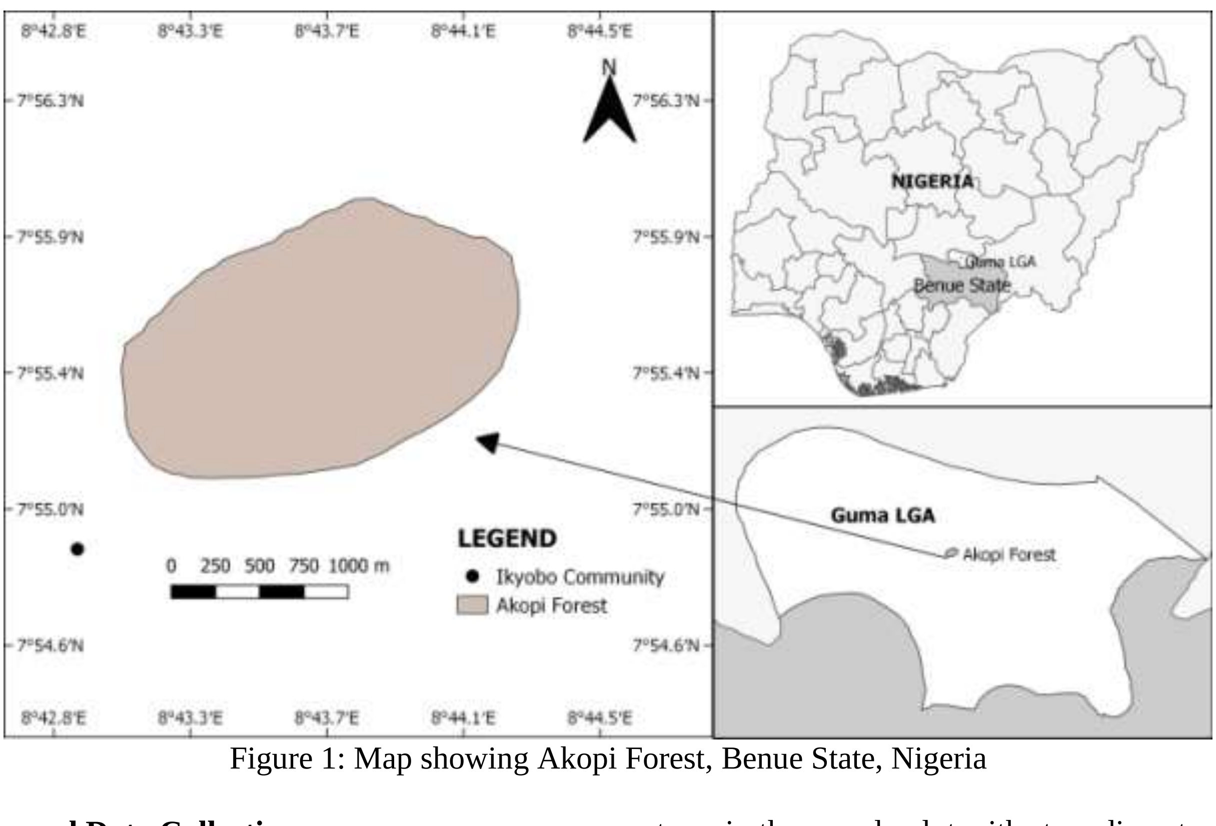

Figure 1: Map showing Akopi Forest, Benue State, Nigeria

### Sampling and Data Collection

Data was collected from seven sample plots of 0.25 ha in the forest using the systematic line plot sampling technique (Avery and Burkhart 2002). All trees in the sample plot with stem diameter at breast height (DBH) of ≥ 5 cm were identified and measurements taken for DBH total tree height (THT), tree crown diameter (CD) and tree crown height (CH). The basal area (BA) of each tree was determined as follows:

$$BA = \frac{\pi DBH^2}{4} \quad \text{.......................} \ (1)$$

**Forest Structure Analysis**

The forest structure was characterized in terms of tree density per hectare, basal area per hectare, and size class distributions of DBH, THT, CD and DBH. The tree density per hectare was determined by dividing the total number of trees by the sampled area. Eight DBH classes were formed, each arranged in 10 cm intervals. Six CD, THT and CH classes were formed, each arranged in 3 m, 5 m and 4 m intervals, respectively.

The diversity of each measured tree attribute (DBH, THT, CD and DBH) was further analyzed using diversity indices. Diversity indices used in this study consist of the following:

1. Shannon-Wiener diversity index (*H*) (Shanon and Weiner, 1949):

$$H = -\sum_{i=1}^{s} p_i \ln p_i \quad \text{.......................} \ (2)$$

where**:** *s* is the total number of classes for any given tree attribute, $p_i$ is the proportion of individuals in the ith class and *ln* is the natural logarithm.

2. Pielou Evenness Index (Pielou, 1969) :

$$E = \frac{H}{lnS} \quad \text{.......................} \ (3)$$

where**:** *H* is the Shannon–Wiener function , *ln* is the natural logarithm and *S* is the total number of classes for any given tree attribute

3. Mean structural diversity (Staudhammer and LeMay, 2001):

$$M = \frac{H_{DBH} + H_{CD} + H_{THT} + H_{CH}}{4} \quad \text{.......................} \ (4)$$

where: $H_{DBH}$, $H_{CD}$, $H_{THT}$, and $H_{CH}$ are the Shannon-Wiener diversity index for DBH, CD, THT and CH, respectively.

These indices have been used in numerous studies to analyze the structural diversity of forest stands (Buongiorno *et al.*, 1995; Staudhammer and LeMay, 2001; Barbeito *et al.*, 2009; Wang *et al.*, 2011; Ercanli and Kahriman 2015; Ercanli, 2018).

**RESULTS**

A total number of 258 individual trees were enumerated and measured within the sample plots. The summary statistics of all measured tree attributes are presented in Table 1. The DBH of measured trees ranged from 5.7 cm to 78 cm, THT ranged from 4.1 m to 28.2 m, CH ranged from 2.1 m to 12.2 m and CD ranged from 2.1 m to 16.9 m. Basal area of trees ranged from 0.0026 $m^2$ to 0.4795 $m^2$. Tree density and basal area of the forest stand was estimated to be 147 trees per hectare and 8.024 $m^2$ per hectare respectively.

**Table 1: Summary statistics of growth variables for trees in Akopi Forest, Benue State, Nigeria**

| Summary statistics | DBH (cm) | THT (m) | CH (m) | CD (m) | BA($m^2$) |
|---|---|---|---|---|---|
| Mean | 23.2 | 12.7 | 6.9 | 6.3 | 0.0544 |
| Standard Deviation | 12.5 | 4.7 | 2.9 | 3.0 | 0.0672 |
| Minimum | 5.7 | 4.1 | 2.1 | 2.1 | 0.0026 |
| Maximum | 78.1 | 28.2 | 12.2 | 16.9 | 0.4795 |

**Key:** DBH = Stem diameter at breast height; THT = Total tree height; CH = Crown height; CD =Crown diameter; BA = Basal area

The size class distribution of DBH, THT, CH, and CD are presented in Figure 2. More trees were within 10 cm to 30 cm in DBH, 5 m to 20 m in THT, 4 m to 12 m in CH and 3 m to 9 m in CD. The DBH distribution of trees indicates an absence of larger diameter trees in the forest stand.

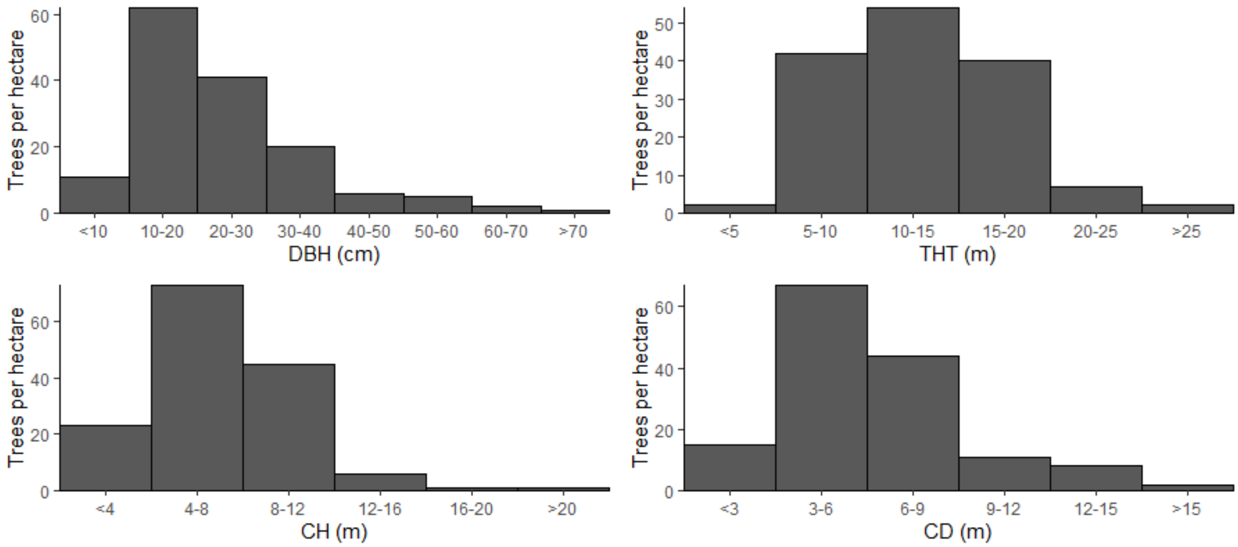


**Figure 2: Distribution of tree attributes in Akopi forest, Benue State, Nigeria**

The structural diversity in the forest stand as analyzed based on the diversity indices indicate low diversity of all measured structural attributes (Table 2). The Shannon-Weiner diversity index (*H*) values for all tree attributes range from 1.185 to 1.521. These low *H* values indicate low variation in the distribution of the respective tree attributes across the forest stand (i.e. more trees falling within the same DBH, THT, CH and CD range). The Pielou evenness index (*E*) value of all the tree attributes ranged from 0.661 to 0.761, indicating a close to even distribution for majority of the trees within a range, thus low structural diversity. The mean structural diversity value was estimated to be 1.354, which indicate an overall low structurally diversity of all measured tree attributes combined.

**Table 2: Results of stand structural diversity indices for Akopi forest, Benue State, Nigeria**

| Parameters | DBH | CD | THT | CH |
|---|---|---|---|---|
| Number of classes | 8 | 6 | 6 | 6 |
| Number of trees ha-1 | 147 | 147 | 147 | 147 |
| Shannon-Wiener index | 1.521 | 1.364 | 1.346 | 1.185 |
| Pielou Evenness | 0.732 | 0.761 | 0.751 | 0.661 |

**Key:** DBH = Stem diameter at breast height; CD = Crown diameter; THT = Total tree height; CH = Crown height

## DISCUSSION

Stand structural diversity can indicate the overall productivity and biodiversity status of a forest stand. Research has shown that structural diversity controls critical resources for forest primary production such as the availability of light and moisture (Brum *et al.*, 2019). The analysis of the structure of Akopi forest shows low structural diversity in terms of tree stem diameter, tree height, tree crown diameter and tree crown height distribution in the forest stand. The observed structural status of the forest, as described by the characteristics of measured tree attributes and diversity indices, is detrimental to overall productivity and biodiversity of the forest stand.

The density of Akpoi forest was estimated to be a staggering 147 trees per hectare as compared to undisturbed tropical forests. Forest density in undisturbed or sustainably managed tropical forests have been reported be above 200 trees per hectare. Across 20 intact tropical forests in Southwestern Brazil, Cummings *et al.* (2002) reported mean densities of 429, 377 and 450 trees per hectare in open, ecotone and dense forest types respectively. Lewis *et al.* (2013) reported mean density of 425 trees per hectare, and a maximum of 650 trees per hectare across 260 African tropical forests. Chenge and Osho (2018) reported 402 trees per hectare in a tropical forest in southwestern Nigeria. Adekunle *et al*. (2013) reported 387 trees per hectare in another tropical forest in southwestern Nigeria. With the exception of the smallest stem diameter class (DBH < 10 cm), the stem diameter distribution of the forest (Figure 2) approximately depicts the inverse J shaped distribution typical of natural forests. A small density of trees was noticed in the smallest stem diameter class (DBH < 10 cm); this reflects low regeneration and recruitment of trees in the forest stand. The stem diameter distribution of the forest also showed absence of larger stem diameter trees (DBH > 80 cm) which suggest larger trees have been logged. This is unfortunate because large diameter trees represent key structures of forest ecosystems. Large diameter trees are mainly mature trees and ultimately responsible for reproduction, regeneration, succession, dynamics and diversity in forests stands. Research has also found that high aboveground biomass in tropical forests is driven by high density of large trees (Bastin *et al.,* 2015; Bradford & Murphy, 2019). The absence of large diameter trees in Akopi forest consequently resulted to absence of larger canopy trees which are important habitats for some wildlife species. Tree canopies also serves to regulate light, temperature and moisture conditions for some plants and animals to thrive. The tree crown diameter distribution of the forest stand show majority of trees have crown diameters between 6 m to 9 m.

The Shannon-Weiner diversity index usually varies from 1.5 to 3.5 and rarely exceeds 4.5 (Kent & Coker 1992). Lower values of the index indicate low diversity and higher values high diversity. The low Shannon-Weiner diversity index values estimated for all measured tree attributes in this study reflects low diversity of these attributes in the forest stand. A structurally diverse forest would be expected to have a Shannon-Weiner index above 2.0 (Staudhammer and LeMay, 2001). The low structural diversity of Akopi forest is detrimental to plant and animal diversity as studies have linked rich plant and animal diversity to high structural diversity of a forest (Pretzsch 1997; Shimatani, 2001; Muller *et al.,* 2010; Horak *et al.,* 2019). Previous research on species diversity in Akopi forest showed low diversity in tree and animal species (Yager *et al.,* 2019). Studies have also established a significant relationship between diverse forest structure and forest productivity (Bohn and Huth, 2017; Brum *et al.,* 2019; LaRue *et al.*, 2019).

The low structural diversity in Akopi forest reflects anthropogenic removal of trees. However, this study did not investigate the underlying drivers of deforestation in the forest stand. Management interventions are crucial to enhance structural diversity of Akopi forest to promote its health and sustainability.

## CONCLUSION

This study analyzed the structural diversity of Akopi forest and found that the forest has low structural diversity. The forest lacks the large variations in tree stem size, tree height and tree canopy that is characteristic of structurally diverse forest stands. The low structural diversity suggests the Akpoi forest is undergoing deforestation. This is a cause for concern as forest structural diversity is crucial for primary productivity, plant diversity, and animal diversity. This study provides important quantitative information on the status of Akopi forest structure, and this information is important to facilitate the onset of sustainable restoration plans for the forest. Further studies that will investigate the underlying drivers of deforestation in the forest are recommended.

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