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Growth Rate and Age Structure in Rosewood (Pterocarpus erinaceus) from Tree Ring Analysis: Implication for Sustainable Harvest Scheduling

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ABSTRACT

Pterocarpus erinaceus is a rosewood species, a multipurpose deciduous tree of Africa savanna. It is widely known for its commercial timber and non-timber products. *P. erinaceus* woodlands is under a problematic state of population decline due to heavy encroachment and unsustainable logging. To sustainably manage such a valuable species, exact knowledge of growth rate and age structure of the trees must be known, such information on tropical trees under natural condition is rather poor. In this study, growth rate and age structure of *P. erinaceus* was determined from tree rings analysis. The study was carried in Mai-labari and Bayan-dutse villages of Bali local government of Taraba State, Nigeria. Thirty-two (32) stem sections were used, sixteen (16) each from Medium (M) and Large (L) sample trees. All sampled trees showed visible annual growth rings with a clear alternation of dark and light layers. The mean annual diameter growth rate of *P. erinaceus* derived from the mean ring-width ranges from 0.1 - 0.2 inch per year for medium and large sample trees. This research observed the ages of Medium sampled trees and that of the Large sampled trees. The girth and diameter at breast height shows highly significant difference while number of growth rings is significantly different for medium and large samples (0.001, $P < 0.05$). The girth, tree age and number of growth rings in large samples were not significant (0.00) at ($P < 0.05$). The study shows a strong relationship between the girth and age of the tree and girth and number of annual growth rings/age respectively. The result from this study is an important input to develop strategic plan for the species regarding logging frequency and intensity as per the annual increment of the species. It is recommended that the use of tree ring analysis as a tool to understand growth dynamics and age structure of other tree species and their response to climate variability should be strengthen in Taraba State.

Keywords:*Pterocarpus erinaceus*, annual growth rings, diameter, growth rate, age structure.

INTRODUCTION

Pterocarpus erinaceus is a rosewood species, a deciduous legume tree of African savannas and dry forests, famous for producing one of the finest woods in its native region [1,2,3] It is a deciduous tree with a high, open, few-branched crown; usually growing 12 - 15 m tall with some specimens reaching 25 m [4,5,6,7].

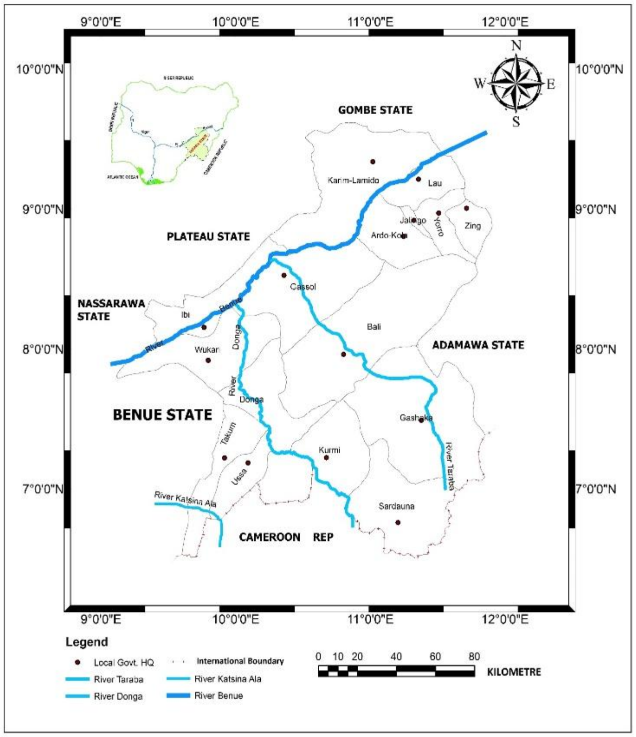
Global Biodiversity Information Facility (GBIF) and World Wildlife Fund (WWF) recorded *P. erinaceus* as occurring across regions, including Senegal, Gambia, Guinea-Bissau, Guinea, Mali, Côte d'Ivoire, Burkina Faso, Ghana, Niger, Benin, Togo, Nigeria and Cameroon [8,9]. In Taraba state, *P. erinaceus* is found mostly in the central senatorial district; high densities of *P. erinaceus* can be found between Ardo Kola, Mutum Biyu, Gassol, Bali, Gashaka, Donga, Kurimi, Ussa and Takum LGAs [10,11,13].

It is found in well-drained soils and rare in deep soils. It occurs in laterites as well as poor soils and it is found more frequently in acid rather than neutral soils. This species is sought-after, exploited and threatened in West Africa for timber [14] and is exported to Asian countries, mainly China [15]. For example, between 2011 and 2012, the export of *P. erinaceus* from Togo increased to 9,690 m^3. Togo has become the transit market of sub-regional trade in *P. erinaceus* logs. The species is also used locally for a variety of non-timber products, including food for human consumption and fodder for animals [16], medicines and raw materials for handicrafts (tannins, dyes, sap and resin) [17]. Study shows that in most West African countries where this large scale exploitation of *P. erinaceus* has taken place, it has created serious environmental problems such as in Mali, Burkina Faso and Gambia where shortage of fresh leaves from the species used for fodder has been reported [17]. This has made some west African countries like Senegal to write to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) requesting for the inclusion of *P. erinaceus* into the list of endangered species of flora [18]. Despite the overuse of *P. erinaceus*, producing countries lack scientific and technical information to guide forestry and integrate the species into reforestation programs. Moreover, there are few studies on the current status of *P. erinaceus* in dry forest and woodlands [19,20]. Furthermore, forest ecosystem management principles require indicators such as minimum felling diameter and minimum management diameter or the scaling rate [21,22,23]. These silvicultural parameters are important for adopting standards of sustainable management and conservation [24]. Over the last decades, the annual character of tree rings has been established for a large number of species in many tropical areas [25]. Tree-ring analysis provides a direct method for age determination and likely the most accurate method to determine tree age [26]. Taraba State in the last couple of years has experience massive exploitation of *P. erinaceus*, it therefore, means that if the present pressure on *P. erinaceus* in the State is not minimized, it may in the near future disappear from the forest of origin with the consequences of increasing the numbers of extinct plant species as well as the animals who use it as a habitat which may invariably affect the ecosystem. In light of these considerations, this study was conducted to examine the annual growth rings in stem discs' samples of *Pterocarpus erinaceus*, determine the growth rate and age structure of *Pterocarpus erinaceus* from tree ring analysis which is an important input to develop strategic plan for the species regarding logging frequency and intensity as per the annual increment of the species in Taraba State.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in two sites, namely Mai-Labari and Bayan-Dutse. Mai-Labari is located between latitude 08° 21 '22.4" N and longitude 011° 11'28.2" E. while Bayan-Dutse is located between latitude 07°46 '27.3" N and longitude 010° 58'05.2" E behind Bali Mountain. Bali local government area of Taraba State Nigeria (Figures 1 and 2). Bali Local Government falls within the Guinea Savanna Agro-ecological zones characterized by heavy wooded vegetation along major water course [13]. Common forest species include: *Pterocarpus erinaceus, Khaya senegalensis, Parkia clappertoniana Butyrospermum paradoxium* etc. The most important human occupation in the area includes fishing, crop farming, livestock rearing, petty trading and civil servants. All the sites are natural forests which are under pressure due to human activities especially overexploitation of *P. erinaceus*.



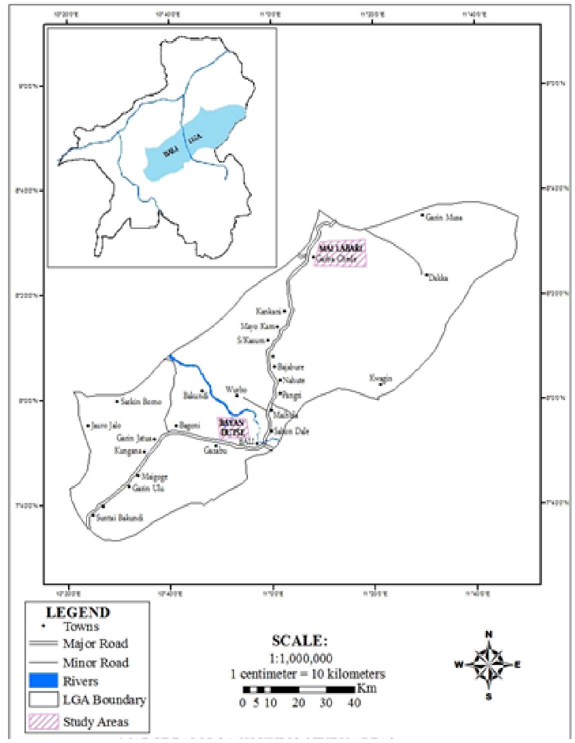


Figure 1. Nigeria Showing Taraba State. **Figure 2. Bali L. G. showing study sites**

Preparation of Sample Plots and Data Collection

Four (4) Plots made up of two (2) each from Mai-Labari and Bayan-Dutse were mapped out measuring 100m x 100m each. In each of the plots, four (4) sampled plots of 25 m x 25m (0.0625 ha) (Figure 3), were located using Geographic Positioning System (GPS). Data from *P. erinaceus* populations in the study areas were collected by means of forest inventories where *P. erinaceus* stands in the 16 sample plots were classified into Basal Area (B_A) classes ranging as: 20 – 40cm (7.9 ¬ 15.8 inches) and 50 – 70cm (19.7 - 27.6 inches) and labelled as Medium (M) and Large (L) respectively. The mean tree representing each Basal area (B_A) class was located by first counting all the *P. erinaceus* in each plot and measuring the girths (g) over bark at breast height. All girths values were then converted to diameter while the diameter data were used to calculate their Basal area (B_A) using the relationship

$$D = g/\pi$$

But $B_A = \pi d^2/4$

Where B_A = Basal area

g = girth

d = diameter

π = Mathematical Constant (P_i) = 3.142 [22].

The mean Basal area for each class were computed and trees whose Basal area was the closest to the class were located in each class mean. The two Basal areas classes; Medium (M) and Large (L) were established in each plot (Plate 1), as such four (4) stem discs each were removed from each plot, by so doing a total of 32 stem discs were collected from 32 sampled mean trees in the study sites. Within each plot, the stem with Medium (M) and Large (L) diameter of *Pterocarpus erinaceus* were selected for the study (Plate I)

Plate I. Sample *P. erinaceus* stands

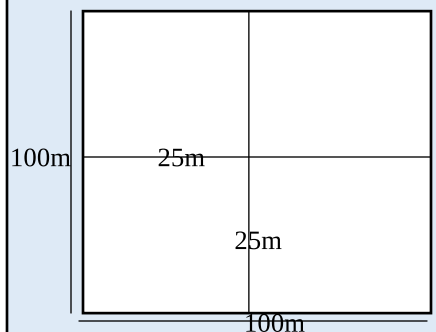


Figure 3. Sample plots

The assumption is that, the Medium and Large *Pterocarpus erinaceus* in each plot is matured enough and therefore were more reliable in determining the relationship between age and number of rings. The stem discs collected were trimmed and smoothened out to clearly show the growth rings for analysis.

Growth Ring Identification and Marking

Stem discs were air-dried and transverse sections were sanded with sandpaper (100 – 1200 grits). Samples were investigated macroscopically, and microscopically to find out which wood anatomical features are responsible for the visible coloured layers and to identify possible growth ring boundaries using the conventional methods in [17]. Marking process for growth-ring boundaries was done in four radii as in [9], and rings were counted along the four radii. By doing this the possibility of missing a ring boundary due to its indistinctiveness or marking a false ring boundary was minimized

Annual growth ring-width diameter in sampled *Pterocarpus erinaceus*

Ring-widths were measured with a precision of 0.01 mm using a digital measuring device LINTAB which is connected to a computer program-TSAP (Time Series Analysis and Presentation). An average ring-width were subsequently calculated for each tree [9].

Age of sampled *Pterocarpus erinaceus*

The ages of the sampled *Pterocarpus erinaceus* were determined by direct counting of the annual growth rings on the sample stem discs using Tree Conservation Notes by Athen-Clark County Community Tree program [7].

Data Analysis

Data obtained was subjected to Analysis of Variance (ANOVA) developed by a statistician and an evolutionary biologist Ronald Fisher to analyze the differences among group means, their associated procedures (such as "variation" among and within groups), while Pearson Product Moment Correlation Coefficient and Paired Samples T-test contained in SPSS 20.0 software package was used to analyze age and growth rings relationship to diameter respectively.

RESULTS

Growth Rings in sampled *Pterocarpus erinaceus*

Plate II. (A) Macroscopically unpolished *Pterocarpus erinaceus* stem disc showing a clear alternation of dark and light layers. (B) Macroscopically polished *Pterocarpus erinaceus* stem disc. (C) Magnified *Pterocarpus erinaceus* stem disc revealing the changing vessel density.

Macroscopic investigation of the sanded stem discs revealed a clear alternation of dark brown and light brown growth layers as shown in (Plate II A). The lighter colour results from the higher number of vessels which is further enhanced by polishing sanded stem discs (Plate II B). Under a low magnification (x10 objective), these coloured layers were found as a reflection of changing vessels density, with light layers exhibiting a higher vessel density than the dark layer as shown in (Plate II C). Under high magnification (x40 objective), the polished stem discs' revealed a gradual transition in the vessel density between the light and dark layer. Although difficulties in ring identification increased with age and size of *P. erinaceus* stem discs, neat polishing allowed the distinguishing of all the growth bands on the stem discs.

Age of sampled *Pterocarpus erinaceus*

The highest age of medium sample trees was 52 years observed in plot C_1 and the lowest age was 39 years in plots A_3 (Figure 4), while the highest age of large sample trees was 103 years observed in plot B_1 and the lowest was 61 years in plot C_1 (Figure 5). The diameter at breast height (DBH) ranges from 25.15cm to 38.61cm in medium sampled trees (Figure 4, plots A_3 and C_1), and 43.43cm to 54.36cm in large sampled trees (Figure 5, plots C_1 and B_1).

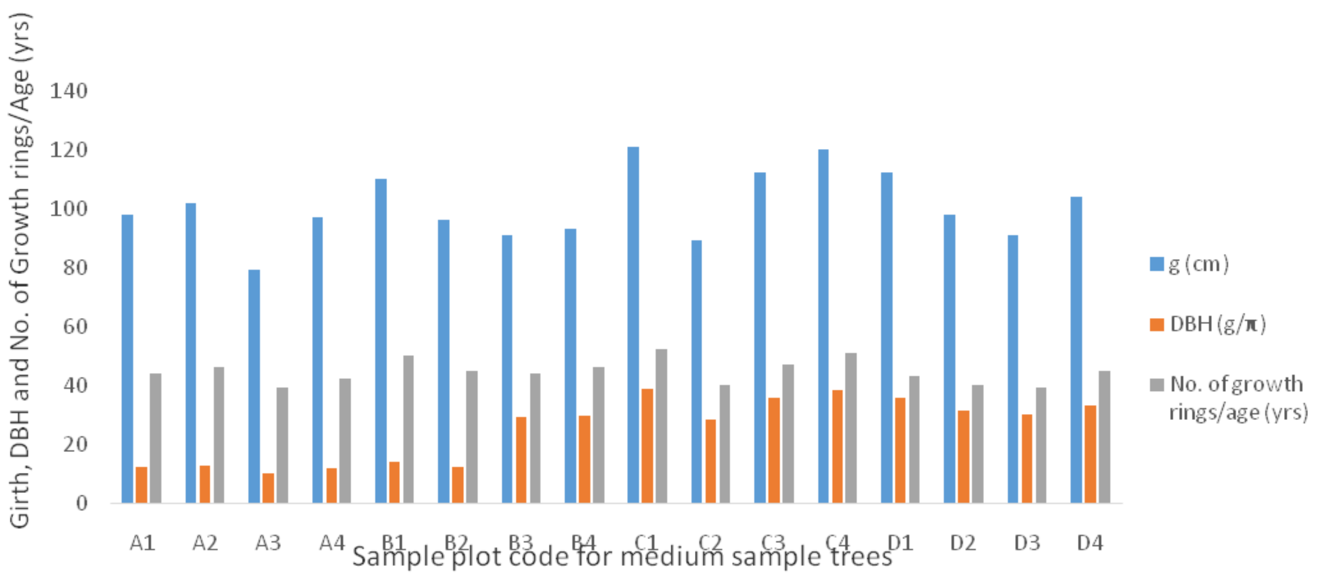


Figure 4. Girth, DBH and Growth Rings/Age of Mediumsample *Pterocarpus erinaceus*

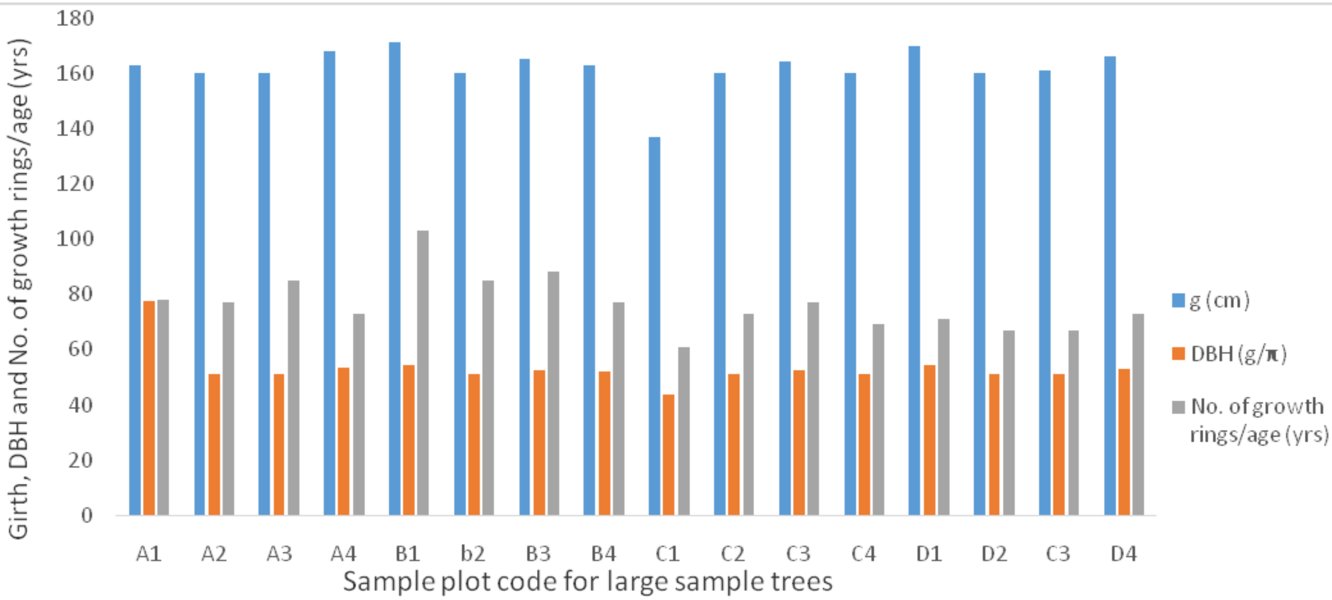


Figure 5. Girth, DBH and Growth Rings/Age of Large sample *Pterocarpus erinaceus*

Average annual ring-width diameter in sampled *Pterocarpus erinaceus*

The average annual diameter growth rate of the specie is between (0.25 - 0.51cm per year) in medium and large sampled *Pterocarpus erinaceus* (Table 1). Variation in the mean annual ring-widths of medium sampled tree in plot D_1 is 0.51cm, while the mean annual ring-widths in plots A_3, B_2, B_3 and B_4 is 0.25cm respectively. Large sampled trees in plots C_4, D_1, D_2 and D_3 is 0.51cm respectively, while the mean annual ring-width diameter of large sampled tree in plot B_1 is 0.25cm (Table 1).

Table 1:Number of annual growth rings and average ring-width diameter for Medium (M) and Large (L) sample *Pterocarpus erinaceus.*

Sample plot code	Number of annual growth rings		Average ring-width diameter (cm)	
	M	L	M	L
A_1	44	78	0.25	0.25
A_2	46	77	0.25	0.25
A_3	39	85	0.25	0.25
A_4	42	73	0.25	0.25
B_1	50	103	0.25	0.25
B_2	45	85	0.25	0.25
B_3	44	88	0.25	0.25
B_4	46	77	0.25	0.25
C_1	52	61	0.51	0.25
C_2	40	73	0.25	0.25
C_3	47	77	0.51	0.25
C_4	51	69	0.51	0.51
D_1	43	71	0.51	0.51
D_2	40	67	0.51	0.51
D_3	39	67	0.51	0.51
D_4	45	73	0.51	0.25

Key: M = medium sample tree, L = large sample tree.

DISCUSSION

Microscopic investigation of the polished stem discs under high power (x40 objective) revealed a gradual transition in the vessel density between the light and dark layer which is in line with the study carried out by [5] on growth rings, growth ring formation and age determination in the Mangrove *Rhizophora mucronata*. The relatively drier and wetter periods usually experienced in the study sites could be the reason for the distinctive tree ring in this study. The result of the research also supported the findings of [14], who carried out a research in La Selva wet tropical forests and [19] who studied tree rings in Bolivian tropical moist forests.

Based on the results of this study, the average annual growth ring-width is between (0.25 – 0.51cm per year) in medium and large sampled *P. erinaceus* (Table 1). The variation is far below the average annual growth ring-width observed by Agus (2016) in which reported annual growth ring width of (0.679 to 1.047cm per year) (0.267 inch to 0.412 inch per year) in a dendrochronology of young *Swietenia macrophylla* in Bengkulu, Indonesia [27, 28, 29]. The result was a deviation from [30, 31, 32] where an increase average ring-width of Big-leaf Mahogany with increasing growing rings and age at Belize was observed. This deviation of the general pattern could be explained by several climatic reasons [33]. [33],explained that when condition encourages growth, a tree adds extra tissue and produce a thick ring. In a discouraging year, growth is slow and the tree produces a thin ring. Much of the variation in tree rings is due to variation in year-to-year climatic changes. He further explained that: firstly, if rain season starts early, the growing season is likely to be longer than usual, causing a tree to have a wider ring. Secondly, late rain season is likely to shorten growing season, causing a tree to have a narrower tree ring. Thirdly, drought decreases growth, producing a narrower ring. Fourthly, species of tree do differ in their response to weather changes. One might respond strongly to changes in overall rainfall, another might be more sensitive to the amount of rain during the late rain season, and another to a temperature change that alters the length of growing season and finally, crowding from neighbouring trees causes a series of narrow rings. Crowding is suspected when the series of narrow rings is more than three, because droughts are usually only one to three years.

This research observed the ages of Medium sampled trees between 39 to 52 years (Table 1, plots A_3 and C_1), and that of the Large sampled trees were between 61 to 103 years (Table 1, plots C_1 and B_1), while the diameter at breast height (DBH) ranges from 9.9 inches to 15.2 inches in medium sampled trees (Table 1, plots A_3 and C_1), and 17.1 inches to 21.4 inches in large sampled trees (Table 1, plots C_1 and B_1). [30], suggests that under natural conditions, *P. angolensis* may live for 150 years or more. Forest management implication is that for a DBH of 12.3 inches and 20.4 inches, *P. erinaceus* may reach 44 years and 78 years or more for medium and large size trees. This is why annual growth ring analysis is important. Tree age variation observed in sample stem discs of the same DBH as shown in Table 1 has also been reported by [29] on management implication of annual growth ring in *P. angolesis* from Zimbabwe. [20], summarized age obtained from tree-ring counts for 19 tropical tree species as 101 years as age varied between 37 and 241 years, although these ages were not obtained at maximum tree size. According to [21], data concerning the relationship of tree age and dendrometric parameters is very important for determining monetary value of tree and cost of replacement. [18], proposed that the knowledge of tree age is necessary for examining growth rate and age structure in forest and urban tree stands to ensure their proper maintenance and preservation.

From the above observations, the age of the sampled trees with respect to ring formations could have significant effects on the environment. For example, a sample tree with girth and DBH as small as 31.10 inches and 9.89 inches respectively as observed in medium sampled tree in plot A_1 was aged 39 years. Forest management implication is that for a small DBH of 12.3 inches as observed in medium sample in plot A_1 and 20.4 inches as observed in large sample in plot A_1 respectively, *P. erinaceus* will take 44 years and 78 years or more to grow to such a size. Hence, small, medium or large trees may be felled but it takes a longer time for such sizes of trees to be regenerated, which also has a corresponding effect on the environment and humans. The absence of this important tree species for such a long period of time is very detrimental to the ecosystem in terms of canopy cover to the soil, control of soil erosion as the roots of this species of tree anchor the soil, nitrogen fixation in the soil due to presence of root nodules and source of soil nutrients due to decomposition of leave litters from the tree, oxygen production and carbon dioxide recycling, habitat/shade and protection to varieties of wild animals, production of leafy fodder high in protein which makes an excellent animal feed crucial for the survival of livestock during the dry season, medicinal value, timber for domestic and industrial uses, economic value for locals and government. The effects of indiscriminate felling of *P. erinaceus* is obvious because it will take a longer time to naturally reproduce or grow one stand. In other words, the benefits accrued from the species will be out of quest, hence this will have adverse effects on both man and the environment, therefore, sustainable utilization of these valuable species of tree is a key to environmental protection and human usage especially in Taraba State, the 'Nature's Gift to the Nation'.

In most West African countries where large scale exploitation of *P. erinaceus* has taken place, it has created serious environmental problems such as in Mali, Burkina Faso and Gambia where shortage of fresh leaves from the species used for fodder has been reported [10]. This has made some West African countries like Senegal to write to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) requesting for the inclusion of *P. erinaceus* into the list of endangered species of flora [10].

CONCLUSION

Sustainable forest management requires reliable data to calculate the consequences of various logging regimes for tree population and future timber availability. Tree-ring analysis is a potential tool to provide reliable information about growth rate and age for trees that forms annual growth rings. Based on the results of this study, *Pterocarpus erinaceus* is a slow growing plant that takes many years to reach harvest size. Therefore, sustainable utilization of this valuable specie of tree is a key to environmental protection and human usage in Taraba State and Nigeria as a whole. The result from this study is therefore, a useful source of information to formulate conservational policies for the sustainable management of natural forest population such as those of *Pterocarpus erinaceus* in Taraba State.

RECOMMENDATIONS

- Based on the findings of this study, there is a need to develop strategic plan for *Pterocarpus erinaceus* regarding logging frequency and intensity for the sustainability of the species.
- In future, the use of tree ring analysis as a tool to understand growth dynamics and age structure of tree species and their response to climate variability should be strengthen in Taraba State, Nigeria.

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