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# Model for Stand Density Management in Oban Forest Reserve, Nigeria

Aigbe H.I and Omokhua G. E

**Abstract**— Management tool is needed for thinning regime and maximum volume growth for effective forest management. Stand density management model was developed for Oban Forest Reserve, Cross River, Nigeria. Multistage sampling technique was adopted for the study. The sampling procedure was made up of primary, secondary and tertiary sampling units of size 40m x 50m (0.2ha) were measured for diameter at breast height dbh ≥ 10 cm. Results showed that the average total stem volume/ha and basal area/ha in Oban forest reserve were 797 $m^3$ 34.67 $m^2$ respectively. The basal area estimate in this study is higher than the 15$m^2$ reported for a well-stocked tropical rainforest in Nigeria. The predicted maximum size-density model for Oban Forest Reserve were $Log\ N = -0.1346\ LogD + 2.6708$ and $ln\ N = -0.1346\ lnD + 6.1497$. The two equations have a downward sloping (negative slope) linear relationship. This slope is used to define the limits of maximum stocking which is termed the reference curve. The equations were used to developed stand density diagram and stock chart for density management regime which has stand density index ranging from 241 to 344 at $D \geq 10cm$. It is hope that the model will serve as a management tool in Oban Forest Reserve for maximum timber yield.

**Index Terms**— Oban Forest Reserve, stand density, stocking chart, modelling, density management

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## INTRODUCTION

The potential of a land area to produce wood is determined by its site quality. The actual growth achieved in a given site is determined by the amount, kind and distribution of trees currently on the site (Davis and Lawrence, 1987). Changing the character of this vegetative growing stock is the principle way foresters manipulate and control growth and yield. Trees form the major structural and functional basis of tropical forest ecosystems and can serve as robust indicators of changes and stressors at the landscape scale (Kumar *et al*., 2006). This structure and functional basis can be influenced by tree density. Stand density evaluate quantitatively with a group of measures, the amount of tree growing stock. LeMay and Marshall (1990) explained that the maximum volume that a stand can attain remains constant over a wide range of densities. However, the patterns of stand development and the sizes and the form of trees in the stand do vary considerably with density. As the individual trees in a stand grow in size, trees begin to compete for resources such as water, light, and mineral nutrients. Maximum growing space can be obtained when the density of tree reached a particular level of competition or probably crowdedness.


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Density is often expressed inform of a factor or index. These indices normally combine measures of quantity (number of tree, volume, basal area per hectare) with some measure of average tree size (LeMay and Marshall, 1990). Commonly used indices include Curtis' relative density index, Reineke's stand density index and the crown competition factor (LeMay and Marshall, 1990). Reineke (1933) devised a measure of density by drawing a series of parallel lines relating the maximum number of trees to the quadratic mean stand diameter. According to Avery and Burkhart (1994), stand density can be expressed in absolute or relative term. Absolute measures of density are determined directly from a given stand without reference to any other stand but relative density is based on selected standard density. Kumar *et al*. (2006) stated that one of the applications of self-thinning in forest management practices has been to derive relative stand density. It is usually expressed as a percent of absolute stand density to the reference level based on average maximum competition (Ernst and Knapp, 1985). Although there are different expressions of relative stand density measures, such as Drew and Flewelling's (1979) relative density (RD) index and Reineke's (1933) stand density index (SDI), they are highly correlated since they all are a function of tree size and density (Jack and Long, 1996). The amount of thinning should reduce density to a level such that the stand will grow back to or slightly above a density level chosen at the next

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scheduled thinning. The maximum size-density relationship and relative stand density measures have been used to develop stand management diagrams (e.g., Reineke, 1933; Drew and Flewelling, 1979; Dean and Jokela, 1992) and stocking charts (e,g., Gingrich, 1967; Solomon and Leak, 1969; 1986). Essentially, these tools are simple average stand models that graphically characterize growth, density, and mortality at various stages and stand development (Kumar *et al.,* 2006).

Stocking chart can be used by forest managers to rapidly design and evaluate alternative density regimes. This practice will help to maximize wood yield (Dean and Jokela, 1992; Kershaw and Fischer, 1991) and to create favourable ecological conditions for vegetation (Barbour *et al*., 1997). Kershaw and Fischer (1991) developed a stand density model for sawn timber- size mixed upland hardwoods in the central United States. According to Solomon and Zhang (1998), from the development, it was found that stand density management model is a useful tool which not only allows estimation of stand stocking but also serve as a stand monitoring system in which stand development and treatment can be traced through the stand management history (Kumar *et al.,* 2006).

Modelling of stand density regime will help forest manager in updating of inventories, choice of silvicultural treatment and long term planning. However, no model for stand density management has been developed for Oban Forest Reserve. The objective of this study is to develop a model for stand density management in Oban Forest Reserve, which will be a useful tool in the hands of the forest manager to ensure effective forest management and scheduling sivilcultural treatment.

## Methodology

### Study Area

Oban group forest reserve (Figure 1), also known as Oban block forest reserve, lies within longitude 8°20′ E and 8°55′ E and latitudes 5°00′ N and 6°00′ N. Presently, the reserve covers an area of 742.55km$^2$.

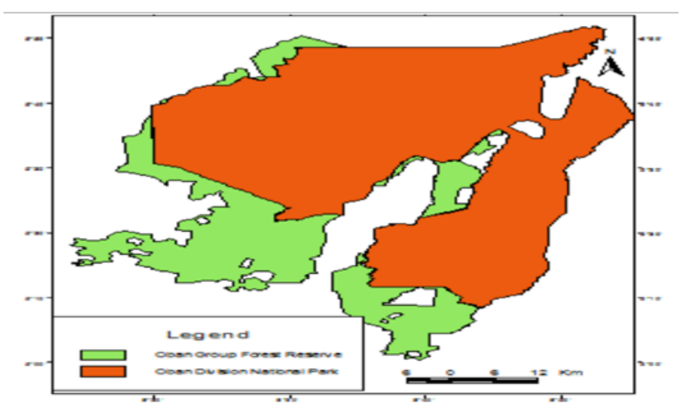


Figure 1: Map of Oban Forest Reserve

The terrain of Oban forest reserve is rugged and its elevation rises from the river valleys to over 1,000 m in mountainous areas (Jimoh *et al.,* 2012). Most of the area is characterized by hilly terrain ranging from 100 to over 1,000 m above sea level. The dominant rock types of the study area are ancient metamorphic rocks of the Basement Complex formation, which cover 50% of Nigeria. Derived from sedimentary rocks and Pre-cambrian in age, these rocks are interspersed with smaller areas of intrusive igneous rocks. The metamorphic rocks are mainly gneisses (biotite-hornblende, granite and migmatitic gneiss and to a lesser extent amphibolite (schist) (Holland *et al*, 1989; Schmitt, 1996). Less sandy soils are found in areas with igneous rocks and deeper soils prevail in the plains of the southern part of the reserve whilst on steeper slopes they are increasingly stony, shallow and erodible (Holland *et al*, 1989).

Mean annual rainfall in Oban forest reserve is generally between 2,500 mm- 3,000 mm but rainfall could be up to 4,000 mm. Temperatures are generally high (average around 27ºC) and vary little throughout the year Mean monthly relative humidity varies between 78% and 91% with an average of 85% (Holland *et al*, 1989; Schmitt, 1996).

### Data Collection

Multistage sampling technique was used to establish primary (1000 m x 1000 m), secondary (1000 m x 50m) and tertiary (40 m x 50 m) sample plots. Fourteen (14) tertiary plots were randomly established within the secondary plots and all trees measurement within the tertiary plots (0.20 ha). Growth data including: diameter at breast height (dbh); diameters over bark at the base, middle and top; merchantable height and total height were collected on all trees with dbh ≥ 10 cm within the 14 tertiary sample plots (Aigbe and Omokhua, 2015).

### Data Analysis

### Basal Area Estimation

The basal area for each tree in the enumerated plots was computed using:

$$BA = \pi D^2/4 \qquad - \qquad (1)$$

Where BA = basal area (m$^2$)

$\pi$ = 3.142 (a constant)

D = dbh (m)

Basal area per plot was obtained by adding the basal area of all individual trees within the plot. Mean plot basal area were computed for each plot. Basal area per hectare was then obtained by multiplying the mean plot basal area by the number of tertiary sample plots per hectare (Aigbe and Omokhua, 2015).

**Volume Estimation**

The volume of individual trees in each plot were computed using Newton's formula (Husch *et al*., 2003)

$$V = h/6(A_b + 4A_m + A_t) \quad - \quad - \quad (2)$$

Where:

V = tree volume ($m^3$)

h = tree height (m)

$A_b$ = Cross –sectional area at the base ($m^2$)

$A_t$ = Cross –sectional area at the top ($m^2$)

$A_m$ = Cross –sectional area at the middle ($m^2$)

Volume per plot was obtained by adding the volume of all individual trees within the plot. Mean plot volume were then computed by summing the total volumes of the sample plots selected from the primary unit and dividing by the number of sample plots selected from that primary unit. Volume per hectare was obtained by multiplying the mean plot volume by the number of sample plots per hectare (Aigbe *et al*, 2013).

**Model Fitting**

A fully stocked stand is required to develop a maximum size-density model which is generally a straight line relationship between logarithms of number of tree per hectare against logarithm of average diameter of tree (Reineke, 1933; Avery and Burkhart, 1994). Model fitting in this study was done using linear regression model of the form (Hutch *et al.*, 2003): $y = \alpha + \beta x$, where $y = Log\ N,\ x = Log\ D$ resulting in the equation below:

$$Log\ N = b\ LogD + a \text{ ---------------------------------- (3)} \quad \text{or}$$

$$ln\ N = b\ lnD + a \text{ ---------------------------------- (4)}$$

Where

$N = Number\ of\ tree\ per\ hectare$

$D = Diameter\ of\ tree\ of\ average\ basal\ area\ (quadratic\ mean\ diameter)$

$a, b\ are\ constants\ and\ D \geq 10cm$

The slope parameter is apparently consistent regardless of species, age and site quality (Hutch *et al.*, 2003).

**Results and Discussion**

**Preliminary data analysis**

A total of 809 trees were measured in the 14 temporary primary plots of 40m x 50m (0.2ha). Results on Table 1 indicate that dbh of trees in Oban forest reserve range from 10cm to 138 cm. The dbh distribution in the study area has more trees in the lower dbh classes than in the upper classes. This implies that the forest reserve is characterized by abundance of trees with small dbh. This trend is not unusual for the tropical rainforests. This is also consistent with the previous reports for two other tropical rainforest (Boubli *et al.*, 2004; Bobo *et al.*, 2006). The implication of this is that the forests are still undergoing regeneration and recruitment, which are vital indicators of forest health and vigour (Jimoh *et al.* (2012).

The minimum and maximum merchantable height obtained is 1.74 m and 40 m respectively while the minimum and maximum total tree heights are 4.5 m and 44 m, respectively. The mean merchantable volume per hectare estimated was 651$m^3$ while total stem volumes per hectare was 797$m^3$, respectively. The average basal area/ha estimated was 34.67 $m^2$, which is higher than the 15 $m^2$ reported by Alder and Abayomi, (1994) for a well-stocked tropical rainforest in Nigeria. This is to be expected since the study area is under protection by law, with minimal human use pressure and also the high annual precipitation rate and tropical climate of the study area may have contributed to high tree growth rates and high tree basal area of the forest.

Table 1. Summary of stand variables for Oban Forest Reserve

| Variable | Mean | Standard error | Maximum | Minimum |
|---|---|---|---|---|
| Dbh (cm) | 33.70 | 0.007 | 138 | 10 |
| Merchantable height (m) | 16.94 | 0.265 | 40 | 1.74 |
| Total height (m) | 21.65 | 0.254 | 44 | 4.5 |
| Basal area ($m^2$) | 34.67 | 0.0051 | 49.35 | 21.73 |
| Merchantable Vol/ha($m^3$/ha) | 651 | 0.145 | 1144 | 331 |
| Total Vol/ha ($m^3$/ha) | 797 | 0.172 | 446 | 1394 |

Source: Field Work, Aigbe *et al*, 2013.

**Model development**

The two regression equations developed for the study area are presented in equations 5 and 6.

$$Log\ N = -0.1346\ LogD + 2.6708 \text{ ----------- (5)}$$

$$Standard\ error = 0.057106$$

$$ln\ N = -0.1346\ lnD + 6.1497 \text{ -------------- (6)}$$

$$Standard\ error = 0.131491$$

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Equations 5 and 6 indicate that the stand density model is a downward sloping (negative) linear (straight line) relationship. The slope parameter ($\beta$) is used to define the limits of maximum stand stocking which is termed the reference curve. Most stand density model has been developed for western and southern coniferous species plantations or even-aged stands in North America (Newton, 1997). Few studies have been conducted for deciduous or mixed forests. Some examples include maximum size-density relationships for mixed-hardwood forest stands in New England (Solomon and Zhang, 1998) and stand density model for mixed upland hardwoods in the central United States (Kershaw and Fischer, 199l).

The two equations developed in this study produced similar value of slope parameter, which is an indication of similar stand density index. A stocking chart as shown in Table 2 was developed from the equations. The chart displayed stand density index from various diameter sizes. From equations 5 and 6, each diameter size (D) which has a relationship with number of tree per hectare (N) is the average diameter of the stand. An under stocked stand can be overstocked stand for another manager depending on the purpose of establishing the stand. In solving this problem, since the model was developed from a fully stocked stand, the equation can be used to compute the maximum stand density ($N_{max}$) and the relative density index (Drew and Flewelling 1979) calculated by $N/N_{max}$ where $N$ is the current stand density. The relative density (RD) with RD > 0.7 can be termed maximum size density. This threshold, according to Solomon and Zhang (1998), was chosen because any stands with the relative density index of 0.7 or higher should have been undergoing the self-thinning process and experiencing density-related mortality. As presented in Table 2, the stand density index range from 241 to 344 for mean stand diameter range of 10 cm – 140 cm. The stand density management diagram is presented in figure 2. The diagram serves as a management tool to guiding forest manager to determine the relative density of stand. If the density is close to or higher than a density specified by the management, then a thinning to reduce density is indicated. The stand density management diagram combined the relationship between the mean stand diameter and average tree per hectare in yielding a given density so that thinning guides can also consider the effect of tree size in thinning strategy.

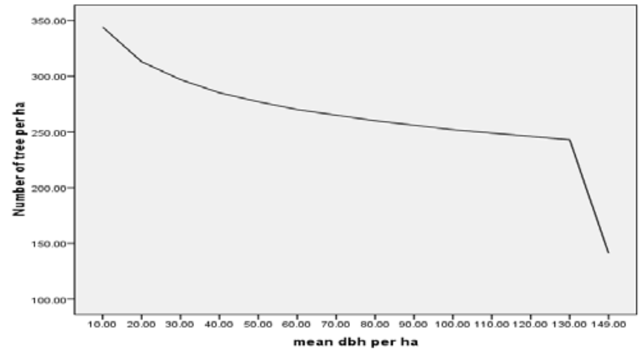


Figure 2: Stand density management diagram

Table 2. Maximum stock chart for Oban Forest Reserve

| Average Diameter(cm)/hectare | Number of tree /hectare |
|---|---|
| 10 | 344 |
| 20 | 313 |
| 30 | 297 |
| 40 | 285 |
| 50 | 277 |
| 60 | 270 |
| 70 | 265 |
| 80 | 260 |
| 90 | 256 |
| 100 | 252 |
| 110 | 249 |
| 120 | 246 |
| 130 | 243 |
| 140 | 241 |

**Conclusion**

Evidently, the Oban Forest Reserve is well stock when compare to report of Alder and Abayomi, (1994) that for a well-stocked tropical rainforest in Nigeria, the mean basal area is 15m$^2$. The stand density management diagram developed is for thinning regime and to maximize volume growth. The predicted stocking chart for Oban Forest Reserve range from 249 to 344 trees per hectare considering minimum and maximum diameter of 10 cm and 110 cm respectively. Although, the term tree maximum size density for a forest reserve can only be defined by the management of the forest reserve, which is dependent on the objective of establishing the forest reserve. Developing stand density model is essential for proper forest management planning. It is a necessary tool for forest management density regime that helps to characterize growth, density and mortality at various stages and stand development.

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Forest manager can use the model to maximize wood yield and to create favourable ecological condition for vegetation.

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