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APPLICATION OF DEVELOPED CROWN-BOLE DIAMETER MODEL TO STAND DENSITY AND STOCK CONTROL ON OPEN GROWN TREES OF *PROSOPIS AFRICANA (GUILL & PERR) TAUB*

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Abstract

At present, there is no work on the applications of developed model to stand density and stock control on natural stands of P. africana trees in University of Agriculture Makurdi in Nigeria. The species numbers are threatened, because farmers and foresters do not actively raise the tree species as plantation. Livestock, fire, and anthropogenic are few factors that limit the success of natural regeneration and is facing regeneration problem. This have led to the species declining in the natural forest areas and the loss of biological values (genetic hereditary). Eighteen temporary sample plots sizes 50 x 50 meters were randomly laid. Simple random sampling design was adopted to collect data (tree diameter at breast height (dbh)) on each of the sample plots. Dbh was used to estimate crown diameter using a developed simple linear crown-bole diameter model. Based on the data collected in the study area, P. africana trees had bole diameters which ranged from 16.7 to 8.77 (cm); most of the trees (42%) had dbh size between 10 to 20.99 cm. Nine percent (9%) of the trees had dbh size between 41 cm and above. Crown diameter distribution ranged between 2.00 to 9.40 m; and most of the trees (53%) had crown diameter sizes between 2 to 5.04 m. As stem and crown diameters increases, silvicultural practices such as thinning can be applied to create more spacing until merchantable timber size is achieved. This study would serve as a guide for stand density and stocking control in natural stands for sustainable forest management.

Keywords: Forest, Growth space, Model, Natural stand, Density, Stocking.

Introduction

Crown width (diameter) and bole diameter at breast height are important tree characteristics where many of the forestry activities and processes were related with it. Any attempt that can improve the accuracy of measuring, predicting and analyzing these variables should be taken into consideration (Elmugheira and Elmamoun, 2014). The close relationship between crown diameter and bole diameter is very important to foresters for predicting growth space, estimating and controlling stand density in a forest plantation and reserves. The growth of a tree depends to a large extent on the tree crown characteristics. Tree crown condition (healthy or unhealthy) can determine tree growth and survival; which is important in merchandizing of the tree into various wood products (Vange et al., 2018).

Crown diameter is used to predict tree growth space and competition within stand, especially where early competition signs are not available to predict resilient from competition when a competitor is removed. Also, crown diameter is used to calculate competition indices based on crown overlap and predicting above ground biomass (Elmugheira and Elmamoun, 2014). For sustainable forest management, this requires precise, accurate, timely and complete forest assessment for information.

Bole diameter at breast height is an important tree characteristic and a more easily measured tree variable; often used as a substitute for a tree's crown diameter. Tree crown diameter is well correlated with a tree's diameter. The crown diameter and bole diameter relationship is useful for estimating crown competition index, stand density and stocking relationships, tree growth and growth space (Cole and Lorimer, 1994; Goelz, 1996).

At present, there has been no adequate information on the application of crown-bole diameter model to stand density and stock control for P. africana open grown trees (natural stand) for sustainable forest management in the study area. The population of the species is threatened as natural resources are depleted and people are suffering from their poor economic situation. Currently, farmers do not actively plant P. africana trees;

therefore, regeneration must be carried out by natural means. Livestock, fire, and humans are some factors that limit the success of natural regeneration. The continuous removal of this tree species could affect the rural dwellers directly or indirectly because of the species importance use for carving and crafting purpose among others (Vange et al., 2018).

Prosopis africana is a pod bearing tree consisting of 44 reported species which are found in arid and semi arid regions of the world (Agboola , 2004). It is the only known species of its genus found in Africa; the species occurring from Senegal to Ethiopia in the zone between the Sahel and savanna forests. The tree plant belongs to the family Fabaceae, sub-family Mimosoideae. The common names include, Iron wood, Ubwa (Ibo), Kiriya (Hausa), Okpehe (Idoma) and Gbaaye (Tiv). Almost all parts of the tree are used for medicinal and economic purposes by rural communities; the bark is used as diuretic and for in the treatment of gonorrhoea, tooth and stomach-ache, dysentery and bronchitis (Abah et al., 2015). It is therefore considered.

Prosopis. africana is a particularly vulnerable species because all parts of the tree are used by rural communities (Laouali et al., 2016). Its wood is dense and highly resistant to fire, it is good for poles, planks, mortars and pestles making. The wood has a high calorific value (Sotelo and Weber, 2009; Sotelo et al., 2011). The tree species is highly valued for charcoal by blacksmiths. In many areas, the fermented seeds are used as a food condiment especially in Northern and the Middle Belt, the seeds are boiled and made into daddawa (Hausa) okpehe (Idoma), Gbaaye (Tiv), a product used for flavouring local dishes (Abah et al., 2015). The leaves and bark are combined to treat rheumatism; remedies for skin diseases and fevers. In Nigeria, the juice from its stem bark is applied on open wounds as an astringent and to cleanse the wound surface. In Mali, the leaves, bark, twigs and roots are used to treat and relieve bronchitis, dermatitis, tooth decay, dysentery, malaria and stomach cramps (Abah et al., 2015).

This study aimed at applying developed crown-bole diameter model for P. africana (guill & perr) taub to density and stocking control in natural stand of P. africana in University of Agriculture Makurdi, Nigeria for sustainable forest management.

Materials and Methods

The Study Area

The study was carried out in University of Agriculture Makurdi (UAM) (Figure 1), Benue state in Nigeria. UAM lies between Longitude 8° 21 and 9° E and Latitude 7° 21' and 8° N in Benue State, Southern Guinea Savanna ecological zone. The climate of the area is tropical sub-humid climate with high temperatures and high humidity. The average maximum and minimum daily temperature of 35 ºC and 21 ºC in wet season; as well as 37 ºC and 16 ºC in dry season (Vange et al., 2018). The climate is characterized by distinct seasons: rainy and dry seasons. The mean annual rainfall is between 1200mm to 1500mm. The vegetation of the area has been described as Southern Guinea Savanna. The major occupations of the people include: farming, civil service, trading and hunting; the major tribes are: Tiv, Idoma and Igede.

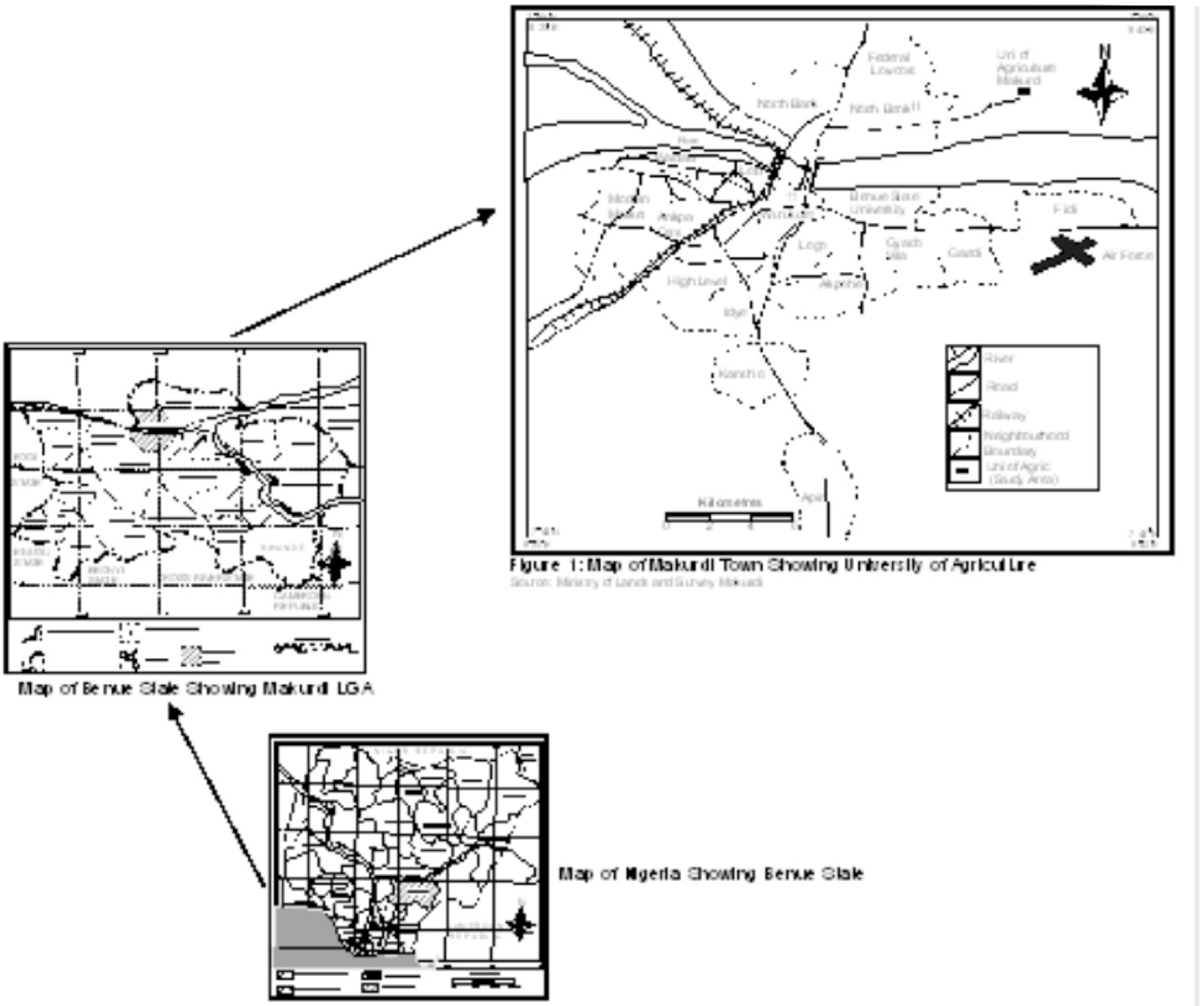

Figure 1: Map of Makurdi Town indicating University of Agriculture (the Study Area)
Source: Ministry of Lands and Survey Makurdi, (2015)

Data Collection

The tree species was selected based on its economic importance to communities in developing countries. Data from P. africana (Iron tree) trees were collected from eighteen temporary sample plots (size 50 m x 50m) each were randomly laid in an interval of 200 m apart within the study area which covered about 91,600 m2. P. africana trees with diameter at breast height (dbh) $\geqslant$ 10 cm were completely enumerated within the study area due to scanty population of the selected tree species (P. africana). The data collected from P. africana trees was diameter at breast height (dbh). Diameter of the sampled trees was determined with the use of girth diameter tape.

Data Analyses

i. Basal area estimation

The diameter at breast height (dbh) was used to compute basal area using the formula:

$$B.A/ha = \frac{\pi D^2}{4} x10{,}000 \qquad \text{Equation} \qquad [1]$$

Where: BA = Basal area ; D = Diameter at breast height (m) and π

ii. Crown -diameter

$$Cd = 0.873+0.174dbh \qquad \text{Equation} \qquad [2]$$

Where: Cd = crown diameter; dbh = diameter at breast height

iii. Limiting stock/ Carrying capacity

The carrying capacity was calculated using the estimated crown diameter and expressed in hectare basis (conversion of crown diameter in meters to area in hectares):

$$N= \frac{1}{A} \qquad \text{Equation} \qquad [3]$$

Where: N = Limiting stock; A= growing space $(\frac{\pi cd^2}{4})/10{,}000$; =π3.142; Cd = crown diameter

Results

The result of this finding on bole diameter for P. africanatree is shown on Figure 2. The result showed the status of the tree species in the study area. P. africana had bole diameters which ranged from 16.7 to– 8.77 (cm). Forty two percent (42%) trees had dbh between 10 to 20.99 cm, followed by 34% of the trees with dbh between 21 to 30.99 cm and 15% trees were recorded under the dbh class of 31 to 40.99 cm while 9% of the trees had dbh of 41 cm and above.

The crown diameter was predicted using the developed linear crown-diameter model by Dau and Chenge (2016). Based on the result from the study area, P. africana trees had crown diameter distribution between 2.00 to 9.40 m. Most of the trees (53%) had crown diameter between 2 to 5.04 m, followed by 31% of the trees which had 5.1 to 7.04 m crown diameter sizes while 12% and 4% of the trees had crown diameter distributions of 7.1 to 9.04 m and 9.1 m and above, respectively (Figure 3).

Table 1 is the summary of statistics (i.e. the mean, standard deviation, co-efficient of variation, minimum and maximum of growth variables) of P. africana trees in the study area. The coefficient of variation for Dbh, crown diameter and B.A were 25.3%, 21.8% and 51.1%, respectively. The mean diameter at breast height was obtained as 30.6 cm, crown diameter 6.20m with a basal area of 0.0790 m3. The minimum and maximum dbh recorded in the study area were 16.7 cm and 48.77 cm, crown diameter had a minimum and maximum crown size of 3.78 m and 9.36 m, respectively while B.A had 0.0219 m3and 0.01868m3 as the minimum and maximum, respectively.

The density and limiting stocking per hectare were estimated using simple linear model for P. africana; the results are shown in Table 2. This finding estimated limiting stocking per hectare (N ha-1) require for producing a complete canopy (i.e. to fully occupy a site) without effect of competition over a period of time. Table 2 shows that open grown trees of P. africana with diameter 20.4 cm would require a growing space of 0.0015ha without crown overlapping another with stocking of 652 trees per hectare in terms of total occupancy by tree crowns.

The results showed that the crown diameter ratio diameter at breast height (crown diameter ratio diameter at breast height) was more elastic between 18.8 and 20.4 cm; but gradually decreased as the diameter size increased (Table 2). The results on ratio showed that for 4.14 m of crown diameter in Prosopis africana, 18.80 cm of bole diameter was accumulated; while for 4.42 m of crown diameter, 20.4cm of bole diameter was added to P. africana tree stands, which was the highest efficient accumulated without serious crown interference or competition.

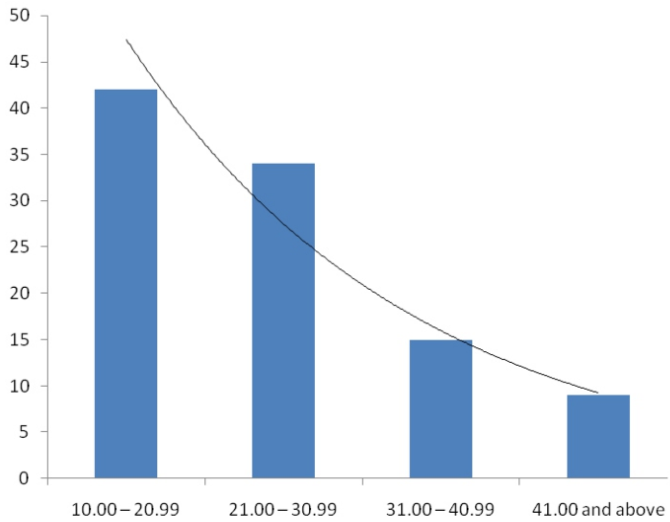

Figure 2: Bole-diameter Distributions on *Prosopis africana* Treeinthe Study Area

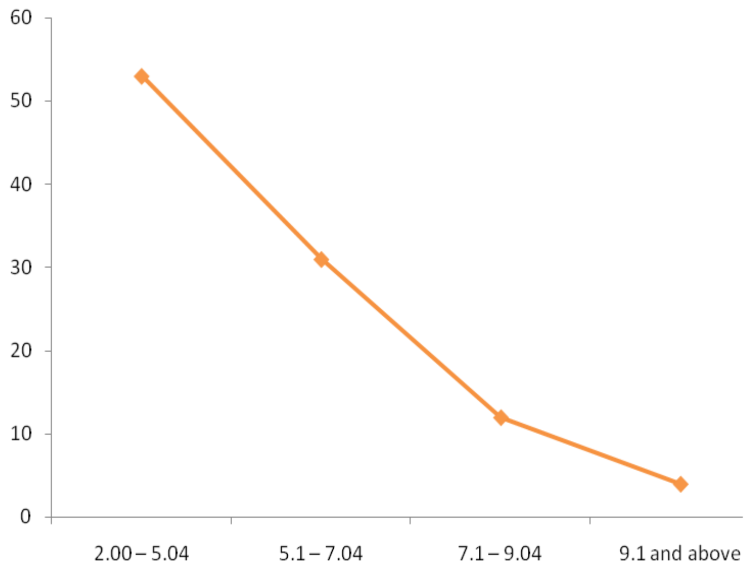

Figure 3: Crown-diameter Distribution on *P. africana* Tree in the Study Area

Table 1: Summary of Statistics for *Prosopis africana* in the Study Area

Variables	Mean	S. Dev.	C. V%	Min.	Max.
DBH (cm)	30.6	7.74	25.3	16.70	48.77
CD (m)	6.20	1.35	21.8	3.78	9.36
B.A (m^3)	0.0790	0.0404	51.1	0.0219	0.1868

DBH = Diameter at breast height (cm), CD = Crown diameter (m), B.A = Basal area (m^2), C.V =coefficient of variation.

Table 2: Estimated crown diameter (cd), Stocking (N) and Stand density (D) for *Prosopis africana* in the Study Area

Dbh (cm)	Cd (m)	Cd/dbh	Stocking/ha^{-1} (1/A)	Stand density (m^{2}ha^{-1})
18.80	4.14	0.220	743	0.00000278
19.80	4.32	0.218	682	0.00000308
20.40	4.42	0.217	652	0.00000327
24.90	5.21	0.209	469	0.00000487
25.50	5.31	0.208	452	0.00000511
27.10	5.59	0.206	407	0.00000577
28.40	5.81	0.205	377	0.00000633
29.10	5.94	0.204	361	0.00000665
30.80	6.23	0.202	328	0.00000745
32.20	6.48	0.201	303	0.00000814
33.40	6.68	0.200	285	0.00000876
36.30	7.19	0.198	246	0.00001035
37.30	7.36	0.197	235	0.00001093
39.50	7.75	0.196	212	0.00001225
41.70	8.13	0.195	193	0.00001366
44.30	8.58	0.194	173	0.00001541
45.80	8.84	0.193	163	0.00001647
48.77	9.36	0.192	145	0.00001868

Where: dbh=diameter at breast height, Cd=crown diameter.

Discussion

The results of this finding on dbh class distribution (Figure 2) revealed that there was more (76 %) concentration of trees with stem diameter at the lower diameter class (10 to 30.99 cm) than at the upper diameter (31 cm and above) class distribution which had 24% of the trees. This could be link to the rate of indiscriminate felling of the tree species in the study area. This implied that as the P. africana trees grow and increase in stem diameter, they were being harvested by communities for charcoal production, crafting/carving, timber, condiment and fodder.

The results of crown diameter distribution can be used as an important visual indicator for tree species health status (either healthy or unhealthy) in the study area. Tree's crown is a major part of tree that can trap light for food production. Trees with full and healthy crowns are generally associated with higher growth rate as a result of an increased rate of photosynthesis. When crowns become unhealthy, the rate of photosynthesis is reduced.

If relationships between crown diameter and bole diameter are known, basal area (B.A), stand density and limiting stocking of tree species in the forest estates can be estimated (Dau et al., 2016; Vange et al., 2018). Tree's dbh is often used as a substitute for tree crown diameters; and tree crown diameter can equally be used as the substitute for dbh (Lockhart et al., 2005). A crown diameter and bole diameter relationship is useful for assessing crown competition factor, stand density, stocking relationship and tree growth (Goelz, 1996).

The crown stem diameter ratio is a measure of the efficiency of a tree to accumulate diameter at breast height per unit of crown area. The higher the ratio, the more efficient a tree species is at accumulating dbh (Brian et al., 2005). The highest bole diameter accumulated without serious competition was sizeable tree with a bole diameter of 20.40 cm, which can only be used as fencing pole and utility pole but not sizeable enough to be used for timber and charcoal productions (Table 2). Prosopis africana trees with dbh of 48.77 cm and crown diameter of 9.36 m would face a serious competition. This implies that P. africana tree stands in the study area would accumulate bole diameter (wood fibre) at slower rate with increasing crown diameter and stand density while the trees stocking was decreasing. It was crystal clear from the Table 2 that higher dbh and Cd mean fewer trees/ha. The density and stocking of P. africana in a plantation can be controlled if the plantation is established for timber production. This is to avoid serious competition and unhealthy crown and slow growth rate of the tree species.

At any given age, there is a lower limit of stand density below which no further increase in diameter growth will result from continued density reduction. At density levels below this lower limit, the trees are growing free of inter-tree competition and usually referred to as open-grown-trees. Other vegetation present on the site may also affect diameter growth even though tree density is below this competition limit. This finding is in line with Jerome et al (1983), which reported that spacing experiments have consistently increases the breast height diameter (dbh) growth with decreasing stand density. Inter-tree competition affects diameter growth at low stand densities, particularly in the case of fast-growing, shade-intolerant species; as a result, very low densities are required to produce maximum diameter growth throughout the life of an even-aged stand.

Tree stands with optimum stocking in time, have larger average stem and crown diameter than similar stands with over stocking (closer spacing). Thus, P. africana tree would require optimum stocking for fast and healthy growth. This result is in agreement with the general belief that low densities are required to produce maximum bole diameter growth throughout the life of an even-age stand (Clutter et al., 1983). Thus, adequate spacing can significantly increase gross volume and growth yield while severe overcrowding of tree stands could greatly restrict root and crown development especially in the absence of thinning. The control of high density at stand establishment by silvicultural practices such as thinning is therefore an important aspect of forest management that can enhance fast growth, high production and yield for sustainable forest management. The rationale for optimum planting during the establishment and sustainable management of tree species (P. africana) should be generally based on fast growth, economic considerations, reduction of mortality and increased total production per unit area in a given period of time.

Conclusion

Stem diameter is the strongest variable as predictor of crown diameter in the study area. Developed crown-diameter model was used to estimate crown diameter, stand density and limiting stock for P. africana for sustainable management of the tree species. As stem and crown diameters increases, silvicultural practices such as thinning can be applied to create more spacing until merchantable timber size is achieved. Linear crown-bole diameter models could simply be used in forest inventory operations for determining the forest stock with less cost and time consuming. This study would serve as a guide for stand density and stocking control in natural stands for sustainable forest management.

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