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Crown-Diameter Model for Madrid Tree (*Pterocapus erinacieus* Poir) in Okpokwu Area of Benue State, Nigeria

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ABSTRACT

Among the current most exploited and threatened species in Western Africa, *P. erinaceus* is an endemic and multipurpose species. Owing to its economic, social, and high cultural potential, the species is subjected to high pressures causing an important regression of its stands. There is a lack of emphasis on the effective management of open-growth tree species in most African nations; these have slow sustainability of economic tree species in most areas, especially in Nigeria. Also, this had led to a decline in the natural forest areas while this economic tree population is gradually becoming extinct. Crown-bole diameter relationship helps to predict growth space requirements for optimum planting and estimation of stand density or stocking for establishing plantations and sustainable management of economic tree species. This study aims to determine the natural spacing among *P. erinaceus* in Okpoga, area of Benue State, Nigeria. The data collected on every standing tree includes crown diameter (using a 30-meter measuring tape) and diameter at breast height (Dbh) using diameter tape. The data collected from the field were fitted to different modified models and the best-fitted model was used to predict crown diameter from stem diameter at breast height. The results of this study show that *P. erinaceaus* would require low densities for optimum planting, fast growth, and high yield for the purpose of timber and high densities for non-timber forest products in the study area; because low densities are required to produce maximum diameter growth throughout the life cycle of trees stand which is applicable to this tree species. For the maximum volume of timber, thinning should be administered at canopy closure; this is to create more spacing for continued growth until the trees only react minimally to thinning. The recommended planting spacing would enhance optimum planting, fast growth, high yield/production, and control competition within each tree species. This study showed that upper diameter class distributions were being over-exploited, without replanting or regeneration in the area. Therefore, model 4 is recommended for crown diameter prediction of *P. erinaceaus* in the study area; the model should be used outside the extent of the original data (dbh 10.00cm - 49.20cm) with caution; as extrapolating to values outside this range may yield misleading results.

INTRODUCTION

Pterocarpus erinaceus Poir. (Fabaceae), also called V`ene or West African rosewood, is a multipurpose endemic forest species of Sahelo-Sudanian and Sudano-Guinean savannas and forests of West Africa. In English, the plant is called Gambia gum, African kino, Senegal rosewood, African rosewood, African teak, molompi wood tree, kino tree and African gum. The trade names of the plant include lancewood, African teak, African rosewood, Senegal rosewood and cornwood.

Among the current most exploited and threatened species in Western Africa, P. erinaceus is an endemic and multipurpose species of Guineo-Sudanian and Sudano-Sahelian zones. In Togo, stands of P. erinaceus are present in the five ecological zones (Segla et al., 2015). Exploitation is mainly focused on its wood with technological qualities that are much appreciated. It is one of the best wood species of the sub region (Adjonou, et al., 2010), chiefly used for commercialization purposes and construction, cabinet making, and heating and for arts. Its different parts are used in the treatment of some diseases, as animals' fodder and for dyeing (Seglaet al., 2015). Owing to its economic, social, and high cultural potential, the species is subjected to high pressures causing an important regression of its stands (Segla et al., 2015).

During the last decades, deforestation constitutes the most disturbing second environmental problem after climate change for developing countries (Damett and Delacote 2011).There is generally lack of emphasis on effective management of natural forest in Nigeria. These have led to decline in the natural forest areas while some economic trees are gradually becoming extinct. Human activities such as deforestation, agriculture, overgrazing and bush fires, coupled with the adverse effects of climate change, are also contributing to the loss of many important native plant species (Assogbadjo et al., 2010) among which the most heavily traded tropical hardwood currently in the world, Pterocarpus erinaceus is now considered endangered (Dumenu, 2019; IUCN, 2018). Also Studies on growth space requirements for Pterocarpus erinaceus are generally lacking and inventory information on the plant is scarce especially in North Central Nigeria. Natural stands of the plant are under constant pressure and heavily exploited for timber, animal feeding and others uses.

Diameter at breast height and crown width are important tree characteristics where many of the forestry activities and process are related with it, therefore any attempt that can improve the accuracy of measuring, predicting and analyzing these variables should be given utmost importance (Elmugheiran and Elmamoum, 2014). The crowns of trees have been subjected to much less study than their stems, primarily due to their lower marketable value. However, crown size being closely related to the photosynthetic capacity of a tree, is an important variable in studies of the growth of individual trees (Helms, 1998). It is also very relevant in studies of the growth of stands due to the close correlation between crown size and stem diameter, and the 'packing' or density of trees in a stand (Amonum and Japheth, 2019).

The strong correlation between crown and bole diameter is particularly useful for predicting and estimating growth space, stand density and limiting stocking relationship (Goelz, 1996; Kigomo, 1998; Hemeryet al, 2005). It is also very relevant in studies of the growth of stands and the packing or density of tree stand (Hemery and Pryor, 2005). The growth of a tree mostly is determined by the tree crown characteristics, tree crown size can determine tree growth and survival; tree height and crown dimension determine length of its clear bole which is important in merchandizing of the tree into various wood products (Dau and Chenge, 2016).

This study aims to determine the natural spacing among Pterocarpus erinaceus in Okpoga, Okpokwu Local Government Area of Benue State. This study highlight the importance of promoting the development of innovative silvicultural strategies for the extension and modeling of natural stands of P. erinaceus in order to meet sustainably the timber needs of the West African region. Also, it helps to strengthening the roles of natural forests in providing ecosystem services and mitigating climate change effects. The study provided the needed data that are largely lacking at the moment for the documentation and improvement of the natural spacing among the plant species especially in Okpoga area of Benue State.

METHODOLOGY

Study area

Okpokwu is a Local Government Area in Benue State, Nigeria. Its headquarters is in the town of Okpoga located in the south of the area. Okpokwu has an area of 731 km2 and a population of 176,647 at the 2006 census and the postal code of the area is 973 (Wikipedia 2021). In Okpoga, the wet season is warm, oppressive, and overcast and the dry season is hot, muggy, and partly cloudy. Over the course of the year, the temperature typically varies from 17.2 °C to 32.2 °C and is rarely below 13.3°C or above 34.4 °C.The rainy period of the year lasts for 9.2 months, from February 20 to November 25, with a sliding 31-day rainfall of at least 0.5 inches. The most rain falls during the 31 days centered on September 5, with an average total accumulation of 8.1 inches.

The vegetation of the local government is that of a transition between the deciduous rain forest of Eastern Nigeria on the Southern part of the local government, and the grassland Savannah towards the North. Some common grass species found in the area include: Bahama grass (*Cynodam dactylon*), Wild sunflower (*Aspilia africana*), Elephant grass (*Pennisetum purpureum*), Carpet grass (*Axonopus compressus*), African Club Moss, African feather grass, African Olive etc. Some common tree species in the area include *Isoberlinia doka*, *I. tomentosa*, locust bean tree (*Parkia biglobosa*), *P erinaceus* etc. The area within 2 miles of Okpoga is covered by shrubs (59%) and cropland (36%), within 10 miles by shrubs (57%) and cropland (29%), and within 50 miles by shrubs (48%) and cropland (31%). The soil texture in the study area is loamy black and clay in some areas.

Data Collection and Analysis

Pterocarpus erinaceus was selected based on its economic value to the Okpoga community. Data from P. erinaceus were collected in Okpoga, Nigeria. A preliminary survey was carried out during which areas populated with the species were identified.

Enumerations of tree species in the study area was carried out and the measurements of the parameters of interest were taken trees with diameter less than 10cm were discarded because they were saplings and will not be good for the modeling exercise while trees with a diameter of 10cm and above were measured and the data which were useful to this study were recorded. The data collected on every tree species includes crown diameter by using a 30-meter measuring tape; DBH, diameter at the base, diameter at the middle, and diameter at the top.

Measurement of tree Parameters

Diameter of the sampled trees was determined with the use of diameter tape on winding the tape around the tree at 1.3 meters above the ground while total height was measured by the use of Haga altimeter.

Crown-diameter measurement was based on the assumption that the vertical projection of a tree crown is circular; four radii were measured (using 30-metre measuring tape) and in the direction forming equal angles (Foli et al., 2003; Zuhaidi, 2009). Along each radius of the tree crown, the diameter tape was held horizontally and extended until each person was vertically under the tip of the longest branch on both sides; a 3.00 - meters ranging pole was used to align vertically to the edge of the crown (Kigomo, 1991, 1998; Amonum and Japheth, 2019). The diameter tape was turned by 90 degrees and measurements were carried out repeatedly along the thinnest part of the tree crown and recorded (Foli et al., 2003).

Average crown diameter (Cd) was calculated by summing up the four radii and divided by 2, thus;

$Cd = \Sigma ri / 2$ --- (1)

Where Cd = average crown diameter; ri = projected crown radii measured on four axes.

DBH over bark was measured at 1.3 meters above the ground for all individual tree ≥ 10 cm by means of diameter tape. The points of the measurement were taken from the uphill sides of the trees and on the inside of the lean for leaning trees (Zuhaidi, 2009). For trees with deformations at 1.3m, the measurement was made at the sound point on the stem above the abnormality. During the measurement, loose bark, climbers and epiphytes were lifted above the measuring tape; this was to avoid measurement errors and reading.

Data Analyses

Model fitting

The data collected from the field were fitted to the following model forms for predicting crown diameter suggested by various authors with the aim of choosing the model form with the best fit characters.

Simple linear regression model

$Cd = b_0 + b_1\, dbh$ - - - [2] Lockhart et al. (2005)

Quadratic/power model

$Cd = b_0 + b_1\, dbh^2$ - - - [3] Foliet al. (2003)

Logarithm model

$Cd = b_0 + b_1 dbh + b_2 \ln dbh$ - - - [4] Zuhaidi (2009)

$LnCd = b_0 + b_1 \ln dbh^2$ - - - [5] Dau and Chenge, 2016

Binomial model

$LnCd = b_0 + b_2 dbh^2 + b_1 \ln dbh$ [6] Zuhaidi (2009)

Where: Cd = crown diameter; dbh = diameter at breast height; b0= intercept; b1 and b2= regression coefficient

Stand density/ basal area per hectare

S.D= D^2/40,000 - - -[7] Zuhaidi (2009).

Where: S. D = Stand density; D= diameter (dbh); = 3.142.

Model selection

The fitted models were assessed and selected with the view of determining their fitness for further use; the performance of each model in the below listed criteria were ranked and the best performed model in the overall rank was selected as the best. The assessment was based on all the following criteria.

(i) Squared multiple correlation coefficient (R^2)

This measures the degree of agreement between the regression model and the observed data. It measures the goodness of fit of the regression equation. The higher the R^2, the better the fit.
R^2=RSS÷YSS X 100; - - - (8)

RSS= regression sum of squares; YSS= total sum of squares

(ii) Root Mean Square Error (RMSE)

This is used to compare equations with the same dependent variable which do not differ. It is the overall error of the estimate. The smaller the RMSE, the more appropriate the model.
RMSS =√SSE/dfe - - -(9)
Where: SSE= error sum of squares; dfe = error degrees of freedom.

Model Ranking

Ranks were assigned to each model based on each criterion; the smaller the rank the better the performance of a model. Ranks were summed up to obtain the overall rank for each model. This highlighted the performance of each model with respect to all criteria considered.

RESULTS

Growth Trend of Madrid Tree (P. erinaceaus) Stand

The results of descriptive statistics of growth variables of Madrid tree species (*P. erinaceaus*) is shown in Table 1. The table showed that diameter at breast height had a mean value of 28.65 meters and standard deviation value of 8.10, Total height had a mean value of 13.87 meters and standard deviation value of 0.83, crown diameter had a mean value of 6.00 meters and standard deviation value of 1.40 while basal area had a mean value of 0.0696 meters and a standard deviation value of 0.0397.

The results of class distribution of Madrid tree (*P. erinaceaus*) stands from 15 -25cm had the highest frequency distribution of 65 tree stands; this was followed by the class diameter of 25.10 – 35.00cm which had a frequency value of 55 tree stands. Class range of 35.10 – 45.00cm had a frequency value of 30tree stands while diameter class greater than 45.00cm had a frequency value of 10 tree stands as shown on Figure 2.

Table 1: Descriptive Statistics of Growth Variables of Madrid Tree Species (*P. erinaceaus*) in the Study Area

Variables	**Mean**	**SE**	**S. Dev.**	**C. V %**	**Min.**	**Max.**
DBH (cm)	28.65	0.67	8.10	28.3	15.80	49.20
Total Height (m)	13.87	0.07	0.83	6.0	12.00	15.40
CD (m)	6.00	0.12	1.40	23.3	3.05	10.00
B.A (m^2)	0.0696	0.0033	0.0397	57.0	0.0196	0.1901

DBH = Diameter at breast height (cm), CD = Crown diameter (m), BA = Basal area (m^2), VOL. =Volume (m^3). Mean interval = ± standard error.

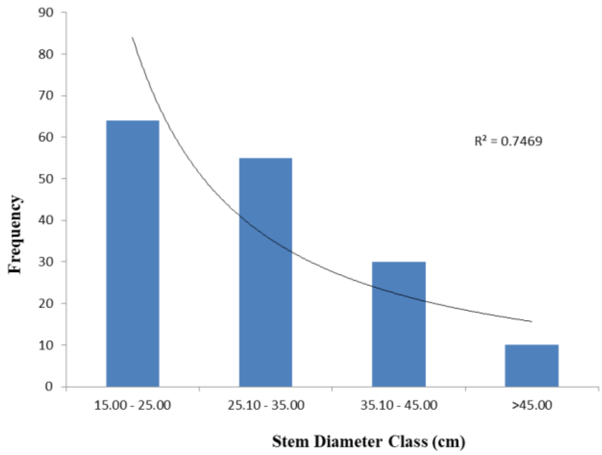

Figure 2: Dbh Class Distributions of Madrid Tree (*P. erinaceaus*) Stands in the Study Area

Crown diameter class distribution of Madrid tree species in the study area

The results of the crown diameter class distribution of Madrid tree species (*P. erinaceaus*) are shown in Figure 3. The Figure showed that the crown class distribution range of 4.2 - 6.00 m had the highest frequency value of 85; this was followed by the class range of 6.10 – 8.00 m with a frequency value of 30. A class range of greater than 8.00m had a frequency value of 25 while a class range of 3.00 – 4.1(m had a frequency value of 20 (Figure 3).

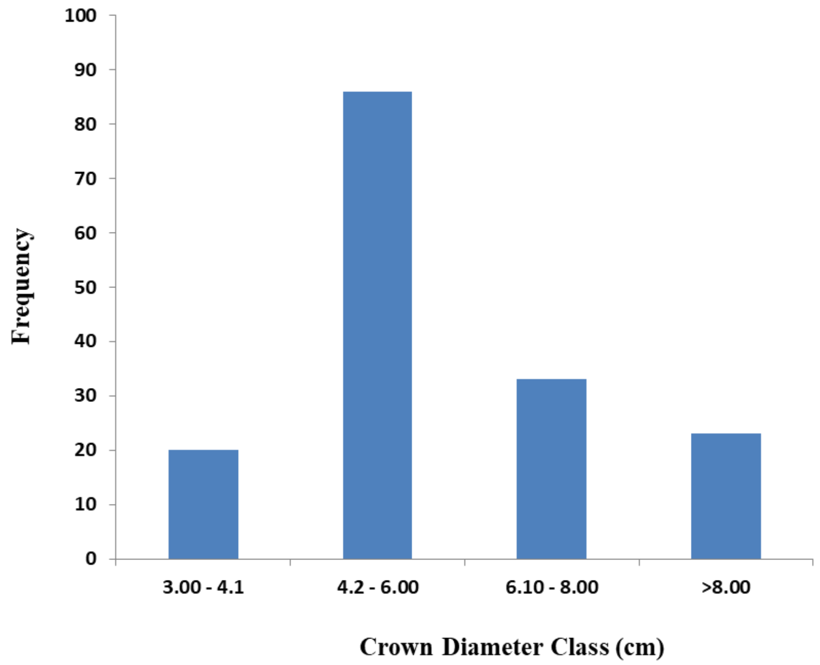

Figure 3: Crown Diameter Class Distribution of Madrid Tree Species (*P. erinaceaus*) in the Study Area

Summary of Regression Parameters for the Madrid Tree (P. erinaceaus) Stands

The results for the summary of regression parameters for the Madrid tree species are shown in Table 2. The Table showed a summary of regression analysis for the various model types and model coefficients. Models 1, 3, and 4 have the highest R2 value of 81 respectively while model 7 has the lowest R2 value of 75. Model 5 has the highest RMSE value of 0.723 while model 6 has the lowest RMSE value of 0.101 hence model 4 has the best fit (Table 2). The result for the Correlation between the Observed and Predicted Crown Diameter of Madrid Tree Species (*P. erinaceaus*) is shown in Figure 4, and the results for the predicted crown diameter and Residual Plot of Madrid Tree Species (*P. erinaceaus*) is shown in Figure 5.

Table 2: Summary of Regression Parameters for the Madrid Tree Species (*P. erinaceaus*) in Okpoga, Nigeria

Model No.	Model type and model coefficients	R (%)	R^2 (%)	Adj. R^2 (%)	RMSE	F-ratio (p<0.05)	Rank Total
[1]	Cd = 1.558+ 0.155 dbh	80	81(1)	81	0.616(4)	599.438*	5
[2]	Cd = 3.809+ 0.002dbh ^{2}	89	80 (4)	80	0.632(6)	560.873*	10
[3]	Cd = 1.973+0.126 dbh + 0.001 dbh^2	81	81(1)	81	0.617(5)	298.792*	6
[4]	Cd = 4.683+0.201dbh - 1.340lndbh	90	81(1)	81	0.615(3)	301.042*	4
[5]	Cd = -8.502 + 4.373 lndbh	88	78(6)	76	0.723(7)	495.946*	13
[6]	LnCd = -0.615+ 0.718lndbh	89	80(4)	80	0.101(1)	571.215*	5
[7]	LnCd = 0.340+ -0.007 Lndbh +0.143Lndbh ^{2}	87	76(7)	75	0.116(2)	404.58 *	9

dbh =Diameter at breast height(cm); =Coefficient of Determination; RMSE= residual mean square error; * = significant at 0.05.

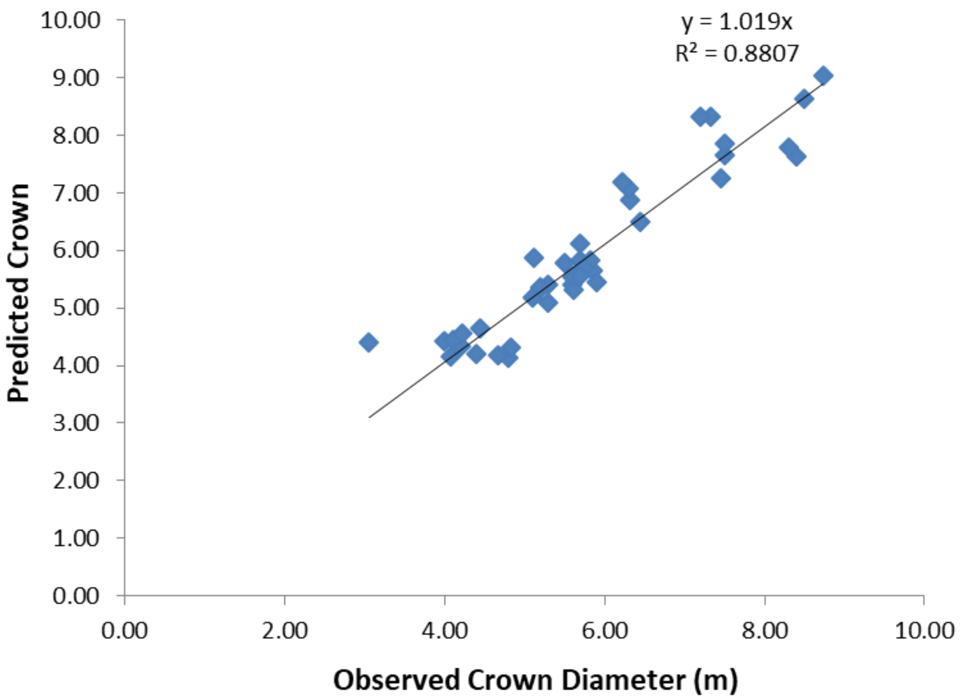

Figure 4: Correlation between Observed and Predicted Crown Diameter of Madrid Tree Species (P. erinaceaus) in Okpoga, Nigeria

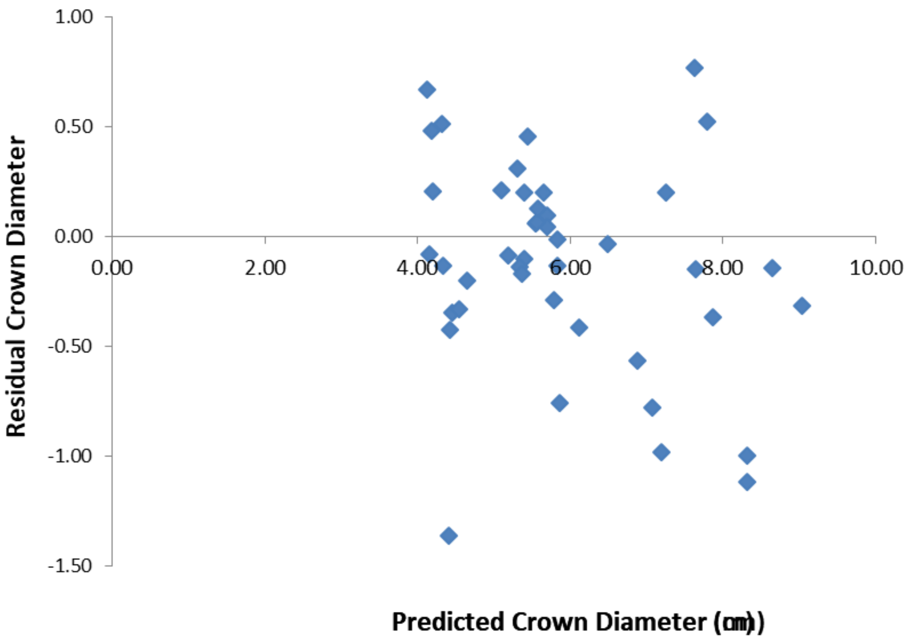

Figure 5: Residual Plot of Madrid Tree Species (*P. erinaceaus*) in Okpoga, Nigeria Models validation and assessment

The results for models validation and assessment is shown in table 4.3 the table showed a mean value of 5.78 for observed, 5.90 for predicted and -0.12 for residual. A minimum confidence interval value of 5.38 was recorded for observed, 5.49 were recorded for predicted and -0.26 was recorded for residual. A maximum confidence interval value of 6.17 was recorded for observed, 6.31 was recorded for predicted and 0.02 was recorded for residual (Table 3).

Predicted Crown Diameter (Cd), Growth Space (S), Stocking (N) and Stand Density (D) for Madrid Tree Species (P. erinaceaus) in the Study Area

The result on predicted crown diameter, growth space, stocking and stand density for Madrid tree species in the study area is shown in table 4. The value for Dbh (m) ranged between 0.158-0.492 while that of Cd (m) ranged between 4.20 - 8.80 Cd/dbh values ranged between 27.5823- 17.8862, Natural space (ha)value ranged between 0.0004 to 0.0019, Stock/ha-1 (1/S)values ranged between 2267.5737 - 516.5289 and SD (m2ha-1) values ranged between 0.0196 to 0.1901. Crown diameter = 1.558+ 0.155dbh; Natural spacing was derived using Cd2 /40, 000, stocking was obtained using 1/ natural space; while Stand Density (SD) = π D2/ 40,000.

Table 3: Models Validation and Assessment (Simple Linear model Cd = 1.558+ 0.155dbh)

Parameters	Observed(m)	Predicted(m)	Residual	% bias
Mean	5.78	5.90	-0.12	-2.59
Minimum Confidence Interval	5.38	5.49	-0.26	-5.49
Maximum Confidence Interval	6.17	6.31	0.02	0.32

Table 4: Predicted Crown Diameter (Cd), Growth Space (S), Stocking (N) and Stand Density (D) for Madrid Tree Species (*Pterocarpus erinaceaus*) in the Study Area

Dbh (m)	Cd (m)	Cd/dbh	Natural space (ha)	Stock/ha^{-1} (1/S)	SD (m^{2}ha^{-1})
0.158	4.20	26.5823	0.0004	2267.5737	0.0196
0.236	5.15	21.822	0.0007	1508.1535	0.0437
0.248	5.25	21.1694	0.0007	1451.2472	0.0483
0.251	5.30	21.1155	0.0007	1423.9943	0.0495
0.257	5.60	21.7899	0.0008	1275.5102	0.0519
0.286	6.10	21.3287	0.0009	1074.9798	0.0642
0.299	6.20	20.7358	0.0010	1040.5827	0.0702
0.314	6.52	20.7643	0.0011	940.9462	0.0774
0.343	6.71	19.5627	0.0011	888.4131	0.0924
0.368	6.85	18.6141	0.0012	852.4695	0.1064
0.396	6.98	17.6263	0.0012	821.0113	0.1232
0.392	6.92	17.6531	0.0012	835.3102	0.1207
0.402	7.20	17.9104	0.0013	771.6049	0.1269
0.404	7.21	17.8465	0.0013	769.4660	0.1282
0.412	7.30	17.7184	0.0013	750.6099	0.1333
0.413	7.35	17.7966	0.0014	740.4322	0.1340
0.457	8.45	18.4902	0.0018	560.2045	0.1640
0.483	8.59	17.7847	0.0018	542.0928	0.1832
0.492	8.80	17.8862	0.0019	516.5289	0.1901

The above table was derived using simple linear model Madrid Tree Species (*P. erinaceaus*): Cd = 1.558+ 0.155dbh; Natural space = Cd^2 π /40 000 and stocking = 1/ natural space; Stand Density (SD) = π D^2/ 40,000.

DISCUSSION

The results of this study highlight the importance of developing a model for the natural spacing of *P. erinaceaus* although the study did not consider the population of the plant species in the study area as distinct groups based on morphological characteristics despite the fact that Koura et al. (2013) showed that generally, morphological data analysis of plant species leads to the identification and determination of diverse groups in order to precise their constitution.

The results for growth variables for the plant species indicated to a large extent that P. erinaceaus has an optimal growth rate in the study area. The distribution of the plant species to a large extent was not sparse and by all indication, the plant is thriving in the study area although studies have shown that trees in protected area show better performance than those of the exploited areas of which the study is one. Furthermore, in the non-protected zones, in addition to exploitation, agriculture is one of the main activities leading to the regular clearing of lands for crop production, reducing available resources and consequently, the landscape become composed of forest fragments (Segla et al. 2016).

In all the data sets from the trees (Figures 4.1 and 4.2), there was more concentration of stem diameter at the upper diameter class (41.00 – 50.1cm) than in the lower diameter class distribution (15.00 – 40.00 cm); this may be as a result of the exploitation of the trees for socio-economic purposes by the people of Okpoga. It could also be due to poor regeneration on the part of the species. In this case, germination trials should be done in the nursery to improve the tree population. Constant farming activities in the area could also affect the regeneration of saplings; mostly saplings are always cleared alongside bushes for farming purposes. This results in the decimation of the population of younger ones.

The result of the crown diameter class can be used as an important visual indicator of tree and forest trends (healthy or unhealthy) in the study area. The tree's crown is a major part of the tree that can trap light for food production; trees with full and healthy crowns are generally associated with higher growth rates as a result of an increased rate of photosynthesis. When crowns become unhealthy, the rate of photosynthesis is reduced. These results described the current status and condition of the trees in the area, i.e. the crown conditions in the study area were healthy and free from high competition. This may be as a result of the low population (declining in population) of the tree species (open-grown trees) or the soil condition of the area. The result is in agreement with that of Dau and Chenge, (2016) who stated that crown degradation is typically the result of past and present stressors such as insects, diseases, weather events, drought, senescence, and competition or other stand conditions and when severe enough, may result in tree mortality.

Growth space requirements was determined based on the findings by Foli et al, (2003) and Dau and Chenge (2016), who stated that growth space was associated with crown size. Therefore, using the calculated crown diameter (Cd), the crown area (A) for each tree was estimated and expressed in hectare basis; to improve production, fast growth and quality of tree species in the study area, individual tree in a stand must have unrestricted continuous free-growing space; this requires knowledge of maximum occupancy [stock] of the sites with time. Thus, to control competition and ensure fast growth and high production/yields, this economic tree would require planting spacing of 4 x 4 meters in the study area; the results also provided a means of estimating the stocking per hectare (N ha-1) require for producing a complete canopy.

Seven models were tested and four criteria [Coefficient of determination (R2), Root mean square error (RMSE)/furnival index, Significance of regression (F-ratio) and Residual analysis] were used in this study. The essence is to select the best model for predicting DBH from CD. Table 4.2 showed that model 1, 3 and 4 had R2 values of 81 respectively indicating that they had the best fit as proposed by Dau et al.(2016) who stated that the higher the R2 values, the better the fit. All the values obtained in this study for F-ratio were significant at $P<0.05$. In interpreting the results, it must be pointed out that the model 4 has the best fit as the fewer the parameters, the better the fit. Model 4 (linear model) emerged the overall best and was used to predict crown diameter and stocking of P. erinaceaus in Okpoga.

CONCLUSION

Crown-bole diameter relationship helps to predict growth space requirements for optimum planting and estimation of stand density/stocking for establishing plantations and sustainable management of economic tree species. This study has shown that P. erinaceaus would require low densities for optimum planting, fast growth and high yield for the purpose of timber and high densities for non-timber forest products in the study area; because low densities are required to produce maximum diameter growth throughout the life cycle of trees stand which is applicable to the studied tree species as showed by the results obtained from the area. To maximize the use of land for timber and non-timber forest products purposes, the tree species would require growth planting spacing of 4 x 4 m (for fencing pole and electric-pole). For maximum volume of timber, thinning should be administer at canopy closure; this is to create more spacing for continue growing until the trees only react minimal to thinning. The recommended planting spacing would enhance optimum planting, fast growth, high yield/production and control competition within each tree species.

Restoration programs should be carried out within and outside the study area to ensure that the tree species does not reduce in the study area and eventually go into extinction as this study shown that, upper diameter class distribution were being over exploited, without replanting or regeneration in the area. Therefore, the study recommended model 4 for crown diameter prediction among *P. erinaceaus* in the study area, the models should be used outside the extent of the original data (dbh 10.00cm - 49.20cm) with caution; as extrapolating to values outside this range may yield misleading results.

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