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ORIGINAL SCIENTIFIC PAPER

Assessing Site Productivity Across Age-Class Structured *Pinus caribaea* Stands, Using Site Index and Growth Variables in Enugu-Ngwo, Nigeria

Procjena proizvodnosti staništa u jednodobnim sastojinama *Pinus caribaea* različitih dobnih razreda primjenom stanišnog indeksa i pokazatelja rasta u Enugu-Ngwo, Nigerija

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ABSTRACT

Assessing site productivity and growth performance is vital for effective management of plantation forests. This study evaluated growth dynamics and site index variation among three age structured *Pinus caribaea* stands (49, 50, and 51year-old) in the Enugu-Ngwo Forest Reserve, Nigeria. Data on diameter at breast height (DBH), Height and basal area were collected systematically from 20 × 20 m plots established. Site index (SI), Basal area, Dominant height, provided measures of productivity indicators. Analysis of variance showed significant differences in growth parameters among plots and stands, revealing notable spatial heterogeneity. Site Index values ranged from 0.652 in the 50year stand to 0.729 in the 49year stand, indicating meaningful productivity gradients. The 49-year-old stand exhibited superior diameter, height and basal area, a, showing the stand with highest productivity. Non uniform site quality across the reserve highlighted localized influences of environmental and historical factors. generally, *Pinus caribaea* plantations demonstrated strong productivity potential, particularly in the 1976 stand, which showed a strong height age trend. The study emphasizes the need for site specific silvicultural practices adaptive rotation planning and continuous monitoring to improve timber yield and sustain long term forest productivity.

Key words: *dominant height, Site index, basal area, Pinus caribaea, plantation productivity*

INTRODUCTION - *Uvod*

Assessment of site productivity is vital to the management of the forest, it represents the capacity of forest site to produce biomass and support tree growth, Skovsgaard and vanclay (2007). Site productivity assessment and plantation forest growth performance is essential for effective estimation of timber production potential, producing stand yield, management planning and planning silvicultural intervention. Ezenwa (976) stated that: Spatial variability in plantation site productivity arises from differences in soil properties, topography, drainage, and stand structure. To estimate site quality and growth performance in conifers Site index, Height

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and basal area remain the most reliable indicators. Understanding how these vary spatially across plantations is essential for sustainable management. This study uses age structured *Pinus caribaea* stands to quantify spatial variation in productivity in the *Pinus caribaea plantation* of Enugu Ngwo, and can also be used for same ecological zone of Nigeria. Diane (2014), Growth variables such as basal area, total height, diameter at breast height (dbh), tree volume, and crown metrics produce quantifiable measurements that shows biomass accumulation and stand development. Together, site index and growth variables enable yield prediction and forest management decisions, facilitating optimal thinning regimes, rotation lengths, and sustainable timber harvest planning. Diane, (2014).

The evaluation of site productivity commonly involves using site index and growth variables to assess the quality and potential timber yield of the site. The site index is typically defined as the dominant height of trees at a specific base age (often 10 years for *Pinus caribaea*). It serves as a key indicator of site quality by reflecting how well trees grow in terms of height on a particular site. Growth variables such as diameter, height increment, volume production, and mean annual increment complement the site index by indicating overall stand performance and productivity over time. Oyebade, 2014

Common methods used to determine site index are based on tree height, plant composition and the use of soil maps. Also it can be achieved by measuring and averaging the total height and age of the trees found on that site (Avery and Burkhart 2002). Height is obtained from dominant or codominant trees in an even aged stand usually from an instrument called Clinometers, and age is calculated from an instrument called an increment borer or from planting or harvest record (Avery, and Burkhart 2002). The estimated height model describes tree heights as a function of diameter at breast height, site index, dominant height and dominant diameter. Total tree height and diameter at breast height (1.3m above ground, DBH) outside bark are essential measurements in forest management and are used for predicting total and merchantable tree volume, estimating site index and other important variables in forest growth and yield (Zhang and Hill 2001). Since tree heights are relatively more difficult and time consuming to obtain, measurement of all sample trees for DBH and a portion of these trees for height is an exceedingly common practice with both permanent and temporary sample plots. Height diameter models are then used to estimate the heights of trees measured only for diameter. Site index is the essential tool for forest management to estimate the productivity of forest land generally. Site index equation is developed and used by relationship between stand and age and dominant tree height. However, there are limit to the use of the site index equation in the application of variable ages, environment influence and estimation of site index for unstocked land. Prediction methods of site index have been of interest to many researchers because of the limitations associated with ground-based measurement of the index, such as the destructive nature of the stem analysis. Additional limitation occurs because there is a certain age for trees below which site factors will not reflect actual condition.

Assessing site productivity in age class structured *Pinus caribaea* stands at Enugu Ngwo Forest Reserve addresses the need for localized growth models in erosion-prone areas of Nigeria. Existing research has developed site index equations for this specific location using a base age of 50 years (oyebade et al 2012), yet broader evaluations across age classes remain limited. This study provides essential data for timber production potential and silvicultural management in challenging terrains. Thus, combining site index and growth variables provides a robust framework to assess site productivity across age-class structured homogeneous stands, enhancing forest resource utilization and ecological sustainability.

METHODS OF RESEARCH – *Metode istraživanja*

Study Area

Enugu-Ngwo Forest Reserve, southeastern Nigeria, classified by well-drained upland soils suited for pine growth. Plantation establishment occurred in phases, resulting in three close age-classes (49, 50, and 51 years) Ngwo town is located in the south-eastern State of Enugu, Nigeria, with a population of about 50,000 people. Enugu Ngwo is situated on Udi escarpment, at an altitude of about 396.24m, longitude 070 271 East and latitude 060 261 North of the equator (Ainslic 1935). The annual rainfall ranges between 32 and 87 degrees centigrade while it is hottest between May and October each year. the plantation was established in 1972 with about 100 hectares size coverage and under close management by forest research institute of Nigeria (FRIN).

Sampling Technique

The sampling technique that will be used for this study is systematic sampling. This is because the plantation is homogenous. Systematic sampling design (systemic line

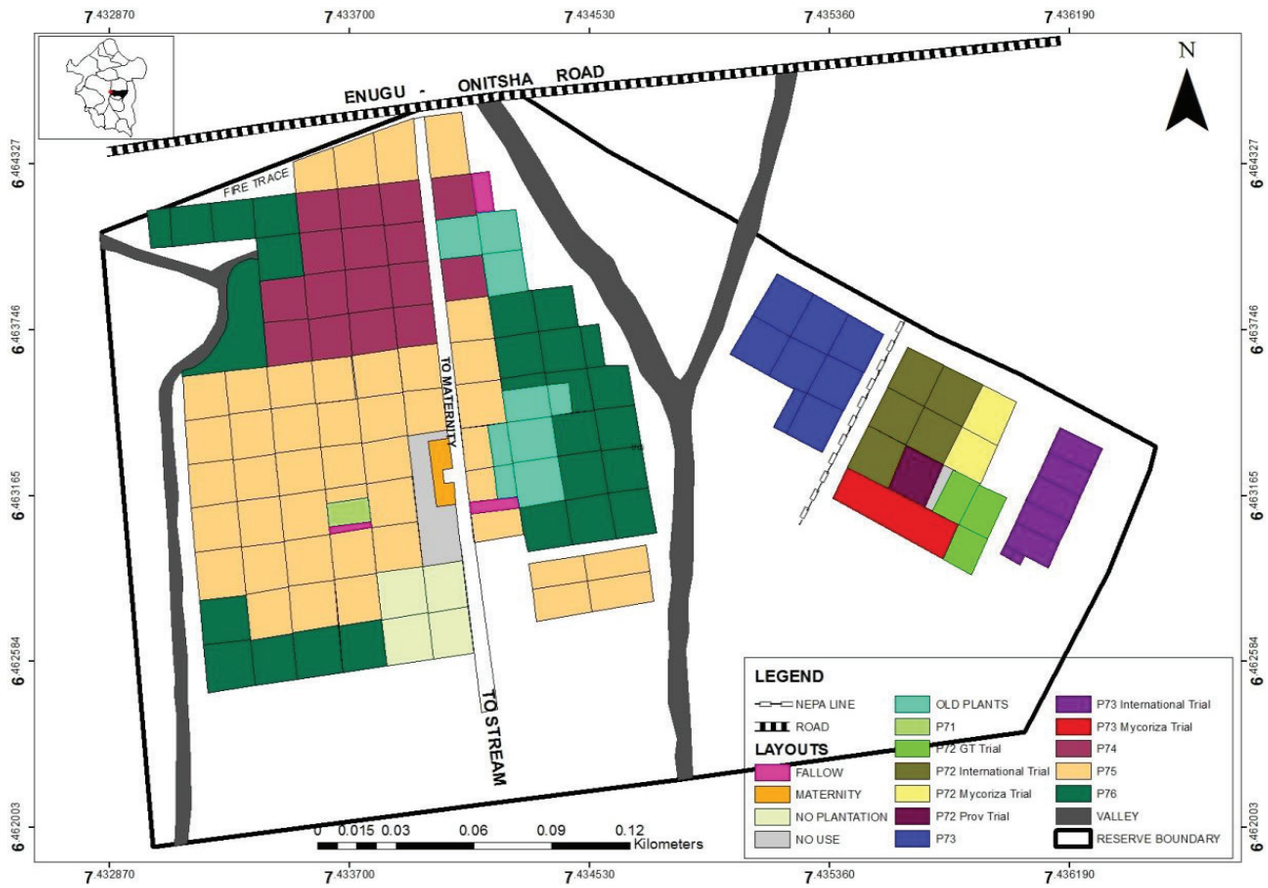


Figure 1. Map of the study area showing experimental layouts in Enugu-Ngwo, Nigeria.
Source: Authors' GIS compilation from field survey data (2024)

Slika 1. Karta područja istraživanja s prikazom rasporeda oglednih ploha u Enugu-Ngwo, Nigerija.
Izvor: GIS obrada autora na osnovu podataka terenskih istraživanja (2024).

transect) was employed for laying of plots. Three transects at 200 m intervals were laid out in Pinus caribaea stands established in 1974, 1975, and 1976. Temporary sample plots of size, 20 m x 20 m (0.04 ha) was laid indifferent direction along each transect at 5m interval and thus adding up to 4 sample plots per transect. In each plot the outside bark diameter at breast height (Dbh) (taken at 1.3m from ground), tree total height and Crown Diameter was taken. Systematic sampling is a form of probabilistic sampling in which the target is divided into equal sized blocks (for example, a series of squares covering a survey region) and a sample taken at a predetermined point in each block (example, on the grid intersection or in the middle or each square). This method is useful for sampling unevenly distributed populations but runs the risk of missing thing that is regularly spaced. The population variance can be expressed as:

$$S^2 = \frac{1}{N-1}\sum_{i=1}^{N}(Yi - \overline{y_k})^2 = \frac{1}{N-1}\sum_{k=i}^{K}(Nk-1)S_k^2 \quad (1)$$

Where ykm refers to individual number in sample number k, the variance withing samples cma be expressed as S^2 within

$$\frac{1}{N-K}\sum_{k-1}^{k}\sum_{m-1}^{NK}(\mathrm{ykm} - \overline{\mathrm{yk}})^2 = \frac{1}{N-K}\sum_{k-K}^{k}(Nk-1)\,\mathrm{S_k^2} \quad (2)$$

Where S_k^2 is the population variance in sample k, the variance between samples is expressed as S_k^2 between =

$$\frac{1}{N-K} \sum_{K-1}^{k} NK(\bar{y}_k - \bar{y})^2 \quad (3)$$

Using this variance simplification it can be shown that

$$\text{Var}((\bar{y}\ sy) = \frac{k\text{-}1}{N} S^2\ Between$$

Or

$$\text{Var}((\bar{y}\ \text{sy}) = \frac{B-1}{N} S^2 - \frac{n-1}{n}\ within \quad (4)$$

Using that $\text{Var}((\bar{y}\ sy) = \frac{n\text{-}n}{nN} S^2$, it follows that

$$\text{Var}((\bar{y}\ sy) > \text{var}\ (\bar{y}\ sy) > \frac{N\text{-}n}{nN} S^2 \quad (5)$$

Method of Data Collection

Data collection is a term used to describe process of preparing and collection data. The purpose of data collection is to obtain quantitative data for the site index equations to be developed. The data on the tree parameters that was collected are height, age, diameter at breast height (dbh) and crown diameter using recent modern measurement equipment's. Dominant trees was selected based on the combined ranks of height and dbh from all sample trees. Between one and three trees per plot and measurement occasion will be identified as dominant trees. In each plot, the outside bark diameter at breast height (Dbh) (taken at 1.3m from ground), crown diameter and tree total height all was measured.

Data Analysis

Determing the height and related growth variable of Pinus caribaea in the study Area

In other to evaluate *Pinus caribaea* growth variable, descriptive statistics was to get the mean,

standard deviation, maximum value and minimum value of the variable, Significant difference

(ANOVA) was used to determine the difference, Mean comparisons among stand ages were

performed using Duncan's Multiple Range Test (DMRT) at a 5% significance level.

Develop empirical models for Site index prediction prediction of *Pinus caribaea* in the Study area

Though several methods have been developed and applied, the method used by Akindele (1990)

was adopted in this study following its simplistic procedures of development of site index

equation for estimating the site indices of the sample plots, the computation of site index values

of the corresponding sample plots, and fitting of the linear regression model for predicting site

index from the growth characteristics variables with agreement of linearized regression function

of Schumacher (1939) for site index estimation of the order:

Hd=exp (b o+b 1(A-1) eqn.1

Where,

Hd=average dominant

height A=Stand Age

bo-b1=Regression coefficients

Taking the logarithm of the equation, the equation becomes:

lnHd=bo+b 1 A-1 eqn.2

Fitting the equation to dominant height data when A equals the index age; the average dominant height (Hd) will be equal to site index (SI). Twenty-Five

Stand Productivity Metrics

- Dominant height = stand growth potential indicator
- Basal area = stand density index
- Site Index (SI) = growth performance classification

RESULTS – *Rezultati*

Evaluation of height and related growth variable of *Pinus caribaea* in the study Area

Evaluation of Pinus caribaea growth variables such as Height, Diameter (Dbh), Crown diameter, Basal area, Crown projection area, Linear crown index and Crown spread ratio in the stands established in 1974, 1975 and

Table 1. Growth Attribute of age 51 Pinus Caribaea Stand Sampled in the Study Area

Tabela 1. Parametri rasta uzorkovane sastojine Pinus caribaea starosti 51 godinu na području istraživanja

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic ± Std. Error
Dbh	119	21.59	55.12	35.0652 ± 0.64237
THT	119	23.06	67.71	38.4046 ± 0.78790
Cd	119	0.75	10.70	5.0982 ± 0.18192
Ba	119	0.04	0.24	0.1004 ± 0.00380
Cpa	119	0.44	89.93	1.54105 ± 16.81084
Lci	119	3.11	28.63	14.4295 ± 0.44422
Csr	119	.03	0.29	0.1335 ± 0.0448

1976 (51, 50 and 49) years are presented in Table 1, 2, .3 and 4 respectively. The results of the evaluation of growth parameters in the plots of 48years old hightest means for total height, Diameter at beast height, Crown diameter, Basal area, Crown projection area, Linear crown index and Crown spread ratio and it is found in Table 1.

Where, Dbh= diameter at breast height (cm), BA= basal area (m^2), CPA= crown projection area (m^2), CD= crown diameter (m). Csr= crown spread ratio, Lci= live crown index, THT= Total height of tree

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Development of Empirical Models for Site Index Prediction of Pinus caribaea in the Study Area

The computed site indices for the Pinus caribaea stands in Enugu-Ngwo are presented in Table 4. The 1976 stand (49 years old) recorded the highest site index (0.729), followed by the 1974 stand (51 years old) with a site index of 0.692, while the 1975 stand (50 years old) had the lowest site index (0.652). Although the differences in stand age were small, the variation in site index val-

Table 2. Growth Attribute of Age 50 Pinus caribaea stand Sampled in the Study Area.

Tabela 2. Parametri rasta uzorkovane sastojine Pinus caribaea starosti 50 godina na području istraživanja

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic ± Std. Error
Dbh	120	20.83	42.67	33.7088 ± .38446
THT	120	3.36	52.77	37.2880 ± .57751
Cd	120	.75	7.70	4.2312 ± .14127
Ba	120	.03	0.14	0.0906 ± .00202
Cpa	120	.44	46.57	15.9287 ± .94915
Lci	120	3.01	36.97	12.5565 ± .44136
Csr	120	.03	1.67	0.1246 ± .01345

Table 3: Growth Attribute of Age 49 Pinus Caribaea Stand Sampled in the Study Area

Tabela 3. Parametri rasta uzorkovane sastojine Pinus caribaea starosti 49 godina na području istraživanja

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic ± Std. Error
Dbh	41	20.53	40.32	32.4353 ± 0.697
THT	41	24.83	47.97	37.1284 ± 0.838
Cd	41	0.95	7.70	4.1971 ± 0.253
Ba	41	0.03	0.13	0.0842 ± 0.003
Cpa	41	0.71	46.57	15.8419 ± 1.811
Lci	41	3.98	35.56	12.8777 ± 0.815
Csr	41	0.04	0.23	0.1113 ± 0.006

ues indicates differences in site productivity among the stands.

Site index is an indicator of site quality based on dominant height development. Higher site index values generally reflect better growing conditions and greater potential for height growth. Therefore, the 1976 stand, with a site index of 0.729, can be considered the most productive site among the three stands, suggesting that it experienced more favourable conditions for tree growth. Conversely, the lower site index of 0.652 recorded in the 1975 stand indicates comparatively lower site productivity.

The average dominant heights of 53.7 m, 45.7 m and 46.0 m recorded for the 1974, 1975 and 1976 stands, respectively, demonstrate that Pinus caribaea attained substantial height growth across the study area. The observed differences in site index may be attributed to variations in soil fertility, moisture availability, micro-topography, stand management history, and other environmental factors influencing tree growth.

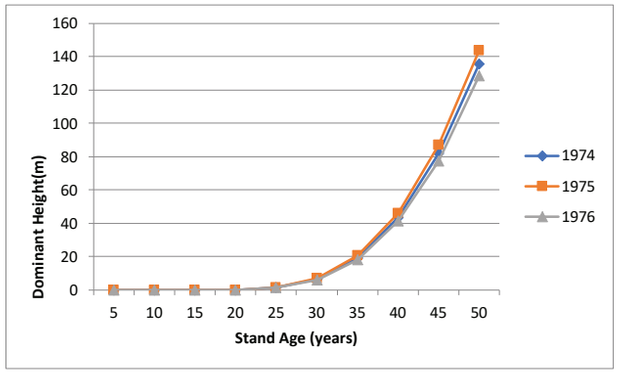


Figure 2. Site index curve for Pinus caibaea in the three-age series of the study area.

Slika 2. Kriva stanišnog indeksa za *Pinus caribaea* za tri dobne serije na području istraživanja.

Table 4: Site Index Equation, Average Dominant and Computed Site Index (SI) According to Sites in the Study Area

Tabela 4. Jednačina stanišnog indeksa, prosječna dominantna visina i izračunati stanišni indeks (SI) prema lokalitetima na području istraživanja

Site	Average dominant height	SI	Site index model	Model parameter R^2
1974	53.7	0.692		
1975	45.7	0.652	$LnHd = b0 + b1(A^{-1})$	0.486
1976	46.0	0.729		

Hd: dominant height, SI: Site index, R^2: coeffient of determination, SEE: standard error.

Table 5: Stand Structural Attributes and Site Index of Age-Class Pinus caribaea Stands in Enugu-Ngwo Forest Reserve

Tabela 5. Strukturne karakteristike sastojina i stanišni indeks sastojina Pinus caribaea različitih dobnih razreda u šumskom rezervatu Enugu-Ngwo

Stand Age	No. of Plots	Trees Measured	Trees ha^{-1}	BA(m^2 ha^{-1})	Site Index
51 years	4	119	744	74.7	0.692
50 years	4	120	750	68.0	0.652
49 years	2	41	513	43.2	0.729

DISCUSSION – *Diskusija*

Evaluation of Growth variable of *Pinus caribaea* in the Study Area

The assessment of site productivity Across age-class structured *Pinus caribaea* stands in the Enugu-Ngwo Forest Reserve, numerous height growth and computed site index showed significant disparities among three sampled sites (49, 50 and 51 years). Despite their close age difference, the observed growth performance differences confirm spatial heterogeneity in site productivity across the reserve. There were clearly defined age classes for size (both when measured height and volume) and crown development in the growth variable assessment across the three Pinus caribaea age classes. It was showed that mean diameter, height, crown diameter, basal area and The crown projection area was greater in the 51-year-old stand than in the 50- and 49-year-old stands. This pattern is not surprising, as diameter and height growth proceed through late stand maturity (though the increments may decline with age. The relative increase in crown dimensions with age also indicates continued crown expansion consistent with stand self-thinning and reduced inter-tree competition

Despite being close in age, the three stands did not converge in growth traits. The 51year stand showed wider height ranges (23.06 – 67.71 m) and crown sizes, indicating heterogeneity in site conditions, genetic variability, or differences in early stand management. The broad variation supports earlier observations that *Pinus caribaea* plantations show considerable differences in tree form and branching habit (Shigeru, 2010). The irregular crown form and fox-tailing tendency pose challenges for silvicultural interventions, especially in maintaining uniform stand structure.

Basal area values calculated from the mean DBH were 0.1004 m^2, 0.0906 m^2, and 0.0842 m^2 per tree for the 51-, 50-, and 49-year-old stands, respectively. These values indicate that trees in the 51-year-old stand had larger stem cross-sectional areas than those in the younger stands. The higher basal area per tree reflects greater stem development and biomass accumulation with stand age. However, because basal area was calculated on an individual-tree basis rather than on a per-hectare basis, it cannot be used to assess stand stocking status or site occupancy. Evaluation of stocking would require stand basal area expressed as m^2 ha^{-1} together with tree density (trees ha^{-1}).

The crown projection area (CPA) values are relatively high, especially in the older stand, indicating broad canopy spread and increased dominance of fewer surviving trees. These findings differ markedly from the lower CPA values reported by Adesoye and Ezenwenyi (2014) for similarly aged *Pinus caribaea* plantations. The larger canopies here may reflect wider initial spacing, reduced thinning intensity, or better site quality. High CPA implies greater light interception capacity, which supports continued height and diameter growth but can increase competition pressure on suppressed trees.

The live crown index (LCI) values trend slightly upward in the older stand, suggesting a healthier crown ratio and good photosynthetic efficiency. Crown spread ratio (CSR) values, although generally low, decrease with stand density, highlighting the effect of competition on lateral crown expansion.

Generally, The 51 year stand recorded the highest mean values in total height, DBH, basal area, crown diameter, and crown projection area, indicating better biomass accumulation and competitive performance on that site. This suggests that slight differences in micro-environmental conditions such as soil richness, early stand treatment, drainage, or topographic position influenced the resource availability for tree growth. Similar variations in *Pinus caribaea* due to site-specific factors were highlighted by Akindele (1991), who noted that exotic pine plantations in Nigeria respond strongly to favorable soils and climate conditions. The need for silvicultural adjustments to improve uniformity and stand stability.

Stand density ranged from 513 to 750 trees ha^{-1} across the Pinus caribaea stands. The 50-year-old stand record-

ed the highest density (750 trees ha^{-1}), followed closely by the 51-year-old stand (744 trees ha^{-1}), while the 49-year-old stand had the lowest density (513 trees ha^{-1}). Basal area per hectare was highest in the 51-year-old stand (74.7 m^2 ha^{-1}), followed by the 50-year-old stand (68.0 m^2 ha^{-1}) and the 49-year-old stand (43.2 m^2 ha^{-1}). The higher basal area observed in the older stands indicates greater stand occupancy, growing stock accumulation, and resource utilization. This suggests that the 51- and 50-year-old stands were better stocked and had higher productivity potential than the 49-year-old stand. The observed differences in basal area and stand density may also explain the variation in site index among the stands, as site quality influences tree growth, stand development, and biomass production.

Site Index Prediction of Pinus caribaea the Study Area

The site index estimation for various age-series of Pinus caribaea (1974, 1975, 1976) at Enugu Ngwo indicates marked difference in the dominant height growth performance. The highest site index (0.729) was seen at the 1976 stand suggesting its comparatively better site productivity from the other two stands. While differences in ages are small, these variations indicate that plantation site-quality can change considerably between plantations even in close proximity as a result of soil fertility gradients, microclimate variances or management history and early stand establishment conditions. This is in accordance with results from Wang et al. (2008), Waring et al. (2006) and Johansson (1995), who highlighted that both environmental and biological factors affect the height growth and following site classes.

The height growth pattern in general shown in Fig. 1 suggest that Pinus caribaea respond well to the growing conditions at Enugu Ngwo, with the best sites supporting early rapid height growth. For example, a 15year old tree on the best site can attain heights around 25 m. This confirms earlier reports by Akindele (1991), who attributed strong growth of exotic conifers in Nigeria to favorable climatic and soil conditions.

The differences in model strength among the sites also reflect site variability. The model fitted for the 1975 stand (R^2 = 0.486) indicates moderate predictive reliability and suggests that height age dynamics are not fully captured by age alone. Similar challenges were reported by Arosław et al. (2021), who demonstrated that incorporating regional or ecological variation improves site index predictions. Dynamic and polymorphic site index models developed using nonlinear regression techniques have been shown to better represent height growth across different site qualities (Mehmet & Oytun, 2015; Deschamps, 1990), implying that model refinement could further improve accuracy in this study area.

The results also support earlier work by Oyebade et al., (2012), who successfully developed a site index model for *Pinus caribaea* in the same forest reserve and concluded that the species has strong timber production potential when properly managed. Likewise, Huebschmann and Martin (1996) stressed the operational importance of site index for identifying stands with high economic value, since those with higher indices tend to reach merchantable size earlier.

Thus, the *Pinus caribaea* plantations at Enugu Ngwo remain productive resources, but ongoing quantitative monitoring is necessary to optimize their sustainable management.

The discrepancy between the highest site index in the 1976 (46 year) stand and the superior current growth performance observed in the 48-year stand reflects differences in the biological interpretation of these metrics. Site index is primarily influenced by dominant height growth during the early stages of stand development and is therefore a strong indicator of initial site quality and early resource availability. The higher site index in the 1976 stand suggests that its trees experienced more favorable growth conditions during establishment. In contrast, the superior DBH, basal area, crown diameter, and crown projection area recorded in the 48-year stand are structural attributes that accumulate over time and are more strongly shaped by stand age, density dynamics, competition effects, and later biomass allocation patterns. Thus, while the 48-year stand has had more time for stem thickening and crown expansion, the 1976

stand retains the advantage in dominant height growth potential. These results emphasize that site productivity assessment requires both early-growth indicators such as site index and contemporary stand structural variables to fully capture stand performance and long-term productivity differences. Diane (2014)

Generally, the variations observed among the age-segregated stands confirm the importance of site-specific evaluation rather than generalized management assumptions across plantations. The results also emphasize that while the Enugu Ngwo Forest Reserve overall supports highly productive *Pinus caribaea* stands, differences in site indices highlight the need for differentiated silvicultural strategies such as tailored thinning intensity, monitoring of stand density, and adaptive rotation scheduling.

CONCLUSIONS – *Zaključci*

The results indicate evident spatial variation in growth performance and productivity in age Structured *Pinus caribaea* stands within the Enugu Ngwo Forest Reserve. Although there are minor differences in age, the 51-year-old stand performs well concerning DBH, basal area, height, and crown dimensions, demonstrating higher biomass accumulation and competitive superiority. On the other hand, the 1976 (49) year-old stand shows the highest site index value, suggesting higher initial growth potential and early site quality. The findings confirm that site index describes the initial productivity level, while the current stand structure indicates accumulated growth and competitive impacts. In general, productivity is consistent within the forest reserve, but uneven site quality calls for site-specific and evidence-based forest management rather than uniform silviculture measures. Combining site index with current structural characteristics is necessary for optimal rotation planning, accurate productivity estimation, and yield maximization in the plantation.

REFERENCES – *Literatura*

Adame, P., del Río, M. & Cañellas, I. (2008). A mixed nonlinear height-diameter model for pyrenean oak (*Quercus pyrenaica* Willd.). *Forest Ecology and Management*, 256(1-2): 88-98.

Adesoye, P.O., & Ezenwenyi E.E (204). Tree Species Diversity and Soil Status of Two Natural Forest Ecosystems In Lowland Humid Tropical Rainforest Region of Nigeria. *Journal of Ecology and the Natural Environment.* 6(9), 268-276.

Akindele, S.O (1991). Development of Site Index Equation for Teak Plantations in Southern Nigeria, *Journal Of Tropical Forest Science*. 4(2), 162 -169.

Alder D. & Abayomi J.O (1994). Assessment of data requirements for sustained Yield Calculation, Unpublished report prepared for the Nigerian Tropical Action Programme, FORMECU, Federal Department of Forestry, Ibadan, Nigeria, P. 28.

Avery and Burkhart (2002). Forest Measurements. 5th McGraw- Hill, Boston, Ma. Xxiii, 456p.

Diane K (2014). Natural Resources Biometrics- Milne Publishing- Chap 9

Huebschmann, M & Martin J (1996). Estimatin And Interpretating Site Index. G3361, Lake State Woodlands. University Of Ui

Oyebade, B.A**,** Popo-ola, F.S. and Aguma S. 2012. Site index equation for *Pinus caribaea* plantation in erosion prone Enugu Ngwo, Nigeria. *International Journal of Science and Nature*. Vol.3 (3). 586-591.

Shigeru .K. (2010). A Theoretical Model for Tree Growth Under One Sided Competition. Ecological Modlling. 22(7), 1041 -1047.

Synott, T.M. (1992). Inventory Techniques for Sustainable Forest Management in Tropical Forests. In Proceedings of FAO Expert Consultation on Sustainable Forest Management. Rome, Italy. Pg25.

Wamg, H., Hall, C.A.S & Cornell. J.D (2008). Assessing Evidence for A Pervasive Alteration In Tropical Tree Communities Plos One, 3(3). Ei807

Waring et al., (2006). Use Of 3-Pg And 3-Pgs to Simulate Forest Growth Dynamics Of Hoop Pine Plantation Queenland, Australia. *Forest Ecology and Management*. 234 (1-3), 306 -319.

SAŽETAK

Procjena proizvodnosti staništa i uspješnosti rasta od ključnog je značaja za efikasno gospodarenje šumskim plantažama. U ovom istraživanju analizirana je dinamika rasta i varijabilnost stanišnog indeksa u tri sastojine Pinus caribaea različite starosti (49, 50 i 51 godina) u šumskom rezervatu Enugu-Ngwo u Nigeriji. Podaci o prečniku stabala na prsnoj visini (DBH), visini stabala i temeljnici sistematski su prikupljani na postavljenim oglednim plohama dimenzija 20 × 20 m. Stanišni indeks (SI), temeljnica i dominantna visina korišteni su kao pokazatelji proizvodnosti.

Analiza varijanse pokazala je statistički značajne razlike u parametrima rasta između oglednih ploha i sastojina, ukazujući na izraženu prostornu heterogenost. Vrijednosti stanišnog indeksa kretale su se od 0,652 u sastojini starosti 50 godina do 0,729 u sastojini starosti 49 godina, što ukazuje na značajne razlike u proizvodnosti. Sastojina starosti 49 godina imala je veće vrijednosti prečnika, visine i temeljnice te je pokazala najveću proizvodnost. Neujednačen kvalitet staništa na području rezervata ukazuje na lokalni uticaj okolišnih faktora i historijskih okolnosti gospodarenja.

Općenito, plantaže Pinus caribaea pokazale su visok proizvodni potencijal, posebno sastojina osnovana 1976. godine, kod koje je utvrđena izražena povezanost visine i starosti. Rezultati istraživanja naglašavaju potrebu za primjenom stanišno prilagođenih uzgojnih mjera, fleksibilnim planiranjem ophodnje i kontinuiranim monitoringom radi povećanja prinosa drvne mase i očuvanja dugoročne proizvodnosti šumskih plantaža.

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