DEVELOPMENT OF A SITE INDEX EQUATION FOR TEAK PLANTATIONS IN SOUTHWESTERN NIGERIA

S. O. Akindele

Department of Forestry & Wood Technology, Federal University of Technology, Akure , Nigeria

Received February 1991

AKINDELE, S.O. 1991. Development of a site index equation for teak plantations in southwestern Nigeria. A site index equation is developed for estimating the site quality of existing teak plantations in southwestern Nigeria. The data used were collected from 72 temporary sample plots spread over thirteen plantations in the area. The plantations ranged from 9 to 21 years in age. Using an index age of 20 years, the site index equation is: $SI = \exp[\ln (Hd) + 6.58 (A^{-1} - 0.05)]$, where SI , Hd, and A are site index, dominant height and plantation age, respectively. The procedure for using the equation is illustrated.

Key words: Site quality - site index equation - teak - Nigeria

Introduction

Site index is the oldest and most satisfactory concept yet developed in evaluating site productivity for forest stands (Husch *et al.* 1972, Smith & Watts 1987). The concept evolved from works in the 1820s by German foresters and was reported in the early decades of the twentieth century in the works of Watson (1917) and Frothingham (1918). Site index is conventionally defined as the average total height of specified trees in a stand at an arbitrary base age (Powers 1973). For plantations in tropical Africa , 20 years is the most common base age (Crowe 1967). The dominant height, defined as the arithmetic mean height of the one hundred trees of greatest basal area per hectare, is considered to be a reasonable numerical expression for the productive capacity of the site.

The site indices of a region are usually obtained either graphically or by the use of mathematical models. Objections to the graphical approach include the element of subjectivity that is necessarily involved and the difficulty of performing statistical tests on the goodness of fit of the curves. These problems are easily overcome when mathematical models are used. The use of mathematical models has been greatly enhanced due to the availability of computer facilities.

In southwestern Nigeria , *Tectona grandis* (teak) is one of the most prominent species in the man-made forests. It is regarded as a very suitable species for the rapid production of large volumes of timber, fuelwood and poles of uniform and desirable quality (Akindele 1989). At present, no equation has been developed for assessing the relative productive capacity of the teak plantations in the area. The purpose of this study, therefore, is to develop and present an appropriate site index equation (*i.e.* a particular measure of site class) which will serve as a measure of site quality for teak plantations in southwestern Nigeria. It is hoped that the equation will be a very useful tool for teak site class assessment.

Methodology

The study area

The study area is specifically the dry high forest area of southwestern Nigeria. The area (lat. 7°05' and 7°45'N; longtd. 3°15' and 4°30'E) has the widest age range of teak plantations in Nigeria. The land surface is gently to strongly undulating with an average altitude ranging from about 120 to 480*m* above sea level. Geologically,

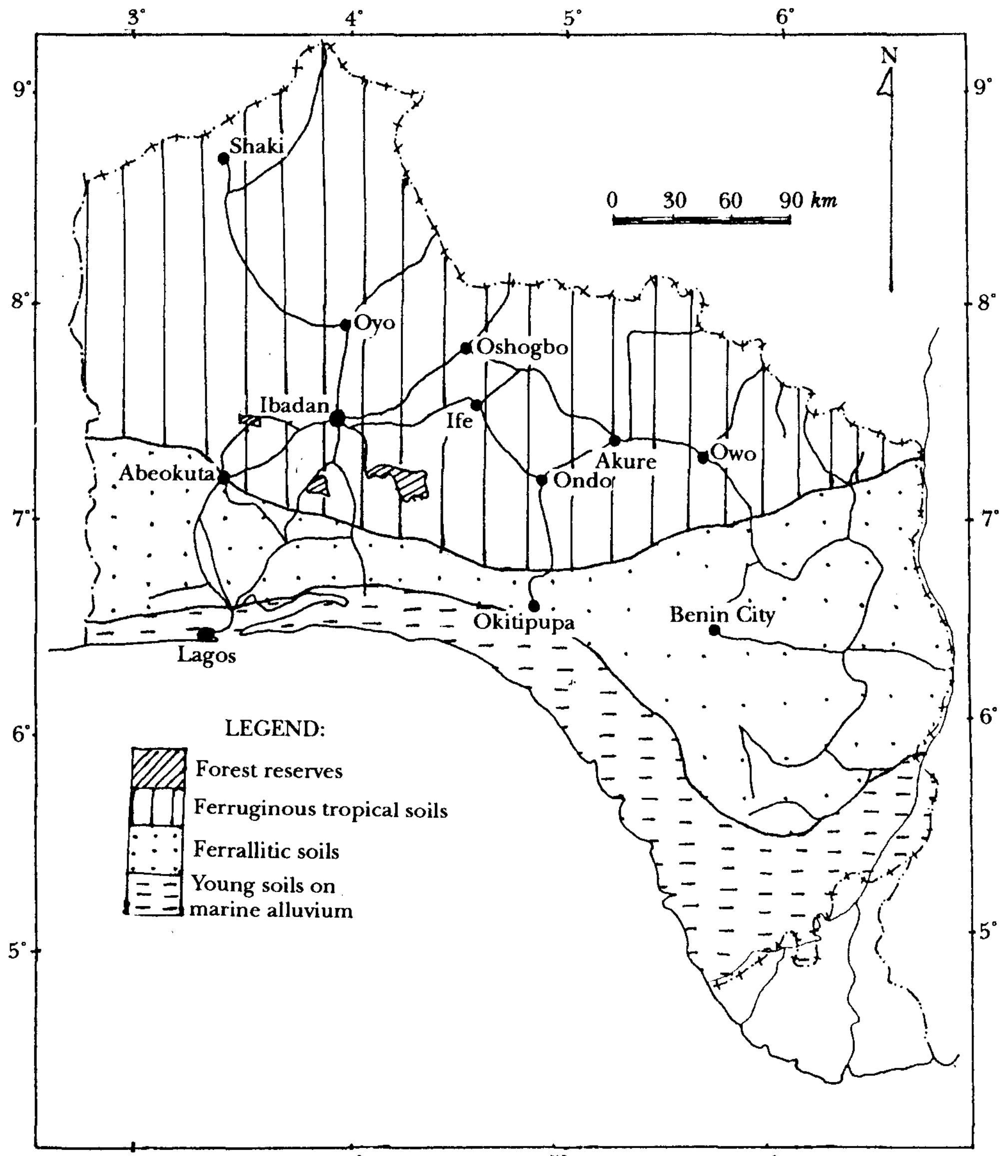

Figure 1. Map of southwestern Nigeria showing the location of the study area (Forest Reserve)

the area is underlain by metamorphic rocks of the Basement Complex, the great majority of which are very ancient, being of Pre-Cambrian age (Smyth & Montgomery 1962). The major soil unit of the area is the Ferruginous Tropical Soils (Figure 1). The mean annual rainfall ranges from 1300 to 1800 *mm* while the mean annual temperature is about 26°*C*.

Data collection

Seventy-two temporary sample plots from thirteen plantations ranging from 9 to 21 *y* in age were used in this study. Each sample plot was a square 0.04 *ha* plot.

In each plot, the diameter at breast height (dbh) of all the trees was measured. From the dbh measurements, the four largest trees per plot (representing the 100 largest trees per hectare) were selected and their heights measured. The mean height of the four largest trees in a plot served as the dominant height for that plot. The plantation age as available in the records was used as stand age.

Development of the site index equation

To develop the site index equation, dominant height and stand age were used. Although it was desirable to have an index age close to the rotation age, the rotation age of teak in Nigeria is not fixed as it varies with the object of management of individual plantation. Consequently, an index age of 20 *y* was chosen since it is the most common base age for plantations in tropical Africa, and if falls within the age range of the plantations used in this study.

In site index studies, many different techniques could be used to generate site index equations. According to Clutter *et al.* (1983), most of these techniques could be viewed as special cases of three general equation development methods, namely, the guide curve method, the difference equation method, and the parameter prediction method. The guide curve method could be used where the data are from temporary sample plots. However, the use of either the difference equation method or the parameter prediction method requires remeasurement or stem analysis data. In the present study, the data used were collected from temporary sample plots, thus permitting the use of only the guide curve method for developing the site index equation. In the method, both linear and non-linear regression models are being used. However, some problems are often encountered in using non-linear regression models for developing site index equations. As pointed out by Newnham (1988), it is sometimes difficult (or even impossible) to obtain a solution to the parameters of the equations, depending on the software used and the initial values specified for the parameters. Also, Smith (1984), based on a study of black spruce (*Picea mariana)* in Northern Ontario, criticized non-linear models because of their asymptotic properties. He found no evidence that height approached a maximum value with age and felt that the same might apply to other species. In view of these setbacks in the use of non-linear regression models, a linearized regression model was used in this study.

The model, referred to as the ln(height)/reciprocal of age model (Clutter *et al.* 1983) is of the form:

$$\ln(Hd) = \beta_o + \beta_1 A^{-1} \qquad 1(a)$$

where Hd = average height of the dominant trees (in *m*); A = stand age (*y*); β_o = intercept value uniquely associated with each particular site index; β_1 = slope with the same value for all site indices; ln = natural logarithm (*i.e.* log to base e). In its original form, that is, before logarithmic transformation, the model is expressed as:

$$Hd = H_{max} e^{\beta_1 A^{-1}} \qquad 1(b)$$

where Hd, A, and β_1 are as defined for Equation 1(a); H_{max} = Intercept value uniquely associated with each particular site index; e = exponential function.

Using b_o and b_1 as sample-based estimates of β_o and β_1, respectively, Equation 1(a) can be rewritten as:

$$\ln(Hd) = b_o + b_1 A^{-1} \qquad 1(c)$$

This equation was fitted to the dominant height-age data to obtain estimates of the regression parameters. The REGRES primary option of the Crops Research Integrated Statistical Package (CRISP) on VAX 1 system of the computer facilities at the International Institute of Tropical Agriculture (IITA), Ibadan was used for this purpose.

By definition, when A equals the index age (*i.e.* 20 years in this study) in equation (1c), Hd will be equal to site index, so that:

$$b_o = \ln(SI) - b_1\left(\frac{1}{20}\right)$$

or

$$b_o = \ln(SI) - 0.05b_1 \qquad (2)$$

where SI = site index.

By substituting equation (2) in equation (1c), the following equation was obtained:

$$\ln(Hd) = \ln(SI) - 0.05b_1 + b_1 A^{-1}$$

or

$$\ln(Hd) = \ln(SI) + b_1(A^{-1} b - 0.05) \qquad (3)$$

Making ln(SI) the subject of the formula, the resulting equation is:

$$\ln (SI) = \ln (Hd) - b_1(A^{-1} - 0.05) \quad (4)$$

This equation was used to construct site index curves for teak in the study area.

Results and discussion

A summary of the data obtained from the stand measurements is presented in Table 1. The height-age equation computed in this study is:

$$\ln Hd = 3.35 - 6.58A^{-1} \quad (5)$$

Table 1. Stand growth data obtained from teak plantations in southwestern Nigeria

Stand age (*y*)	Dominant height (*m*)*	Mean dbh* (*cm*)	Number of plots
9	16.1 ± 0.1	16.7 ± 0.2	8
9	8.2 ± 0.1	11.7 ± 0.5	3
9	14.3 ± 0.1	18.0 ± 1.0	5
12	16.8 ± 0.1	22.9 ± 0.5	8
12	13.2 ± 0.2	17.5 ± 1.4	3
15	19.1 ± 0.3	21.1 ± 0.3	3
15	19.7 ± 0.4	24.0 ± 0.6	5
15	16.6 ± 0.2	21.9 ± 1.5	8
18	21.5 ± 0.1	23.5 ± 0.4	8
18	16.6 ± 0.1	21.2 ± 0.5	5
21	22.5 ± 0.2	24.4 ± 0.7	8
21	17.1 ± 0.1	22.5 ± 0.7	5
21	22.2 ± 0.2	21.9 ± 1.5	8

*Average values ± standard error

When A is the index age (*i.e.* 20 years in this study), the dominant height (Hd) equals the site index (SI). In that situation, equation (5) can be written as:

$$\ln(SI) = 3.35 - 6.58\left(\frac{1}{20}\right)$$

or

$$\ln(SI) = 3.35 - 6.58(0.05) \quad (6)$$

From Equation (6),

$$3.35 = \ln(SI) + 6.58(0.05) \quad (7)$$

Substituting for 3.35 in Equation (5), using Equation (7), we have:

$$\ln(Hd) = \ln(SI) + 6.58(0.05) - 6.58A^{-1}$$

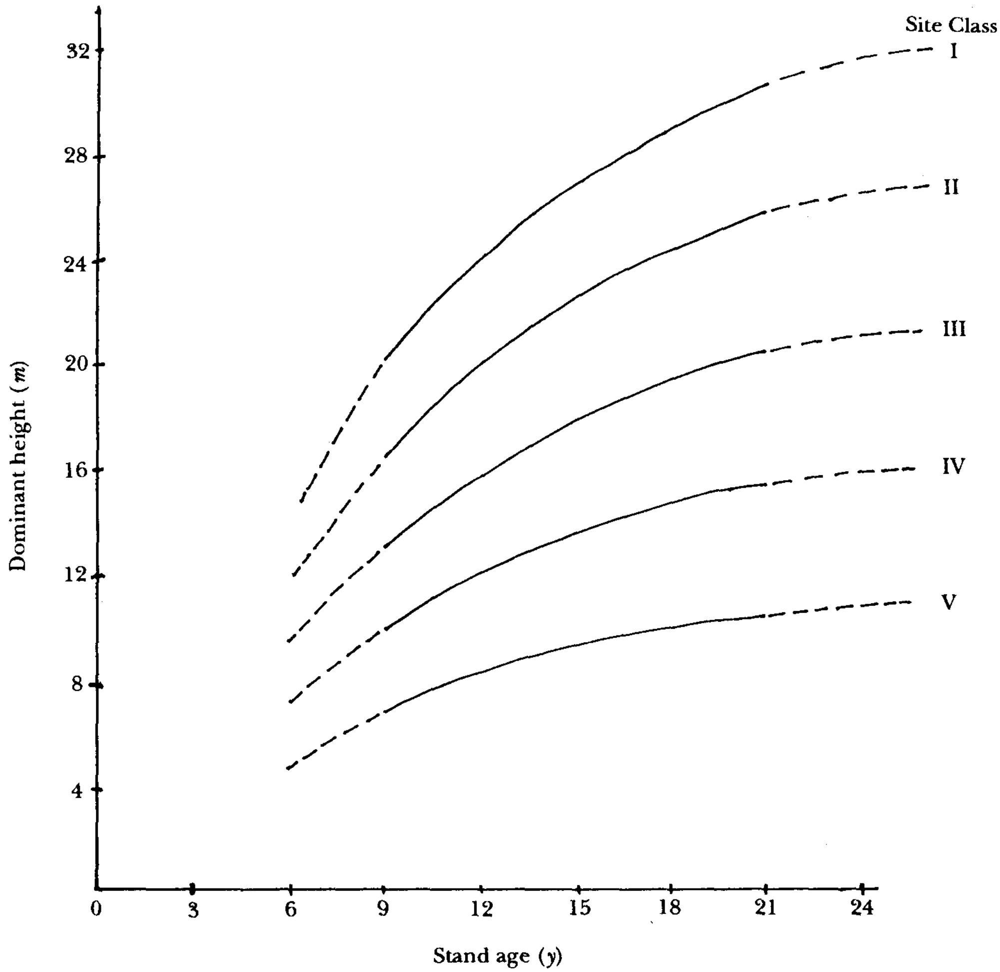

Figure 2. Site index curves for teak plantations in southwestern Nigeria

or $$\ln(Hd) = \ln(SI) - 6.58(A^{-1} - 0.05) \quad (8)$$

From Equation (8), an equation for estimating site index will be

$$\ln(SI) = \ln(Hd) + 6.58(A^{-1} - 0.05)$$

or $$SI = \exp[\ln(Hd) + 6.58(A^{-1} - 0.05)] \quad (9)$$

Thus, Equation (9) is the site index equation derived in this study. The site index curves constructed, based on this equation, are shown in Figure 2.

As noticed from Figure 2, a 10-*y*-old teak stand will attain dominant height of about 13 *m* on average site (Site Quality Class III) and at least 21 *m* on the best site (Site Quality Class I). This shows that teak is growing particularly well in the dry high forest area of southwestern Nigeria. In Thailand, similar results have been reported for the dry upper mixed deciduous forest area which is described as a true home for teak (Jenkin 1961). Teak growth in the study area compares favourably well with the growth in India. Most of the plantations studied belong to Quality Class I in the Indian yield table. The factors enabling such good growth of teak seem to be the climate and relatively good soils (Akindele 1989). Soils of the study area (Ferruginous Tropical Soils) are among the most fertile soils in southwestern Nigeria. They are deep and well-drained and supports teak growth as those in the natural habitat of teak in Burma and India.

To estimate the value of site index for a teak plantation in the study area using equation (9), the plantation age as well as the average dominant height of the stand are required. For example, for a 13-y-old teak plantation with average dominant height of 16 *m*, the site index is:

$$SI = \exp\left[\ln(16) + 6.58(13^{-1} - 0.05)\right] = 19.1\ m$$

In this way, the site indices of several plantations could be estimated, thereby determining the site class. The plantations can then be stratified into different productivity classes, based on the site class. In addition, since site index is an important variable in yield estimation, equation (9) will serve as a basic tool in yield studies within the teak plantations.

Conclusion

The site index equation developed in this study is appropriate for determining the site quality of teak plantations in southwestern Nigeria. It is therefore recommended for use within the age range of the data encountered in the study. Even though the equation may not be directly applicable in other areas, the method used for developing the equation is applicable elsewhere. The method can be used for deriving site index equations in areas where there are already existing teak plantations.

Acknowledgements

I am grateful to the Computer Manager of the International Institute of Tropical Agriculture, Ibadan, for the permission to use the Institute's computer facilities.

References

AKINDELE, S.O. 1989. Teak yields in the dry lowland rain forest area of Nigeria. *Journal of Tropical Forest Science* 2(1): 32-36.

CLUTTER, J.L., FORTSON, J.C., PIENAAR, L.V., BRISTER, G.H., & BAILEY, R.L. 1983. *Timber Management: A Quantitative Approach.* John Wiley and Sons, Inc., New York. 333p.

CROWE, N.D. 1967. Growth, yield and economics of *Pinus patula* in the Natal Midlands. *Annale Universiteit van Stellenbosch* 42(2): 75 - 152.

FROTHINGHAM, E.H. 1918. Height growth as a key to site. *Journal of Forestry* 16(17): 754 - 760.

HUSCH, B., MILLER, C.I., & BEERS T.W. 1972. *Forest Mensuration.* Second Edition. The Ronald Press Company, New York. 410p.

JENKIN, R.N. (1961). A report on teak soils. Department of Forest Research, Ibadan, Nigeria. *Technical Note No. 15.*

NEWNHAM, R.M. 1988. A modification of the Ek-Payandeh non-linear regression model for site index curves. *Canadian Journal of Forest Research* 18: 115-120.

POWERS, R. 1973. Determining site quality in California. Paper presented at *Society of American Forester Annual Meeting.* Kaiser Center, Oakland, U.S.A.

SMITH, V.G. 1984. Asymptotic site index curves: fact or artifact? *Forestry Chronicle* 60(3):150-156.

SMITH, V.G. & WATTS, M. 1987. An assessment of the structural method of deriving a black spruce site equation. *Canadian Journal of Forest Research* 17:1181-1189.

SMYTH, A.J. & MONTGOMERY, R.F. 1962. *Soils and land-use in central western Nigeria.* Government Printer, Ibadan. Nigeria. 265 pp.

WATSON, R. 1917. Site determination, classification and application. *Journal of Forestry* 15(5): 552 - 563.