USE OF NUMERICAL MODELS FOR CHARACTERISING TREE AND FOREST GROWTH

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ABSTRACT

The biological complexity of the humid forests of Anglophone West Africa is discussed. Their slow growth rates in terms of diameter/basal area increment emphasizes the difficulty in growth and yield studies and consequently their management. It is difficult to determine age of trees in these forests. This has further implications for growth and yield modelling in these forests that have all age stands. The relevant models in use in this sub-region can be classified mainly into two groups; single tree distance independent and whole stand distance independent models.

The problems of growth and yield modelling and further implications of models in forestry are also discussed.

Keywords: Growth models, simulation studies, stand growth, silvicultural treatments.

INTRODUCTION

The humid forests in Anglophone West Africa are outstanding examples of complex biological communities. Their diversity and the interdependence of the component parts (plants and animals) is outstanding. Records indicate that up to one hundred species of tree, 10 cm diameter at breast height (dbh) and above per hectare, may occur in any given forest. In Sapoba Forest Reserve, Egunjobi and Bada (1976) recorded a total of over fifty tree species, 15 cm dbh and above, per hectare. Another important characteristics of these forests is the slow rates of growth of many of the tree species. However, growth rates vary within and between tree species. In the unlogged forests the mean annual increment in diameter tends to be very small, (Okojie, 1981). Keay (1961) estimated that species like *Triplochiton scleroxylon* would take about 42 years to achieve a girth of 2.7 m while species like *Lophira alata* would take over 200 years to attain the same girth.

One unique characteristic of these forests is the ability of many species of trees to recover from prolonged periods of suppression especially at the seedling and sapling stages. Consequently, age has no relevance to the sizes of the trees in these forests. It is almost impossible to determine the ages of the trees except through sophisticated methods like carbon dating. The determination of the ages of trees is further complicated by the difficulty in identifying growth rings in the stems.

Growth rates reported by MacGregor (1934) and Keay (1961) were for trees in unlogged humid forests in Nigeria. These observed slow growth rates encouraged the establishment of silvicultural trials and forest management systems. It was reasoned that if environmental conditions were altered in the natural forests it would be possible to encourage the fast development of trees and also improve regeneration. The most popular of these forest management systems is the Tropical Shelterwood Systems (TSS) which was tried in Nigeria between 1944-1961. The operations involved and the results of the treatments applied have been reported byOguntala (1996).

The effective management of these humid forests has been the greatest challenge to forest scientists. These mixed forests do not easily lend themselves to satisfactory scientific investigations. The relevant research outfits in Anglophone West Africa have acquired data, from logged and unlogged sample plots for several decades, from these forests. In Nigeria, the Forestry Research Institute at Ibadan established and maintains temporary and permanent sample plots in these forests. The unlogged plots are in Strict Natural Reserves (SNR). The usual records obtained include regeneration counts, diameter measurement and where possible, tree height.

In spite of these efforts there is a dearth of information on these forests. Where data are available they cannot be subjected to robust analysis for lack of completeness, size of plot and/or faulty design of plot layouts. Although the 'Time of Passage' concept enunciated by Mervart (1972) has been criticised, it represents a significant contribution to the studies on the growth and yield of these mixed forests. `Time of passage' is the number of years it takes for a tree in a diameter class to move to the next higher class. The existing volume and yield tables in Nigeria are mainly for plantation species (Jones, 1964; Ball and Antoine, 1976). No reliable volume and yield tables exist for these humid forests. This has implications for the management of the forests. However, in the advent of high speed electronic computers and improvement in the value and amount of data available, forest scientists in Anglophone West Africa have been encouraged to employ sophisticated analysis in examining the growth and yield in these forests. Such methods include growth and yield modelling.

Forest Growth and Yield Modelling

Regression functions which express stand growth are models. The European method of yield table construction and application still very much influence the Nigerian forestry practices. As a result, previous efforts at growth prediction were based on yield table and stand table projection methods. Such projections are usually unreliable since growth prediction models are not involved in the construction of the yield tables applied. Computer calculation capabilities have enabled the development of complex models utilizing complicated mathematical functions, permitting the solution of yield function, with several number of variables eg. diameter, height and crown class.

In Nigeria, modelling for tree and stand simulation is only recent. Several reasons have been advanced for this. These include poor data in terms of quality and quantity. For tree and stand simulation studies historical trends of parameters on tree sizes is required. It is therefore unreasonable to expect yield forecasting models based only on temporary point data. Data from the Permanent Sample Plots (PSP) and Strict Natural Reserve Plots (SNR) have been employed by forest scientists in Nigeria to model tree and stand growth in these humid forests. Many methods of multivariate analysis have been successfully applied, in Nigeria, in growth and yield modelling. Most of the models applied in Nigeria fall into two categories in the Munro (1974) classification of models.

They are as follows:-

- Distance independent models (Primary Unit - Single tree parameters)
- Distance independent models (Primary Unit - Stand parameters)

Growth models may also be classified as Linear and Non-linear growth function. Traditional growth functions/models are usually non-linear.

The Nigerian Experience in Growth and Yield Modelling

(a) Stem diameter distribution models:

The diameter distribution information of a stand is as important as the information on total volume. But special techniques are involved in summarizing information on diameter distribution. Many probability densities other than the normal distribution are in use. These include the following:-

- the uniform distribution

- the log-normal distribution
- the gamma distribution
- the beta distribution
- and the Weibull distribution

The Weibull distribution is flexible and characterises different actual distributions simply by differences in its parameter values. Okojie (1981) employed the cumulative density function (cdf) of the 3-parameter Weibull distribution to characterise stem-diameter distribution in some mixed plantations of indigenous Meliaceae in Sapoba. The cumulative density function of the Weibull used was of the form:-

$$F(x) = 1 - \exp\left[-\frac{(x-a)^c}{b}\right]$$

Where F(x) measures the area under the curve and (x) is the random variable, diameter. The shape of the Weibull distribution is dependent on the value (c) while (a) and (b) represent the location and scale parameters, respectively. The values of the Weibull parameters have biological interpretation (Okojie, 1981). For uncut even-aged stands on a given site, the value for (c) is directly related to age (Rustagi, 1978). For all-aged stands of tolerant species values of $c > 1$ should occur. If $c > 1$ the curve is unimodal characterising structure of even-aged stands. The location parameter, (a), indicates the beginning of point of distribution. It can either be constant or estimated from data (Somers *et al*, 1980).

A skewness index (SKI) was proposed for the Meliaceae (Okojie, 1981). Given that the value of the shape parameter (c) indicates the skewness of stem-diameter distribution in a stand and the estimated shape parameter (c) for *Lovoa trichilioides, Khaya ivorensis* and *Entandrophragma cylindricum* as 2.91, 2.44 and 1.37, respectively, at age 26 years, the (SKI) of these species are represented by:

(i) $SKI = \frac{2.91}{3.6} = 0.8$ for *L. trichilioides*

(ii) $SKI = \frac{2.44}{3.6} = 0.677$ for *K. ivorensis*

(iii) $SKI = \frac{1.37}{3.6} = 0.38$ for *E. cylindricum*

where 3.6 is the value for (c) in distributions that have zero skewness. Since high skewness values are associated with species intolerance to shade, the higher the index the less tolerant the species. This value can be represented as a percentage and termed the skewness index per cent (SKI%) and are 80%, 68% and 38% respectively for the species considered above. It is assumed here that the stand densities are the same at the given age. Where the densities are different it might be necessary to weigh these values with the number of stems in the stand. The relationship between the Weibull parameters and stand attributes were examined. From the selected stand attributes general multiple linear predictive models were obtained for *Lovoa trichilioides, Khaya ivorensis* and *Entandrophragma cylindricum*, in respect of the Weibull parameters. They were of the form:

$$(a) = 10.224 + 0.241^* \ AGE = 338.04/TREES$$
$$(b) = 17.86 - 0.368 \max D + 1.115^* \ Dm$$
$$(c) = 1.884 - 0.087^* \ AGE + 0.090 Dq$$

Significance: $P<0.05$, $P<0.01$

where *AGE = Stand age,*
TREES = number of trees per stand,
Dm = mean stand diameter,
max D = maximum diameter,
Dq = mean (quadratic) stand diameter.

Distance independent, single - tree non-linear models were also developed for diameter increment in these stands of indigenous Meliaceae (Okojie, 1981). These models were used to determine the expected number of stems in defined diameter classes in the stand, at given future dates. Increment values for diameter were small (0.48 - 1.46 cm/annum) and variable. Skewness indices derived from the Weibull parameters were used to determine the level of tolerance of the species examined. *E. cylindricum, K. ivorensis* and *L. trichilioides* were in that order in the level of tolerance.

(b) Growth models

Bada (1984) employed a modification of the generalized Chapman-Richard growth function based on von Beertalanffy's growth model to examine growth data from a permanent Sample Plot in Usonigbe Forest Reserve, in Nigeria. The predictive basal area growth model was of the form:

BA (1.....7) = [n/k-c*exp (-(1-m) *K*T* (1-7)**(1/(1-m)]

where n, m, K are the growth coefficients to be determined.

c = n/K - (BA**(l-m)

T(1..........7) = The seven predictive years of (1983, 1988, 1993, 1998, 2003, 2008 and 2013).

In addition Bada (1984) used the Markov Model to assess tree population changes and future stand structure in the untreated natural forest. He observed that there were great variations (2.1m to 8.1/ha) in basal area values from one plot to another for all species pooled. As in most unlogged natural forests the mean annual increments in basal area for the Meliaceae were small ($0.45 cm^2$/plot/annum). The tree population structure was also highly variable. Bada (1984) obtained, through iterative procedure, a general solution model for predicting basal area of selected eleven species. It was of the form:

B = (n/k - c*(exp(-(l-m)*k*T** (1/(l-m))

where n and m are growth coefficient to be determined.

Basal area ranged from $2m^2$/ha to $5m^2$/ha for all species examined, at the beginning of the study. At the end of the study the figures ranged from $3.8m^2$/ha - $8.2m^2$/ha.

(c) Matrix models

Osho (1988) applied matrix models to study the population dynamics of trees in Idanre Forest Reserve. He used the population growth matrix model to predict long-term growth of the untreated natural forest. Of particular interest was the stand density and basal area growth. It was also possible to determine the stability of the forest using the dominant given value. Bada (1984) used the value of the dominant latent root to examine the stable state of distribution of the population in the unlogged forest of Usonigbe. He observed that most members of a given size-class remained in the respective size class at some future date because of the slow growth rate. In addition the population of the lower size-classes was zero at the Stable State Distribution (SSD). Osho (1988) developed a linear programming approach to determine the maximum sustainable yield in the forest of Idanre. He also developed a stochastic matrix model for simulating secondary succession in the untreated forest and was able to project the composition of the stand, using the current species composition. The studies involved estimates of recruitment and mortality rates. Osho (1988) concluded that increased growth rate (30-40%) was required to reach a stable state in the forest. In respect of recruitment an improvement of 500% was required. The implications for disturbed natural forest are therefore very grievous. Ojo (1990) used the matrix modelling procedure to project the compositions in Oban, Omo, Owan and Sapoba Forest Reserves, into the future. He investigated the stable structure and obtained the stand table projection using the matrix multiplication sequence. Patterns of growth varied from species in these forests.

Species showed no net change in the number of stems during the measuring periodic intervals. In some cases the species decreased in density. However, he indicated that most of the forests will reach a stable state in 80 years.

Problems of growth and yield modelling in Anglophone West Africa

Some of the problems include the following:-

- errors in measurement which become amplified because of the slow rate of growth of the species of trees;

- irregular periodic measurement which make simulation procedures inaccurate;
- the sample plots are usually unreplicated and validation procedures are usually defective;
- unauthorised disturbance in the unlogged forest due to the activities of poachers of timber and wildlife; and
- the complex nature of the forest ecosystem makes statement on whole stand attributes unreliable. Usually only a few species are considered in the growth and yield models and this does not make for a proper understanding of dynamics of these complex ecosystems.

Future Research Needs

Most of the modelling efforts have been with data from unlogged forests. Data from forests that received silvicultural treatments such as the (TSS) have not been subjected to robust analyses employing relevant growth and yield models. There is need to model the regeneration responses in these forests to complement the information required to provide complete information for whole stand simulation models.

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