# MATHEMATICAL STATISTICS IN A FORCED MARRIAGE WITH FORESTRY

AN INAUGURAL LECTURE, 2011/2012

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UNIVERSITY OF IBADAN

# MATHEMATICAL STATISTICS IN A FORCED MARRIAGE WITH FORESTRY

*An inaugural lecture delivered at the University of Ibadan*

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*By*

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*The Vice-Chancellor, Deputy Vice-Chancellor (Administration), Deputy Vice-Chancellor (Academic), Provost of the College of Medicine, Dean of the Faculty of Agriculture and Forestry, Dean of the Postgraduate School, Deans of other Faculties and of the Students, Distinguished Ladies and Gentlemen.*

## Introduction

First and foremost, I take this very unique opportunity to thank God Almighty through his only son Jesus Christ for granting me the opportunity and undeserved favour to present the 2011/2012 inaugural lecture on behalf of the Faculty of Agriculture and forestry.

My inaugural lecture is the fourth from the Department of forest resources management. The department is the oldest in sub-Saharan Africa. It was established in 1963 through the support of UN – FAO.

The first lecture was delivered in 1978 by Emeritus Professor S. Kolade Adeyoju. The title of his lecture was "Our forests and our welfare". The second lecture was delivered by yet another Emeritus professor, D.U.U. Okali in 1987. His inaugural lecture was on "Ecology in Science and Society". The third and last one was that of late Professor E.E. Enabor – a renowned forest economist. He delivered the lecture in 1992 titled, "Deforestation and Desertification in Nigeria: The Challenge of National Survival.

My inaugural lecture is coming almost 20 years after. With due respect Mr. Vice-Chancellor Sir, I wonder if the University of Ibadan or the Faculty of Agriculture and Forestry forgot, discriminated, or neglected the Department of Forest Resources Management. Some of my senior colleagues retired from the University of Ibadan without the opportunity to deliver their inaugural lectures.

In my choice of topic for this lecture, I had my challenges. Because of my academic background in mathematics/statistics, I had very few friends in the Department of Forest Resources Management, both among staff and students for obvious reasons. Most biological based disciplines do not always like mathematics and statistics. I do not intend to make more enemies, and it is not my intention to turn everybody present to either a statistician or mathematician, but I have deliberately chosen my lecture to reflect my initial background to remind colleagues of my youth in the mathematical/statistical world that I have not abandoned them. I also like to pacify my present home in Forestry and appreciate them for offering me the opportunity to practice my profession and thereby earn my daily bread.

Mathematicians/Statisticians often than not ask me the question, What is Professor Osho doing in Forestry? Also, my colleagues in the Department of Forest Resources Management often claim that Professor Osho is not a forester, despite the fact that I wrote my PhD dissertation on Forest Biometrics. This was made possible through the support of the British Council that supported my stay in the University of Wales, Bangor, U.K. and the Swedish Institute with a fellowship at the Swedish University of Agricultural Sciences, Sweden. This goes to prove that a mathematician/statistician is barely tolerated by forestry. Most often, he is misunderstood and treated with suspicion. Things have since changed when they realized that the multi-disciplinary nature of forest science cannot but include mathematics.

The present lecture titled, "Mathematical Statistics in a Forced Marriage with Forestry" would attempt to answer the above questions. Although I was forced into the marriage with forestry, the marriage has been blessed with many children and grandchildren who are now practising forest biometrics in several universities and research institutions in and outside Nigeria.



## Natural Tropical Rain Forests in Nigeria

Natural forests will continue to be an important natural resource for Nigerians, provided that they are adequately managed and protected against ill-considered land use. Considerable efforts to improve natural forest management are being undertaken by various state governments. Most efforts are directed at sustainable production of timber and other products and services.

The major goals of forest management include:

(i) To ensure sustained timber production;
(ii) To enhance public benefits such as conservation of soil and water recourses;
(iii) Protection of natural environment.

My main objective is to contribute to the development of **ecologically sound, socially acceptable** and **economically viable** management systems for the evergreen tropical rain forest in Nigeria.

In order to contribute my quota to accomplish the stated objectives/goals, my attention has been focused on three non-mutually exclusive areas:

(i) Development of Stochastic Growth and Yield Models for tree population in natural tropical rain forest in Nigeria.
(ii) Development of Tree Harvesting Models in natural tropical rain forest in Nigeria.
(iii) Application of the models so developed to simulate (generate) data for econometric analysis using mathematical programming.

**Stochastic Growth and Yield Models in Natural Tropical Rain Forest**

"One of the consequences of the development of the theory of vegetation climax has been to guide the observer's mind forward. Vegetation is interp:eted as a stage on the way to something. It might be healthier and scientifically more sound to look more often backwards and search for the explanation of the present in the past, to explain systems in relation to their history rather than their goals" (Harper 1977). This statement was made in the context of forest dynamics and implied that the study of the demography of long-lived tree populations should involve a search for the past influences that have contributed to their present structure. In the same context, on the other hand, "Ecology, if it is to gain maturity as a science, must become predictive..." and matrix methods were suggested as one of the most promising approaches (Harper 1977; Usher 1966, 1969 & 1976).

I consider the first approach to be very difficult to achieve particularly in a developing country like Nigeria. Inadequate infrastructure precludes accurate record keeping of the history of forest disturbances. The second approach to ecological studies in Nigeria is more appealing owing to the availability of tree demographic data on recruitment, growth and mortality through the Forest Research Institute of Nigeria. The algebraic theories of matrices are well developed and make the predictive potentials of matrix models useful for studying some of the complex ecosystems of the tropical forest.

**Tree Population Growth Matrix Models**

Populations measured by age classes were investigated by Leslie (1945, 1948), Williamson (1959), Lefkovitech (1965) by the use of insect populations grouped by stages of development.

A mathematical model of the form:

$$N_{t+1,0} = PN_{t,0}$$

$$P = \begin{bmatrix} f_0 & f_1 & f_2 & \cdot & f_n \\ P_0 & \cdot & \cdot & \cdot & \cdot \\ \cdot & P_1 & \cdot & \cdot & \cdot \\ \cdot & \cdot & P_2 & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & P_{n-1} \end{bmatrix}$$

........................................................ (1)

where,

$f_i(i = 0,1,...n) =$ Fecundity of a female in the $i^{th}$ age group.

$P_i(i = 0,1,...n) =$ The probability that a female in the $i^{th}$ age group will be alive in the $(i+1)^{th}$ age group.

$N_{t,i} =$ Known number of animals in the $i^{th}$ age at time $t$

$N_{t+1,i} =$ Predicted number in the same age group at time t+1

The matrix P was now adapted to tree populations. The ages of trees in the natural forests are unknown (due to absence of annual rings). Diameter classes were therefore used as surrogates of age. Although, "it is wholly unrealistic and very dangerous to assume any relationship between the size of trees and their age, other than vague principle that the largest tree in a canopy are likely to be old" (Harper 1977).

Studies on a range of herbaceous and woody perennials have shown different mortalities among young individuals attributable to plant size or biomass rather than age (Sarukhan et al. 1984). Gross (1981) showed that the probability that a rosette would flower was strongly correlated with its size, but was independent of its age. The conclusion is that the use of diameter as an age surrogate is reasonable.

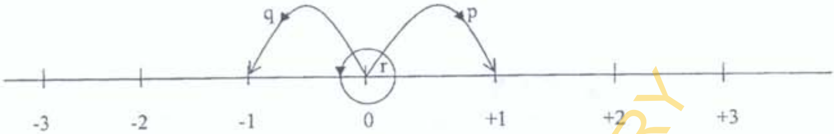
Thus, the Leslie matrix *P* was modified by Usher (1965) for the management of some selection forests where the elements of *P* (*i.e.* $m_{ij}$) represent the contribution to the tree population over a unit time interval (*i, j...n*) and fecundity was redefined as $(C_{ij})$ the average recruitment per individual tree in class *j*.

Assumptions of the matrix model during the growth period are that any tree in the population could make one and only one of the following moves:

(i) Move to a higher diameter class *i*
(ii) Remain in class *i*
(iii) Die in class *i*
(iv) No tree would be allowed to move backwards

Osho (1988, 1991) considered the model's assumptions as a special case of a random walk in a branching process in the probability theory in which the probability of moving backwards would be zero.

Diagram of random walk is as shown




where,

p = Probability of moving forward
q = Probability of moving backwards
r = Probability of remaining stationary

(Note that $p + q + r = 1$)

The elements $m_{ij}$ of $P$ are obtained thus:

$m_{ij} = (1 - P_i) S_i =$ Diagonal elements

$m_{ij} = P_i S_j =$ Off-diagonal elements

$P_j$ = The probability of trees moving from class $j$ to class $j + 1$ at the end of the growth period.

$S_j$ = The survival rate of trees in class j

$C_{ij}$ = Are the elements of the first row of $P$.

These elements represent the fecundity in the female.

The usual convention to estimate the recruitment is through the model introduced by Buongiorno and Michie (1980):

$$I = \beta_0 + \beta_1 \sum_{i=1}^{n} B_i (y_{ij} - h_{ij}) + \beta_2 \sum_{i=1}^{n} (y_{ij} - h_{ij})$$

.................................................. (2)

where,

I = Recruitment

$y_{it}$ = Number of live trees in diameter class *i*

$h_{it}$ = Number of dead (harvested) trees of diameter class *i* ($i = 1....6$)

$B_i$ = Basal area of the tree of average diameter class *i*

$\beta_0, \beta_1$ & $\beta_2$ = Are multiple regression coefficients

$$C_{ij} = \beta_1 B_i + \beta_2$$

.......................................... (3)

$i,j$ = 2, 3….6

Most of the results obtained by equation (2) had always been poor. I suggested a simple procedure for estimating $C_{ij}$. I modelled the ingrowth (Harrison & Michie 1985) as a uniform contribution by the mature trees in the higher diameter classes but weighted proportionately to the number of trees present in each diameter class. The use of uniform distribution worked perfectly as it is now in use.

The matrix *P* was now used to grow the forest and predict yield as well. I applied the model to simulate forest growth in Idanre Forest Reserve. The results of the simulation produced very interesting results. The results are shown in figure 1. The model P predicted a total tree population size of 1120/ha$^{-1}$ for 1974. The true (observed) tree population size was 1148/ha$^{-1}$.

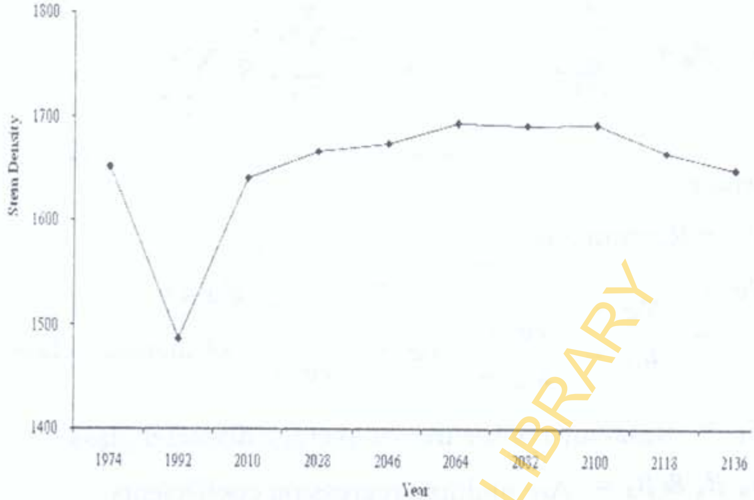



**Fig. 1:** Estimated population sizes of the stand, 1974 - 2136

## Forest Succession

During forest successional changes, vegetation is altered progressively both in structure and species composition. Secondary succession is the process of recolonization of a disturbed habitat and it consists primarily of three developmental stages:

***First stage*:** This is the invasion stage during which time complete canopy is partially established.

***Second stage:*** Dominant species emerge. These are usually single generation species.

***Third stage:*** The replacement of the species from the earlier stages occurs. This process ultimately leads to a climatic climax (Richards 1957).

In my work, I viewed succession as a pure birth and death process or a Linear Growth Process without immigration. Such a process can occur naturally in the study of biological reproduction and population growth. The dramatic property of succession is its repeatable convergence on the same climax community from any of many different starting points. This property is shared by a class of statistical processes known as Regular Markov Chains.

Markov chain is often represented by the random variable $X(t)$ on the states (0, 1....n) and its transition probability $P_{ij}(t)$ which is assumed stationary.

$$P_{ij}(t) = Prob.[X(t+s) = j \mid X(s) = i] \quad \text{.......................................} \quad (4)$$

such that $P_{ij} \geq 0 \; \forall \; ij$ and $\sum_{j}^{n} P_{ij}(t) = 1$

The values of $X(t)$ are the non-negative integers, representing the population size of the tree species at time t. The transition probabilities are guided by the Chapman-kolmohorov equations:

$$P_{ij}(t+s) = \sum P_{ik}(t)\, P_{kj}(s)$$

$$P_r(X(t) = j) = \sum q_i P_{ij}(t) \quad \text{.......................................} \quad (5)$$

where $q_i = P_r(X(0) = i)$

It is generally known that these transition probabilities satisfy a system of differential equation, known as Forward Kolmogorov differential equation (FKDE)

$$P_{ij}(t) = \lambda_{j-1} P_{ij-1}(t) - (\lambda_j + \mu_j) P_{ij}(t) + \mu_{j+1} P_{ij}(t) \quad \text{.......................................} \quad (6)$$

with boundary condition;

$$P_{i0}(t) = \lambda_0 P_{i0}(t) + \mu_i P_{i1}(t)$$

.................................... (7)

where $\lambda =$ birth (recruitment) rate of tree species, and
$\mu =$ death (mortality) rate of tree species

A closed form of solutions of (FKDE) is obtained by the method of probability generating function (Chung 1960; Bailey 1964; Feller 1964; Goel & Ritchter-Dyn 1974, Usher 1981).

**Stochastic Model for Secondary Succession in Natural Tropical Rain Forest**

A finite markov chain is a stochastic process which is determined by a set of species (states) 0, 1....*n* and a set of probabilities $(P_{ij})$, *i*, *j* = 1...n. The transition probabilities define the replacements (movements) between the states—say from initial state *i* to a new state *j* after one step. They are represented by row vectors $(P_{i1}, P_{i2}, \dots, P_{ik})$, i = 1...k. All the elements of the transition probability matrix associated with the markov chain are non-negative, and the sum of elements in each row is equal to 1 for closed systems, i.e.;

$$\sum_{j=1}^{k} P_{ij} = 1$$

............................................. (8)

i = 1.....k.

The major property is that, given the present, the future is independent of the past. The question of interest is on the tree population structure after a specified period of growth:

$$n(T) = Pn(0)$$

$$n(2T) = Pn(T) = P^2 n(0)$$

$$\vdots$$

$$n(KT) = P^K n(0)$$

.................................... (9)

where; $n(0) =$ Initial state of species

$n(T) =$ Current state of species at the end of the growth period.

Furthermore, we like to investigate the equilibrium distribution of $n(KT)$ or the so-called 'climatic climax' of the forest—a topic that has suffered much controversy among ecologists.

$$\lim_{k \to \infty} n(KT) = \lim_{k \to \infty} n(0) P^k$$

.................................... (10)

But,

$$P^k = \sum_{r=1}^{k} \lambda_r^k A_r$$

.................................... (11)

where,

$\lambda_r =$ Eigen value associated with $P$

$A_r$ has the following properties:

$A_r A_r = 0$ if $r \neq s$

$= A_r$ if $r = s$, and

$$\sum_{r=1}^{k} A_r = 1$$

.................................... (12)

In practice, what is of interest to the forest ecologist is a large value of *KT* rather than the theoretical value of $KT \to \infty$ .

We made additional specifications on matrix model *P*, concerning the ingrowth to the tree population.

Let $P_{\bullet j}$ represent the proportions of ingrowth over the growth period *T* into the tree species population. We have;

$$\sum_{j=1}^{k} P_{\bullet j} = 1$$

.................................... (13)

Since all the elements of $P \leq 1$, all given values $\lambda_r \leq 1$. Then $\lim_{n \to \infty} \lambda_r^k = 0$

The expected species distribution after $k^{th}$ growth period is given by:

$$n(KT) = n(0)P^K + P_{\bullet j}^k(KT)$$

.................................... (14)

$$\lim_{n \to \infty} n(KT) = R\, P_{\bullet j}(I - P)^{-1}[(I - P]^k)$$

.................................... (15)

Thus, the limiting distribution is independent of the original species distribution but depends solely on ingrowth distribution and the table of replacement probabilities. The result definitely supports the obvious efforts to improve regeneration in the forest.

From equation (15), we know that $\lim_{n\to\infty} P^k = 0$ (strong Ergodic theorem). Then;

$$\lim_{n\to\infty} n(KT) = R\, P_{0j}(I-P)^{-1}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

$(I-P)^{-1}$ exists because it is positive definite. Thus the tree population would be low if $R$ is low and the population will also become extinct if R = 0 (Osho 1995, 1996).

**Matrix Models for Tree Harvesting in Natural Tropical Rain Forest**

The development of these matrix models is based on the principles of *ecological sustainability*, *social acceptability* and *economic viability*. The sustainable management of a rain forest is achievable only when one knows the maximum potential of the forest and has studied the processes of degeneration and recovery, thereby learning the degree to which vegetation can be used without reducing productivity or perhaps jeopardizing recovery. In Nigeria, the ever-increasing demand for logs for construction and industrial uses, largely arising from rapid population growth, coupled with socio-economic development in rural areas, has broken some aspects of the above conditions for sustainability. Most of the country's tropical rain forests have been abused through unregulated timber harvesting and almost all of them are declining in productivity (Osho 1989, 1990 & 1991). In fact, most tropical rain forests have completely disappeared. Mr. Vice-Chancellor Sir, it is sad enough to report that Nigeria is the first country whose rain forests have almost disappeared.

One of the viable options left for the sustainable management of these abused rain forests is the determination of optimal sustainable harvest models needed to convert a tropical harvest rain forest to a maximum sustainable timber resource. Special attention would be on the quantitative continuity in the use of the rain forest for timber production without undue reduction of its future productivity.

The model that was used to investigate the problem has its roots in the growth model of Buongiorno and Michie (1980).

$$Y_{t+1} = P(Y_t - H_t) + C$$

.................................... (17)

Where $P_{nxn}$ is a square tree population growth matrix whose rows and columns represent n diameter classes used to characterize the diameter distribution of the tree population. $Y_t$ is a column vector of dimension $n$ with the number of trees in the diameter classes in year $t$ before trees are cut. $H_t$ is a column vector containing the number of trees cut from each diameter class in year $t$. $C$ is a column vector whose first element is the total ingrowth period $t$ with the other element equal to zero. $Y_{t+1}$ represents the stand structure after a cutting cycle of length $t$.

Hence, the growth of the forest during $m$ time unit would be represented by:

$$Y_{t+1} = GY_t + U$$

where

$$G = P^m, U = \sum_{i=0}^{m-1} P^i C$$

.................................... (18)

A dynamic equilibrium state (steady state) would be attained if the amount cut from the forest is just equal to the amount by which the forest has grown since the last harvest. The sustained forest structure is given by the equation:

$$Y = P^m(Y - H) + \sum_{i=j}^{m-1} P^i C$$

.................................... (19)

If we fix the harvest vector $H$ such that $H = H^{*}Y$, i.e. harvest is just a fraction of existing population structure, then:

$$Y = [I - G + GH^{*}]^{-1}U \qquad \text{.................................... (20)}$$

The maximum harvesting rate for a given cutting cycle would be identified when the first zero elements are obtained in $Y$ for the diameter size classes 4, 5 & 6; the merchantable classes (Osho & Akinsanmi 1990).

A classical goal of sustained yield management is to maximize volume of wood produced per unit time, while maintaining the forest in a steady state. Solving for $H$, we obtain:

$$H = (I - G^{-1})Y + G^{-1}U \qquad \text{.................................... (21)}$$

$G$ is invertible because it is a semi-positive definite matrix. Since a negative harvest is impossible, we must have the condition that $(I - G^{-1})Y + G^{-1}U \geq 0$. In addition $H \leq Y$.

The optimum harvest from the forest can now be formulated as a mathematical programming problem. Thus, let the basal area of the average tree in each diameter class be defined by the row vector q, then the basal area cut from the forest is given by $Z_q = qH$. The optimum harvest and the residual stock under sustained yield are obtained by solving a linear programming problem.

Maximize $Zq = qH$, subject to

(i) $Y - G(Y - H) = U$

(ii) $Y - H \geq 0$

**Contributions to Scholarship**

Mr. Vice-Chancellor Sir, I will now proceed to give a brief account of my contributions in the development/application of my models to forestry. Indeed, the biggest challenge in building matrix models for growth and yield is the construction of biologically realistic transition matrices.

In my work, I assumed that the transition matrices do not change with successional stages or with local edaphic conditions. This assumption is generally true, since the presence of a particular species in the canopy is itself a fairly accurate indicator of local conditions of shade, drainage, soil texture, nutrients and associated plants.

Further assumptions I made included:

(i) First, that in any tree community, all are capable of replacing each other. The art of replacement is based on randomness, gap formations and availability of propagules. The matrix developed under these assumptions was denoted by *M* 1.

$$MI = \begin{bmatrix} P_{11} & P_{12} & \cdot & \cdot & \cdot & P_{16} \\ P_{21} & P_{22} & \cdot & \cdot & \cdot & P_{26} \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ P_{61} & P_{62} & \cdot & \cdot & \cdot & P_{66} \end{bmatrix}$$

........................................... (22)

*M*1 (6x6) is a square matrix whose rows and columns represent the six tree species composition. $P_{ii}$ is the probability that a tree species *i* is replaced by another tree of its own kind after a growth period *t*, *i* = 1….6. $P_{ij}$ is the probability that a species *i* is replaced by another species *j* at the end of the growth period *t* (*i*, *j* = 1, 2, …, 6), such that

$$\sum_{i=1}^{6} P_{ij} = 1 \qquad \text{for } j = 1 \ldots 6$$

$$P_{ii} = {n_i(t)}/{n_i(0)}, \quad i = 1 \ldots 6, \quad \text{and}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (23)$$

$$P_{ij} = \frac{(1 - P_{ii})R_j}{\sum_{j=1}^{6} R_j}$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (24)$$

such that:

$$\sum_{j=i,i\neq j} P_{ij} = (1 - P_{ii}), \qquad i = 1 \ldots 6 \text{ and}$$

$n_i(0) =$ Number of live trees of species $i$ at the beginning of the growth period

$n_i(t) =$ Number of live trees of species $i$ at the end of the growth period $t$

$R_j$ = Number of recruitments of species $j$

(ii) Second, I introduced a hierarchical replacement procedure whereby the tree community is classified into canopy classes of lower/under storey, middle and top canopy. Species in the lower canopy cannot in the long run replace higher canopy species. This is because most trees in the lower canopy class are one generation species, while trees in the higher canopy class are the known permanent residents of mature natural tropical rain forests. The matrix developed under these assumptions was denoted my *M* 2:

$$M2 = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} & P_{15} & P_{16} \\ 0 & P_{22} & P_{23} & P_{24} & P_{25} & P_{26} \\ 0 & 0 & P_{33} & P_{34} & P_{35} & P_{36} \\ 0 & 0 & 0 & P_{44} & P_{45} & P_{46} \\ 0 & 0 & 0 & 0 & P_{55} & P_{56} \\ 0 & 0 & 0 & 0 & 0 & P_{66} \end{bmatrix}$$

.................................... (25)

whose rows and columns represented the six species. $P_{ij}$ are replacement probabilities.

$$P_{ii} = \frac{R_i}{n_i(0)}, \qquad i = 1 \ldots 6$$

$$P_{ij} = (1 - P_{ii}) x w_j, \qquad i \neq j, \qquad j = i = 1 \ldots 6$$

with $P_{ij} = 0$ **for** $i > j$

> $w_j$ = Species *j*'s relative tree vigour as measured by Mean Annual Increment (MAI) of the tree diameter.

Matrix models *M* 1 and *M* 2 were applied to a tropical rainforest in Idanre Forest Reserve in Ondo State, Nigeria. Input data came from the Forestry Research Institute of Nigeria, and spanned a growth period from 1956 – 1974. Models *M* 1 predicted that the top canopy species would replace the under-storey species within 50 years of undisturbed growth. On the other hand, *M* 2 predicted that the under-storey and middle-canopy would drop out between 40 and 60 years of the replacement stage of secondary succession, while the upper canopy species would be expected to die off between 100 and 150 years.

If we combine the expected lengths of stay in the population from both *M* 1 and *M* 2, the under-storey and middle-canopy species would have about 100 years and the top canopy species between 200 and 250 years. These predictions for the species are very close to their known life spans (Richards 1957; Walter 1964; Vanclay 1991).

It is well known that the rate of the process of replacement is very fast near the beginning of the succession but slows as vegetation becomes more mature and the lifespan of dominant species longer. These models thus successfully simulated the processes of the development of a real tropical rain forest. The results of the simulations are shown in figures 2 – 4.

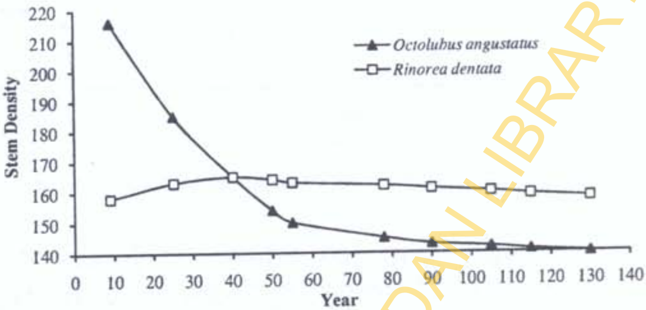



**Fig. 2:** Projected population sizes of the under-storey species

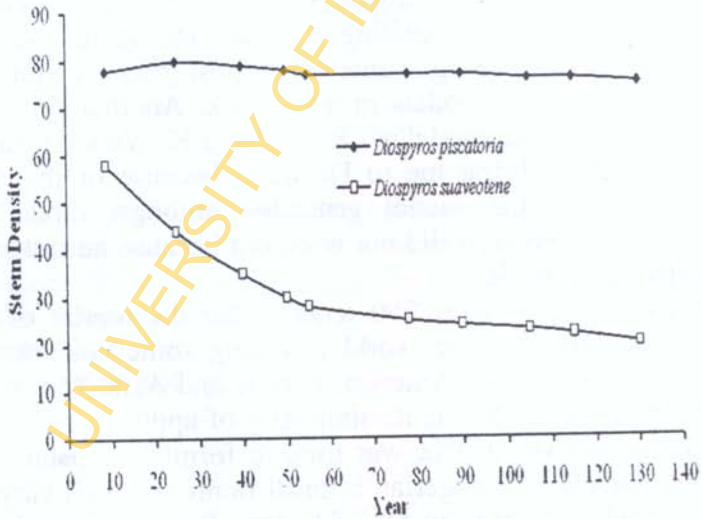



**Fig. 3:** Projected population sizes of the middle-storey species

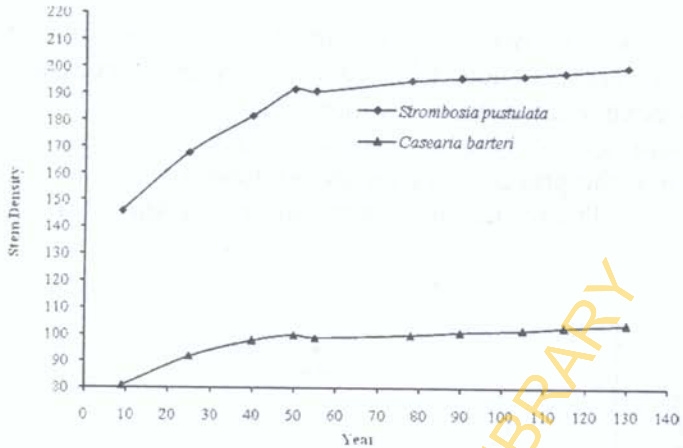



**Fig. 4:** Projected population sizes of the top-canopy species

I was pleasantly surprised when the Professor and Director of the Centre of African Ecology, the University of Witwatersrand, South Africa requested for my paper on Population Growth Matrix in 1993, a time when apartheid rule was still in place in South Africa. I subsequently ended up in the centre as a visiting scientist and spent fourteen months in Johannesburg. Some of the post-graduate students adopted my matrix models in their work. Another foremost Growth and Yield modeller, Professor J.K. Vanclay made frantic effort to bring me to Denmark because of the high promise which the model generated amongst modellers. However, the proposal did not work out because he suddenly relocated to Australia.

I also received over 250 requests for the reprint of the paper from all over the world including some countries in North America, South America, Europe and Asia. The major attribute of the work was its simplicity of application. A tree population growth matrix was used to formulate sustainable harvest models in a Nigerian tropical rainforest with varying cutting cycles of between 18 – 54 years. Results showed that 36-year rotation was the best instead of the current practice of 50 years (Osho 1995).

## Conclusion and Recommendations

There is great concern over the eventual loss of the tropical rain forest in Nigeria. The ever-increasing pressure from state governments for Internally Generated Revenue (IGR) derivable from logging forced the forestry officials to break the rules of sustainable management of the forests. The present policy of 100% removal of all trees of merchantable sizes is over-exploitative of the timber resources of the forest (Osho & Akinsanmi 1990), no matter the cutting cycle.

The lowering of diameter limits for timber harvesting from the present 48cm to 30cm could be helpful but has to be coupled with a 50% reduction in the quantity of harvest from all the new merchantable classes. Although appropriate machines to convert smaller diameter logs are not available, we could encourage local manufacturers to direct their efforts to make such machines.

There is another major effect of the abuse of our forests such as the effect on global climatic patterns, loss of or reduced ability to sequester carbon leading to the greenhouse effect. Deforestation reduces the ability of a country to achieve sustainable economic development. We all remember the damages inflicted on our infrastructures as a result of flood that ravaged some areas of Lagos and Oyo States recently.

Are there remedies? Maybe.

If we improve on the tree planting programme. Surely, tree planting will enhance tree stocking/vegetation cover (Akindele 2010). However, this cannot be achieved unless there is adequate supervision and good extension services. Government should put in place a technical board to carry out the maintenance of the planted trees.

To date, Nigeria has no National Forestry Act. We are still using the old act handed down to us by our colonial masters. We implore the National Assembly to pass the National Forestry Act Bill submitted since year 2000. The expected National Forestry Act should clearly spell out the Annual Allowable Cut which can fully restore the productivity of the natural tropical rain forest.

Some well-placed foresters have themselves undermined the development of forestry in Nigeria. We agreed that a single tree cannot make a forest. Why do we still have a single Forestry Research Institute of Nigeria to solve all the challenges facing forestry development in Nigeria? This is not realistic; we need more forestry research institutes in Nigeria. The new institutes should include:

(i) Institute of Forest Biology and Silviculture
(ii) Nigerian Institute of Ecology
(iii) Institute of Forest Economics/Management
(iv) Institute of Wildlife
(v) Institute of Forest Surveys

All forest reserves in each state should be jointly managed by an agency through Public Private Participation (PPP) as is being done in other countries of the world. Adequate compensation should be paid to the local communities who own the forest lands. How can you legislate and manage a resource that is owned by someone else?

Finally, more mathematicians and statisticians should be encouraged to come and help look into the mysteries surrounding the disappearance of the old dense jungles of the natural tropical rainforests in Nigeria. The tree climbers, the taxonomists and the silviculturist cannot alone navigate very easily in these jungles.

Most experiments on growth and yield take far much longer than the lifespan of the individual forest scientist. However, the simulation studies of the 'mathematical forester' can use computers even in the midnight to look into decades/centuries of forest growth for some useful information.

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## BIODATA OF
## PROFESSOR JOHNSON AJOSE OSHO

Johnson Ajose Osho was born on 6th December, 1949 in Itapa Ekiti, Oye Ekiti Local Government Area of Ekiti State, Nigeria.

He had his primary education at the Methodist Primary School, Itapa Ekiti (1960) and part of his secondary school education in Ekiti Parapo College, Ido Ekiti (1964). He secured admission to the University of Ife (now Obafemi Awolowo University) and graduated with a B.sc Honours degree in Mathematics (second class lower division) in 1971.

He proceeded to the U.S.A to study statistics at the famous Snedecor Statistical Laboratory, Iowa State University Ames, where he obtained his M.Sc. Statistics in 1977.

Professor Osho joined the University of Ibadan as Lecturer II on 1st March, 1984. Between 1984 and 1988, he worked on his PhD degree programme under collaborative arrangements with three universities:

(i) University of Ibadan, Nigeria
(ii) University College of North Wales, Bangor, U.K
(iii) Swedish University of Agricultural Sciences, Sweden

He became a senior lecturer in 1990 and was promoted a Professor in 1998. Professor Osho has held many administrative positions in the University of Ibadan and other universities:

(1) Sub-Dean (Forestry), Faculty of Agriculture and Forestry (1987/1989);
(2) Ag. HOD, Department of Forest Resources Management (1997 – 1999);
(3) Substantive HOD, Department of Forest Resources Management (2002 – 2005);
(4) Chairman, Campus Tree Management Committee (2002 – 2005);

(5) Head of Department, Mathematics/Statistics, Cross River University of Technology Calabar—while he was on sabbatical leave (2007);
(6) Current Hall Master, Obafemi Awolowo Hall.

Professor Osho was a recipient of:

(1) The Federal Government Scholarship for Undergraduate (1969 – 1971);
(2) The Federal Government Scholarship for Postgraduate (1975 – 1977);
(3) The British Council Higher Education Award, tenable at the University College of North Wales Bangor;
(4) Fellowship by the Swedish Institute, at the Swedish University of Agricultural Sciences (1987/1988);
(5) The Award of Mellon Foundation Fellowship at the Centre for African Ecology, The University of Witwatersrand, Johannesburg South Africa (1993/1994).
(6) He had the privilege to be in Stockholm during the award of the nobel prize in literature to Professor Wole Shoyinka. Professor Osho has over 50 publications comprising mainly journal articles and a few conference proceedings and technical reports.