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Timber-flow Policy Models for the Management of *Nauclea diderrichii* stands in Omo Forest Reserve

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ABSTRACT

Timber-flow policy model was developed and used to investigate three timber-flow policies (free-flow, even-flow and accelerated cut policies) for the management of *Nauclea diderrichii* stands in Omo Forest Reserve, Nigeria throughout a planning period of 20years. To achieve this, 33 temporary sample plots (20m x 20m) were randomly laid in stands of *Nauclea*, aged 7, 8, 10, 24, 25, 27 and 29 years. In each sample plot, complete enumeration and measurement of all trees were carried out. The growth data sets collected include diameters at breast height, base, middle and top; total and merchantable heights of all trees. The data collected were processed to obtain expected stem volume per hectare at four 5-year intervals. The results were then used for the formulation of timber-flow policy models. The models were solved using the linear programming option of the Quantitative System for Business Plus (QSB+) package. The results of the three timber-flow policies are discussed. The most appropriate timber-flow obtained in this study is the even-flow policy.

Keywords: *Nauclea diderrichii*, Omo Forest Reserve, policy, timber-flow

INTRODUCTION

Management policy plays an important role in forestry, and indeed economy of any nation, by providing decisions on the courses of action which ensure effective utilization of forest resources. Because of the complexity of forestry systems, foreseeing the likely consequences of a particular decision is not an easy task. The resource allocations that result from policy making are almost invariably irreversible and have substantial economic impacts on investment, benefit flows, environment and community activities. In such situations, models help policy makers predict the consequences of their decisions before implementation. According to Hoganson and Burk (1997), a model is a simplified representation of reality. Models are tools with which one can experiment and learn about a specific problem situation.

Policy makers can carry out experiments with the model that would be impossible in reality. A type of model applicable in forest management is timber-flow patterns which can be tried on a forest model and observe the consequences, a thing that is practically impossible with the real forest. This ability to experiment, predict and choose from alternative courses of action makes the art of modelling an exciting field, with great potentials for policy making.

Optimization models used in forest management planning are often referred to as forest management scheduling models. This is a misnomer because these models have many potential roles in decision-making, far beyond the development of specific management schedules. They can be used to examine a range of issues including various forest policy options, industry expansion and wood utilization options as well as the potential impacts of new silvicultural management systems (Hoganson and Burk 1997).

Currently, most policy-making processes, especially in Nigerian Forestry are subjective, lacking relevant quantitative information for objectivity. To date, relatively little research has focused on modelling timber-flow policies with a view to analyzing their efficiency. These include Schweitzer *et al.* (1972), Teeguarden (1973), Walker (1977) and Nelson *et al.* (1991). These works ranged from effects of allowable cuts to economic assessment of harvest flow. Without specific timber-flow pattern, linear programming solutions may give erratic patterns of production over time.

Nauclea diderrichii is one of the major indigenous tropical hardwood species grown in plantations in the high forest zone of Nigeria. It is the source of transmission poles and the well known timber called Opepe. Very few hundred of hectares of *Nauclea diderrichii* trees exist in Omo forest reserve. Policies on logging in Nigeria over a long time have been made without opportunity of prior investigation of the likely consequences of such policy. There is therefore the need to develop models to study policies controlling the flow of timber production from the forest. This will enhance the decision-making process of the policy makers. This study was carried out to investigate three timber-flow policies, namely, free-flow, even-flow and accelerated cut policies. The timber-flow policy models were fitted to *Nauclea diderrichii* data set obtained from Omo forest reserve, Nigeria. It is hoped that knowledge gained in this study will be of help to forest managers and policy makers.

MATERIALS AND METHODS

Study Area

The study was carried out in Omo forest reserve, Ogun State, Nigeria. It is situated between latitudes 6° 42′ and 7° 00′ N and longitudes 4° 17′ and 4° 25′ E. The reserve shares its northern boundary with Osun and Ago Owu forest reserves in Osun State and Oluwa forest reserve in Ondo State. The Omo and Oni rivers mark the southern boundary. The topography of the reserve is generally gently undulating with average elevation of 125m above sea level (Akindele and Abayomi, 1993). The general geology of the reserve is undifferentiated basement complex with outcrops of older granites in some places (Anon. 1964). This study covers the existing *Nauclea diderrichii* plantations in Omo which form two age series, the 1970s and the 1990s series.

Field Sampling

Due to the fact that suitable permanent sample plots (for this study) are not available for the *Nauclea* plantations in the study area, data were collected from temporary sample plots. A modified simple random sampling method was used. Specified number of sampling units (called sample plots) was purposively allocated to the *Nauclea* plantations, but they were randomly located within each stand. The random allocation of sample plots within each stand was to ensure the validity of the usual tests of significance of the final models (Weisberg, 1985). Each sample plot was 20 m X 20 m (i.e. 0.04ha) in size. A total of 33 sample plots were laid in the plantations established in 1993, 1992, 1990, 1976, 1975, 1973 and 1971. The data were collected in 2000, and in each sample plot, complete enumeration and measurement of all trees were carried out. The growth data sets collected include diameters at breast height, base, middle and top, total and merchantable heights of all trees within each plot.

Data Processing

The data collected were processed as follows:

Basal Area Calculation

The basal area of each tree was calculated from the dbh measurement using the formula:

$$BA = \pi D^2/4 \quad \ldots\ldots\ldots\ldots\ldots\ldots \textit{eqn.1}$$

Where, BA= Basal area (m^2)

$\pi = 3.142$

D = Diameter at breast height (m)

For each plot, the total basal area was multiplied by 25 to convert it to basal area per hectare, since each plot is 0.04ha.

Volume Computation

The volume of each tree was calculated using Newton's formula:

$$V = \frac{h}{6}\left[A_b + 4A_m + A_t\right] \quad \ldots\ldots\ldots\ldots\ldots \textit{eqn.2}$$

Where, V = Volume (m^3)

h = Merchantable height (m)

A_b, A_m and A_t = Cross sectional area at the base, middle and top respectively of the trees.

The total plot volume was multiplied by 25 to obtain volume per hectare for each plot.

Site Index Estimation

The site index of each plot was estimated using the model:

$$SI = Exp\left(\ln H_d - b_1\left(A^{-1} - A_i^{-1}\right)\right) \quad \ldots\ldots\ldots \textit{eqn.3}$$

Where, SI = Site index (m)

H_d = Dominant height (m)

A = Present age

A_i = Index age (which is 25 years in this study).

The volume per hectare, basal area per hectare, age and site index values were used to calibrate yield model for estimating both current and future yields. The Regression option of STATISTICA software was used. A linear programming model for examining timber-flow policies was also formulated. The model was used to obtain management strategies that maximize the stem volume of *Nauclea* stands under three timber-flow policies. The linear programming option of the Quantitative System for Business plus (QSB+) package was used to obtain solutions.

Model Development

Model development in this study involves:

(1) The development of suitable yield model for estimating expected yield at specified point in time in the future. Data from six stands were used for model calibration, while data from the oldest stand (i.e. stand established in 1971) was reserved for validation.

(2) The development of timber-flow policy models. This involves choice of decision variables to symbolize decisions, stating the objective and the constraints (Leuschner 1990, Hof 1993). The decision variables that define the future management strategy most simply are the areas cut from each initial stand in every period of the plan (in this study, 20 years). In order to keep the number of variables relatively small, a sufficiently long lapse of time of 5-year-operating periods was chosen. This will lead to decision variables of the form: $X_{i,j}$; Where, $X_{i,j}$ = area cut from stand i in period j.

There are twenty-eight of such variables in this study, since the study covered seven stands, and there are four 5-year operating periods. The expression of the objective function is

$$Max\,Z_n = \sum_{i=1}^{n=7}\sum_{j=1}^{p=4} V_{i,j} X_{i,j} \qquad \text{eqn.4}$$

Where. Z_n = Stem volume per hectare

$V_{i,j}$ = Expected volume per hectare in stand i and period j

$X_{i,j}$ is as earlier defined

There are two kinds of constraints in this model:

(a) Land availability constraints – this states that the area of land that is cut in each stand cannot exceed area available

(b) Timber-flow policy constraint – this expresses the pattern of flow of timber during the period of the plan. In this study, we have three timber-flow policies that will be investigated one at a time, free-flow, even-flow and accelerated cut policies.

The final form of the model is:

$$Max.Z_n = V_{1,1}X_{1,1} + V_{1,2}X_{1,2} + V_{1,3}X_{1,3} + V_{1,4}X_{1,4} + V_{2,1}X_{2,1} + V_{2,2}X_{2,2} + V_{2,3}X_{2,3} + V_{2,4}X_{2,4} + V_{3,1}X_{3,1} + V_{3,2}X_{3,2} + V_{3,3}X_{3,3} + V_{3,4}X_{3,4} + V_{4,1}X_{4,1} + V_{4,2}X_{4,2} + V_{4,3}X_{4,3} + V_{4,4}X_{4,4} + V_{5,1}X_{5,1} + V_{5,2}X_{5,2} + V_{5,3}X_{5,3} + V_{5,4}X_{5,4} + V_{6,1}X_{6,1} + V_{6,2}X_{6,2} + V_{6,3}X_{6,3} + V_{6,4}X_{6,4} + V_{7,1}X_{7,1} + V_{7,2}X_{7,2} + V_{7,3}X_{7,3} + V_{7,4}X_{7,4} \qquad \text{eqn.5}$$

Subject to:

(a) *Land availability:*

$$X_{1,1} + X_{1,2} + X_{1,3} + X_{1,4} \le A \qquad \text{eqn.6}$$

(i.e. available area in stand aged 7 years = 26.50ha)

$$X_{2,1} + X_{2,2} + X_{2,3} + X_{2,4} \le B \qquad \text{eqn.7}$$

(i.e. available area in stand aged 8 years = 44.23ha)

$$X_{3,1} + X_{3,2} + X_{3,3} + X_{3,4} \le C \qquad \text{eqn.8}$$

(i.e. available area in stand aged 10 years = 20.95ha)

$$X_{4,1} + X_{4,2} + X_{4,3} + X_{4,4} \le D \qquad \text{eqn.9}$$

(i.e. available area in stand aged 24 years = 44.50ha)

$$X_{5,1} + X_{5,2} + X_{5,3} + X_{5,4} \le E \qquad \text{eqn.10}$$

(i.e. available area in stand aged 25 years = 28.00ha)

$$X_{6,1} + X_{6,2} + X_{6,3} + X_{6,4} \le F \qquad \text{eqn.11}$$

(i.e. available area in stand aged 27 years = 50.50ha)

$$X_{7,1} + X_{7,2} + X_{7,3} + X_{7,4} \le G \qquad \text{eqn.12}$$

(i.e. available area in stand aged 29 years = 45.60ha)

[*Note:* The area data stated above are secondary data obtained from Ogun State Forestry Plantation Project, Omo in 1999].

(b) Timber-flow

(i) Free-flow policy: this implies that no constraint limit timber-flow during each period of the plan. Hence, in the first investigation, there will be no timber-flow constraint.

(ii) Even-flow policy: this implies that timber-flow must be the same during each period of the plan. This is mathematically expressed as:

$$a_1 = a_2;\ a_2 = a_3;\ a_3 = a_4$$

$$a_1 = V_{1,1}X_{1,1} + V_{2,1}X_{2,1} + V_{3,1}X_{3,1} + V_{4,1}X_{4,1} + V_{5,1}X_{5,1} + V_{6,1}X_{6,1} + V_{7,1}X_{7,1} \qquad \text{eqn 13}$$

(i.e. possible total volume cut during the first 5 years)

$a_2 = V_{1,2}X_{1,2} + V_{2,2}X_{2,2} + V_{3,2}X_{3,2} + V_{4,2}X_{4,2} + V_{5,2}X_{5,2} + V_{6,2}X_{6,2} + V_{7,2}X_{7,2}$ .... *eqn 14*
(i.e. possible total volume cut during the second 5 years)

$a_3 = V_{1,3}X_{1,3} + V_{2,3}X_{2,3} + V_{3,3}X_{3,3} + V_{4,3}X_{4,3} + V_{5,3}X_{5,3} + V_{6,3}X_{6,3} + V_{7,3}X_{7,3}$ .... *eqn 15*
(i.e. possible total volume cut during the third 5 years)

$a_4 = V_{1,4}X_{1,4} + V_{2,4}X_{2,4} + V_{3,4}X_{3,4} + V_{4,4}X_{4,4} + V_{5,4}X_{5,4} + V_{6,4}X_{6,4} + V_{7,4}X_{7,4}$ .... *eqn 16*
(i.e. possible total volume cut during the fourth 5 years)

(iii) Accelerated-cut policy: this is a compromise between free-flow and even-flow. Timber flow must not be less during each period. It may however be higher. This is mathematically expressed as:

$a_2 \geq a_1,\ a_3 \geq a_2,\ a_4 \geq a_3$
a_1, a_2, a_3 and a_4 are as earlier defined.

Algorithm for the Timber-flow Policy Model

The timber-flow policy model developed in this study was based on linear programming technique. Hence one of the appropriate algorithms for solving the model is the simplex method. The method is based on a steepest-ascent algorithm. The first step of the simplex method is to transform all inequalities in the model into equalities. This is done because equalities are much easier to handle, mathematically. This step is often stated as introduction of slack variables.
The second step involves finding an initial feasible solution. The next step involves moving from one extreme point to an adjacent extreme point in the direction that maximizes the change in the objective function Z_{sv}. This step is repeated if there is improvement in the objective function. The iterations continue until no improvement in Z_{sv} occurs, indicating that the optimum solution has been obtained in the penultimate iteration.
The mathematical computations involved in the simplex method could be laborious. However with the advent of the computers and their use in optimization models, complex problems can be solved routinely.

RESULTS

The prediction equation obtained in this study, suitable for current and future yield prediction is given by:

$\ln SV = 6.2732 - 22.3343A^{-1}$ *eqn.17*
Where, SV = Stem volume per hectare (m^3/ha)
A = Stand age (years).

The coefficient of determination (R^2) and mean square error (MSE) are given as 0.6404 and 0.5483 respectively. Although, site index was used in calibration, it was not significant in the model. The basal area variable gave a good fit when included in the model but requires series of equations to estimate the future stand density.

Validation Test

The results of validation test for the yield model for future volume prediction are presented as follows:

Table 1: Validation of equation 17:
$\ln SV = 6.2732 - 22.3343A^{-1}$

	Mean	N	df	t-value	p-value
Observed SV	281.90	5	8	0.7673	0.4649 (ns)
Predicted SV	245.44	5			

ns = not significant at α = 0.05

Equation 17 was used to compute the expected volume (m^3/ha) of *Nauclea diderrichii* stands in Omo Forest Reserve. This represents the potential quantity of *Nauclea* available in each stand per unit area, throughout the planning period of 20 years at 5-year interval.

Table 2: Expected volume of *Nauclea* stands

Stand	Volume (m^3/ha)			
	1st Interval	2nd Interval	3rd Interval	4th Interval
1993	82.43	142.51	192.10	231.83
1992	95.12	153.30	200.77	238.78
1990	119.61	173.55	216.99	251.82
1976	245.44	274.87	299.02	319.13
1975	251.82	280.08	303.34	322.75
1973	263.82	289.91	311.51	329.64
1971	274.87	299.02	319.13	336.10

The timber-flow policy model for the management of *Nauclea diderrichii* is given as :

Find $X_{1,1}$, $X_{1,2}$, $X_{1,3}$, ... , $X_{7,4}$ all non-negative, such that:

$$Max.Z_{sv} = 82.43X_{1,1} + 142.51X_{1,2} + 192.10X_{1,3} + 231.83X_{1,4} + 95.12X_{2,1} + 153.30X_{2,2} + 200.77X_{2,3} + 238.78X_{2,4} + 119.61X_{3,1} + 173.55X_{3,2} + 216.99X_{3,3} + 251.82X_{3,4} + 245.44X_{4,1} + 274.87X_{4,2} + 299.02X_{4,3} + 319.13X_{4,4} + 251.82X_{5,1} + 280.08X_{5,2} + 303.34X_{5,3} + 322.75X_{5,4} + 263.82X_{6,1} + 289.91X_{6,2} + 311.51X_{6,3} + 329.64X_{6,4} + 274.87X_{7,1} + 299.02X_{7,2} + 319.13X_{7,3} + 336.10X_{7,4}$$

.... *eqn.18*

Subject to:

Land availability

$X_{1,1} + X_{1,2} + X_{1,3} + X_{1,4} \leq 26.50ha$ *eqn.19*

$X_{2,1} + X_{2,2} + X_{2,3} + X_{2,4} \leq 44.23ha$ *eqn.20*

$X_{3,1} + X_{3,2} + X_{3,3} + X_{3,4} \leq 20.95ha$ *eqn.21*

$X_{4,1} + X_{4,2} + X_{4,3} + X_{4,4} \leq 44.50ha$ *eqn.22*

$X_{5,1} + X_{5,2} + X_{5,3} + X_{5,4} \leq 28.00ha$ *eqn.23*

$X_{6,1} + X_{6,2} + X_{6,3} + X_{6,4} \leq 50.50ha$ *eqn.24*

$X_{7,1} + X_{7,2} + X_{7,3} + X_{7,4} \leq 45.60ha$ *eqn.25*

Timber-flow policy

(1) **Free-flow policy:** i.e. no constraint limits timber flow.

(2) **Even-flow policy:**

$$142.51X_{1,2} + 153.30X_{2,2} + 173.55X_{3,2} + 274.87X_{4,2} + 280.08X_{5,2} + 289.91X_{6,2} + 299.02X_{7,2} - 82.43X_{1,1} - 95.12X_{2,1} - 119.61X_{3,1} - 245.44X_{4,1} - 251.82X_{5,1} - 263.82X_{6,1} - 274.87X_{7,1} = 0$$

.... *eqn.26*

$$192.10X_{1,3} + 200.77X_{2,3} + 216.99X_{3,3} + 299.02X_{4,3} + 303.34X_{5,3} + 311.51X_{6,3} + 319.13X_{7,3} - 142.51X_{1,2} - 153.3X_{2,2} - 173.55X_{3,2} - 274.87X_{4,2} - 280.08X_{5,2} - 289.91X_{6,2} - 299.02X_{7,2} = 0$$

.... *eqn.27*

$$231.83X_{1,4} + 238.78X_{2,4} + 251.82X_{3,4} + 319.13X_{4,4} + 329.64X_{6,4} + 336.10X_{7,4} - 192.1X_{1,3} - 200.77X_{2,3} - 216.99X_{3,3} - 299.02X_{4,3} - 303.34X_{5,3} - 311.51X_{6,3} - 319.13X_{7,3} = 0$$

.... *eqn.28*

(3) **Accelerated -cut policy:**

$$142.51X_{1,2} + 153.30X_{2,2} + 173.55X_{3,2} + 274.87X_{4,2} + 280.08X_{5,2} + 289.91X_{6,2} + 299.02X_{7,2} - 82.43X_{1,1} - 95.12X_{2,1} - 119.61X_{3,1} - 245.44X_{4,1} - 251.82X_{5,1} - 263.82X_{6,1} - 274.87X_{7,1} \geq 0$$

.... *eqn.26*

$$192.10X_{1,3} + 200.77X_{2,3} + 216.99X_{3,3} + 299.02X_{4,3} + 303.34X_{5,3} + 311.51X_{6,3} + 319.13X_{7,3} - 142.51X_{1,2} - 153.3X_{2,2} - 173.55X_{3,2} - 274.87X_{4,2} - 280.08X_{5,2} - 289.91X_{6,2} - 299.02X_{7,2} \geq 0$$

.... *eqn.27*

$$231.83X_{1,4} + 238.78X_{2,4} + 251.82X_{3,4} + 319.13X_{4,4} + 322.75X_{5,4} + 329.64X_{6,4} + 336.10X_{7,4} - 192.1X_{1,3} - 200.77X_{2,3} - 216.99X_{3,3} - 299.02X_{4,3} - 303.34X_{5,3} - 311.51X_{6,3} - 319.13X_{7,3} \geq 0$$

.... *eqn.28*

The solutions of the policy models under the three timber-flow policies investigated are presented in Tables 3, 4 and 5. The tables express the area cut in every stand and period.

DISCUSSIONS

For sound management decisions and sustainable timber flow policy, there is need to fully understand the potentials of mathematical programming as applied to timber flow decision – making. According to Hoganson and Burk (1997), to make applications of forest management models practical, direct linkage to a forest growth model is required. Hence in this study, obtaining a prediction equation for both current and future yields was considered a very significant prerequisite for assessing timber-flow policy models.

The yield model developed is simple and suitable for prediction purposes. The model has relatively high R^2 value (64.04) with lower value of mean square error (0.5483). The validation test showed that there were no significant differences between the observed and the predicted values obtained from the yield model (eqn.1). Thus, the model is considered appropriate for predicting future yields at specified points in time.

The timber flow-policy models developed and investigated in this study were aimed at studying the timber flow patterns (with respect to harvesting and

Table 3: Optimal Logging Plan under Free-flow policy

Stand		Area Cut (ha) per period			
		1st Period	2nd Period	3rd Period	4th Period
1993	Stock	26.50	26.50	26.50	26.50
	Cut	0	0	0	26.50
1992	Stock	44.23	44.23	44.23	44.23
	Cut	0	0	0	44.23
1990	Stock	20.95	20.95	20.95	20.95
	Cut	0	0	0	20.95
1976	Stock	44.50	44.50	44.50	44.50
	Cut	0	0	0	44.50
1975	Stock	28.00	28.00	28.00	28.00
	Cut	0	0	0	28.00
1973	Stock	50.50	50.50	50.50	50.50
	Cut	0	0	0	50.50
1971	Stock	45.60	45.60	45.60	45.60
	Cut	0	0	0	45.60
Total	Stock	260.28	260.28	260.28	260.28
	Cut	0	0	0	260.28

Table 4: Optimal logging plan under Even-flow policy

Stand		Area Cut (ha) per period			
		1st Period	2nd Period	3rd Period	4th Period
1993	Stock	26.50	26.50	26.50	26.50
	Cut	0	0	0	26.50
1992	Stock	44.23	44.23	44.23	44.23
	Cut	0	0	0	44.23
1990	Stock	20.95	20.95	20.95	2.34
	Cut	0	0	18.61	2.34
1976	Stock	44.50	44.50	44.34	0
	Cut	0	0.16	44.34	0
1975	Stock	28.00	28.00	0	0
	Cut	0	28.00	0	0
1973	Stock	50.50	32.45	0	0
	Cut	18.05	32.45	0	0
1971	Stock	45.60	0	0	0
	Cut	45.60	0	0	0
Total	Stock	260.28	196.63	136.02	73.07
	Cut	63.65	60.61	62.95	73.07

hence regeneration) under three flow policies and having the goal for volume maximization. Table 3 shows the sequence of harvest that maximizes the volume of *Nauclea* under free flow policy. The entire 260.28ha will be cut only during the last five years of the plan. Thus, during the 1st, 2nd and 3rd five years, none of the stand will be cut. This policy does not appear to be reasonable. This kind of production can lead to congestion of logs and hence depression in economic value (or stumpage price) of *Nauclea* trees.

This will in fact be an illegal policy in a national or state forest, because it does not fulfill the non-declining even-flow policy. Table 4 shows the sequence of harvest that will maximize stem volume of *Nauclea* under even-flow policy. A strict interpretation of this policy requires that the production of the forest be the same during each period of the cut. This policy in a way slow down liquidation of stands, or better still, regularize

Table 5: Optimal logging plan under Accelerated cut policy

Stand		Area Cut (ha) per period			
		1st Period	2nd Period	3rd Period	4th Period
1993	Stock	26.50	26.50	26.50	26.50
	Cut	0	0	0	26.50
1992	Stock	44.23	44.23	44.23	44.23
	Cut	0	0	0	44.23
1990	Stock	20.95	20.95	20.95	20.95
	Cut	0	0	0	20.95
1976	Stock	44.50	44.50	44.50	44.50
	Cut	0	0	0	44.50
1975	Stock	28.00	28.00	28.00	28.00
	Cut	0	0	0	28.00
1973	Stock	50.50	50.50	50.50	50.50
	Cut	0	0	0	50.50
1971	Stock	45.60	45.60	45.60	45.60
	Cut	0	0	0	45.60
Total	Stock	260.28	260.28	260.28	260.28
	Cut	0	0	0	260.28

production of stands from one cutting period (i.e. 5-year interval) to another throughout the planning period. Economically the value of the trees is effectively controlled through steady supply. This finding is similar to the findings of Kaiser (1997). Table 5 shows the sequence of harvest that maximizes stem volume under accelerated cut policy. The pattern of harvest is identical with the solution obtained under free-flow policy. The policy is however suitable to a forest in which there is a large amount of over matured timber, that grow little in value either physically or economically. This is obviously not the case in this study. The entire stand (according to the solution obtained under this policy) will be cut during the last five years of the plan. Again this will lead to congestion of logs and does not appear sensible.

A thorough appraisal of the solutions of the three timber-flow policies reveals that even-flow is the most appropriate. This policy ensures sustained timber production and a non-declining timber-flow. In addition to this, the policy is environmentally friendly since forest removal at a point in time is minimal compared to the other two policies. Forest removal increases the magnitude and intensity of net radiation reaching the soil surface. Ghuman and Lal (1987) observed that in the south central Nigeria, on average, 10.5 and 11.5 MJ/m^2/day of insolation were received on a cleared site compared to 0.4 and 0.3 MJ/m^2 day in the forest during the dry seasons of 1984 and 1985 respectively. There is no doubt that there are high and widely varied demands and expectations on biological resources. These however call for more rational and objective approaches that go beyond merely reacting to resource crises and concerns in an environmentally unfriendly and unsustainable manner. This is in line with Szaro and Salwasser (1991), Szaro (1992) and Ferguson (1996).

CONCLUSION

This study has provided information on modelling timber-flow policies for the management of *Nauclea diderrichii* plantations in Omo Forest Reserve. The model was expanded to investigate three timber-flow policies: free flow, even flow and accelerated cut policies. It was shown that in the absence of any constraint on the flow of timber over (i.e. free flow policy) and also under accelerated cut policy, harvesting is restricted only to the last 5-year period of the plan. Under a strict even-flow policy, harvesting was spread throughout the period of the plan. This appears to be the appropriate timber-flow policy for the *Nauclea* stands in Omo forest reserve.

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