This is to certify that the

thesis entitled

A Proposed Management Model for Brazil's
Tapajos National Forest

presented by

Jorge Paladino Correa de Lima

has been accepted towards fulfillment
of the requirements for

Ph.D. degree in Forestry

Victor J. Rudolph
Major professor

Date July 21, 1981

A PROPOSED MANAGEMENT MODEL FOR BRAZIL'S TAPAJOS NATIONAL FOREST

BY

Jorge Paladino Corrêa de Lima

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1981

ABSTRACT

A PROPOSED MANAGEMENT MODEL FOR BRAZIL'S TAPAJOS NATIONAL FOREST

By

Jorge Paladino Corrêa de Lima

Brazil's Amazon region contains the largest tropical forest resource in the world. To change the present pattern of exploiting this resource without planning for its continuous production, the Brazilian government established its first national forest, the 531,200 hectare Tapajos National Forest near Santarem in the state of Para, to serve as a pilot project for multiple use and sustained yield. This study presents the development and proposed application of a simulated forest management model for that forest.

The computer - simulated management model is called TAPAFOR, and consists of one main program and twelve subroutines. The various subroutines simulate management activities and stand growth, and generate various outputs. Major components of the simulation model include harvesting and silvicultural operations, stand growth predictions, and economic considerations. Short-term and long-term goals for

managing t

evaluating

included v

cycle leng

and close

in develop

Since

Forest are

forestry l

Forest by

in develop

results, t

total volu

residual

assumed to

and differ

trees larg

Based

simulating

TAPAFOR, t

dations:

1.

managing the Tapajos National Forest formed the bases for evaluating twenty treatment combinations. The treatments included various combinations of cutting intensity, cutting cycle length, natural regeneration, and enrichment, line, and close plantations. The general form of management used in developing TAPAFOR has been the uneven-aged approach.

Since specific inventory data for the Tapajos National Forest are as yet not available, information from tropical forestry literature, and the results of observations in the Forest by the author, were used for much of the input data in developing TAPAFOR. By optimizing the simulation model results, three variables were maximized: present net worth, total volume removed over the 30-year planning period, and residual stand value. The Tapajos National Forest was assumed to be composed of four stands with differing areas and differences in the number, volume, and basal area of trees larger than 45 cm in DBH, and total basal area.

Based on all considerations taken into account in simulating the management of the Tapajos National Forest by TAPAFOR, the results can be grouped into two major recommendations:

1. For the long term, apply clearcutting in small patches, with close plantation to follow. This will maximize timber output from the forest. A second ranking alternative would be to use natural regeneration.

2.

Resul

reasonable

knowledge

been any

yield mana

data. Thus

management

the Tapaj

tive meth

mills, tra

mill conve

losses, an

silvicultu

In sp

TAPAFOR si

of planned

National F

cally feas

and effici

become avai

ness of T

2. For the short term, apply a 70 percent intensity cutting of commercial trees in two or three harvests over the 30-year period in some stands, and a 100 percent intensity cutting of commercial trees with an enrichment planting in other stands.

Results from the TAPAFOR simulation model appear to be reasonable, and consistent with currently avaliable knowledge in tropical forestry literature. There have not been any forest areas in the Amazon region under sustained yield management in the past on which to draw for response data. Thus, the major limitation of TAPAFOR as a forest management planning tool is the lack of data specific to the Tapajos National Forest. Research results on alternative methods of transporting timber from the forest to mills, transport cost, utilization of lesser known species, mill conversion processes, species' growth rates, mortality losses, and the effectiveness of natural regeneration as a silvicultural technique are urgently needed.

In spite of this limitation, results of using the TAPAFOR simulation model show that immediate implementation of planned forest management operations in the Tapajos National Forest appear to be silviculturally and economically feasible, and provide initial guidelines for rational and efficient use of the resource. As more specific data become available, they can be used to improve the effectiveness of TAPAFOR as a planning model, not only for the

Tapajos Nat

the Amazon

Tapajos National Forest, but also for other forest areas in the Amazon basin.

Dedi

my wi

Dedicated to my parents, Mauro and Carmella;
my wife, Helena; and my sons, Ronny and Dmitry.

I offer m
to Dr. Victor
guidance comm
patience, and
was once only

To Dr. E
support in th
on the guida
computer-simu
James for his
study as a c
ledgement is
member.

Apprecia
for his initi

I am gr
State Univer
people durin
ed to the
State Univer

The Fir

ACKNOWLEDGEMENTS

I offer my warmest appreciation and profound gratitude to Dr. Victor J. Rudolph, my major professor, research and guidance committee chairman. His steady encouragement, patience, and advice over the years helped me attain what was once only a distant dream.

To Dr. Erik D. Goodman special thanks are due for his support in the development of this study, for his service on the guidance committee, and for introducing me to computer-simulation thought. Sincere thanks to Dr. Lee M. James for his suggestions on the economic aspects of this study as a committee member. To Dr. Carl W. Ramn, acknowledgement is due for his statistical advice as a committee member.

Appreciation is also extended to Dr. Wayne L. Myers for his initial support at Michigan State University.

I am grateful to the Forestry Department of Michigan State University for the assistance received from many people during my graduate program. Thanks are also expressed to the staff of the Computer Laboratory of Michigan State University for their valuable cooperation.

The Financial Assistance of Instituto Brasileiro de

Desenvolvimento
Pesquisa Agrop
Desenvolvimento
ly acknowledge

I am inde
(RADAMBRASIL),
Amazonia (SU
(IIE) and Pur
culture, who c

Special
throughout t
Brasileiro de
Brasileira
providing me

To my pa
gratitude is
sacrifices c
special debt
and support
tion. To my
bundles of
long and ard

Again,
experienced
THANKS.

Desenvolvimento Florestal (IBDF), Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA) and Conselho Nacional de Desenvolvimento Cientifico e Tecnologico (CNPq) is gratefully acknowledged.

I am indebted to IBDF, EMBRAPA, Project Radar Amazonas (RADAMBRASIL), Superintendência do Desenvolvimento da Amazonia (SUDAM), Instituto of International Education (IIE) and Purdue University International Programs in Agriculture, who contributed to the completion of this study.

Special thanks are due to the Brazilian government throughout the Ministry of Agriculture - MA, Instituto Brasileiro de Desenvolvimento Florestal - IBDF, and Empresa Brasileira De Pesquisa Agropecuaria - EMBRAPA, for providing me this opportunity.

To my parents, Mauro and Carmella, my appreciation and gratitude is expressed for their constant encouragement and sacrifices over the years. To my wife, Helena, a very special debt of gratitute is owned for her confidence, love and support that helped me to pursue this venture to completion. To my sons, Ronny and Dmitry, my thanks for being bundles of joy and a source of inspiration throughout this long and arduous task.

Again, to Dr. Victor J. Rudolph a constant source of experienced advice, encouragement and understanding -- THANKS.

TABLE OF CONTENTS

Page

Table

LIST OF TABLES

Figure

LIST OF FIGURES

Figure

Simulatio

of real system

used for the

conditions, ar

and procedures

A model i

It is usually

process that i

Computer

because of i

system and its

bles. Accordin

model cannot b

inherent in pr

rich way, and

for such applic

Forest ma

when presente

simulation-gami

played with th

watching effec

CHAPTER I

INTRODUCTION

Simulation -- defined as a method for solving problems of real systems by using models (Lucas et at., 1978) -- is used for the design of a system in terms of certain conditions, and the analysis of specific rules, policies and procedures.

A model is simply a substitute expression for reality. It is usually simpler than the real world objective or process that it represents (Kessel 1979).

Computer simulation has been used in forestry largely because of its inherent characteristics as a complete system and its endogenous and exogenous correlated variables. According to Churchman (1979), even though a precise model cannot be constructed, the 'mode of thinking' that is inherent in programming models can be utilized in a very rich way, and forestry systems offer a variety of options for such application.

Forest management simulation obtains more versatility when presented in a gaming model format. A computer simulation-gaming model, defined by Nor (1977) is a game played with the model by inserting decisions as inputs and watching effects or consequences of the decisions in the outputs. Th.

order to s

decision and

Clearly

simulation m

attached to

the user mus

Amazoni.

A look at

between the

(1966) point

the humid tr

with areas o

Forest

rapidly with

utilization.

timber in th

three years,

of the Amazo

2000. Neto

resources,

technology a

known.

A study

that the Bra

outputs. This is the method utilized in this study, in order to stimulate interest and encourage innovation in decision and strategy formulation.

Clearly, the accuracy of the results obtained from any simulation model depends on the constraints and complexity attached to it. When using the model in decision-making, the user must be aware of these factors.

Statement of the Problem

Amazonia exhibits the world's largest tropical forest. A look at its forested area shows a striking disparity between the resource and its commercial development. Lamb (1966) pointed out that in the world and more apparently in the humid tropics, a lag in economic growth is correlated with areas of extensive forest resources.

Forest exploitation in the Amazon region is expanding rapidly without accompanying regional growth and forest utilization. Kerr (1980) claims that the depletion of timber in the region has increased 170 percent in the past three years, and if this trend continues, about 60 percent of the Amazon forest will be cleared illegally by the year 2000. Neto (1979) recognizes that the Amazon's natural resources, which could generate investments in capital, technology and research, are at the present largely unknown.

A study recently conducted by Cherfas (1980) forecast that the Brazilian population will double in the next 25

years, and co
to increased u
ed to an incr
grate the eco
long-term pro
president of
(IBDF), states
viable forest
ed for the
National Fores
al Forest, lo
Amazon basin,
testing manag
determine the
feasibility.

An under
ments and int
the full rang
through proper
Amazon forest
area, consist
is to improve
when grown in
derations be
consist of man

years, and consequently its natural forest will be subject to increased utilization. All these factors have contributed to an increase in Brazilian government efforts to integrate the economic growth of the Amazon region with the long-term productivity of its forests. Reis (1980), the president of the Brazilian Forestry Development Institute (IBDF), states that clearly, a rational forest policy and viable forest management alternatives need to be established for the Amazon region. He reports that the Tapajos National Forest, Brazil's first and, thus far, only National Forest, located near Santarem (State of Para) in the Amazon basin, will be the pilot project area used for testing management techniques on an industrial scale to determine their ecological impacts and socio-economic feasibility.

An understanding of the complex ecological requirements and interrelationships of the forest, as well as of the full range of economic values, will be realized only through proper management. One of the goals in managing the Amazon forest is to produce the maximum yield per unit area, consistent with product quality. A second objective is to improve the form of certain native and exotic species when grown in plantations. It is important that these considerations be included in management proposals which may consist of many options for the future.

This stu

process of pr

havesting, in

on sustained

is to portra

economic val

forest envir

Amazon fores

those who pa

and will c

information

making.

The se

process, ar

planned ch

objectives,

management

adopted, re

It is

this study

planning w

encountere

developmen

also in r

available

necessari

Study Objectives

This study has two objectives. The first is to trace a process of predicting growth and yield of the forest after havesting, in order to maintain the Tapajos National Forest on sustained yield. More specifically, the simulation model is to portray the behavior of growth and yield with its economic value at different stages in a special kind of forest environment so as to add to the knowledge of the Amazon forest's proper management and use. This will aid those who participate in ongoing forest research processes, and will contribute significantly to forest management information to be utilized in forest planning and decision-making.

The second objective is to identify elements of that process, and analyze its development into a model for planned change in that process. In accomplishing these objectives, this study may lead to proposed changes in management strategies for the Amazon forest, which can be adopted, rejected or studied further in the future.

It is hoped that the simulation model developed in this study will provide guidelines for forest management planning with various alternatives. The problems which were encountered in this study can be useful, not only in the development of forest management plans at this time, but also in revising those plans as more information becomes available. Other studies of biological processes not necessarily forestry studies, may benefit from the design and the chan

development e

The Tap

in the Amazo

situated in

River and th

ters to the

area is esti

are generall

tion of surf

The average

2300 mm wit

between July

ly Febuary

pattern (FA

26^{o} C and

The majorit

only occasic

To att

work was unc

1. Ide

mar

pro

and the change process used in this study, in their model development efforts.

The Study Area

The Tapajos National Forest, the only National Forest in the Amazon Basin, was selected for this study. It is situated in the state of Pará, Brazil, between the Tapajos River and the Santarem-Cuiaba Road. It lies some 50 kilometers to the south of Santarem, the nearest city. The total area is estimated at 531,200 hectares (Fig. 1). The soils are generally deep and well drained, with little accumulation of surface organic matter, and are of low fertility. The average annual precipitation lies between 2100 mm and 2300 mm with rainfall each month. The drier season falls between July and November and the wettest month is generally Febuary but there are annual variations to this general pattern (FAO / IBDF, 1980). Mean annual temperature is 26^{o} C and mean annual relative humidity is 85 percent. The majority of the area appears to be relatively flat, only occasionally broken by drainage systems.

Study Methods

To attain the objectives of this study, the following work was undertaken:

1. Identification of the data required for forest management planning and financial appraisal of proposed plans.

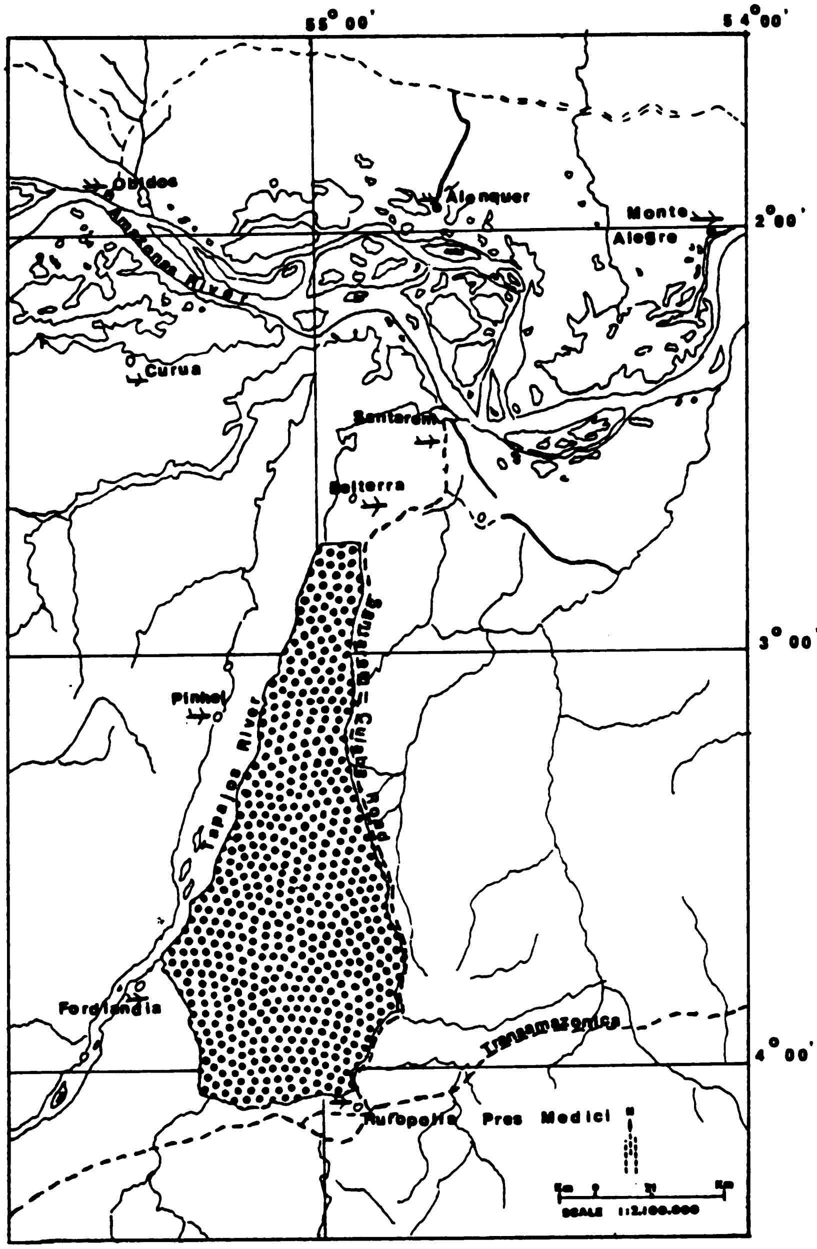


Figure 1. The Tapajos National Forest

2. Coll

Braz

repo

SUDA

and

stud

Univ

3. Elab

desi

auth

4. Asse

sens

5. Eval

mana

6. Pres

This re

computer mode

---

[1] IBDF - Inst
(Bra

EMBRAPA - E
(

SUDAM - Sup
(Su
Ama

RADAMBRASIL

2. Collection of available data and information in Brazil from administrative sources and government reports. These were obtained from IBDF, EMBRAPA, SUDAM and the RADAMBRASIL[1] project during June and July, 1980. Other material pertinent to the study area was obtained from the Michigan State University Library.
3. Elaboration of biometric functions and model design based on local conditions observed by the author during the data collection period.
4. Assessment of the simulation model components by sensitivity analysis.
5. Evalution of the model's contribution to forest management planning.
6. Presentation of results and conclusions.

This report is a description and analysis of a computer model which simulates forest management on the

---

[1] IBDF - Instituto Brasileiro de Desenvolvimento Florestal (Brazilian Institute for Forestry Development)

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Company)

SUDAM - Superintendência do Desenvolvimento da Amazônia (Superintendency for the Development of the Amazon)

RADAMBRASIL - Radar Amazonas (Radar Survey Agency, Ministry of Mines and Energy)

Tapajos Nationa
blems and proce
of an adequate
best informati
growth and its
treatments.

Tapajos National Forest in Brazil. It also includes problems and procedures to be aware of in the implementation of an adequate forest management plan in the field. The best information available is used to describe forest growth and its interactions with logging and prescribed treatments.

MANA

The Amazo

of the future'

history, and r

management in t

but no formal

limited availab

Technical

species have r

authors. Pitt

results for na

as well as che

Loureiro, et a

Amazon woods,

of many native

cultural treatm

In a series o

carried out bet

ed economic dat

region. Method

Dubois (1967,

CHAPTER II

MANAGEMENT IN BRAZIL'S AMAZON FOREST: A LITERATURE REVIEW

The Amazon forest is unquestionably the epithet 'land of the future' that was fastened on Brazil early in its history, and remains to taunt its foresty experts. Forest management in the Amazon has been studied in a general way, but no formal studies have been reported. A review of the limited available literature is presented.

Technical and silvicultural characteristics of some species have received a great deal of attention from many authors. Pitt (1969) has addressed methodoloy and primary results for natural regeneration of some species in Para, as well as chemical soil analysis and climatic conditions. Loureiro, et al. (1968) in their two volumes cataloguing Amazon woods, have contributed to the general utilization of many native species. Volpato (1972) outlined the silvicultural treatment of Andiroba (Carapa Guianensis Aubl.). In a series of field experiments for FAO in the Amazon carried out between 1956 and 1961, SUDAM (1973) has published economic data and volume tables for some species in that region. Methodology for a detailed study is suggested. Dubois (1967, 1971, 1973, 1979, 1980) has presented the richest contr

and guideline

has pointed o

al way. Sloot

durability ar

has publishe

characteristi

Researc

species were

Congress at

was noted t

due to the

related to

Reis (

for ration

1977, 197

exclusively

incentives

tries, as

logging an

Loggi

economic

upland fo

operations

explored

flooded g

procedure

richest contribution to understanding Amazon silviculture and guidelines for its application in forest management. He has pointed out appropriate systems to be used in a rational way. Slooten (1976) analyzed sixteen species as to their durability and physical-mechanical properties. SUDAM (1979) has published silvicultural, technological and durability characteristics of thirty-two species from the Amazon.

Research, policy and the potential use of exotic species were covered in a report presented to the Brazilian Congress at the National Amazon Seminar (IBDF, 1975). It was noted that the use of exotic species in the region was due to the difficulty of obtaining native seeds, and not related to quality or growth performance of the exotics.

Reis (1978) pointed out technical-political guidelines for rational utilization of the forest. Pandolfo (1973, 1977, 1978) has suggested the establishment of forests exclusively for timber production in the Amazon Basin, incentives for the vertical integration of forest industries, as well as the introduction of new technology for logging and other innovative techniques.

Logging and harvesting systems and their techno-economic viability were studied by PRODEPEF (1978) in the upland forest basin. The procedures and costs for various operations were presented. Filho, et al. (1979) have explored similar aspects in forests located on periodically flooded ground (varzea forest). They have analyzed basic procedures for mechanical forest exploitation. Guides for

logging road
(1980). Tamer
tivity. He po
soil-climatic-
maintenance o
superficially
clear-cutting
quickly in th
will be almos
of fertilizer

Mercado
methods and p

Wetterbe
ties for the
point out tha
been created

Pitcher
for the regio

In an i
submitted to
Forests, po
tropical moi
work of Dub
were made of
forest opera
environment.
forest after

logging road construction were described by Filho, et al. (1980). Tamer (1971) has cited findings on soil productivity. He points out that the forest is the product of a soil-climatic-plant equilibrium, characterized by the maintenance of a minimum level of nutrients in the soil superficially in a cycle of growth and decomposition. After clear-cutting, he noted, the organic material decomposes quickly in that climate, and a short-term agricultural crop will be almost impossible to produce without adequate use of fertilizers.

Mercado (1980) has described timber transportation methods and presented production and market data.

Wetterberg, et al. (1978) have elaborated on priorities for the preservation of the Amazon environment. They point out that only one area, the Amazon National Park, has been created by law in the Brazilian Amazon.

Pitcher (1976) suggested a tree improvement program for the region and methods for its establishment.

In an informative document by the Brazilian government submitted to the Technical Conference on Tropical Moist Forests, possible management systems applied to the tropical moist forests and its implications, based on the work of Dubois, were reviewed (PRODEPEF, 1975). Analyses were made of the following problem areas: administration, forest operations, silviculture, markets, industries and environment. Based on the distribution of the residual forest after mechanical exploitation in Curua-Una (state of

Para), Jankaus

regeneration b

defined shade

forest can be

Lanly (1

sampling proce

on the work of

IBDF (1980) a

three major ty

for pre-invest

tions formulat

To evalu

Forest for a

forest, a se

executed by F

some initial

He suggested

and greater u

vided guideli

summarized log

ed a road con

meter, based

Olin (1978) c

decline with

complete soil

growth rates,

needed for

Para), Jankauski (1978) has developed methods to improve regeneration by the elimination of undesired species, and defined shade requirements of desired species. He claims a forest can be "educated" for growth.

Lanly (1978) has outlined volume equations and sampling procedures for a pre-investment inventory. Based on the work of A. Nyyssonen, a forest inventory consultant, IBDF (1980) assessed additional information needs for the three major types of inventories: 1) for reconnaissance, 2) for pre-investment, 3) for management. A set of recommendations formulate priorities for the inventory program.

To evaluate the condition of the Tapajos National Forest for a pilot project in the management of the Amazon forest, a series of field studies have recently been executed by FAO consultants. Wadsworth (1978) has proposed some initial steps before starting the harvesting process. He suggested strategies for obtaining natural regeneration, and greater use of native species. Letourneau (1978) provided guidelines for logging and log transportation. He summarized logging costs as did Kluwer (1978), and suggested a road construction cost equal to one dollar per cubic meter, based on an annual harvest of 150,000 cubic meters. Olin (1978) concluded that soil and site quality tend to decline with increasing slope, but he added that more complete soil studies in relation to forest cover types, growth rates, stand volumes, and other forest features are needed for forestry planning. As an alternative for forestry and

Tapajos, Spe

private indu

supervised by

ment (IBDF).

the initial p

the earliest

mills are b

import and e

ted improveme

logs and lu

planing mill

on the fore

cited the po

established

ment guides

the possibil

cial and man

management

appear to b

these diffic

cation of

desirability

Amazon regio

All of

tributed to

of forest u

forestry and forest industry development programs in the Tapajos, Speidel (1978) suggested forest exploitation by private industrial enterprises with concession contracts supervised by the Brazilian Institute for Forestry Development (IBDF). Webb (1978) recommended the export of logs in the initial phase of exploitation, to create a cash flow at the earliest opportunity, while the sawmills or plywood mills are being constructed. Lemaingnen (1978) reported import and export data for tropical hardwoods, and suggested improvements in the cutting, marketing, and grading of logs and lumber. General descriptions of sawmills and planing mills were made by Wahl (1978). Regarding effects on the forest after management, Dourojeanni (1978) has cited the possibility that undesired forest species may be established by natural regeneration. In addressing management guides for the region, Fraser (1978) has recognized the possibility that institutional, organizational, financial and managerial difficulties may prevent the successful management of the Amazon forest, but, he added, there appear to be no technical nor ecological solutions for these difficulties. In addition to the ecological implication of exploitation, Poore (1978) pointed out the desirability of establishing a biosphere reserve in the Amazon region.

All of the above reports on the Amazon basin have contributed to basic information, but the economic viability of forest utilization on an industrially large scale was not addressed.

shown the pos

forest fee to

financing the

basis.

Other li

Forest region

Queiros (1978)

procedure for

different func

diameter distr

best results w

tial type I

function from

ry for reconn

square sample

Forest m

targeted in

(1976). Based

planning expe

plan for the

government. T

administrative

practical gui

suggested, an

years.

not addressed. An analysis by Beattie, et al. (1979) has shown the possibility of economic exploitation based on a forest fee to be charged by IBDF, with the objective of financing the management of the forest on a sustained yield basis.

Other literature related to the Tapajos National Forest region has offered some background for this study. Queiros (1978) defined an economically efficient sampling procedure for the region. Barros (1980) tested seven different functions and three DBH classes to determine the diameter distribution of the forest. He concluded that the best results were obtained with a Beta function, an exponential type I function from Meyer (1952) and a polynomial function from Goff, et al. (1975). In his study of inventory for reconnaissance Carvalho (1980) found the 1/4-chain square sample adequate for natural regeneration studies.

Forest management planning as a process has been targeted in guidelines for the Tapajos region by Dubois (1976). Based on the work of T. W. W. Wood, a management planning expert, FAO/IBDF (1980) has prepared a management plan for the Tapajos National Forest for the Brazilian government. The plan presents detailed operational and administrative procedures which are the most concrete and practical guides available to date. Yield regulation is suggested, and the entire forest is to be cut over in 35 years.

Created

National Cong

a total area

A). The actua

ximately 531

base map of

throughout t

plants, inclu

not excessiv

effective for

ture, princip

and fire prot

favorable to

within the for

Small hu

have been p

years, and h

hand, they wi

tural systems

CHAPTER III

THE TAPAJOS NATIONAL FOREST AND IMPLICATIONS FOR ITS MANAGEMENT

Land and Vegetation Types

Created in 1972, and legally constituted by the National Congress in 1974, the Tapajos National Forest has a total area estimated at 600,000 hectares (see Appendix A). The actual area, according to FAO/IBDF (1980) is approximately 531,200 hectares, obtained from a planimetered base map of 1:250,000. Climate is essentially uniform throughout the forest area and is very favorable for plants, including tree growth, since there is adequate but not excessive rainfall in most months. A dry season effective for four months raises some problems for silviculture, principally planting periodicity, species selection and fire protection. Topography as well as soils are very favorable to yearround logging and associated transport within the forest (Olin 1978).

Small human settlements in the Tapajos National Forest have been practicing shifting cultivation for several years, and have acquired land-use rights; on the other hand, they will provide a source of labor. Silvo-agricultural systems might be of great assistance in stabilizing these settleme

1975). Actual

but indetermin

agricultural

second-growth

have long r

classification

optimum land u

Closed tr

as many as 10

are now consi

considers tha

are the only

Palm (<u>Orbigny</u>

two types. It

frequency of

<u>Jarana</u>, <u>Qua</u>

and <u>Pau jaca</u>

distribution

experimental

of <u>Andiroba</u>

and <u>Tachi bra</u>

In gene

followed Dubo

1. Zona

a.

b.

these settlements and improving their social status (IBDF 1975). Actual land use in the region includes substantial but indeterminate areas of cropped land and abandoned agricultural clearings, presently in young invasive second-growth (Olin 1978). Resource planners and managers have long recognized the need for systematic land classification so that sound judgments can be made about optimum land use.

Closed tropical forests may have on any given hectare as many as 100 or more tree species, only a few of which are now considered commercially valuable. FAO/IBDF (1980) considers that the High forest, with and without babaçu, are the only commercially exploitable types. The Babaçu Palm (Orbignya speciosa) is utilized to distinguish the two types. Its presence means a flatter region with a high frequency of mature-sized species, such as Tachi vermelho, Jarana, Quarubarana, Melancieira, Tavari poqueca, and Pau jacare. Barros (1980) has described the species distribution for High forest without babaçu in an experimental unit, and it shows a relatively high abundance of Andiroba, Maçaranduba, Louros, Tachi preto, and Tachi branco.

In general, the classification of vegetation has followed Dubois's (1976) guidelines:

1. Zonal primary forests
    a. High forest with babaçu
    b. High forest without babaçu

c. T

d. P

2. Azona

a. S

b. C

3. Secon

In this

babaçu will be

National

managed for p

costs, output

public than f

scarce resour

outputs (whet

public as to

wildlife, wat

be available

below their e

outputs of a

ing a direct

value of thes

tous one in f

Multiple

among alterna

c. The complex of cipoalic forests and "cipoal"

d. Paraclimax flanco forests

2. Azonal primary forests

a. Sedentary creek forest

b. Creek swamp forest

3. Secondary growth

In this study, only the high forest with and without babaçu will be considered for management.

National Forest Multiple Use

National forests, as public enterprises, are not to be managed for profit in the way private business is. However, costs, outputs, and efficiency are no less important for public than for private enterprises. Economizing the use of scarce resources and productive factors to produce desired outputs (whether sold for cash or not), is as applicable to public as to private enterprises. Wilderness, recreation, wildlife, water, and other outputs of national forests must be available to the public free or at prices substantially below their economic value. This is also true for the same outputs of a privately-owned forest. The problem of securing a direct financial return comparable to the economic value of these outputs is a persistent and nearly ubiquitous one in forestry.

Multiple use forestry requires making hard choices among alternative uses or use mixes where the ultimate goal is to maxi

these choic

groupings

intensity o

possible al

great numb

objectives

cannot be s

ing the co

that the s

planner an

ly, psycho

(1978) to

which cann

The m

habitats a

the land

and withc

demands (I

species c

considered

systems of

contribute

apparent.

impairment

wildlife a

on some f

is to maximize outputs. The dominating factors affecting these choices are the values of individual trees or small groupings of vegetation and the relative values and intensity of competition for resources (Cordell 1979). Many possible alternatives must be compared in the light of a great number of more or less consistent or conflicting objectives (aims, goals) between which functional relations cannot be specified. In the process of comparing and assessing the consequences of the alternatives, it is unavoidable that the subjective preferences of the decision-maker and planner and of institutions play a vital role. Consequently, psychometric methods have been introduced by Henne (1978) to obtain solutions corresponding to objectives which cannot be expressed in physical or monetary units.

The multiple use concept recognizes wildlife and its habitats as major renewable resources; it stipulates that the land can be used without environmental deterioration and without impairing its capabilities to meet other demands (Lennart 1979). It is known, however, that several species of forest wildlife and plants are presently considered threatened with extinction and that prevailing systems of forest management in some regions of the world contribute to that threat. The basic conflict is very apparent. Multiple-use, which promises protection from impairment, deterioration, and irreversible damage to wildlife and plant communities may have limited application on some forest lands, not in the concept itself, but rather in the way the

using the conc

to be considere

The free

wilderness, wi

planning very

National Fore

Economic tests

levels are a

process have

benefits which

National

can produce i

ness, wildli

national fore

made for the

little or no

decisions. Ma

pilot project

useful to the

Possible

forests are c

1. Excl

seco

2. Taun

in the way the concept has been traditionally applied. In using the concept in the Tapajos region, these facts have to be considered.

The free outputs from a National Forest, such as wilderness, wildlife, and water, make rational economic planning very difficult. The free capital embodied in the National Forests similarly distorts economic management. Economic tests for forest practices and management at all levels are a requirement. The actors in the management process have to rely on the careful weighing of costs and benefits which is the essence of economic management.

National forests are a valuable national asset. They can produce important amounts of wood, recreation, wilderness, wildlife, and water, with good management. The national forests are capital intensive, and charges must be made for their use. The availability of their outputs at little or no cost to the users will distort management decisions. Management of the Tapajos National Forest as a pilot project can make other Brazilian forests much more useful to the nation's people.

Management Systems

Possible management systems to be applied in tropical forests are considered by IBDF (1975) as:

1. Exclusive forest production systems - timber and secondary forest production.
2. Taungya production systems - all silvo-agricultural

sys

is

est

3. Com

nat

(un

tr

4. Wi

Clearc

and the un

ments whic

an exclusi

uneven-age

pilot fore

Forest, to

<u>Th</u>

For

into even-

ly, even-

about the

ment, deve

cant bord

trees of

interactio

classified

systems in which one short agricultural rotation is associated with the early stage of timber crop establishment.

3. Combined timber and cattle management systems - native or man-made forest over grassland (uniformly or discontinuously), or in belts of trees between tracts of pasture.
4. Wildlife production systems.

Clearcutting with artificial or natural regeneration and the uniform shelterwood system are the common treatments which have been usually recommended to be utilized in an exclusive forest production system. I propose that an uneven-aged management system be implemented as part of the pilot forest management project for the Tapajos National Forest, to emphasize exclusive forest production.

The Philosophy of Uneven-aged Management

For organizational purposes, forests are classified into even-aged stands or uneven-aged stands. Silviculturally, even-aged stands contain trees which originated at about the same time and, following a period of establishment, develop under full light conditions, without significant border competition (Davis 1966). Stands containing trees of several ages that develop with significant interaction with surrounding trees of different ages are classified as uneven-aged (Hann 1979). The regulatory control varia

stand volume

stand struct

uneven-aged r

as well as e

aged silvicu

selection o

selection me

nents of th

be practice

tolerant sp

reproduce a

modificatio

timber is

Group selec

intolerant

selection m

The ph

mainly in

the even-a

based on t

art that

forester's

and silvic

ment plan

silvicultu

method emp

control variables in even-aged management are stand age or stand volume. In uneven-aged management the variables are stand structure and stocking. The choice between even or uneven-aged management systems is dictated by silvicultural as well as economic and operational considerations. Uneven-aged silviculture may be applied either by single tree selection or by group selection. Under the single tree selection method, size, thrift, and quality of the components of the stand are the primary considerations. It can be practiced continuously only in stands composed of tolerant species, of which the commercially important reproduce and grow well under shade. Group selection is a modification of the selection method whereby the mature timber is removed in groups rather than by single trees. Group selection can be used with species which are too intolerant of shade to reproduce satisfactorily under the selection method.

The philosophy of uneven-aged management was developed mainly in France and Switzerland after the advancement of the even-aged philosophy. Hann (1979) states that it was based on the concept that forest management is primarily an art that relies heavily upon the continuous input of a forester's ecological experience (with its scientific base) and silvicultural judgment in order to implement the management plan and to meet the stated objectives. Uneven-aged silviculture is determined by the harvest-regeneration method employed, and it is just as amenable to systematic treatment

uneven-aged

ment of a

forest sust

quality ti

tives shoul

on forest

simplicity.

Forest

The ty

management

Although th

major steps

1. Th

2. Th

me

3. Th

si

The ma

ed in appl

must be

suggests t

the follow

1. T

a

treatment as is even-aged management. The philosophy of uneven-aged management emphasizes protection and improvement of a stable forest environment, the guarantee of forest sustentation and production of large-sized, high-quality timber. Its proponents believe that these objectives should not be sacrificed for higher rates of return on forest capital, greater wood fiber yield, or management simplicity.

Forest Management Planning for Timber Production

The typical planning process used for developing land management plans follows a sequence of several phases. Although this process might be described in many ways, the major steps are:

1. The identification of issues and objectives.
2. The development of the resource system and management options.
3. The analysis of tradeoffs that accompany decisions, and feedback (Betters 1978).

The major decisions facing the forest manager interested in applying uneven-aged management for timber production must be specified and understood. Available literature suggests that most of these decisions can be reached when the following items have been thoroughly examined:

1. The optimal, sustainable diameter distribution for a given stand, expressed as number of trees in

each
and
2. The
meet
3. The
infl
cal
dist
will
4. The
peri
sust
5. The
and
the
met.
modi

The une
system to be
order to meet
and to reduce
ment plan mus
include speci
optimal biol
Forest as a w

each diameter class to establish optimal stocking and maximum tree size.

2. The optimal species mix for a stand in order to meet final product objectives.
3. The optimal cutting cycle length for each stand as influenced by logging equipment limitations, physical and economic accessibility, and by minimizing disturbance to the stand and site, and how these will influence optimal diameter distribution.
4. The optimal conversion strategy and conversion period length for each stand to meet the optimal sustainable condition.
5. The optimal scheduling of compartment treatments and the date of entry for each compartment so that the treatment of the forest as a whole can best be met. Optimal stand treatment may have to be modified in order to meet forest-wide objectives.

The uneven-aged management approach should be the system to be applied in the Tapajos National Forest in order to meet the objectives of sustained yield production and to reduce impacts on its natural habitat. Any management plan must be consistent with this philosophy and must include specified guidelines for each stand to meet the optimal biological-economic objectives for the National Forest as a whole.

Utiliza

A spect

National For

trolled by

specific use

administrati

occur on tha

In the

from one wh

life and un

in a natura

es economic

tic positio

be develop

management

assessment.

There

progress i

River area

million he

of melina

tons-per-da

sawmill th

mine; a

irrigated

5,500 buff

table prod

Utilization Impacts and Long-Term Productivity

A spectrum of alternatives exists for each parcel of National Forest land. The range of this spectrum is controlled by the inherent suitability of the land to satisfy specific uses and the degree to which past legislative or administrative action has limited or extended what can occur on that land.

In the Tapajos National Forest the alternatives range from one which places maximum emphasis on the amenities of life and under which a significant area could be preserved in a natural and unmodified condition, to one which stresses economic considerations. Lying between these two puristic positions are a great number of alternatives which can be developed by giving varying weighted values to the management opportunities in the near future, after adequate assessment.

There are no large scale forest management plans in progress in the Amazon area at present, except in the Jari River area. The Jari project is developing more than a million hectares in Northern Brazil, with 100,000 hectares of melina (Gmelina arborea) and pine plantations; a 750 tons-per-day bleached kraft pulp mill; a native wood sawmill that cuts 100,000 board feet per day; a kaolin mine; a 500 tons-per-day refinery; 4,000 hectares of irrigated rice with a rice mill; herds of 6,500 cattle, 5,500 buffalo, and 800 pigs; and poultry, fruit and vegetable production (Briscoe 1980).

Implement

Tapajos Natio

impact upon

social implic

resources as

opportunities

region will b

local economy

in the base

also increase

Timber harves

resident bird

types and for

and number of

will be increa

change in spe

are associated

or other vege

results in th

there are sit

and increased

for erosion,

yield analysis

harvests. Care

minimize advers

Short-term

be significa

Implementation of any management proposal for the Tapajos National Forest will have a continuing physical impact upon the environment as well as having certain social implications. More people are expected to use the resources as the proposal is implemented. Diversity of opportunities and the attraction of people from outside the region will be expected to add additional revenue to the local economy. This will be offset in part by a reduction in the base timber growing area. Additional people will also increase the potential for various forms of pollution. Timber harvesting will cause temporary displacement of resident birds and animals. Changes in vegetative cover types and forest class distribution will affect the species and number of both birds and animals. The greatest effect will be increasing the variety of habitats with a resultant change in species represented. Certain hydrologic impacts are associated with road construction, timber harvesting, or other vegetative manipulation. Such activity normally results in the exposure of mineral soil and frequently there are situations that result in concentrations of water and increased surface run-off. To minimize the potential for erosion, flooding, or habitat degradation, a water yield analysis procedure must be part of planned timber harvests. Careful design and construction of roads will minimize adverse effects.

Short-term timber yields under a managed situation may be significantly reduced compared to unmanaged

exploitatic
managed to
Relatively
must be th
Forest. Tra
recognize
tributary
impact wil
structures
sedimentat

Natio
that each
succeeding
be predica
social pr
may not b
public pr
projection
ment of
successful
proposed p
(1975) has

Perma
manag
horiz
Integ
produ
econo
of th
in vi
yield

exploitation, particularly in those areas which will be managed to maintain an uneven-aged continuous forest cover. Relatively short-term planning with periodic reevaluations must be the appropriate procedure for the Tapajos National Forest. Transportation planning and timber harvesting will recognize the significance of the Tapajos River and its tributary streams in providing for fish spawning. This impact will be minimized by designing and installing stream structures to minimize the effects of increased stream sedimentation during critical fish spawning periods.

National Forest management is based on the premise that each generation is a trustee of the environment for succeeding generations. Projecting long term effects will be predicated on certain assumptions with respect to future social preferences. Any single specified direction today may not be acceptable through time, because of changes in public preference. The risk and uncertainties of future projections lend support to directions favoring the enhancement of long term productivity, and will depend on how successful and how detailed the implementation of a proposed plan for the Tapajos National Forest will be. IBDF (1975) has suggested:

> Permanent forest estates should be exploited and managed in order to attend the requirements of horizontally integrated wood-based industries. Integrated wood-based industries of overall large production capacity are the only ones able to economically justify and support the implantation of their own technical and social infrastructure in virgin areas. Their location within sustained yield logging areas, or within the shortest

possible
their cap
(maximized
produce a
tion and l

Maintaining

impairment of

air and of

providing suit

spaces are s

assessing pote

> possible distance from log supplies, as well as their capacity to carry intensive exploitations (maximized output of cubic meter-log/hectare) produce appreciable savings on felling, extraction and log transportation costs.

Maintaining the inherent soil capability without impairment of productivity, maintaining the quality of the air and of the surface and ground water resources, providing suitable wildlife habitat and maintaining open spaces are some of the factors to be considered in assessing potential long term productivity.

Timber

decisions

scheduling

reforestatio

former prov

the planni

timber and

needed refo

and the r

alternative

management

stock, and

and/or ref

The

spatial a

species.

energy, n

the livin

trophic c

for growi

an arbit

CHAPTER IV

THE MANAGEMENT MODEL DESIGN

Timber management planning essentially involves decisions on two basic issues: temporal and spatial scheduling of harvests during a planning period and the reforestation strategy that is to follow each harvest. The former provides the amount of timber and income flow during the planning period. The latter indicates the flow of timber and income expected one rotation in the future, the needed reforestation investment during the planning period, and the rate of return to the land under the proposed alternative. These short and long-run flows are shaped by management objectives, spatial distribution of growing stock, and restrictions, if any, on the level of harvest and/or reforestation activities.

The uneven-aged forest stand is a heterogeneous spatial arrangement of trees varying in age, size, and species. It is constantly changing. Utilization of solar energy, nutrients, and water produces a size increase in the living trees. Mortality, either from natural or catastrophic causes, removes individual trees that are competing for growing space. Ingrowth, the accretion of trees above an arbitarily defined lower size boundary, represents an increase of

niche in the

In essei

system that

components.

with the comp

In desic

effects of

growth and y

integration o

1. Harv

2. Silv

3. Grow

4. Econ

Harvesting

Harvest

focuses prim

planning per

used between

extreme and

extreme. Beca

near future,

planning.

Logging,

secondary eco

increase of the accountable trees that are competing for a niche in the measurable stand.

In essence, the foregoing process defines an evolving system that is composed of several specified measurable components. To the forest manager, these are synonymous with the components of net forest growth.

Subsystem Definition

In designing a management model, the prediction of the effects of harvesting and silvicultural treatments on growth and yield in the Tapajos National Forest is made by integration of the following components:

1. Harvesting
2. Silviculture
3. Growth
4. Economics

Harvesting

Harvest scheduling is a disinvestment process, and focuses primarily on timber and cash flow during the planning period. Any harvest scheduling strategy may be used between the performance standard approach at the one extreme and equal annual or periodic volume at the other extreme. Because of its focus on output and income in the near future, harvest scheduling may be termed short-range planning.

Logging, in effect, is a perturbation that initiates secondary ecological succession. The vegetation response to perturbation

tal conditi

success of

immediately

considered

A typi

ings; felli

tion; and p

1979). Thi

stock in

thinning a

vines whic

but depend

the canopy

grow to th

they are g

during the

The

forests fo

consist of

1. W

s

c

f

2. C

3. W

a

perturbation depends upon the type of logging, environmental conditions, local patterns of plant succession and the success of regeneration efforts. Changes in the vegetation immediately following harvest are an important factor to be considered in stand regeneration.

A typical harvest operation requires roads and landings; felling, bucking and hauling of logs; site preparation; and planting or reseeding of the site (Cromack et al. 1979). Thinning is the systematic regulation of growing stock in a forest (Malmberg 1965). To increase growth, thinning and brush control are often practical. Lianas are vines which are rooted in the soil and form a rigid stem but depend on the trees for support as they grow upwards in the canopy. In a tropical forest, vines and epiphytes can grow to the point where they strangle the tree upon which they are growing. For this reason they must be eliminated during the logging and tending operations.

The extraction systems usually utilized in tropical forests for off-road log moving, according to Andel (1978), consist of the following machinery:

1. Winch-lorries, usually locally adapted army surplus three-axle vehicles, self-loading, with a capacity of 4-5 cubic meters. They are also used for log transport over forest roads.
2. Crawler-tractor, for off-road log moving.
3. Wheeled-skidders, for log moving along skid trails at higher speeds.

4. Cab

mov

Combina

winch, and

log-loading

radiating f

yarder with

tree locati

or transfe

movement.

Operat

on the re

stand whil

machine op

tinuous tr

infrastruc

and quanti

ing and f

operations

sound bec

zones. Me

labor bec

productiv

due pri

"nationa

will ha

4. Cable yarders, for high-lead yarding or skyline movement of logs.

Combinations of these machines may include a crawler, winch, and lorry along secondary roads without distinct log-loading yards, a crawler and skidder on skid trails radiating from a roadside log-loading yard, and a highlead yarder with 6-10 cable-ways radiating from a hilltop spar-tree location, to which logs are yarded for direct loading or transfer to log-loading yards by skidding or skyline movement.

Operations with these systems have considerable impact on the residual stand. Reducing damage to the residual stand while removing trees requires proper training for machine operators. Despite having the world's largest continuous tropical forest resource, Brazil's tree harvesting infrastructure is very underdeveloped, both qualitatively and quantitatively. Felling is with ax or chain saw; bunching and forwarding are largely a manual operation. Such operations may in fact be financially and economically sound because of low wage rates and unemployment in rural zones. Mechanization should be carried out only if rural labor becomes scarce and/or no longer competitive in cost/ productivity terms. The lack of development in this area is due principally to government regulations concerning "nationalization" of equipment manufacture. Manufacturers will have to develop machines appropriate to Brazil's conditions

will have

determine

Brazil (Be

considered

Table 1, b

ing 150,00

Silvicultu

The

natural sc

the laws

trees and

Stand

also large

Since the

cycle, the

ing with

factors ne

1. T

b

2. T

a

b

3. T

t

o

conditions, and promote new harvesting techniques, but this will have to be preceded by careful economic analysis to determine if such mechanization is economically viable for Brazil (Beattie 1980). Logging costs and operations to be considered on the Tapajos National Forest are presented in Table 1, based on the work of Letourneau (1978) in producing 150,000 cubic meters of timber per year.

Silviculture

The immediate foundation of silviculture in the natural sciences is the field of silvics, which deals with the laws underlying the growth and development of single trees and of the forest as a biological unit (Smith 1962).

Stand density influences not only growth and yield but also largely determines stem quality (Godman, et al. 1971). Since the role of density is important throughout the stand cycle, the regeneration system must assure adequate stocking with a minimum establishment period. The following factors need to be considered:

1. The presence of seedlings on the forest floor before exploitation;
2. The ability of these seedlings to remain alive for a period long enough to bridge the interval between seed years;
3. The ability of these practically dormant seedlings to respond with vigor to any light increase from opening up the canopy.

Tabl

Op

1. Fellin

(two m

2. Skiddi

(crawle

3. Loading

(hydrau

mounte

4. Hauling

(poletyp

on two

5. Dumping

(large

end lo

6. Roads

(tempora

7. Overhea

1 Estimat

Table 1. Costs of logging operations in the Tapajos National Forest[1]

Operation	Cruzeiros/m^3
1. Felling and cross-cutting (two man team using chain saws)	50.
2. Skidding (crawler or rubber-tired tractors)	220.
3. Loading (hydraulic heel boom crawler mounted loader)	80.
4. Hauling (poletype trailer trucks on two shifts per day)	460.
5. Dumping (large articulated rubber-tired front end loader equipped with log forks)	85.
6. Roads (temporary and permanent)	95.
7. Overhead	350.
Total	1,340.

[1] Estimates based on Letourneau (1978).

One can s
regenerati
of seedlin

On th
tions wil
of the cr
greater qu

In th
tives are

1. N
2. E
   T
   c
3. I
   e
   I
4. (
   e
5. I

Natu
Enrichmen
plantatio
and tend
effectuat
clearcutt
non-produ
(1980),

One can see then that it is unrealistic to expect rapid regeneration after logging in areas with inadequate numbers of seedlings already on the ground.

On the Tapajos National Forest, silvicultural operations will be principally concerned with the regeneration of the crop and with its gradual refinement to produce greater quantities of fewer but more desirable species.

In the light of these factors, the following alternatives are presented for obtaining regeneration:

1. Natural regeneration.
2. Enrichment planting with natural regeneration - The planting of valuable commercial species in the open spaces in the forest.
3. Line plantation with natural regeneration - The establishment of a tree crop in spaced lines (see Appendix D).
4. Close plantation - Plantation of trees close to each other in deforested areas.
5. Exclude from production.

Natural regeneration may be assisted by some release. Enrichment planting in open spaces in the forest, and line plantation will be made with fastgrowing desirable species and tended until established. Close plantations will be effectuated with fast commercial growing species after clearcutting. Stands to be excluded from production include non-productive forest areas that, according to FAO/IBDF (1980), are secondary growth, windblow, forest, creek forest (art

meters per

aside for

studies.

Becaus

above presc

available,

tion alter

tions and

silvicultu

selection,

high densi

stand cond

Silvi

cutting cy

1. M

2. B

3. M

4. S

Growth

In t

quantities

of trees,

meter tha

stand dev

tion is at

forest (art. 2, Appendix B), forest with less than 5 cubic meters per hectare of merchantable timber, and areas set aside for phenological, silvicultural or management studies.

Because information on the exact conditions for the above prescriptions in the Tapajos National Forest is not available, the designed model will analyze these regeneration alternatives under different initial stocking conditions and stochastic seed generation. The uneven-aged silvicultural system to be applied will be single tree selection, because of local observation by the author of high density of tolerant species and generally uneven-aged stand conditions.

Silvicultural factors that affect the length of the cutting cycle in management can be considered as:

1. Maximum use of the area by growing stock.
2. Biological control of the stand.
3. Mortality.
4. Species requirements for regeneration.

Growth

In the uneven-aged stand, tangible parameters or quantities that represent the forest system may be number of trees, diameters, basal area, or volume. Age, a parameter that is commonly utilized in the study of forest stand development, is not included, since its interpretation is at best nebulous for the uneven-aged stand.

The s

represents

tables, beca

management c

individual

major parame

was DBH (D

ground).

One pu

is to deter

the dimensi

(Chapman 19

development

into a comp

be characte

ment. These

analysis wi

Diamete

number of

trees per h

1. Cu

wi

de

2. Ge

fa

co

wi

The simulation of growth with computer models represents a considerable advance in the use of yield tables, because the effects of many more silvicultural and management options can be examined quickly, and because the individual conditions of each stand can be considered. The major parameter applied for the growth model in this study was DBH (Diameter at Breast Height -- 1.30 meters above ground).

One purpose of studying the diameter growth of trees is to determine the total volume of trees or to determine the dimensions or sizes reached by trees in a given period (Chapman 1924). The biometric functions forecasting the development of various stand parameters, which are combined into a compatible system enabling the stand as a whole to be characterized, are mainly a function of diameter increment. These functions were prepared by using regression analysis with available data.

Diameter growth is affected mainly by competition or number of trees (Kirchner, et al. 1979). The number of trees per hectare is determined by:

1. Cutting intensity. A function of available trees with DBH greater than 45 cm per hectare and the desired volume output.
2. Germination and seedling survival. These are major factors which determine regeneration. Climatic conditions, animal browsing and mechanical damage will determine germination and survival.

Ge

wi

sm

Tr

on

3. Mo

ea

ra

Re

of

ed

ha

4. Gr

in

bi

The t
rapidly tha
The nature
breeding a
growth of s
more resear
a high gr
produce na
number of t

Germination may be delayed for some seeds, and will occur over all cycles in the model, but in small proportions if no seed trees are available. Trees with a DBH greater than 45 cm, are the only ones able to produce seed.

3. Mortality. Under the natural process, during the early years, the number of trees is reduced more rapidly because of intraspecific competition. Reduction continues at a lower rate for the rest of the life of the stand. Mortality may be increased in the residual stand when some treatment or harvesting is executed.
4. Growth delay. This is an indirect relationship to intraspecific competition, and will affect the biometric increment of the stand.

The trees to be planted are expected to grow more rapidly than those which will provide the initial output. The nature of interactions between effects (e.g., tree breeding and thinning), and the long-term upper limits to growth of stands under new conditions are matters requiring more research. These planted trees will be assumed to have a high growth rate in the model. They are expected to produce natural regeneration as soon as a considerable number of them reach a diameter of 45 cm.

Economics

More component parts besides the physical processes of forest production are needed to enable the model to translate the physical consequences of a management alternative into information about economic returns. Both prices and unit costs are needed to bring the model one more step closer to reality. The interrelationships of costs and revenues are an important part of any economic appraisal of a project.

The level of forest investment coupled with the productive potential of the forest essentially determine future productivity and profitability. Because of their future implications, forest investments may be termed long-range. A number of economic parameters have been used to analyze long-term profitability of investments (Noqueira 1980). In this study, we will use Present Net Worth (PNW), generally defined as the present value of expected future returns over the forest cycle minus the present value of expected future costs, with costs and returns discounted at an appropriate rate of interest. Revenues from the forest will be based on the final output. Costs for harvesting and transport of sawlogs, silvicultural treatment, protecting and maintaining the forest's productive capacity will also be considered. The use of PNW as a measure of management simulation implies that the government is indifferent to risk as measured by, for example, the variance of expected values. According to Squire, et al. (1979), this is

justifiabl
projects a
population
project i
income of
Altho
simple a
substantia
unlikely t
the rate
income me
exchange
a lack o
interpret
marginal
alternati
Econ
cycle in
1.
2.
3.
4.
The
the inte
(Figs. 2

justifiable provided the risks of all public sector projects are pooled and spread over the country's entire population so that a change in the outcome of any single project is unlikely to have a significant impact on the income of any single group.

Although a great deal of planning is based on the simple assumption that present prices will continue substantially unchanged, experience suggests that this is unlikely to happen. A utilization of the discounted rate as the rate of decrease over time in the value of the public income measured in domestic currency equivalent to foreign exchange can approach results close to reality. Because of a lack of such information, the discounted rate will be interpreted in this study in the traditional way, as the marginal productivity of additional investment in the best alternative uses.

Economic factors affecting the length of the cutting cycle in uneven-aged management can be considered as:

1. Size of product needed.
2. Required volume to be cut per hectare to justify logging expenses.
3. Need for a frequent periodic income from the area.
4. Less accessible areas may require longer cutting cycles with a heavier cut.

The gross logical flow of the designed model reflects the integration approach to the phases discussed above (Figs. 2 and 3).

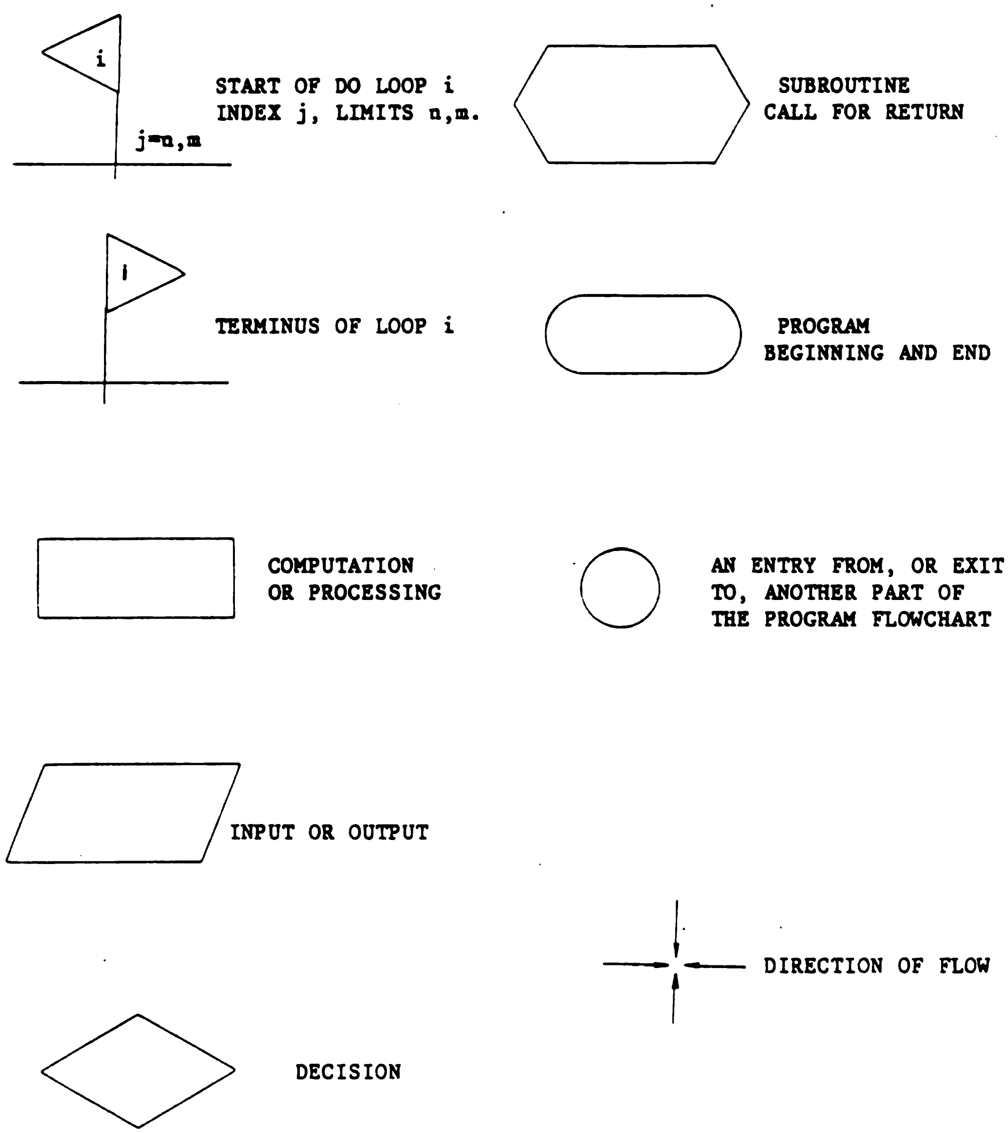


Figure 2. The legend for the flowcharts

Figu

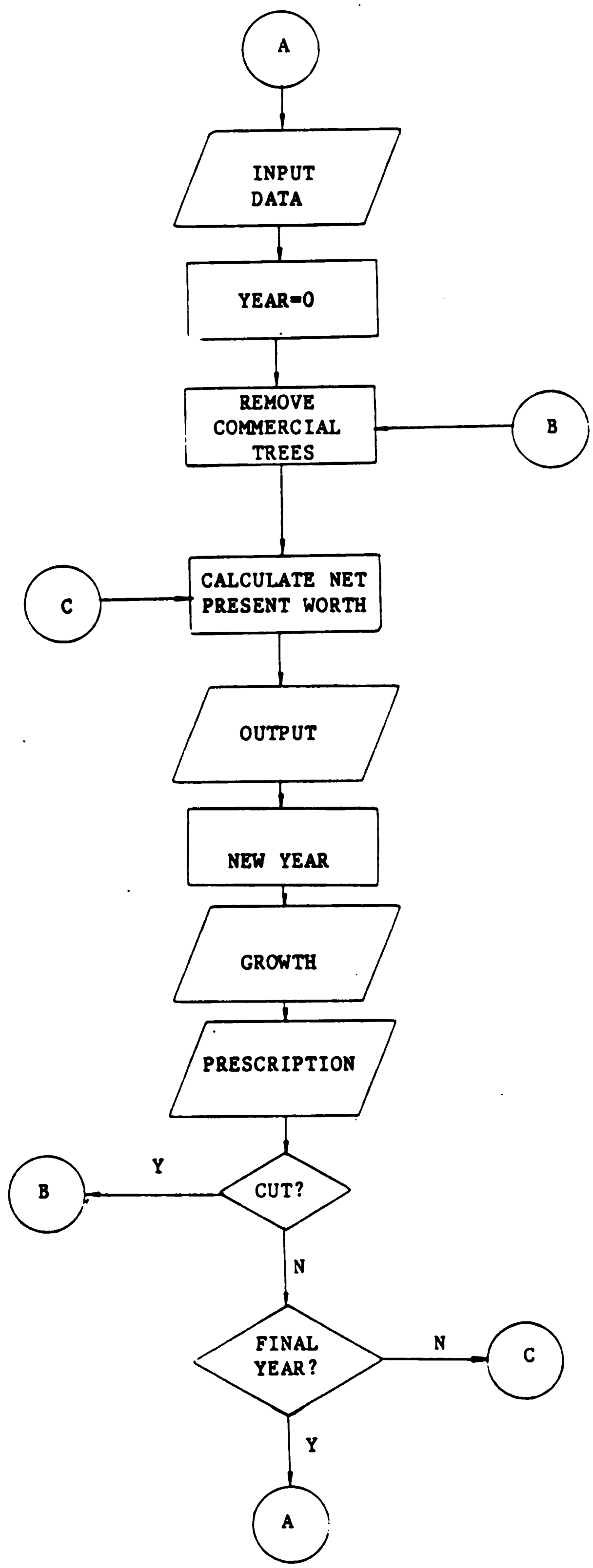


Figure 3. Gross logical flowchart for TAPAFOR

The approa
dynamic pr
number of
cyclic harv
ture. To a
point to a
stand and
the forest
specific tr

The sc
que used
employed i
applied wh
incapable
available
probability
population
simulate na

In or
be divided
for an est
as 10 cm
ments incl

1. N
c

The Model Design Approach

The approach adopted in this project has been to use a dynamic process in which the changing distribution of the number of trees in the forest is modified by initial and cyclic harvest intensity of timber, and by applied silviculture. To avoid errors of aggregation, it is expected to point to an optimum treatment consistent with a particular stand and its environment. The model is structured to bring the forest to a prescribed condition as a result of specific treatments.

The so-called "Monte Carlo" method is a common technique used in simulation models. It will be the technique employed in different phases of this study. Monte Carlo is applied when data are incomplete or relationships are incapable of rigorous solution, and the only information available pertains to the mathematical characteristics of a probability distribution. Random samples are drawn from a population with this probability distribution in order to simulate naturally occurring variations.

In order to design the model, the stand is assumed to be divided into 15 DBH classes, with a minimum DBH of 15 cm for an established tree. The class interval was determined as 10 cm based on the work of Barros (1980). Stand treatments include:

1. Natural regeneration of exportable trees, local commercial trees, and non-commercial trees.

2. Ar

tr

3. Ar

tr

4. Ar

cl

Forest

in the mod

(productive

logical f

process

model--TAP

described

<u>Harvesting</u>

Basic

of an ide

the intens

under exis

products,

ly valuab

removed.

clearcutti

forest ha

cut, can

high cost

2. Artifical regeneration by line plantation with treatment 1.
3. Artifical regeneration by enrichment planting with treatment 1.
4. Artifical regeneration by close plantation after clearcutting.

Forest types have been considered as of no influence in the model, since it was developed only for high forest (productive forest), with no slope influence. The detailed logical flowchart in Figure 4 presents the development process of the Tapajos National Forest management model--TAPAFOR-- and it was implemented by the subsystems described above in the following manner.

Harvesting

Basically, the single tree selection process consists of an identification of trees to be cut, when to cut, and the intensity to cut. Because Amazon species are unsuitable under existing manufacturing technology for pulp and paper products, the output will be sawlogs. Thus only commercially valuable trees with a DBH greater than 45 cm will be removed. Under a close plantation alternative treatment, clearcutting in small patches will be used. Residues from forest harvesting operations, depending on intensity of cut, can represent sound quantities of material, but the high cost of their removal will limit their use, as a raw

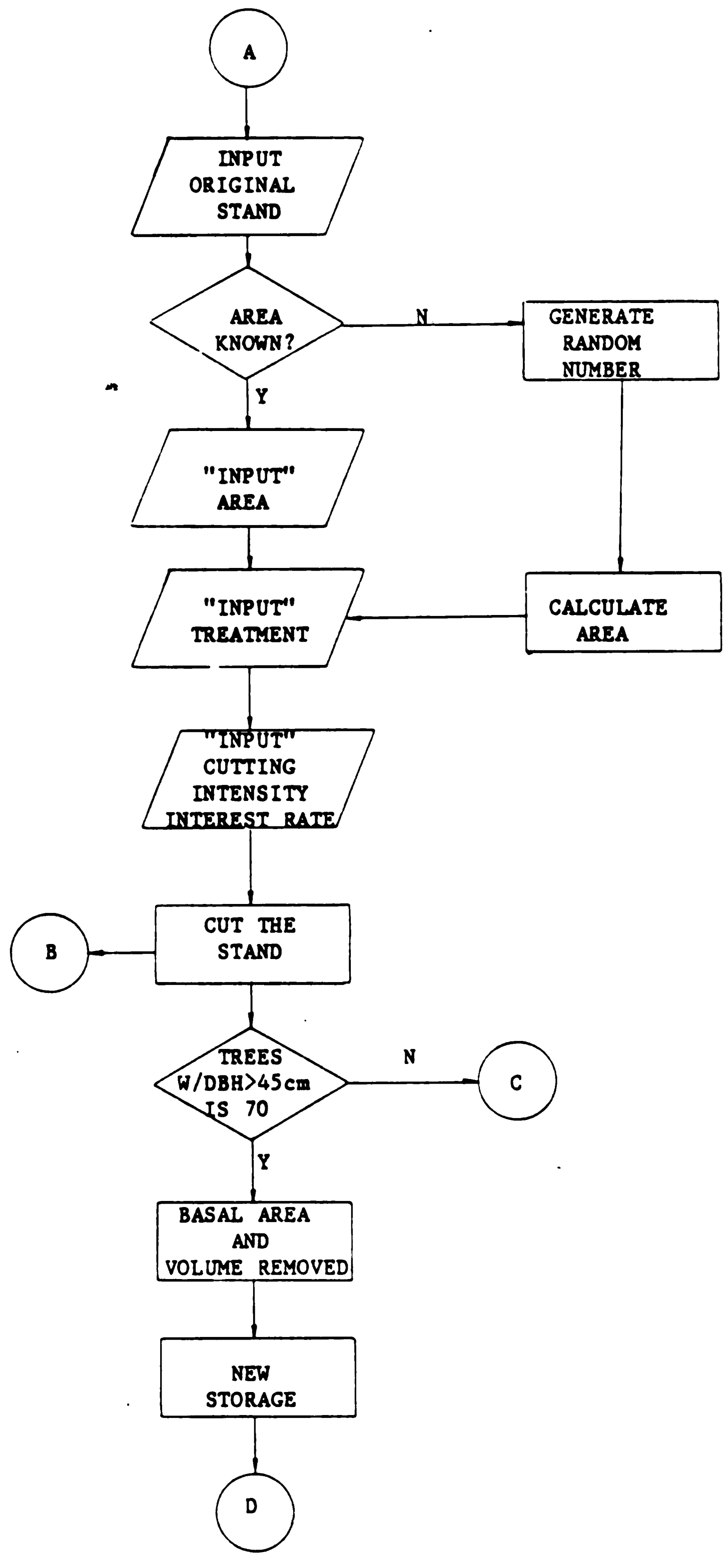


Figure 4. Detailed logical flowchart for TAPAFOR

Figu

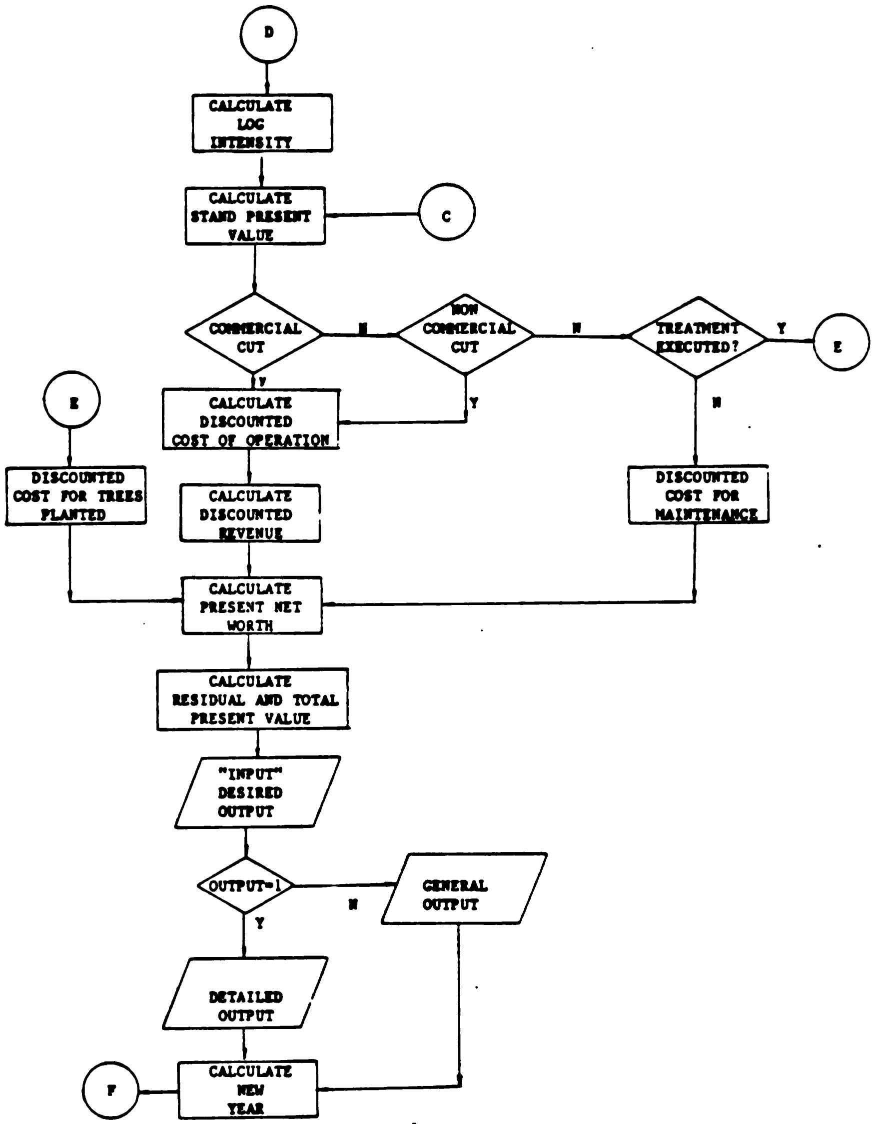


Figure 4. (cont'd.).

Fig

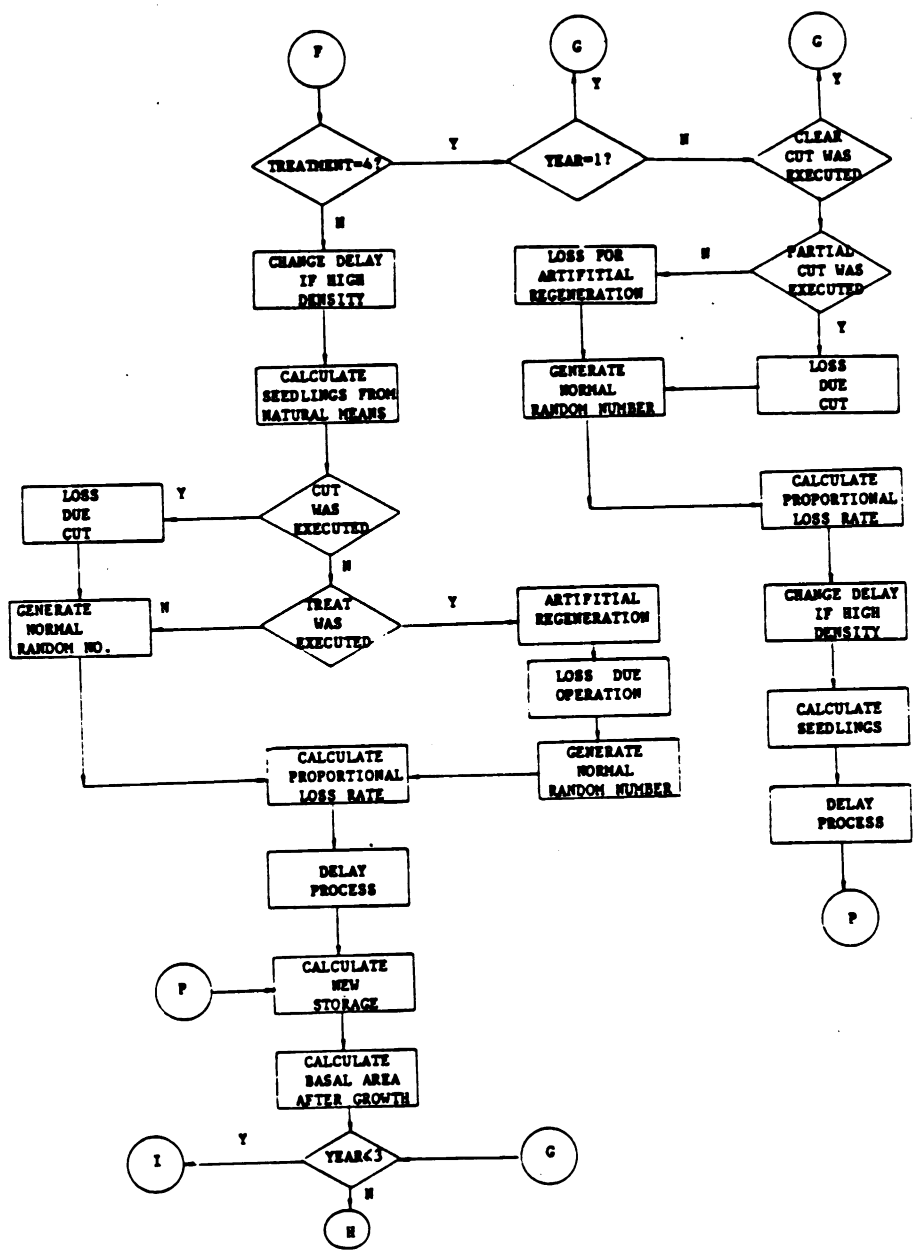


Figure 4. (cont'd.).

F

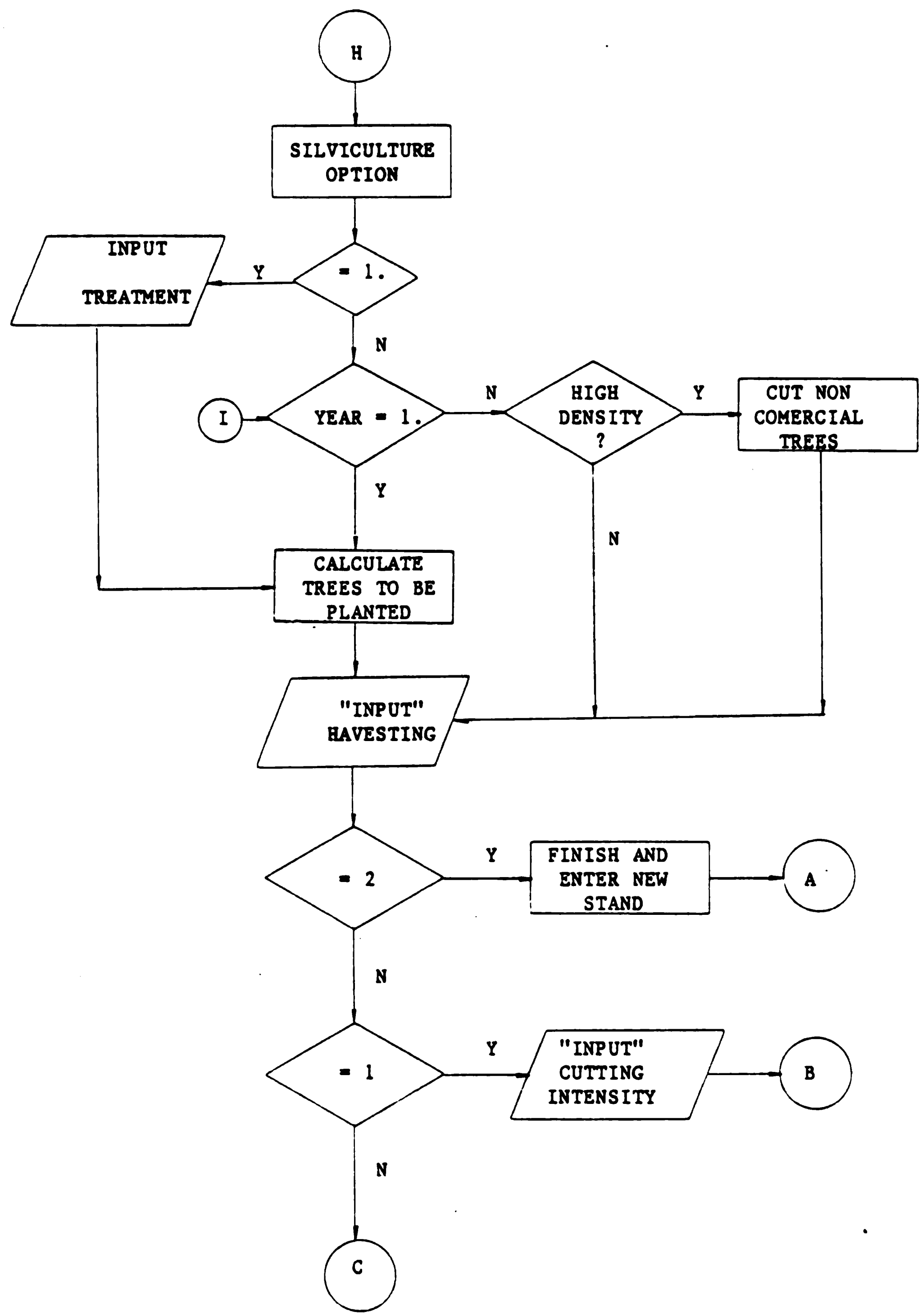


Figure 4. (cont'd.).

material

is expecte

1961).

Cutti

ed as sen

defined by

The
certa
varia
certa

Cutti

determined

mance. It

studies o

in the f

present.

time acco

tural cha

of seed t

The

process w

1.

material for energy production for example. Logging slash is expected to decompose in about two to three years (Nye, 1961).

Cutting cycle and cutting intensity can be characterized as sensitivity components of the system. Sensitivity is defined by Ackoff (1962) as:

> The variation in simulation necessary to produce certain changes in structural properties... and variations in simulation required to produce certain changes in functional properties.

Cutting cycle length will be a flexible option to be determined by the model user according to stand performance. It can also be modified on the basis of projection studies of markets to determine desired tree distributions in the future as influenced by prescribed inputs in the present. Cutting intensity will be an input at harvesting time according to the desired output or to determine structural changes in a particular stand related to availability of seed trees.

The principal parameters to be utilized in this process were considered as:

1. Average logging intensity. This depends on basal area and will determine the damage to the residual stand. Damage is characterized as broken off, crown damage, bark damage, or crown and bark damage to trees. Ranges in damages for each DBH class in relation to logging intensity are based on data in tropical forest literature. This topic should be a high priority for future field studies

in the Tapajos region. Table 2 presents the estimated damage values used in this study.

2. Removed volume. Volume is defined by Husch (1963) as the three-dimensional magnitude of an object. The volume to be removed was estimated for each DBH class based on an equation developed for the model, and is expressed in cubic meters. The volume removed is calculated for exportable trees and local commercial trees; planted trees are considered exportable species. Losses from felling breakage and natural defects were considered in a conservative way at 39 percent of the volume, with this deduction taken into account in the volume equation.

In harvesting, trees are removed according to cutting intensity specifications proportionately from each DBH class in order to keep the stand distribution characteristics.

Silviculture

Many silvicultural measures may be recommended to the timber manager, and each measure can affect either the amount or the timing of revenues and costs (Gregory 1972). Thus, the length of the investment period may also be affected. Silvicultural operations affect growth rate, damages to the residual stand, and economic considerations.

Table

Loss Class	
	A) 1
1	1
2	
3	
4	B)
5	C)
6	D)
7	E)

Table 2. Ranges of damage to the residual stand for each DBH class.

		DBH CLASS				
Loss Class	Cause	0.0-14.9 cm	15.0-24.9 cm	25.0-34.9 cm	35.0-44.9 cm	45.0-54.9 and + cm
	A) log intensity					
1	100% - 80%	a=70%	a=5%	a=.9%	a=.06%	a=.05%
		b=95%	b=30%	b=10%	b=9%	b=8%
2	80% - 50%	a=60%	a=2%	a=.1%	a=.08%	a=.07%
		b=72%	b=10%	b=7%	b=6%	b=5%
3	50% - 0%	a=50%	a=1%	a=.2%	a=.01%	a=.01%
		b=63%	b=8%	b=6%	b=4%	b=3%
4	B) enrichment	a=70%	a=2%	a=.1%	a=.01%	a=.01%
	planting	b=95%	b=10%	b=5%	b=8%	b=7%
5	C) line	a=80%	a=10%	a=.5%	a=.01%	a=.01%
	planting	b=95%	b=40%	b=20%	b=1%	b=5%
6	D) natural for	a=70%	a=1%	a=.1%	a=.01%	a=.009%
	natural trees	b=80%	b=9%	b=.9%	b=.5%	b=.02%
7	E) natural for	a=.8%	a=.01%	a=.01%	a=.005%	a=.005%
	planted trees	b=8%	b=.9%	b=.09%	b=.05%	b=.008%

a = Lower range

b = Upper range

These require
terized as a
mentation is
ficial regen
selected spe
valuable tim
C). Enrichme
tion are th
plantation
on Dawkin'
suggests a
in complet
commercial
first har
executed.

The
to mature
planted
expected
Since de
ble in
has been
competit
valuable
126 per

Cl
some ar

These require changes in the model, and they can be characterized as a sensitive component of the system. The implementation is based on two alternatives: natural and/or artificial regeneration. Artificial regeneration will utilize selected species with a good growth rate, that produce valuable timber and are free from insect attack (Appendix C). Enrichment planting, close plantation, and line plantation are the alternatives for artificial regeneration. Line plantation technique as presented by FAO/IBDF (1980) based on Dawkin's (1967) work is reproduced in Appendix D. He suggests artificial regeneration of 100 trees per hectare in completely open conditions. If the stand has 100 or more commercial trees with DBH greater than 15 cm after the first harvest, no line or enrichment planting will be executed.

The process from seed germination to seedling survival to mature tree status is a cyclic one in general. The trees planted in an enrichment or line plantation technique are expected to compete effectively in that natural cycle. Since definitive results of these techniques are not available in the literature, an approximate stand distribution has been estimated, based on current literature about tree competition over time (Fig. 5). The maximum number of valuable commercial trees to be planted is suggested to be 126 per hectare.

Close plantation will be executed after clearcutting some areas, and 400 trees per hectare spaced 5 m. x 5 m.

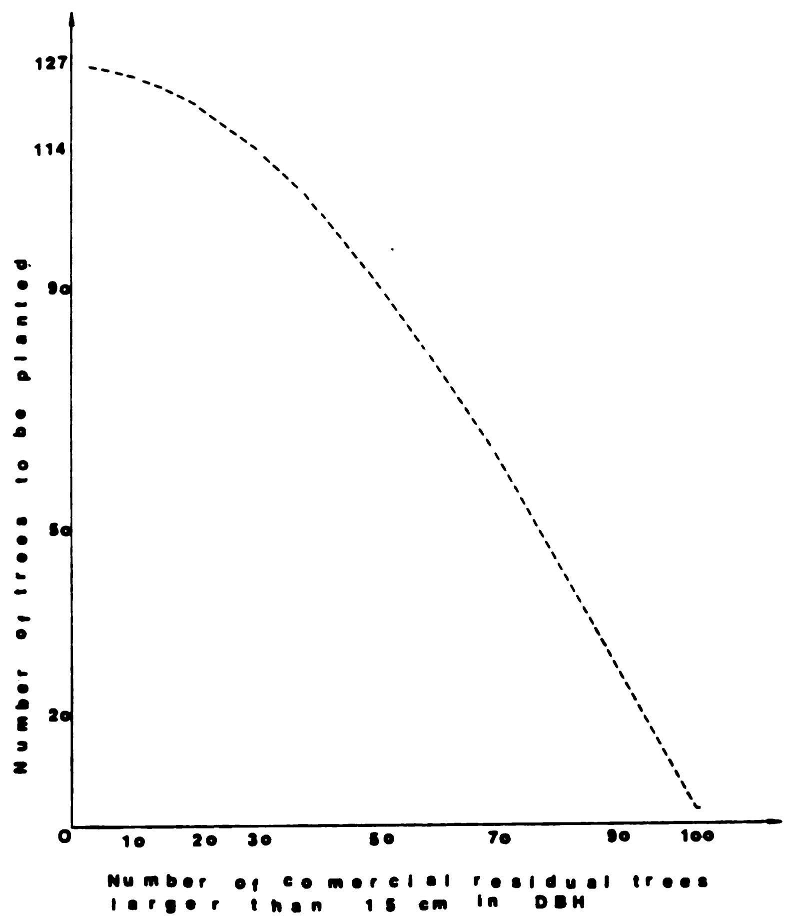


Figure 5. Number of trees to be planted per hectare

are sugge

reserved f

trees and

adequate f

may be nec

on the soi

Non-c

favor val

planting i

greater th

Growth

The a

routine el

buted Dela

by using n

> This
> delay
> in th
> of th
> compu
> stabi
> routi
> loss
> are
> stora

This

order con

into the

result of

The

are suggested. Close plantation in practice must be reserved for stands with high density of mature commercial trees and low availability of seedlings on the ground. An adequate fertilizing procedure and a longer cutting cycle may be necessary because of the impact of the clearcutting on the soil and environment.

Non-commercial thinning or silvicide treatment to favor valuable trees may be executed in years when no planting is done and where the number of trees with DBH greater than 15 cm is more than 300 per hectare.

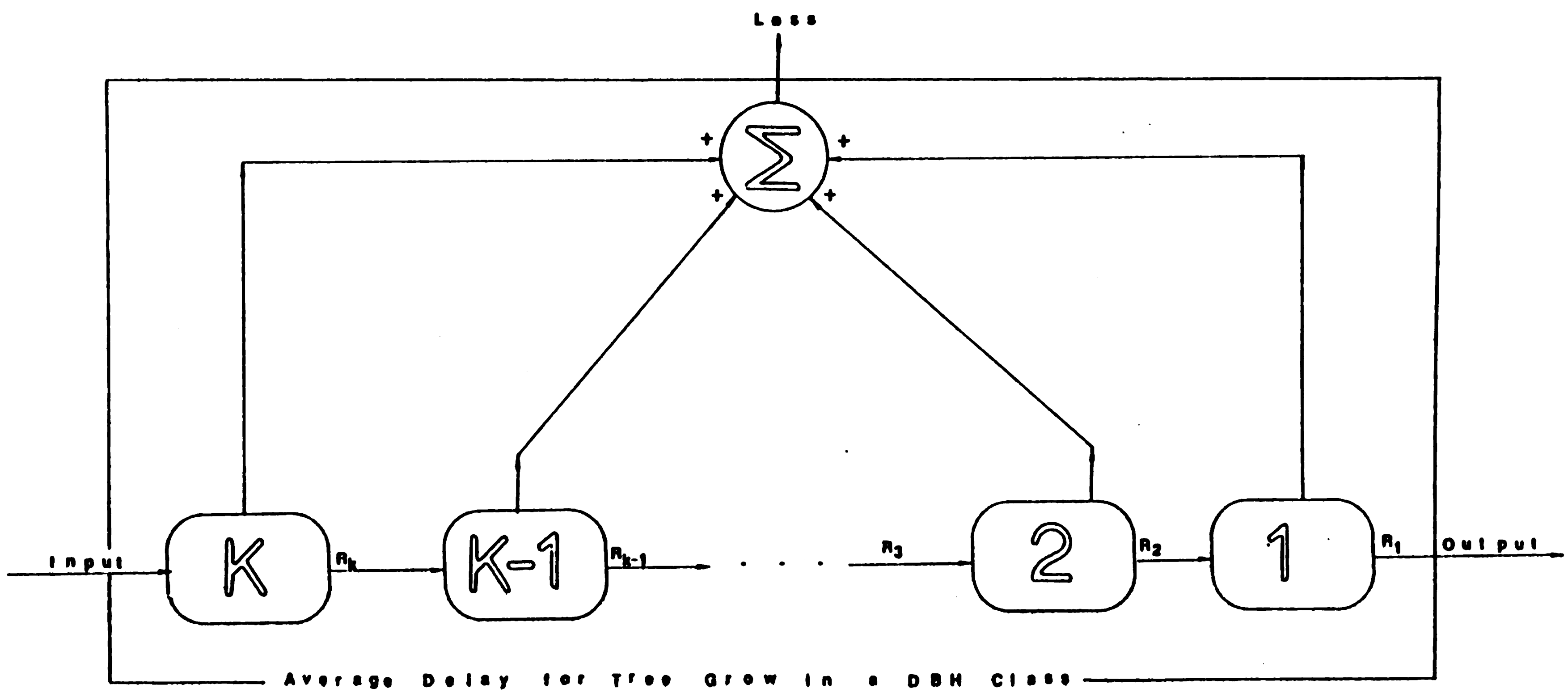
Growth

The approach utilized to predict growth was based on a routine elaborated by Abkin and Wolf (1980), called Distributed Delay with Storage Losses, and Variable Delay Time, by using numerical integration. They stated:

> This routine simulates a K^{th} order continuous delay process with storage losses and accreations in the course of the delay and where the length of the delay varies over time. It automatically computes a smaller increment if necessay for stability and non-negative flow. Inputs to this routine are the flow into delay, the proportional loss rate and the length of the delay. Outputs are the flow out of the delay and the delay storage.

This procedure divides the DBH classes into K^{th} order continuous delay processes and projects the trees into the future through diameter class distributions as a result of ingrowth, growth, and mortality (Fig. 6).

The trees in a stand are divided into 15 DBH classes,



K: stages in a DBH class
R: intermediate rates

Figure 6. K^{th} order distributed delay process with storage losses for a DBH class

and by sp
During a
diameter
larger si
that clas
the inter
each DBH
all possi
artificia
of trees
interval

To q
average d
DBH class
indicates
from 1.5
delay rat

To s
phenomeno
specified
Erlang fa
variance
divided b
the fami
increases
distribut
(Fig. 7).

and by species groups according to their commercial value. During a specific growth period DT the trees in a given diameter class may remain in the same class or advance to a larger size class according to the tree distribution in that class and the average delay. They may also die during the interval DT, or they may be harvested. The mortality in each DBH class will be based on probability and includes all possible factors that can cause mortality. Ingrowth or artificial regeneration will determine the expected number of trees entering in the smallest size class during the interval DT.

To quantify the delay process, the model considers the average delay, which is based on the average growth rate by DBH class and treatment. Available data in the literature indicates growth from 1 to 1.5 cm for natural trees and from 1.5 to 2.5 cm a year for planted species. Specific delay rates are presented in Table 3.

To simulate the delay process in the actual growth phenomenon, the density function for each DBH class must be specified, which then establishes the order of delay. The Erlang family of density functions was used to establish a variance approximately equal to the square of the delay divided by K stages. When K=1 the Erlang distribution is the familiar exponential density function, but as K increases, the Erlang distribution approaches the normal distribution with zero variance (Manetsch, et al. 1977) (Fig. 7). By appropriate selection of K, the Erlang density

Table 3. Average number of years and stage for stand growth by DBH class and treatment.

DBH CLASS		
45.0-54.9	55.0-64.9	65.0-74.9

Table 3. Average number of years and stage for stand growth by DBH class and treatment.

	DBH CLASS													
	0.0-14.9 cm		15.0-24.9 cm		25.0-34.9 cm		35.0-44.9 cm		45.0-54.9 cm		55.0-64.9 cm		65.0-74.9 cm	
Treatment	K	D	K	D	K	D	K	D	K	D	K	D	K	D
Natural Regeneration														
Exportable	12	12.0	15	8.3	15	9.1	15	9.3	15	8.7	15	8.8	15	9.2
Local Commercial	12	10.0	15	9.3	15	8.5	15	9.0	15	10.0	15	10.0	15	11.0
Non-Commercial	12	10.9	15	10.1	15	20.8	15	25.5	15	29.8	15	30.0	15	30.7
Line Plantation	20	7.6	22	4.9	22	5.1	22	5.0	22	5.5	22	7.6	22	7.2
Enrichment Plantation	18	8.0	20	5.2	20	5.1	20	5.0	20	4.9	20	7.1	20	6.8
Close Plantation	22	8.0	25	6.0	25	6.0	25	6.0	25	6.5	25	8.0	25	8.2

	DBH CLASS													
	75.0-84.9 cm		85.0-94.9 cm		95.0-104.9 cm		105.0-114.9 cm		115.0-124.9 cm		125.0-134.9 cm		135.0-144.9 cm and +	
Treatment	K	D	K	D	K	D	K	D	K	D	K	D	K	D
Natural Regeneration														
Exportable	15	10.3	15	10.4	15	10.6	15	12.0	15	12.0	15	12.0	15	12.0
Local Commercial	15	11.0	15	12.0	15	14.0	15	14.0	15	14.0	15	14.0	15	14.0
Non-Commercial	15	33.1	15	34.2	15	35.0	15	35.0	15	35.0	15	35.0	15	35.0
Line Plantation	22	8.7	22	9.1	22	9.5	22	9.0	22	9.0	22	9.0	22	9.0
Enrichment Plantation	20	8.2	20	9.8	20	9.7	20	9.0	20	9.0	20	9.0	20	9.0
Close Plantation	25	10.9	25	10.0	25	10.6	25	10.0	25	10.0	25	10.0	25	10.0

K: stages of growth in each DBH class
D: average number of years to change of DBH class

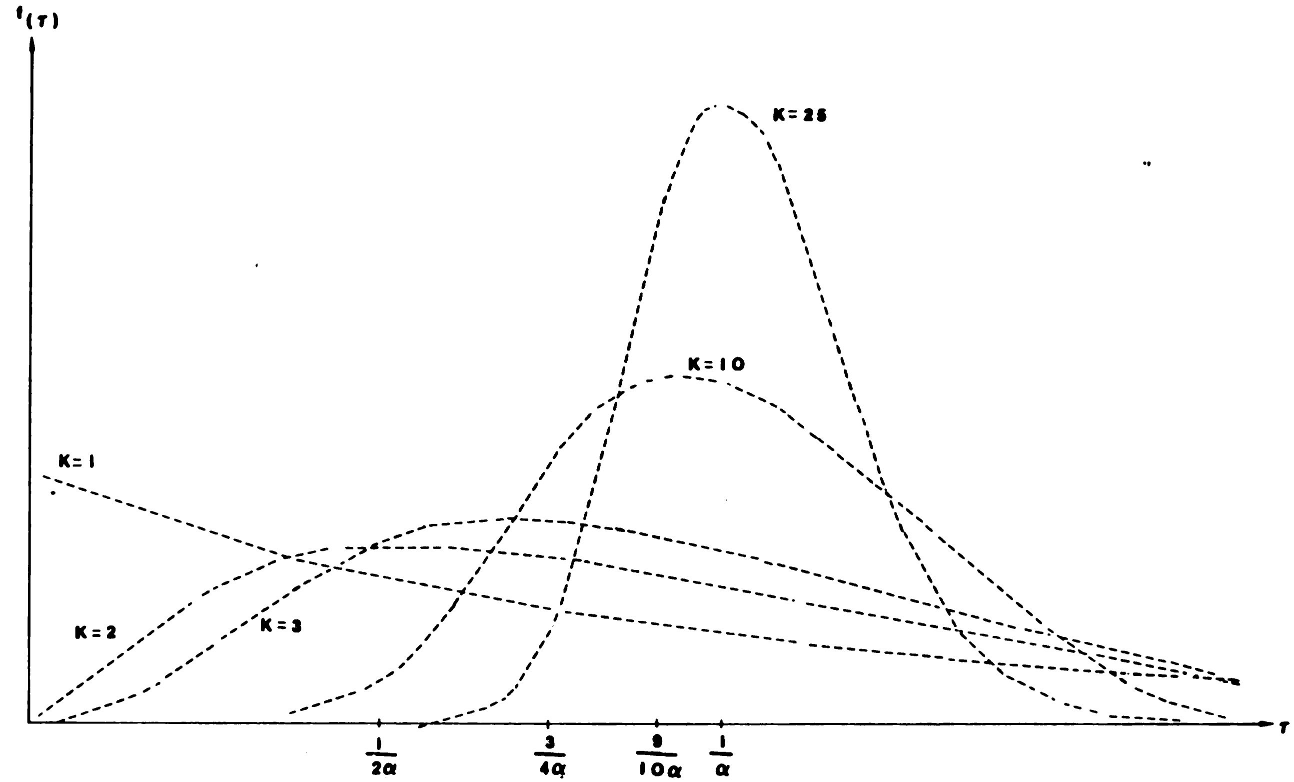


Figure 7. The Erlang family of density functions

function ca

mena. As c

calculate v

DBH class,

tend to a

competition

different

class dete

close plan

an almost

In t

based on

In line a

for tree

greater,

basal are

plantatic

for tree

500 or b

Tim

year. D

is unst

not ann

smaller

negativ

not nec

Th

function can represent a wide range of real world phenomena. As complete inventory data are not available to calculate variance and then determine the stages in each DBH class, the basic assumption in TAPAFOR is that trees tend to approach a normal distribution after initial competition, which appears to be close to reality. The different indices of competition for each treatment and DBH class determined the order K presented in Table 3. In a close plantation treatment, there is less competition, so an almost perfect normal distribution results.

In the simulation process, the change in delay is based on the density of the stand and/or basal area growth. In line and enrichment planting the delay in DBH movement for trees less than 25 cm, where the competition is greater, will double if the number of trees exceeds 400 or basal area exceeds 45 square meters per hectare. In a close plantation treatment, the delay is also expected to double for trees with DBH less than 25cm, when total trees exceed 500 or basal area exceeds 70 square meters per hectare.

Time increment (DT) in TAPAFOR was determined as one year. DT strongly influences model stability. If the model is unstable, its validity and usefulness are impaired if not annihilated. Since the delay routine used computes a smaller increment if necessary for stability and non-negative flow, additional DT adjustments for stability were not necessary.

The damage losses in each simulation run are

associated v
presented i
utilized in
based on th
process. In

1. Ca
   cl
2. Ca
   Si
   ol
   r
   s
   t
3. C

Inpu
natural
complete
ingrowth
based o
expected

1.

associated with the operation executed in that year as presented in Table 2. The Proportional Loss Rate (PLR) utilized in the delay process is a stochastic variable based on the normal distribution, since it is a biological process. In predicting PLR, the steps are:

1. Calculate the mean of the loss for a specific DBH class;
2. Calculate the standard deviation of the mean. Since smaller DBH classes normally have been observed to have more losses, the variation in relation to the mean loss decreases. Then, the standard deviation of the mean loss is considered to increase as DBH class increases.
3. Generate a normal random PLR using a random generator between zero and one, and a function that interpolates numbers with equal increments (Llewellyn 1965), having a normal distribution as the basis.

Inputs in the delay process are mainly from the natural process of ingrowth or some executed planting. To complete the model, a specific form must be given to the ingrowth function. It was set as a stochastic variable, and based on a normal distribution. Natural regeneration is expected to follow the following pattern:

1. If there are no trees with DBH greater than 45 cm, an average of 500 seeds (S.D.=$\pm$200) will be produced.

2. I

a

p

The s

wide range

wide varia

The r

average, b

condition

planted t

is expect

line or

regenerat

trees hav

seedling

plantatic

needed,

to produ

field s

reestabl

favor s

quality

Economi

Pr

operati

duct.

2. If there are trees with DBH greater than 45 cm, an average of 800 seeds (S.D.=±300) will be produced.

The standard deviation is included above to show the wide range in the availability of seeds, and the consequent wide variation in seed germination and seedling survival.

The number of seeds is expected to be larger than the average, but in reality only a few are expected to be in a condition good enough to germinate and survive. With planted trees, a small proportion of natural regeneration is expected, mainly because of the planting treatment. A line or enrichment planting is expected to produce natural regeneration of 100 trees per hectare when at least ten trees have a DBH greater than 45 cm. The mortality for this seedling class is assumed at about 85 percent. In a close plantation, at least 200 trees with a DBH of 45 cm are needed, in order to consider the stand sufficiently mature to produce enough seeds for adequate regeneration. Future field studies of these rates are necessary to guide the reestablishment of the forest by natural regeneration, to favor species which can be utilized and to improve the quality of timber at low cost.

Economics

Present Net Worth (PNW) calculations are a routine operation in TAPAFOR, based on sawlogs as the final product. The present value of expected future returns over the simulation

costs, with

rate of i

analyze pro

The op

can be use

different

rate of va

user must

In p

(1979) and

cruzeiros

Sawlogs a

two cubi

produce

assumed

as follow

1.

2.

3.

4.

simulation cycle minus the present value of expected future costs, with costs and returns discounted at a specified rate of interest, will be the economic parameters to analyze profitability.

The opportunity cost of capital is an alternative that can be used in TAPAFOR. The user has the option to use different rates of return in alternative treatments. If the rate of value growth falls below the best alternative, the user must choose the next most appropriate treatment.

In predicting PNW, costs were derived from Beattie (1979) and IBDF records. Costs are expressed in the form of <u>cruzeiros</u> per hectare based on approximate 1981 data. Sawlogs are considered the final product, and in general, two cubic meters of commercial volume are necessary to produce one cubic meter of sawlogs. If the market is assumed to be in the city of Belem, costs were considered as follows:

1. Harvesting, logging, industrialization and transportation to produce one cubic meter of sawlogs -- CR$ 3,540.00
2. Non-commercial thinning, independent of output -- CR$ 1,200.00/hectare
3. Weed control and maintenance -- CR$ 580.00
4. Planting, including all requirements:
    a. Close plantation -- CR$ 30.00 per tree
    b. Line plantation -- CR$ 26.00 per tree
    c. Enrichment planting -- CR$ 24.50 per tree

The r

multiplying

meters of

Prices were

1. L

7

t

2. F

Actu

availabl

this ti

estimate

Fo

comple

well

tions;

cient

ing

Proce

al.

mode

for

The revenue at any point in time is obtained by multiplying output by price. The output will be two cubic meters of valuable trees for each cubic meter of sawlogs. Prices were established as follows:

1. Local commercial trees, an average price of CR$ 7,000.00 per cubic meter of final product or per two cubic meters of commercial volume.
2. Exportable trees or artificially regenerated species, an average price of CR$ 10,000.00 per cubic meter of sawlog or per two cubic meters of commercial volume.

Actualized and updated data are expected to be available in the near future for an update of TAPAFOR. At this time, the above costs and prices are the best estimates available.

Mathematical Components of the Model

For the construction of valid mathematical models, a complete knowledge of the system which is being modeled as well as proficiency in mathematics are necessary conditions; however, in no sense can they be considered sufficient conditions, since successful mathematical model building depends in part on the analyst's experience, trial procedures, and a considerable amount of luck (Naylor, et al. 1968). In predicting the mathematical portion of the model, the equations were derived from the available data for each component using regression analysis available in the Statis

the Michig

sion anal

among the

however,

relationsh

variables

the curve

transform

form of

data, on

giving t

chosen.

Seve

1.

2.

TP

the Statistical Package for the Social Sciences (SPSS) at the Michigan State University Computer Laboratory. Regression analysis asumes that the underlying relationships among the variables are linear and additive. It is, however, sometimes possible to reinstate a non-linear relationship in a linear form by transforming the orginal variables (Nie, et al. 1975). Knowledge about the form of the curve produced by each relationship is required for the transformation of the variables. In the actual process, the form of the curve was obtained by plotting the variable data, on a graph, thus trying various models. The model giving the best fit using the least squares method was chosen.

Several equations used in the model are as follows:

1. Net commercial volume (cubic meters per tree) with 39 percent loss due to dark, natural defects and felling:

$$V = 0.00576\ (DBH) + .000529\ (DBH)^2$$

Where

V = volume in cubic meters

DBH = diameter at breast height (1.30 meter above the ground) in centimeters

2. Total commercial trees to be planted under enrichment or line plantation option, per hectare:

$$TP = 26.2666114 + 100.93310COS[(TOTAL)(2.0)(\pi/360.0)]$$

Where

TP = total trees to be planted per hectare

TOTAL = present number of commercial trees per hectare with DBH greater than 15 centimeters

π = 3.1416

COS = cosine in degrees

Other equations were obtained from available literature as follows:

3. Basal area was derived from an equation given by Husch, et al. (1972):

$$BA = \pi (DBH)^2 / (4 \times 10^4)$$

Where

BA = basal area in square meters per hectare

DBH = diameter at breast height in cm

π = 3.1416

4. Average logging intensity:

$$ALI = (TBA2 / TBA1)(100)$$

Where

ALI = logging intensity in percentage

TBA1 = total basal area in square meters before logging

TBA2 = total basal area in square meters after logging

5. Initial intermediate density rates in each DBH class for proper performance of delay routine:

$$Ri(O) = S(O) / DIL(O)$$

Where

$Ri(O)$ = intermediate rates according to delay order

$S(O)$ = storage in DBH class

$DIL(O)$ = average delay for the specified DBH class

6. Present Net Worth (PNW):

$$PNW = Ry / (1 + i)^{y} - Cy / (1 + i)^{y}$$

Where

PNW = present net worth in <u>cruzeiros</u>

y = year

Ry = revenue in year y

Cy = cost in year y

i = rate of interest

The

which nee

ments for

selected

ted, resu

facilitat

system me

it is co

the syste

behavior

than the

The

model is

managemen

of TAPAF

the mana

developed

relevant

Tapajos

of the A

CHAPTER V

TAPAFOR DOCUMENTATION

The System

The systems approach can be defined as a process by which needs are identified, problems are selected, requirements for problem solutions are identified, solutions are selected from alternatives, methods and means are implemented, results are evaluated and revisions to the system to facilitate need removal are identified. To describe a system means that some kind of representation or model of it is constructed. A model is the analyst's description of the system. To be useful for communicating the nature and behavior of the system, the model must be less complicated than the real system (McMillan et al. 1973).

The Tapajos National Forest management simulation model is the basic representation of an uneven-aged management system for a tropical forest. The prime purpose of TAPAFOR is to present an open-ended system designed for the management of an Amazon basin forest, which can be developed further through time. The model presents the relevant points that require attention in the use of the Tapajos National Forest as a pilot project for management of the Amazon forest. Based on further practical results, additional

to play a

Brazil.

The

The compo

manipulat

schedules

growth,

decisions

his objec

This

twelve s

activitie

variables

with equ

4 gives

of their

The

function

For eac

NETVAL,

are cal

initial

user, t

activiti

and har

basis.

additional development of TAPAFOR will be necessary for it to play a realistic and useful future role in forestry in Brazil.

The basic concept of TAPAFOR is presented in Fig. 8. The components discussed previously constitute the basic manipulative representation of the model. Harvesting schedules and intensity, silvicultural treatment, forest growth, and financial factors will influence the user's decisions about which alternatives are appropriate to meet his objectives.

This simulation model consists of one main program and twelve subroutines. Six subroutines simulate management activities, two simulate stand growth, one generates random variables, two generate output and one interpolates numbers with equal increment based on a normal distribution. Table 4 gives a listing of the subroutines, and brief statements of their purposes.

The main program--TAPAFOR--performs some input functions and controls the various subroutines (Fig. 9). For each year in the simulation run, the subroutines NETVAL, GROWTH, DELICT, PRESCR, LOSS, TABLIE, and OUTPUT are called. Subroutines SCREEN and COVER are called in the initial simulation run. Once every period specified by the user, the subroutine REMOVE is called. All management activities are performed on an annual basis. Silvicultural and harvesting operations are performed on a periodic basis. Stand growth is simulated by subroutine GROWTH. Each

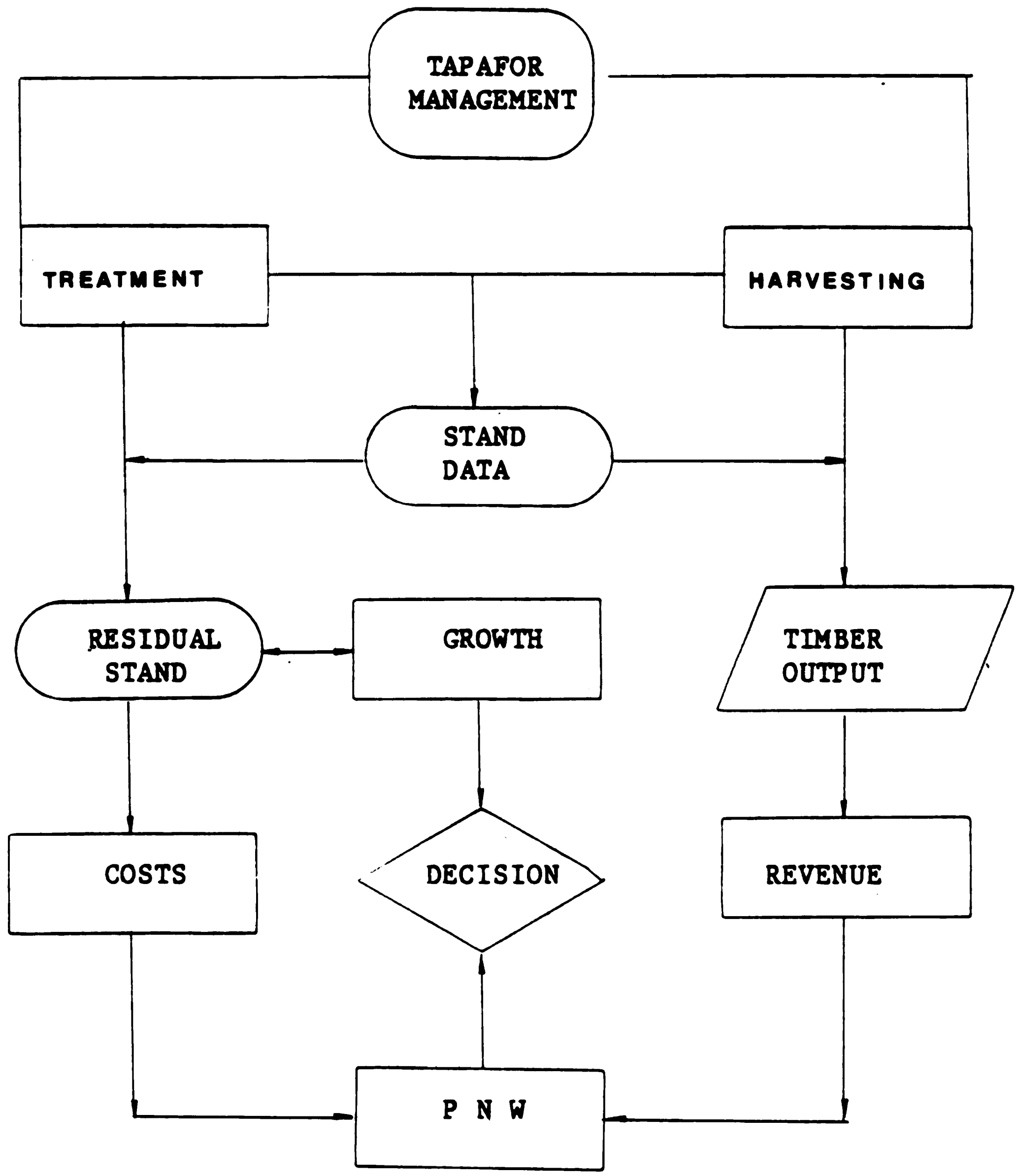


Figure 8. The basic concept of TAPAFOR

COMPONE

1. Program

Main ca

up and

organi

routin

select

---

2. Subrou

Called

the i

compu

the K

cess.

3. Subro

Calle

pute

area

Table 4. TAPAFOR and its subroutines

COMPONENT	FUNCTION
1. Program TAPAFOR Main calling routine, sets up and initializes arrays, organizes calling of subroutines,and reads user-selected options.	MAIN PROGRAM
2. Subroutine SCREEN Called from TAPAFOR, to read the initial input values and compute initial storage in the K-stages of delay process. 3. Subroutine COVER Called from SCREEN, to compute a stochastic variable area.	INPUT

Table 4 (co

COMPONE

4. Subrou

Called

GROWTH

interp

equal

----

5. Subrou

Called

a deta

select

6. Subrou

Called

a gene

select

----

7. Subrou

Called

trees

and to

----

8. Subrou

Called

all co

operat

Table 4 (cont'd.)

COMPONENT	FUNCTION
4. Subroutine TABLIE Called from COVER, GROWTH 1, GROWTH 2, and LOSS, to interpolate numbers with equal increment.	MATHEMATICAL FUNCTIONS
5. Subroutine OUTPUT 1 Called from TAPAFOR, to provide a detailed output by year if selected by the user. 6. Subroutine OUTPUT 2 Called from TAPAFOR, to provide a general output by period selected by the user.	OUTPUT
7. Subroutine REMOVE Called from TAPAFOR, to remove trees to meet user specification and to calculate output.	HARVESTING
8. Subroutine NETVAL Called from TAPAFOR, to calculate all costs and revenues from operations executed.	ECONOMICS

Table 4 (c

COMPO

9. Subro

Calle

calcu

selec

alloc

and c

10. Subro

Calle

execu

Growt

a clo

11. Subro

Calle

GROWT

incre

in ea

12. Subro

Calle

GROWT

stoch

loss

distr

Table 4 (cont'd.)

COMPONENT	FUNCTION
9. Subroutine GROWTH 1 Called from TAPAFOR, to calculate the growth of trees, select trees for mortality, allocate changes in DBH class, and calculate ingrowth.	STAND GROWTH
10. Subroutine GROWTH 2 Called from TAPAFOR, to execute the function of Growth for a stand under a close plantation option.	STAND GROWTH
11. Subroutine DELICT Called from GROWTH 1 and GROWTH 2, to determine the increment and new density in each DBH class.	STAND GROWTH
12. Subroutine LOSS Called from GROWTH 1 and GROWTH 2, to determine the stochastic proportional loss rate based on a normal distribution.	STAND GROWTH

Table 4 (co

COMPON

13. Subrou

Called

calcul

genera

non-co

Table 4 (cont'd.)

COMPONENT	FUNCTION
13. Subroutine PRESCR Called from TAPAFOR, to calculate artificial re-generation and to execute non-commercial treatment.	STAND TREATMENT

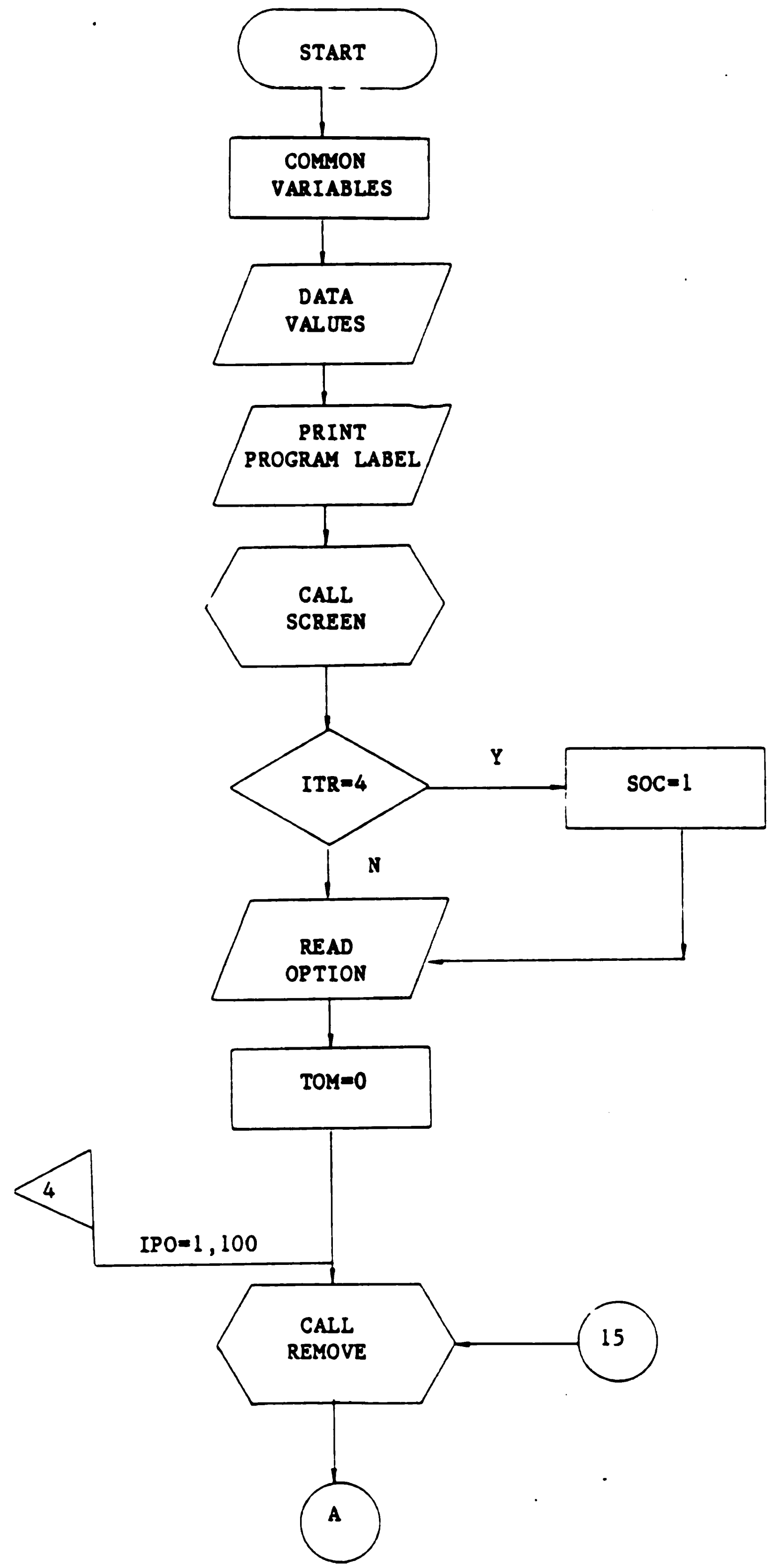


Figure 9. Detailed program flowchart for TAPAFOR

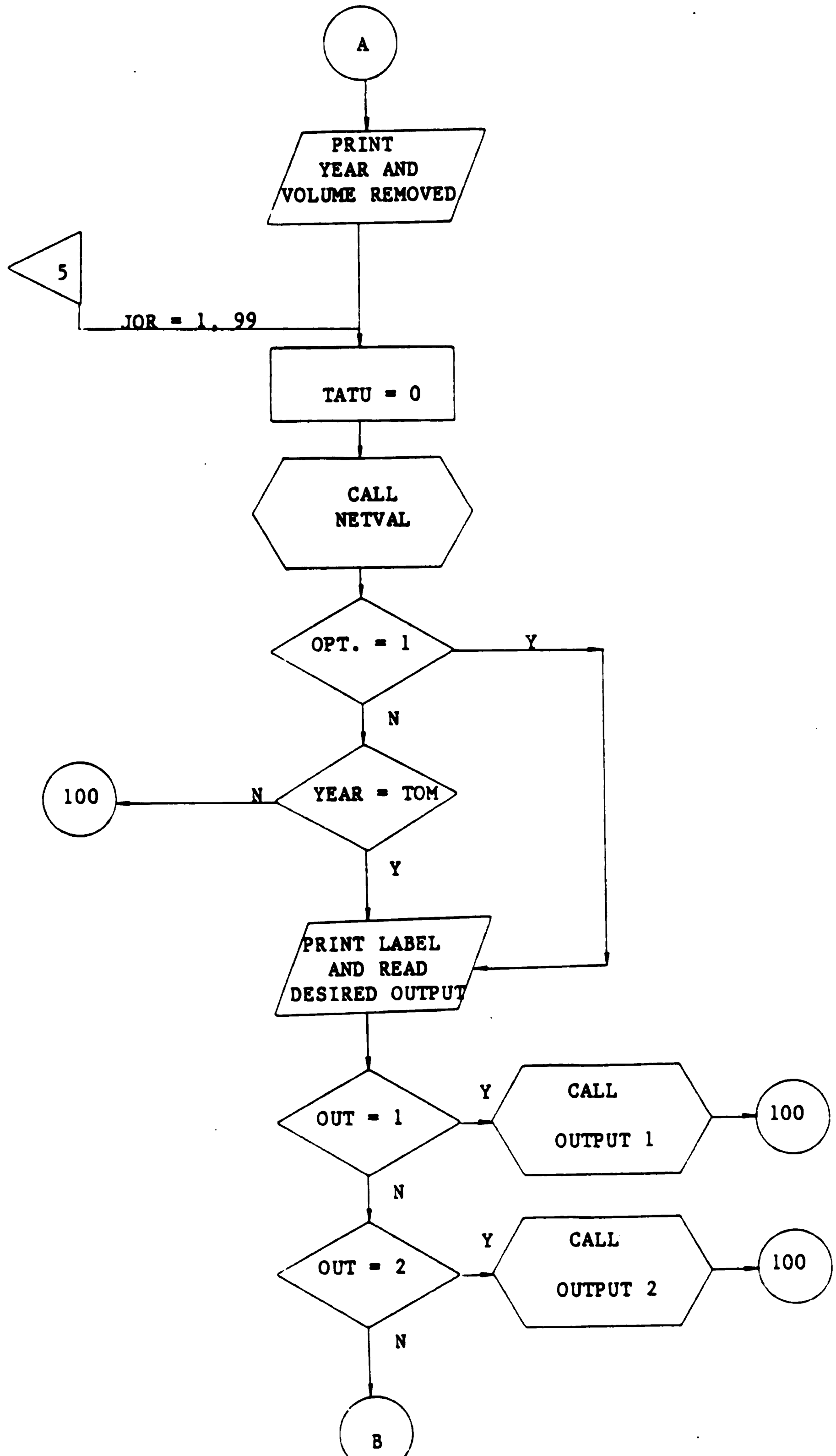


Figure 9. (cont'd.).

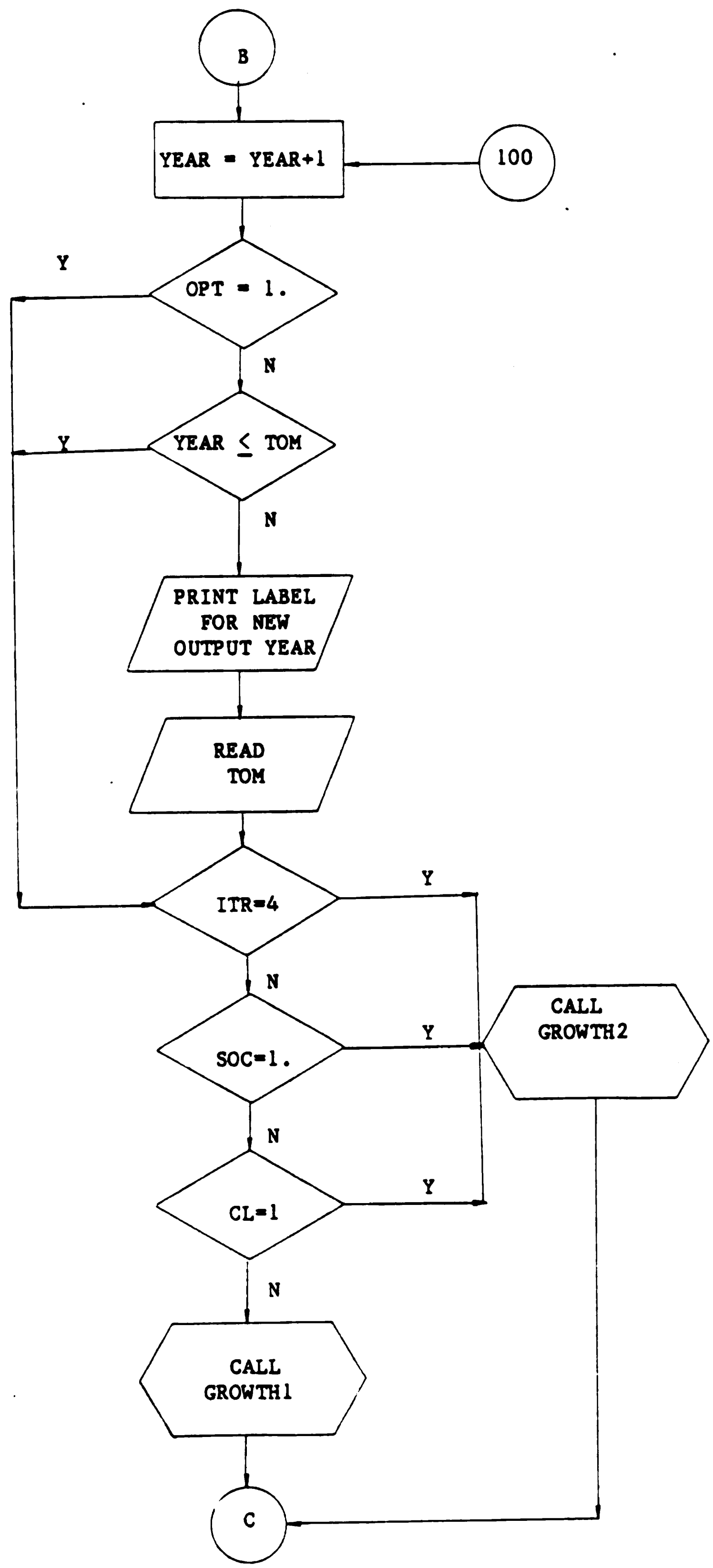


Figure 9. (cont'd.).

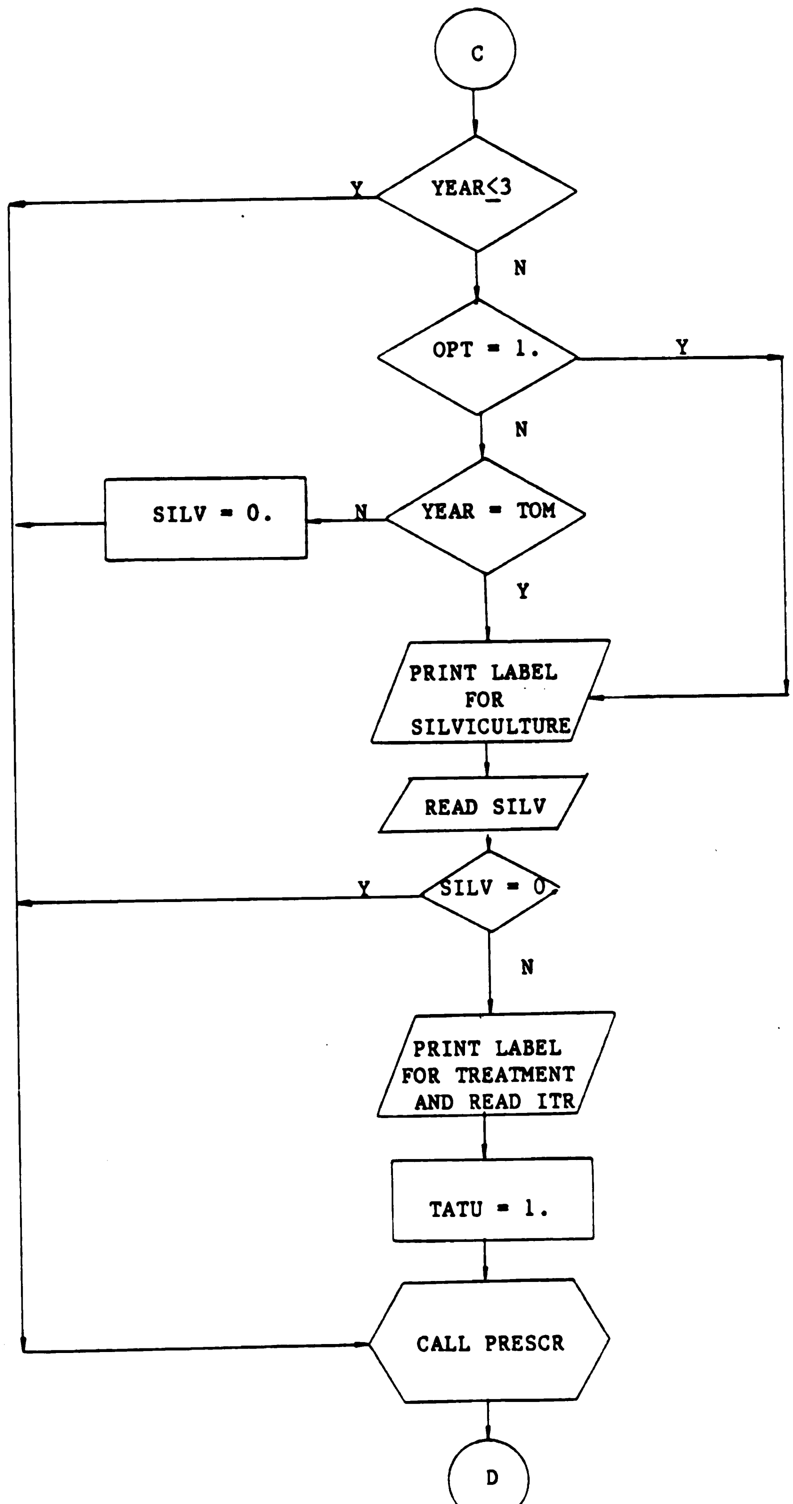


Figure 9. (cont'd.).

Fi

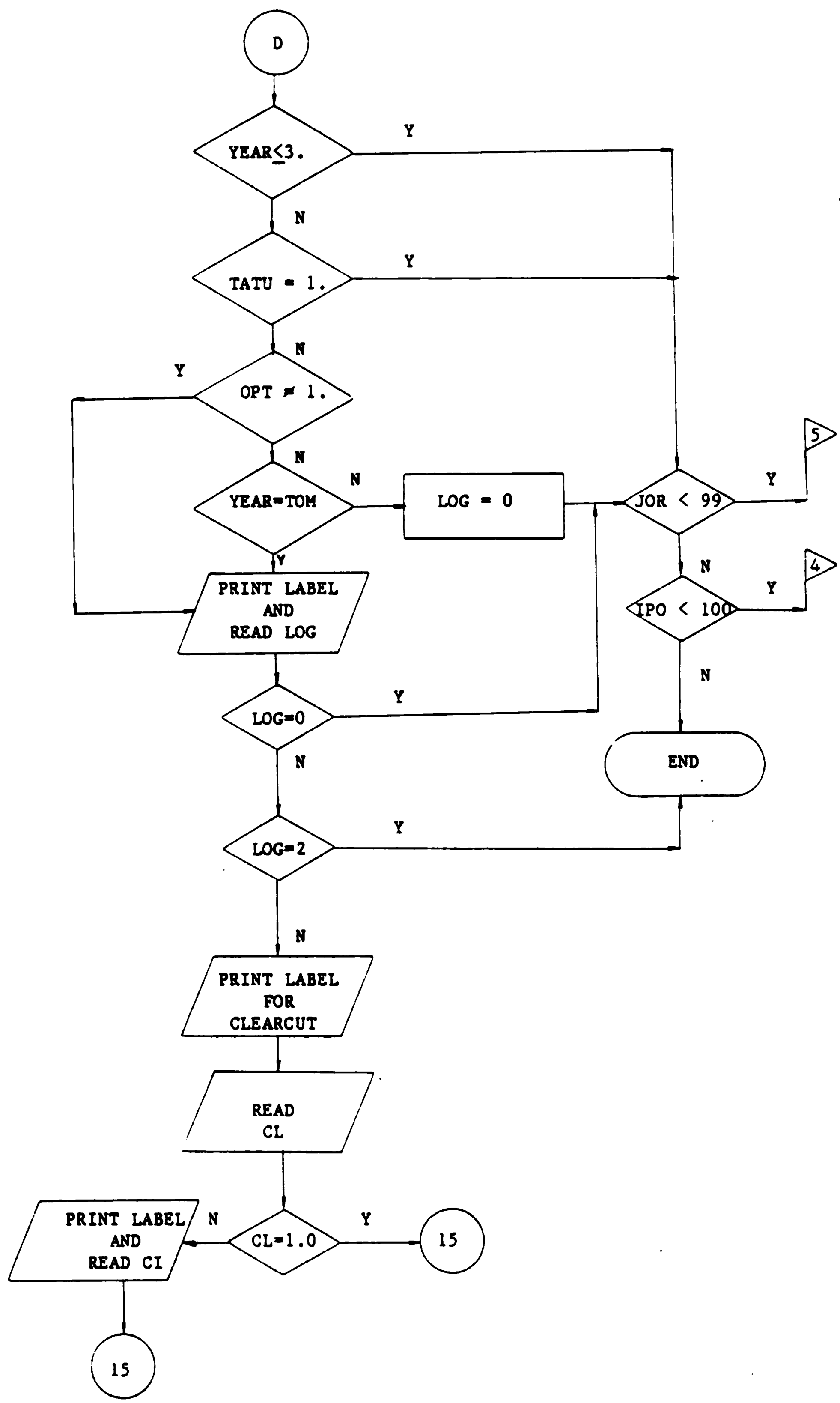


Figure 9. (cont'd.).

year cash

and the pr

the standi

Initi

brium stag

process ir

be genera

developmen

if the st

cultural

on a per

Inpu

1.

2.

3.

The

active s

the inpu

Appendix

In

subrouti

<u>Subrouti</u>

The

year cash flows for the various activities are calculated and the present net worth of revenues and the net worth of the standing timber are displayed, at the user's option.

Initially, the stand is assumed to be at an equilibrium stage. A harvest at year zero will start the change process in the forest. A detailed or a general output will be generated according to user specifications to show the development of the stand, which the user can check to see if the stand should be scheduled for harvesting or silvicultural treatment. All performances of TAPAFOR are based on a per hectare basis.

Input Phase

Input data for TAPAFOR are separated into three sets:

1. Forest data.
2. Management-decision variables.
3. Financial variables.

The data must be provided by the user on an interactive system. A general description of the execution of the input data is given in TAPAFOR's User's Manual in Appendix E.

In the implementation of the above input phases, subroutines SCREEN, COVER, and TABLIE are used.

Subroutine SCREEN

The subroutine reads the initial density of trees in each DBH cl

rates. The s

1. Fo

cl

ta

ev

nu

th

r

C

e

b

t

c

2.

each DBH class as well as generates intermediate density rates. The steps listed below are followed:

1. Forest Input Data. The program accomodates 15 DBH classes and three initial species groups: exportable, locally commercial, and non-commercial. For every DBH class in each group of species, the number of trees has to be provided. The subroutine then reads and allocates intermediate density rates according to mathematical model 5, in Chapter IV. The initial number of seedlings provided by the user, if not actually known, must be between 50 and 150. This is due to the assumption that the forest is in equilibrium, with few seeds germinating. Another factor will be the delay in tree diameter change, and the subroutine will allocate proportional numbers in stages at the initial condition. The area of the stand must be provided; otherwise, a stochastic value is generated.

2. Management decision variables. This set of variables includes the initial cutting intensity and stand treatment. Treatments are classified as:

   1) Natural regeneration.

   2) Line plantation with natural regeneration.

   3) Enrichment planting with natural regeneration.

   4) Close plantation.

   In the case of Treatments 1, 2 and 3, an initial cutting intensity from 1 to 100 percent has to be specified. With a close plantation option, the program will execute a clearcutting.

3. Financial variables. The price and cost variables for each operation are pre-set in the program as described previously. The interest rate for discounting future costs and revenues is the additional financial input variable to be provided by the user.

Fig. 10 presents the integration of these phases in a gross logical flowchart for subroutine SCREEN.

Subroutine COVER

This subroutine generates a stochastic area, at the user's option, based on a normal distribution of random numbers (Fig. 11). The main objective is to give flexibility to TAPAFOR when used for educational purposes. A mean of 10 hectares and standard deviation of 1.5 hectares for each stand is assumed, since an exact variation is not available. A small area of 10 ha is proposed with the objective of minimizing the risk of applying an equivocal treatment to the stand, or unexpected results. An area from .01 to 20 percent is expected to be classified as non-productive forest. A random number is generated and then subtracted from the previously calculated area.

Figure 10. (

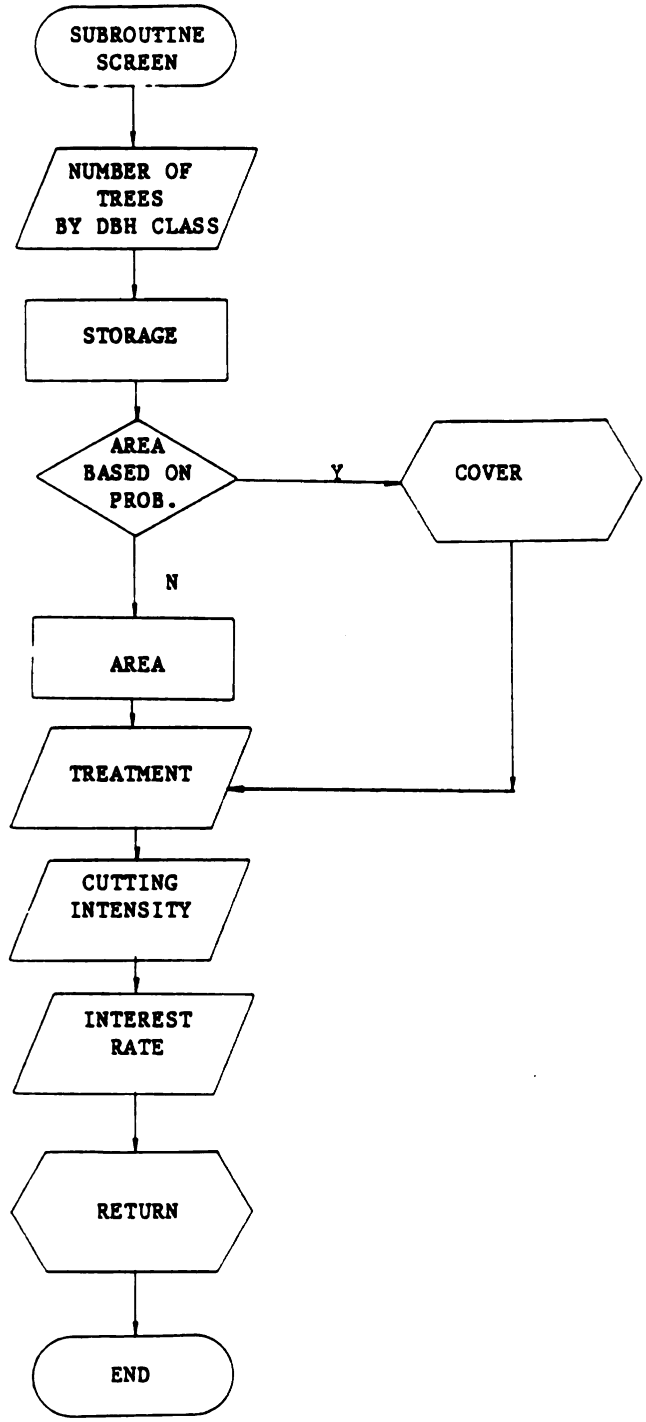


Figure 10. Gross logical flowchart for subroutine SCREEN

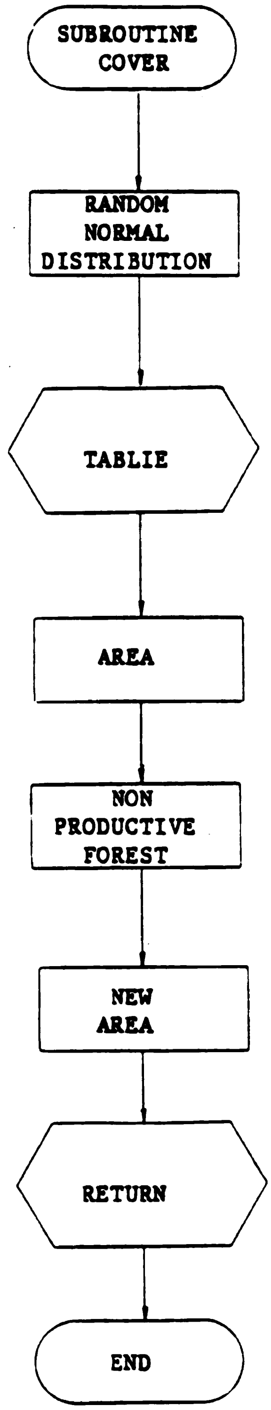


Figure 11. Gross logical flowchart for subroutine COVER

Subrou

T

ting

number

T
s
c
d
a

The ar

ly spa

normal

interp

will b

value

callin

variab

the fo

Normal

T

The f

along

The s

only

initia

main

output

treatm

Subroutine TABLIE

TAPAFOR uses the table look-up function for interpolating values in a normal distribution based on a random number. As stated by Llewellyn (1965):

> The TABLIE function stands for a Table look-up subroutine in which the value returned to the calling program is limited to be within a predetermined range and in which the elements of the array are equally spaced.

The array utilized here ranges from -3.65 to +3.65 in equally spaced intervals of .25, being constituted in a standard normal distribution. The input which is the basis of the interpolation is a number between 0 and 1. The output value will be in units of the array utilized, in this case, a value of Y from -3.65 to +3.65. Any part of this program calling TABLIE to generate a standard normal stochastic variable will utilize the Y returned value from TABLIE in the following way:

Normal stochastic variable = Mean $\pm$ Y(Standard Deviation)

The TAPAFOR program offers two options to the user. The first one will print the general or detailed output along with inquiries about management decisions each year. The second one will provide output and referred inquiry only in the years to be specified by the user. After initial harvesting, the input phase is controlled by the main program, which consists practically of the desired output and a prescribed harvesting or silvicultural treatment as specified in Appendix E.

Output Phase

The opportunities for using a forest to produce sawlogs for income considerations lets the user determine production over time by controlling the allowable cut. To provide guides for action based on output, two options are available to the user in each year, OUTPUT 1, and OUTPUT 2.

Subroutine OUTPUT 1

This subroutine provides a detailed output of the stand data if selected during the simulation period (Fig. 12). The functions of this subroutine are to calculate the total present net value from values of subroutine NETVAL, and to print labels and variables calculated in other components of TAPAFOR. The variables are:

1. Year after first harvest.
2. Total basal area before growth per hectare.
3. Total mortality per hectare at referred year.
4. Present net worth per hectare.
5. Accumulated removed value per hectare.
6. Residual stand present net value per hectare.
7. Total present net value per hectare.

In addition the subroutine provides a table for storage of stand data by DBH class and treatment.

Subroutine OUTPUT 2

Subroutine OUTPUT 2 in its present form provides a

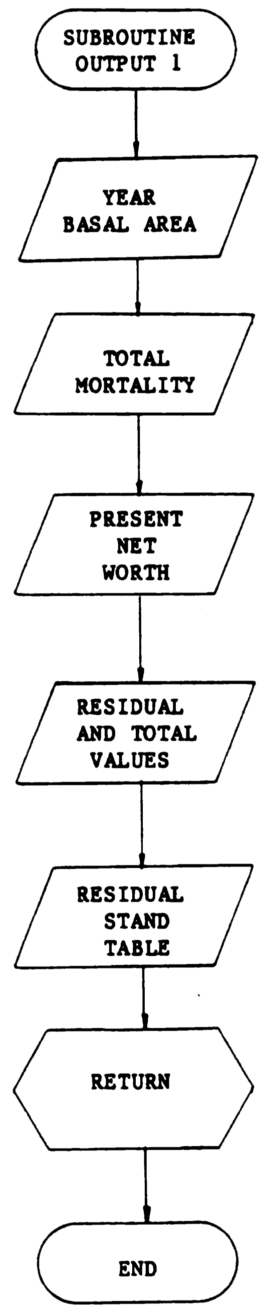


Figure 12. Gross logical flowchart for subroutine OUTPUT 1

general output when selected (Fig. 13). Variables are printed in the following sequence:

1. Year after first harvest.
2. Present net worth per hectare.
3. Residual stand present net value per hectare.
4. Total present net value per hectare.
5. Total trees with minimum 15 cm DBH per hectare.
6. Total number of commercial trees with minimum 15 cm DBH.
7. Total number of commercial trees with minimum 45 cm DBH.

It executes the main calculations for the printout of the above variables except for the first three.

Harvesting Subsystem

Harvesting operations are performed on a one-hectare basis at the beginning of the simulation run and can be specified by the user any time after the third year after initial disturbance. Subroutine REMOVE simulates timber harvests and provides the basic information for calculations of revenue per hectare from the stand.

Subroutine REMOVE

This subroutine harvests trees from the forest stand according to the cutting regime selected by the user. If only part of the stand is to be harvested, the percentage

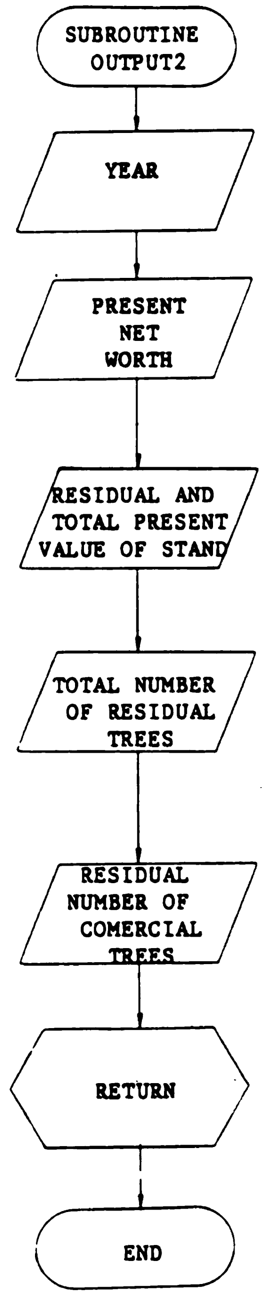


Figure 13. Gross logical flowchart for subroutine OUTPUT 2

of cut per hectare needs to be specified in the input phase. The program records harvest volume and residual stand volume in order to calculate the cash flow associated with the harvesting operations, as well as logging intensity to determine damages to the residual stand. The basic steps in this subroutine as presented in Figure 14 are as follows:

1. Calculate basal area before harvesting.
2. Calculate volume to be removed.
3. Cut the stand.
4. Calculate basal area after harvesting.
5. Calculate logging intensity.

Logging intensity as computed by mathematical model 4 in Chapter IV will determine the range of the proportional loss rate of damage because of the harvesting process (Table 2).

Economic Subsystem

Revenues are a function of cutting intensity, the volume of timber removed, unit value of the final product, and silvicultural and harvest costs incurred during the management period. The economic feasibility of harvesting a stand will be presented by values from subroutine NETVAL. It will give the user some indications as to the economic attractiveness of harvesting the stand under various treatments and market conditions.

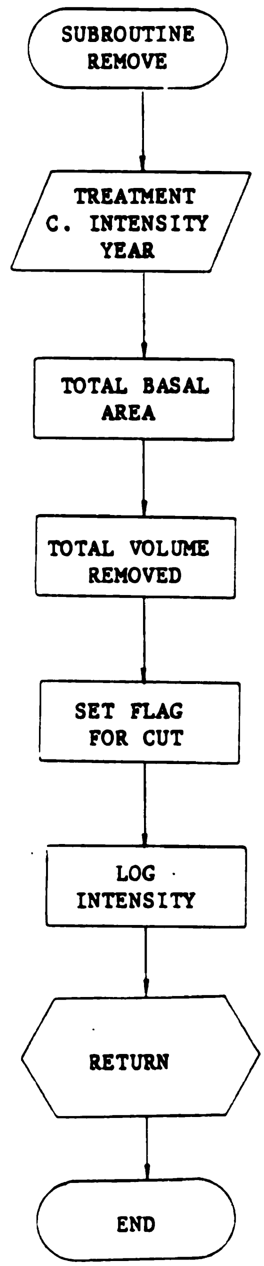


Figure 14. Gross logical flowchart for subroutine REMOVE

Subroutine NETVAL

The basic function of this subroutine is to calculate the present net worth according to operations previously executed. If no operation has taken place, a cost of maintenance is computed. A flag at the beginning of the program will indicate the incurred procedure. Fig. 15 presents a gross logical flowchart of subroutine NETVAL based on the following steps:

1. Check if non-commercial thinning was executed.
2. Check if harvesting or silviculture was executed.
3. Calculate revenue from the operation.
4. Calculate cost for the operation.
5. Calculate cost for maintenance if no operation was executed.
6. Calculate present net worth.
7. Calculate present value of the residual stand based on its sawlog volume.

Growth Subsystem

The development of individual stand characteristics over time is simulated by the integration of subroutines GROWTH 1 and GROWTH 2, subroutine DELICT and subroutine LOSS. Natural and artificial regeneration is simulated by the GROWTH 1 subroutine. The increment of DBH in the stand is executed by DELICT, and the proportional loss rate according to the operation executed as specified by subroutine DELICT is executed by subroutine LOSS.

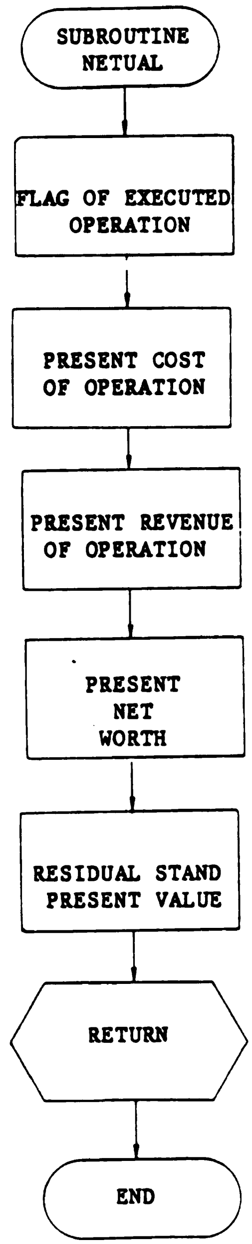


Figure 15. Gross logical flowchart for subroutine NETVAL

Subroutines GROWTH 1 and GROWTH 2

These subroutines as presented in Fig. 16 provide the basic requirements for the DELICT subroutine and record the structural change of the stand. The predicted annual changes in the delay rate, based on the density of the stand, the input from natural regeneration of standing trees, and loss boundary indications are the basic functions of these subroutines. The difference between them is that subroutine GROWTH 2 simulates a planted stand under a close plantation technique, and its regeneration. Subroutine GROWTH 1 monitors the natural regeneration of exportable, local commercial, and non-commercial species groups, as well as enrichment and/or line plantation treatments. In general, they follow the procedure below:

1. Calculate total number of trees and basal area before growth.
2. Change delay.
3. Calculate number of trees with DBH greater than 45 cm.
4. Calculate input for DELICT.
5. Indicate loss boundaries.
6. Call LOSS and DELICT.
7. Calculate total mortality.
8. Calculate basal area after growth.

To accomplish the DELICT subroutine requirements for stability, small proportions (.01) are subtracted from the

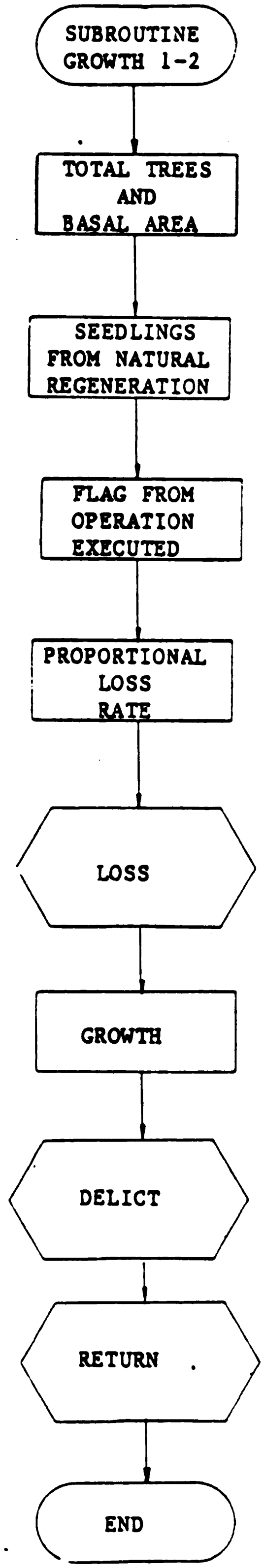


Figure 16. Gross logical flowchart for subroutines GROWTH 1 and GROWTH 2

delay mean time for each DBH class over a year, if no real change occurs in density or basal area.

Subroutine LOSS

Reductions in residual stand density caused during or after any operation are computed by subroutine LOSS, which generates a value from a probability distribution with a specified mean and variance. The constant use of probability in TAPAFOR is necessary because of a lack of specific, actual information. As pointed out by Freeman (1979), probability is a language for dealing with subjective estimates in a consistent and logical manner, and it can be interpreted consistently by others.

By considering a biological system's normal distribution, subroutine LOSS utilizes the TABLIE function to generate a stochastic variable called Proportional Loss Rate (PLR) based on a normal distribution. This subroutine will reduce the stand density by means of storage losses in the course of the delay process. Fig. 17 presents the general functions of subroutine LOSS.

Subroutine DELICT

As presented in Fig. 18, subroutine DELICT simulates a K^{th} order distributed delay where DIL is the mean lag time for each DBH class change and specified treatment. Accretions or negative losses in the intermediate rates are not considered in this program. The K-stages utilized in

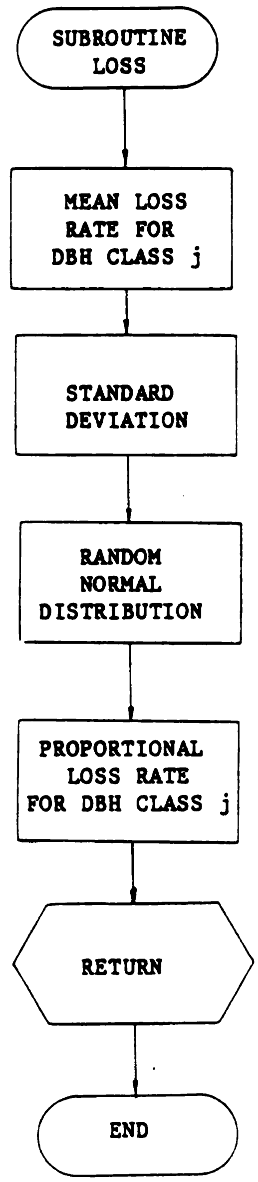


Figure 17. Gross logical flowchart for subroutine LOSS

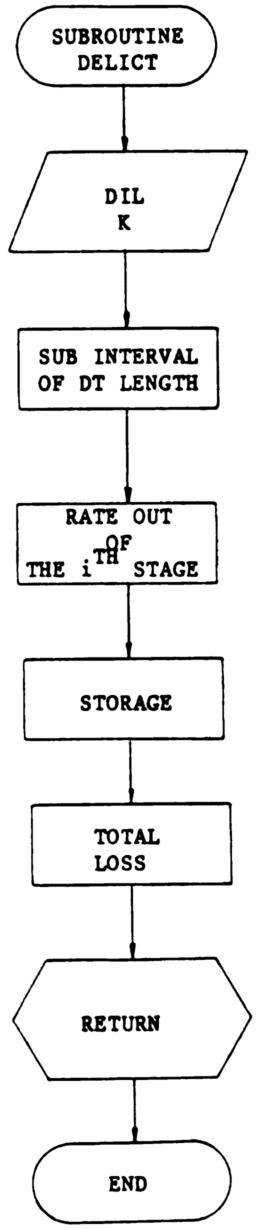


Figure 18. Gross logical flowchart for subroutine DELICT

this subroutine as presented in Table 3 are large so that the distribution will approximate a normal distribution. The intermediate storages are calculated based on the integration of a differential input/output process over time in a specified interval DT. The DBH class storage in that interval is based on the sum of intermediate storage times the specified delay divided by its order:

$$\frac{DIL}{K} \sum_{i=1}^{K} Ri$$

In the DELICT subroutine, the delay times, DIL, may vary over time, storage losses may occur in the course of the delay, and/or finer time cycles may be required for stability and non-negative flow assurances. In TAPAFOR, the proportional loss rate and delay rate (DIL) will vary over time; then the subdivision of interval DT by DELICT may vary over time, and will include a margin of safety for stability and non-negative flow, according to Abkin and Wolf (1980).

Silvicultural Subsystem

The main purpose of a silvicultural treatment is to guarantee the regeneration of stands that have been harvested, by artificial and/or natural regeneration prescription. The appropriate treatment, according to user specification, will be effectuated by subroutine PRESCR, and must rely on ecological requirements for the regeneration of commercial species, environmental management, and management efficiency, based on local observations.

Subroutine PRESCR

This subroutine will provide the basic calculations for input in the growth system when artificial regeneration is to be used (Fig. 19). It will execute a non-commercial thinning five years after initial disturbance, if no other treatment takes place and the total number of trees per hectare exceeds 300. The basic approach by PRESCR is as follows:

1. Check year and commercial density of stand.
2. Check if artificial regeneration is to be executed.
3. Calculate the number of trees to be planted under artificial regeneration.
4. Check if non-commercial thinning is to be done and executes it.
5. Calculate new density if non-commercial thinning was executed.

This subroutine provide the basic information for calculation by subroutine NETVAL of costs involved in artificial regeneration and non-commercial thinning.

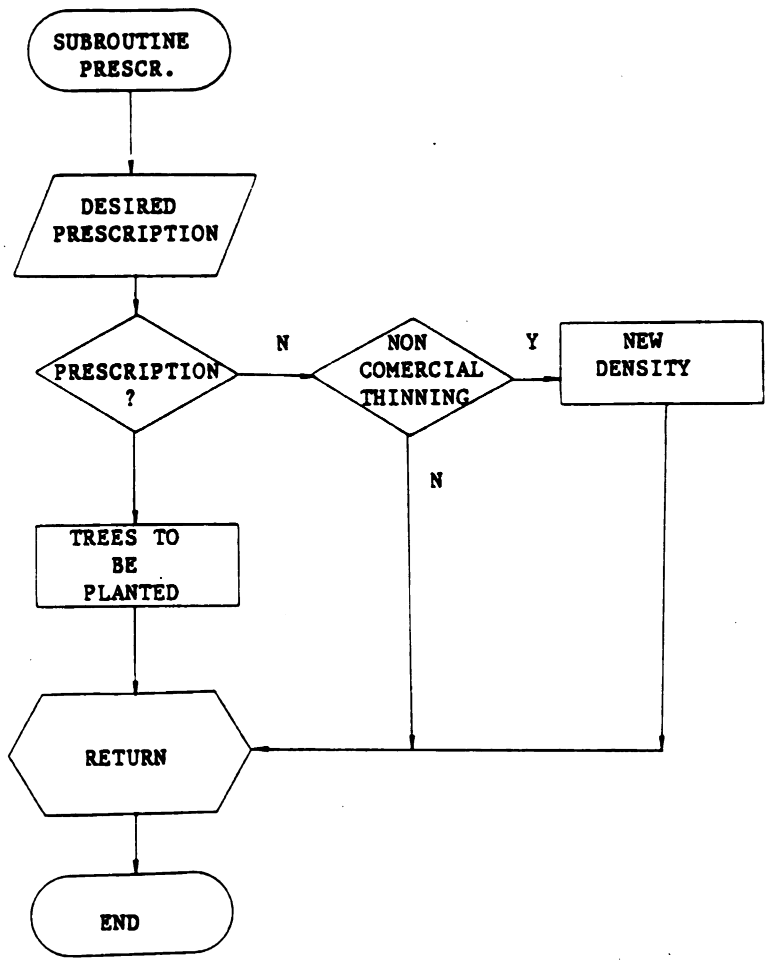


Figure 19. Gross logical flowchart for subroutine PRESCR

Operation Requirements

In many cases, the performance of a simulation model implies that a number of important operational conditions are pre-set or under control. There are cases in which the duration of the simulation run is not an essential issue. In terms of accuracy, the amount of information that can be derived from simulation is not restricted by time or by the number of runs. Restrictions may be induced by economic considerations or by other practical limitations. The observation time is restricted, either through economic necessity or for fundamental engineering reasons. Then, estimations have to be performed under specified operating conditions.

TAPAFOR is written in FORTRAN IV language and was implemented on the CDC Cyber 170, Model 750 at the Michigan State University Computer Center. The program itself requires 1.876 CP seconds of compilation time. In running the program, the needed memory capacity depends on how much the user requires from it.

The output in normal operation, over a 30-year simulation period, with six output years under Option 2, without using all the alternatives of this model required:

CP use -- 4.630 seconds

PP use -- 99.289 seconds

CP use -- 7.396 W-H

CT use -- .244 hrs

It should be observed that slight modification may be necessary before TAPAFOR can be used with other computer systems. Appendix F presents the source listing.

Validation of TAPAFOR

Validation of a model has been extensively discussed in simulation literature. A model must not only contain sound data when it is run, but it must also be sound structurally. Before a model can be used it must be tested to see that it conforms to the system for which it was designed. Since real systems operate dynamically in time, simulation models must be tested to insure that they behave in the same way. In essence it requires an examination of the outputs of the simulation model in comparison to those for the real world system in order to assess the agreement between the two. Unfortunately, lack of available data prevented the undertaking of an evaluation of the TAPAFOR model with conventional statistical testing (i.e., chi-square). The real world data necessary for such an evaluation will require the passage of time and much inventory effort, and hence is not immediately available for the Tapajos National Forest.

My validation has consisted, in part, of a comparison of the model results with data for other tropical regions, and a calibration of components.

TAPAFOR needs to be throughly reviewed before it can play an effective role in Amazon forest management in

Brazil. It can be used as an effective planning tool if the planner is willing to accept the assumptions used. As more data are accumulated for forest treatment responses in the Tapajos region, more comprehensive validation can be undertaken.

CHAPTER VI

MODEL EVALUATION

Indentifying Research Needs

In modeling the Tapajos National Forest management system with the objective of permanent forest production, it became very clear that most of the available data are very inadequate and inappropriate. More specific knowledge of tropical forest management is lacking. A great deal of qualitative information is presented in many reports, but they are generally devoid of quantitative data. In the TAPAFOR design process, important results can be demonstrated where more research is urgently needed with emphasis on quantification of information and relationships, in order to improve the reliability of the model. Weaknesses of the simulation model essentially identify further needed developmental work. The following areas have been identified where priority work is needed:

1. Changes in stand density by natural regeneration.
2. Harvesting techniques related to stand damage and regeneration.
3. Seed and seedling availability, and their mortality.
4. Ideal stand basal area to maximize productivity.

5. Response of species to various cutting intensities and treatments.
6. Operable and inoperable forest areas.
7. Growing stock; tree and stand growth; cutting regime and intensity with quantitative relationships of growth to stand density and composition, climate, and silvicultural practices.
8. Quantitative relationships of species, stand density, site characteristics, and climatic conditions necessary for more intensive management and simulation purposes.
9. Normal mortality; permanent plots, remeasured periodically, to accumulate mortality data.
10. Provision for accumulation of information on operational costs and revenues as well as the inflation of various costs related to the input/output process in the forest.
11. The response of non-stocked and poorly stocked lands to production by natural or artificial regeneration based upon site capability and coordination with other management objectives.

Limitations of TAPAFOR

The user will find flexibility in the utilization of TAPAFOR to accomplish the goal of managing the forest's potential yield of wood products. Clearly the accuracy of the results of the simulation model depends on two factors:

1. The authenticity of the model as a representative description of the tropical forest system.
2. The accuracy of the data input.

The first of these problems, authenticity of the model, with the strengths and weaknesses of its individual components, is apparent from the documentation. In the second aspect, there are many data inputs used in TAPAFOR that need to be revised. Costs, values, growth and mortality rates may be close to reality in the model, but they are not actual data. Simulation models permit evaluation of ideas and assumptions provided by the user, and therefore they are only as good as the information and data supporting them. Obtaining accurate input data is a difficult problem, often underestimated or neglected. Assumed, common sense relationships and coefficients should be replaced with documentable data as soon as the latter are available.

Immediate responses, those that occur once in the simulated year; responses over time, those that occur in more years than the one in which the associated game decisions are made; and interrelated responses, the net result of more than one game decision, can be drawn from TAPAFOR. The model behavior has performed favorably in all tests to which it was submitted to evaluate its adequacy for use in conjunction with forest management simulation planning.

The design approach and quantitative values utilized in this model are based on very meager data for the Tapajos

National Forest region. This lack of adequate data constitutes the main limitation of TAPAFOR.

TAPAFOR in Forest Planning

TAPAFOR permits close monitoring by the user during the simulation run. It prints out the development of the stand for each cycle, so that the suitability of the management system for development of the forest and maintaining the environment can be checked. In uneven-aged management, area control must be combined with volume control based on the growth potential of the stand. TAPAFOR will assist the user in deciding on an appropriate initial cutting regime and treatment for a specific stand, and use the selected cutting regime in the planning process. Advantages of TAPAFOR as a tool for forest planning can be cited as follows:

1. Provides for better understanding of the forest system by those who operate it.
2. Promotes complete analysis of the operational factors, which can be expanded to great depths.
3. The model does not depend on an exclusive alternative, in order to prescribe regeneration. A complete range of variables, as well as their relationships for future analysis, can be utilized.
4. An emphasis on sequences of actions over time permits new concepts to be included in the model.

5. It recognize short, intermediate and long term consequences; hence, it operates in a projection mode.
6. The design recognizes superior alternatives as products of creative search as well as synthesis and assembly.

TAPAFOR can contribute substantially to the forest planning process. Once the management decisions regarding allocations have been made, the model can help to prescribe the best cultural treatment from among those known to be biologically sound for use in the Tapajos National Forest. The model can be used to simulate creative alternatives. There should be some evaluation process in conjunction with the exercise to suggest which alternatives generated justify further analysis. The consequences of decisions made, the relationships between decisions made and the resulting consequences, the interrelationships among decisions, and the interrelationships among consequences are concerns that can be addressed by TAPAFOR in the planning process. TAPAFOR is a gaming-simulation exercise, which capitalizes on the best use of both people and computers, by having people make decisions and computers make repetitious calculations (Countryman 1973).

TAPAFOR was explicitly prepared to appraise the pros and cons of a management proposal for the Tapajos National Forest and to best orient the forest management prescription process. It provides for understanding the relevant factors and of the ways they interact; it predicts the possible consequences of alternative actions; and it assists in the selection of the best path to the desired goal. TAPAFOR is not a substitute for management judgment, but an aid. It is not a substitute for intuition; rather, it helps to channel it. A formal evaluation of the model in the planning process will come from future forest responses, with testing and verification.

An Application of TAPAFOR

In timber management, a harvest regime is often sought which will satisfy two objectives. First, it should produce a constant periodic harvest without depleting the growing stock. Second, the harvest should be such that it will maximize the volume produced per unit of time, or in economic terms, maximize the present value of production assuming adequate prices and interest rate (Buongiorno 1980).

To establish any given harvest schedule, it is necessary to clarify the essential concepts of supply and demand to be utilized. As sustained yield is the purpose of managing the Tapajos National Forest, a decline in supply is not expected. At this point it is assumed that the current demand for timber is the current annual harvested volume, and the current supply as the harvestable surplus under the current management strategy. A discount rate of 10 percent will be utilized here as a reasonable rate, based on t

interest ra

Two

applicatio

1. C

2. N

I

Both of

will have

Commercia

inventory

available

are as fo

1.

2.

3.

Specific

less tha

informat

range:

1.

based on the relationship between "breakeven stumpage" and interest rate presented by Fraser (1978).

Two parameters are considered essential in the application of TAPAFOR:

1. Commercial volume available to cut, per hectare.
2. Number of commercial trees per hectare with DBH less than 45 cm.

Both of these parameters in the initial forest condition will have a direct effect on the forest change process. Commercial volume available to cut was estimated from inventory data in the literature since no specific data are available for the Tapajos National Forest. These estimates are as follows:

1. An average basal area of 20 square meters per hectare.
2. An average maximum commercial volume available to cut of 40 cubic meters per hectare.
3. An average minimum commercial volume available to cut of 14 cubic meters per hectare.

Specific data for the number of commercial trees with DBH less than 45 cm are not available either, so approximate information taken from the literature shows the following range:

1. An average minimum of 10 commercial trees per hectare with DBH less than 45 cm.

2. An

he

Based

tics, four

represent

follows:

P

------

1. Commer

m^3 per

(DBH

2. Numbe

with

per h

3. Basal

trees

4. Basa

Sil

various

2. An average maximum of 50 commercial trees per hectare with DBH less than 45 cm.

Based on various combinations of these characteristics, four different stand conditions are assumed to represent conditions in the Tapajos National Forest as follows:

Parameters	Stand number 1	2	3	4
1. Commercial volume in m^3 per ha (DBH greater than 45 cm)	40	14	14	40
2. Number of commercial trees with DBH less than 45cm per ha	10	50	10	50
3. Basal area of commercial trees in m^2 per ha	5.94	4.57	2.41	8.10
4. Basal area per ha in m^2	20	20	20	20

Silvicultural prescriptions to be utilized with various intensities of logging in commercial trees will be as follows

1. N

2. N

3. E
   n

4. E
   n

5. I
   n

6. I
   n

All p
over 30 y
ied. Thre
each cutti

1.

2.

3.

To t
prescripti
ments wil
10, with

as follows:

Prescriptions	Cutting Intensity of Commercial Trees
1. Natural regeneration	70 percent
2. Natural regeneration	100 percent
3. Enrichment planting with natural regeneration	70 percent
4. Enrichment planting with natural regeneration	100 percent
5. Line plantation with natural regeneration	70 percent
6. Line plantation with natural regeneration	100 percent

All prescriptions will be applied at Year 1 and extend over 30 years for the four stands, unless otherwise specified. Three different cutting cycles will be connected with each cutting intensity:

	Years of Cut
1.	0 - 30
2.	0 - 15 - 30
3.	0 - 10 - 20 - 30

To test the versatility of TAPAFOR for variations in prescriptions specified by the user, two additional treatments will be tested. First, an enrichment planting in Year 10, with a cut of 100 percent of the commercial trees with

DBH great

7). Secon

in the f

be execu

final val

The

intensiti

follows:

Treatmen

1 natu

2 natu

3 enr

4 enr

5 lin

6 lin

7 nat

8 nat

9 enr

10 enr

11 lin

12 lin

13 nat

14 nat

DBH greater than 45 cm at Year 0 and Year 30 (Prescription 7). Second, a clearcutting at Year 0 and a close plantation in the following year (Prescription 8). No more cuts will be executed under a close plantation alternative, but the final value will be tested after the 30-year period.

The various combinations of prescriptions, cutting intensities and cutting cycles result in 20 treatments as follows:

Treatment number	Combinations
1	natural regeneration - CI = 70% at Years 0 and 30
2	natural regeneration - CI = 100% at Years 0 and 30
3	enrichment planting - CI = 70% at Years 0 and 30
4	enrichment planting - CI = 100% at Years 0 and 30
5	line plantation - CI = 70% at Years 0 and 30
6	line plantation - CI = 100% at Years 0 and 30
7	natural regeneration - CI = 70% at Years 0, 15 and 30
8	natural regeneration - CI = 100% at Years 0, 15 and 30
9	enrichment planting - CI = 70% at Years 0, 15 and 30
10	enrichment planting - CI = 100% at Years 0, 15 and 30
11	line plantation - CI = 70% at Years 0, 15 and 30
12	line plantation - CI = 100% at Years 0, 15 and 30
13	natural regeneration - CI = 70% at Years 0, 10, 20 and 30
14	natural regeneration - CI = 100% at Years 0, 10, 20 and 30

15 enrichm

16 enrich

17 line p

18 line p

19 enrich

20 close

The r
over a 30-
presented
constraint
treatment
period.

All t
yield bas
Optimum v
percent i
planting
annual ha
ment pla
though th
treatment
percent
10, 20, a
present

15 enrichment planting - CI = 70% at Years 0, 10, 20 and 30

16 enrichment planting - CI = 100% at Years 0, 10, 20 and 30

17 line plantation - CI = 70% at Years 0, 10, 20 and 30

18 line plantation - CI = 100% at Years 0, 10, 20 and 30

19 enrichment planting at Year 10 - CI = 100% at Years 0 and 30

20 close plantation - clear cutting at Year 0

The results of applying TAPAFOR to the four stands over a 30-year period for the 20 treatment combinations are presented in Tables 5, 6, 7 and 8. Due to budget and time constraints in this study, the number of trials for each treatment in each stand was limited to one over the 30-year period.

All treatments were to bring the forest to a sustained yield basis, including those which showed optimum results. Optimum volume removed over 30 years resulted from a 100 percent intensity cut at Years 0 and 30 and an enrichment planting at Year 1. Volume is maximized if a constant annual harvest is not maintained. The advantage of enrichment planting over the line plantation was small even though the enrichment planting has less stand damage at treatment implementation. Optimum PNW has been met with 100 percent intensity cutting of commercial trees at Years 0, 10, 20, and 30, and a line plantation at Year 1. Thus, the present net worth is maximized with a harvest of valuable

Table 5. Results of applying 20 treatment combinations to Stand 1 in the Tapajos National Forest over a 30-year period, per hectare basis.

Table 5. Results of applying 20 treatment combinations to Stand 1 in the Tapajos National Forest over a 30-year period, per hectare basis.

Treatment number	Prescri-ption	Volume Removed in m^3/ hectare at specified year					Total Volume m^3/ha	Residual Basal Area m^2/ha	P N W in CR$/ha	Residual Value in CR$/ha	Total present value in CR$/ha
		0				30					
1	1	32.66				39.76	72.42	25.14	71,740.13	6,254.79	77,994.92
2	2	41.01				32.90	73.91	23.89	85,498.98	5,257.87	90,756.84
3	3	32.66				189.54	222.20	30.65	96,560.04	17,243.96	113,804.00
4	4	41.01				247.66	288.67	21.94	123,074.50	4,182.49	127,257.00
5	5	32.66				184.92	217.58	30.50	95,735.73	17,154.78	112,890.51
6	6	41.01				242.54	283.55	22.10	122,166.01	4,164.33	126,330.34
		0		15		30					
7	1	32.66		15.24		20.41	68.31	24.99	76,477.97	6,135.64	82,613.60
8	2	41.01		6.80		21.02	68.83	24.01	87,482.81	5,387.77	92,870.58
9	3	32.66		14.70		166.61	213.98	30.23	100,560.97	16,584.86	117,145.83
10	4	41.01		6.60		228.88	276.49	22.19	123,665.12	4,487.15	128,152.26
11	5	32.66		14.56		162.33	209.55	30.19	99,751.97	16,510.31	116,262.28
12	6	41.01		6.31		224.46	271.77	21.92	122,643.30	4,163.06	126,806.36
		0	10		20	30					
13	1	32.66	11.04		8.06	14.86	66.62	24.54	79,247.16	6,218.44	85,465.60
14	2	41.01	2.85		7.80	15.55	67.20	23.77	88,224.92	5,604.86	93,829.78
15	3	32.66	10.63		23.51	127.10	193.90	29.71	104,264.14	15,340.04	119,604.18
16	4	41.01	2.75		30.24	162.18	236.18	23.11	123,889.27	5,595.35	129,484.62
17	5	32.66	10.74		30.81	118.92	193.13	28.97	106,432.32	14,910.01	121,342.33
18	6	41.01	5.37		50.77	141.96	239.11	23.11	133,495.10	5,594.76	139,089.86
		0				30					
19	7	41.01				85.19	126.20	30.40	94,376.13	16,330.01	110,706.15
		0									
20	8	46.32					46.32	65.17	91,820.00	104,380.58	196,220.91

Table 6. Results of applying 20 treatment combinations to Stand 2 in the Tapajos National Forest over a 30-year period, per hectare basis.

Treatment number	Prescri-ption	Volume Removed in m^3/ hectare at specified year				Total Volume m^3/ha	Residual Basal Area m^2/ha	P N W in CR$/ha	Residual Value in CR$/ha	Total present value in CR$/ha
		0			30					
1	1	11.60			91.12	102.72	29.62	28,968.97	8,081.30	37,050.27
2	2	14.33			110.47	124.80	26.28	35,619.67	5,415.54	41,035.21
3	3	11.60			188.89	200.49	33.03	43,614.76	17,693.83	61,308.59
4	4	14.33			259.98	274.31	23.73	62,032.34	3,916.02	65,948.35
5	5	11.60			180.44	192.00	32.53	42,504.17	17,120.04	59,624.20
6	6	14.33			248.49	262.82	23.41	60,366.67	3,888.06	64,254.73
		0	15		30					
7	1	11.60	25.83		56.58	94.00	31.69	37,988.47	7,355.40	45,343.88
8	2	14.33	30.41		58.74	103.48	26.40	44,833.15	5,543.99	50,377.14
9	3	11.60	25.01		142.29	178.89	32.34	51,083.64	16,533.65	67,617.29
10	4	14.33	29.46		204.73	248.52	24.43	70,012.45	4,622.40	74,634.85
11	5	11.60	24.66		144.88	181.13	31.73	51,341.46	15,778.08	65,119.54
12	6	14.33	28.87		194.67	237.87	24.32	68,246.69	4,623.51	72,870.21
		0	10	20	30					
13	1	11.60	13.94	28.57	35.86	89.96	27.68	42,910.50	7,057.87	49,968.37
14	2	14.33	15.32	32.16	32.17	93.99	26.07	49,125.89	5,766.62	54,892.51
15	3	11.60	13.44	38.82	113.77	177.62	31.46	58,497.25	14,825.73	73,322.98
16	4	14.33	14.77	47.48	135.32	211.90	25.34	73,829.56	5,777.38	79,606.95
17	5	11.60	13.64	41.77	103.49	170.50	30.92	58,907.71	14,182.19	73,089.90
18	6	14.33	15.01	51.80	121.49	202.63	25.30	74,284.57	5,750.23	80,034.80
		0			30					
19	7	14.33			140.60	154.93	29.37	40,938.69	11,769.97	52,708.66
		0								
20	8	40.11				40.11	65.17	77,390.20	194,380.58	181,770.78

Table 7. Results of applying 20 treatment combinations to Stand 3 in the Tapajos National Forest over a 30-year period, per hectare basis.

Treatment number	Prescri-ption	Volume Removed in m^3/ hectare at specified year				Total Volume m^3/ha	Residual Basal Area m^2/ha	P N W in CR$/ha	Residual Value in CR$/ha	Total present value in CR$/ha
		0			30					
1	1	11.60			31.08	42.68	29.23	20,662.77	6,185.24	26,848.01
2	2	14.33			32.90	47.31	28.07	25,575.09	5,257.87	30,832.96
3	3	11.60			182.40	194.00	34.33	45,779.06	16,918.16	62,697.22
4	4	14.33			247.66	261.99	25.45	63,150.61	3,761.50	66,912.11
5	5	11.60			177.67	189.27	33.94	44,492.10	16,583.64	61,525.74
6	6	14.33			242.54	256.87	25.40	62,242.12	3,737.03	65,979.15
		0	15		30					
7	1	11.60	8.49		19.43	39.52	29.08	23,367.51	6,114.02	29,481.53
8	2	14.33	6.80		21.02	42.15	28.17	27,558.92	5,387.77	32,946.69
9	3	11.60	8.22		166.65	186.47	33.92	47,749.15	16,382.98	64,132.12
10	4	14.33	6.60		228.88	249.81	25.60	63,741.23	4,072.24	67,813.47
11	5	11.60	8.10		162.34	182.04	33.75	46,903.47	16,091.29	62,994.76
12	6	14.33	6.38		224.46	245.17	25.55	62,819.41	4,051.33	66,870.74
		0	10	20	30					
13	1	11.60	5.02	7.27	14.62	38.50	28.57	24,786.70	6,212.22	30,998.92
14	2	14.33	2.85	7.80	15.55	40.53	35.41	28,301.03	5,604.86	33,905.89
15	3	11.60	4.85	22.84	127.48	166.77	32.42	50,143.14	14,379.04	64,522.18
16	4	14.33	2.75	30.24	162.18	209.51	26.26	63,965.38	5,001.10	68,966.48
17	5	11.60	4.89	30.18	119.29	165.96	32.32	52,282.96	14,138.28	66,421.24
18	6	14.33	2.77	40.78	147.61	205.49	26.93	66,445.63	5,594.77	72,040.40
		0			30					
19	7	14.33			85.19	99.52	34.41	34,452.25	16,330.01	50,782.26
		0								
20	8	19.64				19.64	65.17	31,896.44	104,380.58	136,277.032

Table 8. Results of applying 20 treatment combinations to Stand 4 in the Tapajos National Forest over a 30-year period, per hectare basis.

Treatment number	Prescription	Volume Removed in m^3/hectare at specified year				Total Volume m^3/ha	Residual Basal Area m^2/ha	P N W in CR$/ha	Residual Value in CR$/ha	Total present value in CR$/ha
		0			30					
1	1	32.66			99.52	132.18	26.25	80,018.70	8,178.47	88,197.17
2	2	41.01			110.47	151.48	22.79	95,543.56	5,415.54	100,959.10
3	3	32.66			194.28	226.94	29.94	94,101.53	17,885.34	111,986.87
4	4	41.01			259.99	300.99	20.66	121,956.23	4,132.56	126,088.79
5	5	32.66			185.93	218.59	29.30	93,011.44	17,325.34	110,336.78
6	6	41.01			248.49	289.50	20.63	120,290.56	4,315.42	124,605.98
		0	15		30					
7	1	32.66	32.58		57.54	122.79	25.25	91,098.48	7,376.81	98,475.29
8	2	41.01	30.41		58.74	130.16	22.96	104,757.04	5,543.99	110,301.03
9	3	32.66	31.49		150.89	215.04	29.33	105,076.81	16,556.54	121,633.35
10	4	41.01	29.46		204.73	275.20	21.65	129,936.34	5,005.60	134,941.94
11	5	32.66	31.21		143.19	207.06	29.01	103,913.95	16,269.08	120,183.03
12	6	41.01	28.87		194.67	264.55	22.14	128,170.58	5,600.39	133,770.97
		0	10	20	30					
13	1	32.66	19.96	29.36	36.10	118.08	24.31	97,371.20	7,064.05	104,435.25
14	2	41.01	15.32	32.16	32.17	120.66	22.69	109,049.78	5,766.62	114,816.25
15	3	32.66	19.22	39.28	112.04	203.20	28.18	112,317.74	14,729.60	127,047.34
16	4	41.01	14.77	47.48	135.32	238.58	22.13	133,753.45	5,777.38	139,530.84
17	5	32.66	19.45	42.13	101.90	196.18	27.47	112,736.60	14,062.92	126,799.52
18	6	41.01	15.01	51.80	121.49	229.31	21.83	134,208.46	5,750.23	139,958.68
		0			30					
19	7	41.01			140.60	181.61	26.68	100,862.58	12,329.69	113,192.27
		0								
20	8	66.79				66.79	65.17	137,314.09	104,380.58	241,694.67

trees every 10 years. In practice, line plantation may present an advantage over enrichment planting when PNW is maximized because the planting is concentrated, permitting more control of the valuable species. Optimum residual stand value and basal area, without a close plantation option, occurs with a 70 percent cutting intensity of commercial trees at Years 0 and 30, and enrichment planting at Year 1. A similar result was obtained by line plantation over the same cutting cycle and cutting intensity. If the cutting intensity is decreased and the cycle of cut is increased, with line or enrichment planting, an excellent residual stand will be left.

Natural regeneration has produced reasonable results. However, natural regeneration is decreased when cutting occurs at Years 0, 10, 20, and 30, because of the frequent interference in the forest growth process.

The average volume removed per hectare per year, for the entire forest and all treatments, ranges from one cubic meter to nine cubic meters. In general, the results of applying TAPAFOR to the four stands in the Tapajos National Forest are favorable. Thus, management of the Tapajos National Forest along guidelines and treatments indicated in the simulation model appears feasible.

A Proposed Plan

In the results obtained by using TAPAFOR, the structural changes in the forest have resulted as a reaction of the forest to applied management practices. Thus the simulation model can be an invaluable tool in management planning in this forest.

The proposed plan which follows has been prepared for the whole forest, with the assumption that it is made up of the four stands described earlier.

The total area of the forest to be managed is considered to be 170,000 hectares. As no data are available about area distribution by forest cover types, the four stands are assumed to have the following areas:

Stand 1 = 45,000 ha

Stand 2 = 40,000 ha

Stand 3 = 55,000 ha

Stand 4 = 30,000 ha

TOTAL = 170,000 ha

The objective in the proposed plan is to maximize the following variables:

1. Present net worth.
2. Total removed volume over the period.
3. Residual stand volume.

They will be analyzed separately, and the results will be by considered as different maximization objectives for the 30-year planning horizon.

Present Net Worth Maximization

The objective here is to maximize the total present worth value over the planning horizon, subject to an acceptable residual stand basal area and value. In doing so, it is assumed that the demand for timber is perfectly elastic within the specified range of volumes removed. Constraints can vary according to user option. Appendix G presents the source listing of program OPTIMUM developed for these analyses.

The following criteria for any four treatment combinations for the four stands have been established:

$$\text{Max NPV} = \sum_{i} \sum_{j} N_{ij} X_i$$

Where

i = stand number

j = treatment alternative

N_{ij} = present net worth per hectare when stand i is managed according to alternative j

X_i = number of hectares in stand i

NPV = Net Present Worth over the 30-year simulation period.

Constraints include the following:

1. $$\frac{\sum_i \sum_j V_{ij}\, X_i}{AREA} < 7 \text{ m}^3\text{/ha/year}$$

2. $$\frac{\sum_i \sum_j V_{ij}\, X_i}{AREA} > 4 \text{ m}^3\text{/ha/year}$$

3. $$\frac{\sum_i \sum_j Ba_{ij}\, X_i}{AREA} > 24 \text{ m}^3\text{/ha/year}$$

4. $$\frac{\sum_i \sum_j RSV_{ij}\, X_i}{AREA} > \text{CR\$ } 7{,}000\text{/ha}$$

Where

V_{ij} = volume removed per year per hectare according to i and j

X_i = area in hectares for the stand i

AREA = total area of the forest

Ba_{ij} = residual basal area in m^2/ha according to i and j

RSV_{ij} = stand discounted residual value/hectare according to i and j

Results with the above constraints show the following best combinations:

1. Considering close plantation in the analysis:

   Stand 1 = treatment 18

Stand 2 = treatment 20

Stand 3 = treatment 18

Stand 4 = treatment 20

2. Excluding the close plantation option:

Stand 1 = treatment 18

Stand 2 = treatment 18

Stand 3 = treatment 17

Stand 4 = treatment 18

It is apparent that frequent harvests from the forest (treatment 18) will have a maximum PNW. Clearcutting with close plantation (treatment 20) offers a good second choice to treatment 18.

Sensitivity analysis involves the change of a constraint value used in the original analysis, and holding the other values constant. The idea behind such perturbation is to assess the effect of each constraint on the best treatment combination for the forest.

In applying sensitivity analysis to PNW, four input values will be changed:

1. Stand area
2. Minimum residual basal area
3. Minimum residual stand value
4. Maximum and minimum volume to be removed.

Areas of the four stands were changed as follows:

	From	To
Stand 1	= 45,000 ha	60,000 ha
Stand 2	= 40,000 ha	30,000 ha
Stand 3	= 55,000 ha	20,000 ha
Stand 4	= 30,000 ha	60,000 ha

For these changed stand areas, PNW was maximized as follows:

1. Including close plantation in the analysis:

   Stand 1 = treatment 18

   Stand 2 = treatment 20

   Stand 3 = treatment 18

   Stand 4 = treatment 20

2. Excluding the close plantation option:

   Stand 1 = treatment 18

   Stand 2 = treatment 17

   Stand 3 = treatment 19

   Stand 4 = treatment 18

With the inclusion of the close plantation option in the analysis, the results did not change. Excluding the close plantation option changes the optimal treatment for Stands 2 and 3.

Details of determining the best stand area distribution to maximize PNW are presented in Appendix H.

Minimum residual basal area was changed from 24 m^2 per hectare to 27 m^2 per hectare. With this change the PNW was maximized as follows:

1. Including close plantation option in the analysis:

   Stand 1 = treatment 18

   Stand 2 = treatment 20

   Stand 3 = treatment 18

   Stand 4 = treatment 20

2. Excluding the close plantation option:

   Stand 1 = treatment 18

   Stand 2 = treatment 17

   Stand 3 = treatment 18

   Stand 4 = treatment 15

There were no changes when the close plantation option was included, and a change for Stands 2, 3 and 4 when it was excluded.

Minimum residual stand value was changed from CR$ 7,000.00 to CR$ 10,000.00. Maximum PNW's were as follows:

1. Including the close plantation option in the analysis:

   Stand 1 = treatment 18

   Stand 2 = treatment 20

   Stand 3 = treatment 18

   Stand 4 = treatment 20

2. Excluding the close plantation option:

   Stand 1 = treatment 18

   Stand 2 = treatment 17

   Stand 3 = treatment 17

   Stand 4 = treatment 18

Only the result for Stand 2 changed with the exclusion of the close plantation option; otherwise, the results were the same.

The maximum and minimum volumes to be removed were also changed as follows:

Maximum from 7 m^3/year/ha to 5 m^3/year/ha

Minimum from 4 m^3/year/ha to 3 m^3/year/ha

Results maximizing PNW were as follows;

1. Including the close plantation option in the analysis:

   Stand 1 = treatment 18

   Stand 2 = treatment 20

   Stand 3 = treatment 17

   Stand 4 = treatment 20

2. Excluding the close plantation option:

   Stand 1 = treatment 14

   Stand 2 = treatment 17

   Stand 3 = treatment 18

   Stand 4 = treatment 14

With the inclusion of the close plantation option, only the result for Stand 3 changed, and its exclusion changed the results for all stands in favor of natural regeneration.

Removed Volume Maximization

The total removed volume from the forest will be maximized as follows:

$$\text{Max VR} = \sum_i \sum_j V_{ij} X_i$$

Where

VR = volume removed from the forest in cubic meters over the 30-year period

V_{ij} = total removed volume according to stand i and treatment j

X_i = area of stand i (in hectares)

Subject to:

1. $$\frac{\sum_i \sum_j Ba_{ij} X_i}{\text{AREA}} > 24 \text{ m}^2/\text{ha}$$

2. $$\frac{\sum_i \sum_j RSV_{ij} X_i}{\text{AREA}} > \text{CR\$ } 7{,}000.00$$

3. $$\frac{\sum_i \sum_j N_{ij} X_i}{\text{AREA}} > \text{CR\$ } 60{,}000.00/\text{ha}$$

Where

Ba_{ij} = Residual basal area in m^2/ha according to i and j

RSV_{ij} = Stand discounted residual value/hectare according to i and j

N_{ij} = Present Net Worth by hectare according to Stand i and treatment j

For the initial conditions, the volume removed was maximized with the following combinations:

Stand 1 = treatment 4

Stand 2 = treatment 3

Stand 3 = treatment 4

Stand 4 = treatment 4

Including or excluding the close plantation option did not result in any differences in the results.

For sensitivity analysis, the same stand area changes as used in PNW showed the following as the best combinations:

Stand 1 = treatment 4

Stand 2 = treatment 3

Stand 3 = treatment 3

Stand 4 = treatment 4

In changing the minimum desired residual basal area/hectare from $24m^2$ to $27\ m^2$, the results become:

Stand 1 = treatment 4

Stand 2 = treatment 3

Stand 3 = treatment 4

Stand 4 = treatment 3

When the minimum desired residual stand values is changed from CR$ 7,000.00 to CR$ 10,000.00, the best stand treatment combinations become:

Stand 1 = treatment 3

Stand 2 = treatment 3

Stand 3 = treatment 4

Stand 4 = treatment 4

It appears that treatments 3 and 4 will give the maximum total removed volume from the forest.

Residual Stand Value Maximization

The goal here is to maximize the residual forest value over the 30-year period:

$$\text{Max RSV} = \sum_i \sum_j SV_{ij}\ X_i$$

Where

SV_{ij} = discounted residual forest value according to stand i and treatment j.

X_i = area of stand i in hectares

Subject to:

1. $$\frac{\sum_i \sum_j Ba_{ij} X_i}{AREA} > 24 \text{ m}^2/\text{ha}$$

2. $$\frac{\sum_i \sum_j N_{ij} X_i}{AREA} > \text{CR\$ } 60{,}000.00/\text{ha}$$

3. $$\frac{\sum_i \sum_j V_{ij} X_i}{AREA} \quad \begin{matrix} < 7 \text{ m}^3/\text{ha/year} \\ > 4 \text{ m}^3/\text{ha/year} \end{matrix}$$

Where

Ba_{ij} = Residual basal area in m^2 according to Stand i and j

N_{ij} = Present Net Worth according to Stand i and j by hectare

V_{ij} = Volume removed per year per hectare according to Stand i and treatment j

In maximizing the residual stand value, the following results were obtained:

1. Including the close plantation option in the analysis:

   Stand 1 = treatment 20

   Stand 2 = treatment 4

   Stand 3 = treatment 20

   Stand 4 = treatment 3

2. Excluding the close plantation option:

   Stand 1 = treatment 3

Stand 2 = treatment 3

Stand 3 = treatment 3

Stand 4 = treatment 3

When the cutting intensity is decreased and the frequency of cut is reduced, a more valuable residual stand results.

In applying the same changes as before for sensitivity analysis in the residual stand value, the following best combinations were obtained when the stand areas were changed:

1. Including the close plantation option in the analysis:

   Stand 1 = treatment 20

   Stand 2 = treatment 20

   Stand 3 = treatment 20

   Stand 4 = treatment 10

2. Excluding the close plantation option:

   Stand 1 = treatment 3

   Stand 2 = treatment 3

   Stand 3 = treatment 19

   Stand 4 = treatment 3

Stand area changes significantly influence the best treatment combinations for maximizing residual stand value.

When minimum residual basal area desired/hectare was changed from 24 m^2/ha to 27 m^2/ha, the best treatment combinations were:

1. Including the close plantation option in the analysis:

   Stand 1 = treatment 20

   Stand 2 = treatment 4

   Stand 3 = treatment 20

   Stand 4 = treatment 3

2. Excluding the close plantation option:

   Stand 1 = treatment 3

   Stand 2 = treatment 3

   Stand 3 = treatment 3

   Stand 4 = treatment 3

Changes in the minimum basal area did not significantly affect the residual stand value.

If the maximum and minimum volumes removed per hectare per year are changed as before, the best combinations become:

1. Including the close plantation option in the analysis:

   Stand 1 = treatment 20

   Stand 2 = treatment 4

   Stand 3 = treatment 20

   Stand 4 = treatment 20

2. Excluding the close plantation option:

   Stand 1 = treatment 19

   Stand 2 = treatment 5

Stand 3 = treatment 19

Stand 4 = treatment 5

Line plantation at Year 1 with a cutting intensity of 70 percent at Years 0 and 30 (Treatment 3) and enrichment planting at Year 10 with a cutting intensity of 100 percent at Years 0 and 30 (Treatment 4) are the best treatment combinations when the close plantation option is not considered.

Treatment 19 is indicated as the treatment to be applied to stand 3 when PNW and residual stand value are to be maximized. The same is true for Stands 1 and 3 when residual stand value was maximized by varying the volume removed each year. Based on these results, it is evident that the year of applying a silvicultural treatment strongly influences the maximization results. Alternative investments for the revenues obtained from the first harvesting will improve the net worth maximization, since only at Year 10 will it be necessary to apply an enrichment planting in the forest.

In summary, without considering constraint variations, the following results have been obtained:

	With close plantation				Without close plantation			
	Stand number				Stand number			
Variable Maximized	1	2	3	4	1	2	3	4
	Treatment combination				Treatment combination			
Present net worth	18	20	18	20	18	18	17	18
Volume removed	4	3	4	4	4	3	4	4
Residual stand value	20	4	20	3	3	3	3	3

By taking into consideration the above results, the following plan is suggested for the four stands:

Stand 1: Cut 100 percent of the commercial trees with DBH greater than 45 cm at Years 0, 10, 20, and 30; make a line plantation at Year 1.

Stand 2: Cut 70 percent of the commercial trees with DBH greater than 45 cm at Years 0 and 30; execute an enrichment planting at Year 1.

Stand 3: Cut 100 percent of the commercial trees with DBH greater than 45 cm at Years 0 and 30; execute an enrichment planting at Year 1.

Stand 4: Treat the same as Stand 2.

If the constraint variations are taken into consideration as presented in the sensitivity analysis, different treatment combinations will be indicated. The best treatment combination will depend on the variable maximized, the area of each stand, and other constraints. An acceptable combination to maximize the output of forest products and the residual forest value can be reached. Such an ideal plan can be drawn from TAPAFOR results based on treatment combinations, maximization requirements and knowledge of local conditions by the forest planner.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

The Amazon region contains the largest tropical forest resource in the world. Exploitation of that resource is expanding rapidly, but without significant planning for its continious production. In this region near Santarem, the Brazilian government has established the Tapajos National Forest, the nation's first national forest. It is to serve as a pilot project for the orderly management and development of the forest in the Amazon basin for multiple use and sustained yield.

This study was made to establish a process for predicting the growth and yield of the Tapajos National Forest after harvesting operations, and to provide a planning model for managing the forest for continuous yield. Simulation was used as the process for developing that model.

Because specific inventory and growth data for the Tapajos National Forest are generally not available, reasonable assumptions based on tropical forest literature and local observation were used in building the model. As actual data for the Tapajos become available with the passage of time, such data can be used to improve the applicability of the model.

The forest management simulation model which was prepared for the Tapajos National Forest is called TAPAFOR, and consists of one main program and twelve subroutines. Six subroutines simulate management activities, two simulate stand growth, one generates random variables, two generate output, and one interpolates numbers from a normal distribution. The major components of the main program and its subroutines are harvesting operations, silvicultural operations, growth prediction, and economic considerations.

In planning for the Tapajos National Forest, the forest itself cannot be dealt with as an independent resource. The impacts of its management on the economics of the region and the nation must definitely be considered. Plans for improved forest management ultimately must be addressed within economic development goals designed to provide food, shelter, energy, raw materials, and many manufactured goods for domestic use and export. Decisions about how land shall be used should be based on a proper understanding of each different kind of land, its capability for different uses, and the constraints which must be observed if it is to be managed for productive purposes. Land capability for various uses should be assessed separately so that alternative patterns of development can be compared. Laws, regulations and policies on land use which will affect forest areas should be subjected to an environmental impact assessment before being implemented. While it is beyond the scope of this study to discuss alternative regional and national goals for the Amazon basin, major forestry goals have been identified as follows:

1. Short term goals:
   a. Implement a forest management program for the Tapajos National Forest based on prescriptions discussed in this study.
   b. Create at least two more National Forests in the Amazon region for the parallel application of the recommended methodology to be utilized in the Tapajos National Forest so as to obtain a wider range of responses.
   c. Initiate action programs in forest research, information exchange, and technical assistance, along with the forest management program.
   d. Analyze the causes and rates of forest loss, including socio-economic factors, and the magnitude and trends of the impacts.
   e. Develop local and regional markets in coordination with regional plans.
   f. Apply improved management methods to the wildlife resources in the forest.
   g. Activate a specific program to decrease Amazon forest depletion.

2. Long term goals:

   a. Undertake economic studies of the profitability of plantation operations, results of natural regeneration, and/or enrichment and line plantation (including TAUNGYA).

   b. Expand the application of management methods for sustained yield harvesting in the Amazon forest.

   c. Increase utilization of presently non-commercial species for wood products manufacture to meet future expanding consumer demands.

   d. Devote more publicly-owned forest areas to multiple use for wood and food production, biomedical products, wildlife, and other values.

   e. Encourage policies and laws for establishing forest planning priorities and improved institutions with management capabilities dedicated to sound forest resource management.

   f. Expand biosphere reserved and protected areas.

Formulating a comprehensive management plan for a large wild land area such as the Tapajos National Forest requires the consideration of not only the above goals, but also many issues, demands, management strategies, and system responses. Such a plan must incorporate the requirements of many regulations, must be responsive to public issues and management concerns, and must utilize the best technical information available. Changes over time in forest management concerns and available technical information can be integrated in the TAPAFOR simulation model so as to broaden the future prespective required in any management planning procedure.

Based on these considerations, the results of applying TAPAFOR to the Tapajos National Forest can be grouped into two major recommendations:

1. Long Range Plan:

   Treatment: Clear-cutting with close plantation

   Objective: Maximization of long-run timber output or rate of return to the land.

   Contraints: Available budget needed to implement the treatments; subsequent management costs; expected annual rate of return to the land; expected product output; area to be considered; best alternative for the stand as part of the entire forest.

   Optional Treatment: Natural regeneration

2. Short Range Plan:

   Treatment: Line plantation with 70 percent cutting intensity and two or three harvests for some stands, and enrichment planting with 100 percent cutting intensity in the initial year in the other stands.

Objective: Maximization of discounted harvest income from existing stands or maximization of total timber yield during the conversion period.

Constraints: Cutting cycle; area to be harvested; expected annual rate of return to the land; expected stumpage prices for each year of the conversion period.

Short term management objectives can be guided by the TAPAFOR results, along with spatial distribution of the growing stock, and restrictions, if any, on the level of harvest and/or reforestation activities. Restrictions may need to be imposed on the level of activities in order to ensure long-run sustained yield of timber.

Management decisions in the Tapajos National Forest must consider the inherent low productivity of the forest when the number of harvests is increased over a period. The present net worth will be maximized with more frequent harvests, but the quality of the residual stand may be reduced. TAPAFOR results strongly suggest that where wood production must continue to have management priority, efficiency of utilization can be increased at least over the tested period, if alternative treatments are used for different stands based on initial stand quality and stocking. Small, irregularly-shaped clearcut areas with close plantations are also an attractive management option for long term planning in low productive areas.

Determination of the best cycle on which a forest should be harvested is among the oldest and most important problems in forestry. At the outset, it is important to recognize that an optimum solution depends upon the objectives of management. The value of the forest can lie primarily in the wood produced or in the forest's aesthetic or recreational benefits, in erosion or run-off control, or as shelter for wildlife. For the Amazon region, maximization of the value of wood production may be the appropriate approach. Other benefits of the forest should be considered where they are significant.

To avoid adverse consequences from wrong judgments in what the best harvest cycle is for the forest to ensure long term productivity, the following precautionary measures are recommended for the Tapajos National Forest:

1. Harvesting:
   a. Harvesting equipment must be restricted and used only where necessary to protect all resource values.
   b. Allowable harvests must be reviewed annually and adjusted to assure that lands on which they are based are available and suitable for timber production.
   c. Both permanent and temporary roads should be used to facilitate harvesting.
2. Regulation:
   a. Cutting may be done to accomplish resource

management objectives specified in the plan.

b. Cutting schedules may be revised through annual programming.

c. Vegetation management activities must be scheduled to be carried out in seasons with reduced insect, fire and disease control problems.

d. Failure to harvest some specified areas must not be compensated by additional cutting in other specified areas.

3. Priorities:

a. Non-stocked and poorly stocked stands must be brought into full production by natural means if possible, to reduce costs.

b. Partial cuttings must achieve prescribed objectives.

c. Treatments to accomplish stand improvement must vary depending upon the original local conditions.

d. Planting stock characteristics must be matched closely with prescribed treatments to enhance planting success in adverse situations.

e. Stand treatments may be modified to reduce the possibility of damage to water resources.

4. Regeneration:

a. The minimum stand area to be artificially regenerated for timber production is to be ten hectares; however, other resource benefits may justify artificial regeneration of smaller areas.

b. Utilization of seed or seedlings of exotic species should be restricted to those which have been proven adaptable to the area and capable of producing the kind and quality of trees desired.

5. Utilization:

a. Standards must be designed to obtain optimum utilization of the timber designated for harvest. Penalties for lesser utilization may be stipulated.

b. Market research and sales promotion are sine qua non activities for the planned and improved utilization of the Amazon's forest resources.

Planning for the Amazon forest must be a truly dynamic process for making the best possible continuing adjustments between man and his environment because of the necessity of meeting relatively uncertain needs in an expanding and open economy. Simulation, such as TAPAFOR, holds great promise for pre-testing the impact that new policies are likely to have on the forest for many years. However, the use of TAPAFOR requires specific data and information, and these are a necessary prerequisite to better evaluate public investments in the Tapajos National Forest.

The methodology of this simulation model approach is available to anyone who wishes to use it--there is nothing mysterious about it. In its simplest form TAPAFOR is a process designed to guide the efficient management of the Tapajos National Forest. The approach dictates that the user abide by three simple guidelines:

1. View the problem from a holistic focus, visualizing the many influences that impinge upon it.
2. Pursue the problem in an eclectic and analytical manner, both quantitatively and qualitatively.
3. Search the 'universe' for better alternatives than those used in the TAPAFOR approach.

Calibration of TAPAFOR was achieved by successive runs with variations in the number of growth stages in each DBH class and other parameters. It was found that residual stands were extremely sensitive to the length of the cutting cycle and cutting intensity, as well as the year that silvicultural treatments are applied.

Results from the TAPAFOR simulation model appear reasonable and consistent within the limits of current available knowledge. However, no forest stand in the Amazon region has been under sustained yield management in the past, and it is obvious that this simulation exercise extends beyond the limits of the available data base. Comparisons of estimates with actual field responses in the future will be needed to verify simulated responses. Basic results from TAPAFOR can be used as a starting point.

To improve TAPAFOR as a planning model for forests in the Amazon region, field experiments need to be conducted with precise techniques and specialized systems of the several disciplines. Technology and forest management can then be brought into harmonious relationships for sustained forest yields. Research needs are clear, and if forest management is to serve the public in the future, then those elements of forestry which the public values must quickly be discovered; the extent to which they are valued must be estimated; and the costs of obtaining these products and services must be determined. The major limitation of TAPAFOR as a planning tool is the lack of adequate data specific to the Tapajos National Forest. The tremendous potential of the Amazon forest is available for immediate exploitation, but exploitation without protection and reestablishment must be avoided to prevent total forest destruction. Research results are urgently needed for this purpose.

Alternative methods of transporting timber from the forest to the mill, transport costs, both by river and by road, the prices which could be obtained for the lesser known commercial species, and mill conversion are some studies to be undertaken. Natural regeneration as a basis for more effective and economical silvicultural practices, species' growth rates, and natural and logging damages to native species are other aspects on which information is needed for TAPAFOR.

The optimization routine employed in this study has suggested that a balance can be maintained between retaining natural forest conditions from an ecological point of view, and converting the forest to more intensively managed stands to achieve higher timber production. The choice between natural regeneration, enrichment or line plantation and close plantation after harvesting will depend on the objectives to be attained in the specific area.

The proper delineation of the Tapajos National Forest into compartments and stands must await adequate inventory and mapping information. The best area distribution for each stand to achieve maximization objectives was obtained by an optimization process using OPTIMUM, a supplemental routine to TAPAFOR, with an algorithm called COMPLEX.

Successful continuous natural systems will depend partly on the existing structure of the stand and particularly on the amount and quality of advance growth, but after any disturbance, felling damage and the availability of adequate seed sources of desirable species will become increasingly important. Results of the TAPAFOR simulation model have shown that immediate implementation of forest management operations in the Tapajos National Forest appears to be silviculturally and economically feasible, and should lead to more rational and more efficient use of the Amazon forest resource. TAPAFOR as a forest management planning tool will be improved as some of the many concepts and techniques explored in this study are applied by the Brazilian government in the management of the Tapajos National Forest by skilled personnel. This should lead to more adequate infrastructural and economic development in the Amazon region and eventually all of Brazil.

LITERATURE CITED

LITERATURE CITED

Abkin, M.H. and C. Wolf. 1980. A collection of notes and readings for SYS-814: Advanced Systems Methodology and Simulation. Department of Electrical Engineering and System Science. Michigan State Univ. East Lansing. Mimeo.

Ackoff, R.L. 1962. Scientific Method. Optimizing Applied Research Decisions. John Wiley and Sons. New York.

Andel, S. 1978. The impact of havesting systems on tropical forest management in South East Asia. Eighth World Forestry Congress. FID-I/18-1. 16-28 Oct. Jakarta.

Barros, P.L.C. 1980. Estudo das distribuicoes diametricas da floresta do Planalto Tapajos - Para. Tese de mestrado, 123f. Universidade Federal do Parana. Curitiba.

Beattie, W.D. 1975. An economic analysis of the Brazilian fiscal incentives for reforestation. Ph.D. Thesis, Purdue University.

-----------, and J.R. Nascimento. 1979. Calculo do valor residual da madeira em pe, com referencia especial a floresta nacional do Tapajos, Pa-Brasil. IBDF-COPLAN. Brasilia.

-----------. 1980. Energy production from the Brazilian forestry subsector. A report prepared for the World Bank. FAO/UN. Project BRA/78/003. Brasilia.

Betters, D.R. 1978. Analytical aids in land management planning. Operational forest management planning methods. Proceedings of steering systems project group, International Union of Forestry Research Organizations. Bucharest, Romania.

Box, M.J. 1965. A new method of constrained optimization and a comparison with other methods. Computer Journal 8: 42-52.

Briscoe, C.B. 1980. Intensive management of forest plantations in northern Brazil. Jari Florestal e Agropecuaria, LTD. Para.

Buongiorno, J. and B.R. Michie. 1980. A matrix model of uneven-aged forest management. Forest Science, 26: 4. 609-625.

Carvalho, J.O.P. 1980. Inventario diagnostico da regeneracao natural da vegetacao em areas da floresta nacional do Tapajos. Boletim de Pesquisa numero 2. CPATU. EMBRAPA. Belem.

Chapman, H.H. 1924. Forest Mensuration. Second edition. John Wiley & Sons, INC. New York.

Cherfas, J. 1980. Population bomb revisited. The World Fertility Survey Conference. Special Report, SCIENCE 80 - Nov. American Association for the Advancement of Science. Washington, D.C.

Churchman, C.W. 1979. The System Approach. Delta, New York.

Cordel, H. K. 1979. Multiple use of urban forests. Multiple-use Management of Forest Resources. Proc, Symp. Clemson University. Clemson, S.C..

Countryman, D.W. 1973. SNAFOR - A computer simulation for use in forest resource management games. University of Michigan. Ann Arbor.

Cromack, K. Jr., F.J. Swanson and C.C. Grier. 1979. A comparison of havesting methods and their impact on soils and environment. Fifth North Amer. For. Soils Conference, Colorado State University. Fort Collins.

Davis, K.P. 1966. Forest Management: Regulations and Valuation. 2nd ed. McGraw-Hill Book Co., New York.

Dawkins, H.C. 1967. Line Planting: A definition and principles for the technique on tropical high-forest land. A report to the Ghana Academy of Sciences.

Dourojeanni, M.L. 1978. Ecological aspects and wildlife conservation requirements for the management and development of Tapajos National Forest. TCP Project 06/BRA/05/I/FAO. Brasilia/Belem.

Dubois, J.L.C. 1967. A floresta Amazonica e sua utilizacao face aos principios modernos de conservacao da natureza. Atas do Simposio sobre Biota Amazonica, 7: 115-146. CNPq. Rio. de Janeiro.

-----------. 1971. Silvicultural research in the Amazon. FO:SF/BRA 4. Tech. Report 3, 192 pp. FAO. Rome.

-----------. 1973. A exploracao das matas amazonicas e a renovacao de seus recursos madeireiros. I Reunion Tecnica de Programacion sobre Desarrolo Americano, IICA - Tropicos/Inderena. Documento 14, 16 pag. Medellin.

-----------. 1976. Preliminary forest management guidelines for the National Forest of Tapajos. PRODEPEF, 42 p. Belem.

-----------. 1977. Silvicultura natural Y artificial bosques Amazonicos: Aspectos ecologicos y socioeconomicos. Seminario sobre ecologia del tropico humedo Americano, Merida. 20-26/11/1977, CONICIT.

-----------. 1979. Los sistemas de produccion mas apropiaados para el uso racional de las tierras de la Amazonia. IICA - Tropicos. Belem.

-----------. 1980. Os tipos de inventarios empregados no manejo de florestas tropicais por sistemas naturais ou semi-naturais. IICA - Tropicos. Belem.

FAO/IBDF. 1980. Management plan for The Tapajos National Forest FO: BRA/78/003. Tech. Report 2. UNDP-FAO-MA-IBDF. Brasilia.

Filho, P.P.C., H.M. Marn and T. Pergstrom. 1979. Exploracao mecanizada em matas de varzea. IBDF. DPq. Brasilia.

-----------, and H.B. Costa,. 1980. Construcao de estradas florestais e transporte florestal rodoviario na regiao Amazonica. Circular Tecnica Numbero 6. CPATU, EMBRAPA. Belem.

Fraser, A. I. 1978. Management of The Tapajos National Forest. TCP-Project 06/BRA/05/I. FAO. Belterra, Belem, Brasilia.

Freeman III, A. Myrick. 1979. The Benefits of Environmental Improvement: Theory and Pratice. Johns Hopkins University Press. Baltimore and London.

Godman, R.M. and D.J. Books. 1971. Influence of stand density on stem quality in pole-size northern hardwoods. USDA. Forest Service. Res. Pap. NC-54, 7p., St. Paul.

Goff, F.G. and D. West. 1975. Canopy understory interactions: Effect on forest populations structures. Forest Science, 21 (2): 98-108.

Gregory, G.R. 1972. Forest Resource Economics. John Wiley & Sons. New York.

Hann, D.W. and B.B. Bare. 1979. Uneven-aged forest management: state of the art (or Science?). General Technical Report Int - 50. USDA - Forest Service.

Henne, A. 1978. "NUTZWERTANALYSE". General Tachnical Report PSW - 32. USDA. Forest Serviee.

Husch, B. 1963. Forest Mensuration and Statistics. The Ronald Press Co. New York.

-----------, C.I. Miller and T.W. Beers. 1972. Forest Mensuration. The Ronald Press Co. New York.

IBDF, 1975. Documento informativo sobre a Amazonia. Simposio Nacional da Amazonia. IBDF. Brasilia.

-----------. 1980. Inventories for Amazonian forestry development. FO: DP/BRA/76/027. Tech. Report N: 8. UNDP-FAO-IBDF. Brasilia.

Jankauskis, J. 1978. Recuperacao de florestas tropicais mecanicamente exploradas. SUDAM. Belem.

Kerr, W.E. 1980. A Amazonia sem floresta. Jornal do Brasil, julho. Rio de Janeiro.

Kessel, R.S. 1979. Gradient Modeling. Springer - Verlag, Berlin.

Kirchner, F.F. and J.P.C. Lima. 1979. Simulation of the growth and yield of jack pine after fire in the Manistee National Forest. Department of Forestry, Michigan State University, East Lansing. Mimeo.

Kluwer, T. 1978. Accessibility assessment and logging costs of Tapajos National Forest. TCP-Project 06/BRA/05/I. FAO. Brasilia.

Kuester, J.L. and J.H. Mize. 1973. Optimization Techniques with Fortran. Mcgraw-Hill Book Co., New York.

Lamb, F.B. 1966. Marketing and Utilization of Tropical Forest Products. Proceedings of the Sixth World Forestry Congress. Madrid. 3098-3104.

Lanly, J.P. 1978. Metodologia e procedimentos operacionais para o inventario de pre-investimento na floresta nacional do Tapajos. PNUD/FAO/IBDF/BRA/76/027. Serie divulgacao, n:15. MA-PRODEPEF. Brasilia.

Lemaignen, G. 1978. A pilot strategy for integrated forestry and forest industry development of Tapajos National Forest with special reference to marketing and logging. TCP Project 06/BRA/05/I. FAO. Belem/Brasilia.

Lennartz, M.R. 1979. Multiple-use management for some, a promise unfulfilled. Multiple-use management of forest resources. Proc. Symp. Clemson University. Clemson, S.C.

Letourneau, L.R. 1978. Logging and log transportation in the Tapajos National Forest. TCP-Project 06/BRA/05/I. FAO. Brasilia.

LLewellyn, R.W. 1965. FORDYN - An industrial dynamics simulator. North Carolina State Univ. Raleigh.

Loureiro, A.A. and M.F. da Silva. 1968. Catalogo das madeiras da Amazonia. SUDAM. Belem.

Lucas, R.C. and M. Schechter. 1978. Simulation of recreational use for park wilderness management Resources for The Future, Inc. Washington, D.C.

Malmberg, D.B. 1965. Early thinning trials in western hemlock (Tsuga heterophyla (Raf.) Sarg.). Ph.D. thesis. University of Washington. Seattle.

Manetsch, T.J. and G.L. Park. 1977. System analysis and simulation with applications to economic and social systems - Part II. Department of Electrical Engineering and Systems Science. Michigan State Univ., East Lansing.

Mercado, R.S. 1980. Timber production and marketing in the Brazilian Amazon. Ph.D. thesis. Michigan State Univ., East Lansing.

Meyer, H.A. 1952. Structure, growth and drain in balanced uneven-aged forests. J. For., 50: 85-92.

McMillan, C. and R.F. Gonzales. 1973. System Analysis - A Computer Approach to Decision Models. Third edition. Richard P. Irwin, INC. Homewood, Illinois.

Naylor, T.H., J.L. Balintfy, D.S. Burdick and K.Chu. 1968. Computer Simulation Techniques. John Wiley & Sons, Inc. New York.

Neto, M. 1979. O Dilema da Amazonia. Editora Vozes LTDA. Petropolis. Rio de Janeiro.

Nie, N. H., C.H. Hull, J.G. Jenkis, K. Steinbrenner and D.H. Bent. 1975. Statistical Package for The Social Science-SPSS. Second edition. McGraw-Hill book Co., New York.

Nogueira, U.B. 1980. Charcoal production from Eucalyptus in southern Bahia for iron and steel manufacture in Minas Gerais, Brazil. Ph.D. thesis. Michigan State Univ., East Lansing.

Nor, S.M. 1977. A preliminary simulation model for forest stand management in Peninsular Malaysia. Ph.D. thesis. Michigan State Univ., East Lansing.

Nye, P.H. 1961. Organic matter and nutrient cycles under moist tropical forest. Plant and Soil 13: 333-347.

Olin, A.T. 1978. Ecological survey requirements and management implications for Tapajos National Forest. TCP-Project. 06/BRA/05/I. FAO. Brasilia.

Pandolfo, C. 1973. Estudos basicos para o estabelecimento de uma Politica de desenvolvimento dos recursos florestais e de uso racional das terras na Amazonia. SUDAM. Belem.

-----------. 1977. Analise conjuntural do problema florestal na Amazonia Brasileira. SUDAM Belem.

-----------. 1978. A floresta Amazonia Brasileira: Enfoque economic ecologico. SUDAM Belem.

Pitcher, J.A. 1976. A tree improvement programme for Amazonia. IBDF-FAO. FO: DP/BRA/71/545. Technical Report 3. Brasilia.

Pitt, J. 1969. Relatorio ao governo do Brasil sobre aplicacao de metodos silviculturais na Amazonia. FAO-SUDAM. Belem.

Poore, D. 1978. Ecological implications of forest industry development of Tapajos National Forest. TCP-Project 06/BRA/05/I. FAO. Brasilia.

PRODEPEF. 1975. Amazonian Forestry: Present situation and perpectives for its development. MA-IBDF-PRODEPEF. Rio de Janeiro.

-----------. 1978. Estudo da viabilidade tecnica-economica da exploracao mecanizada em floresta de terra firme-regiao de Curua-Una. PRODEPEF-SUDAM-IBDF. PNUD/FAO/BRA-76.

Queiroz, W.T. 1978. Efeitos da variacao estrutural em unidades amostrais na aplicacao do processo de amostragem em conglomerados, nas florestas do planalto do Tapajos. Tese de mestrado. 109f. Curitiba.

Reis, M.S. 1978. Uma definicao tecnico-politica para o aproveitamento racional dos recursos florestais da Amazonia Brasileira. MA-IBDF-PRODEPEF. Brasilia.

-----------. 1980. Tropical forest products in world timber trade. Monthly Bulletin, FO: MIS/80/24. June 1980. FAO. Rome.

Slooten, H.J. 1976. Especies florestais da Amazonia: caracteristicas, propriedades e dados de engenharia da madeira. PNUD/FAO/IBDF/BRA - 45. Serie-Tecnica 6. Brasilia.

Smith, D.M. 1962. The Practice of Silviculture. John Wiley & Sons. New York.

Speidel, G. 1978. Forestry institutions. TCP-Project 06/BRA/05/I. FAO. Brasilia.

Squire, L. and H.G. Van der TAK. 1979. Economic analysis of projects. Johns Hopkins University Press. Baltimore.

SUDAM. 1973. Levantamentos florestais realizados pela missao FAO na Amazonia (1956-1961). MI-SDA-SUDAM. Belem.

-----------. 1979. Pesquisas e informacoes sobre especies florestais da Amazonia. SUDAM Belem.

Tamer, A. 1971. Transamazonica: Solucao para 2001. APEC. Segunda edicao. Rio de Janeiro.

Volpato, E.P.B. Schmidt, and V.C. de Araujo. 1972. Carapa Guianensis Aubl. (Andiroba). Estudos comparativos de tratamentos silviculturais. Acta Amazonica. 2:3. Amazonas.

Wadsworth, F.H. 1978. Silvicultural aspects of integrated development of the Tapajos National Forest. TCP-Project 06/BRa/05/I. FAO. Brasilia.

Wahl, O. 1978. Mechanical wood industry. TCP-Project 06/BRA/05/I. FAO. Brasilia.

Webb, K.V. 1978. Marketing prospects. TCP-Project 06/BRA/05/I. FAO. Brasilia.

Wetterberg, G.B. and M.T.J. Padua. 1978. Preservacao da natureza na Amazonia Brasileira. PRODEPEF. Serie Tecnica 13. Brasilia.

APPENDICES

APPENDIX A

TAPAJOS NATIONAL FOREST CREATION DECREE

Decree Number 73,684 - February 1974

Creates the National Tapajos Forest and

gives other provisions.

The President of the Brazilian Republic, in use of his attributions according to Article 81, Item III, of the Federal Constitution,

Considering line 'b' of Article 5 from Law Number 4,771 of September 15, 1965,

DECREES:

Article 1: In Para State, the Tapajos National Forest will be created, under the jurisdiction of the Brazilian Institute of Forestry Development, an organ of the Ministry of Agriculture, with an estimated area of 600,000 hectares (six hundred thousand hectares), within the following limits:

WEST: Tapajos River;

EAST: Santarem-Cuiaba Road;

NORTH: A straight line that passes through the 50 kilometer mark from Santarem-Cuiaba Road and

Latitude point 2^{o} 45' S, at the right margin of the Tapajos River;

SOUTH: Cupari River and its tributary Santa Cruz, also called Cupari; west to the intersection of this or of an extension of its axis with the Santarem-Cuiaba Road.

Article 2: The Brazilian Institute of Forestry Development, by silvicultural research means, will promote the multiple use of natural resources of the Tapajos National Forest on a sustained yield basis.

Article 3: Within one hundred eighty days (180 days), the Brazilian Institute of Forestry Development will select an area for the implementation of an experimental station, with the objective of performing research and experimentation with significant regional value.

Sole Paragraph: The experimental station will be administratively subordinate to the Brazilian Institute of Forestry Development.

Article 4: The Brazilian Institute of Forestry Development has the legal right to set aside areas from the forest for biological reserves and for development as tourist attractions.

Article 5: The Brazilian Institute of Forestry

Development has the authorization to consult or convene with public or private organizations for the rational use of the forest's natural resources.

Article 6: The Ministry of Agriculture, by proposition of the Brazilian Institute of Forestry Development, will create norms for adequate organization, functioning and multiple use of natural resources of the forest.

Article 7: This decree will be in effect as of the date of its publication, and can be revoked only by contrary dispositions.

Brasilia, the 19th Day of February 1974, 153rd Year of Independence and 86th Year of the Republic,

(Signed),

EMILIO G. MEDICI

MOURA CAVALCANTI

APPENDIX B

BRAZILIAN FORESTRY CODE[1]

Law Number 4771 of September 15, 1965

Article 1: The forests existing on the national territory, as well as any other forms of vegetation, which are known to help protect the soils they cover, are a stock of common interest for all of us, and therefore proprietary rights should be exercised within the limitations of the general legislation and of this law specifically.

Sole paragraph: Any actions or omissions contrary to the provisions set forth herein, practiced in the use or exploitation of forests, shall be termed as misuse of the land (Art. 302, XI, b of the Civil Code).

Article 2: For the purposes of this law, forests and other forms of vegetation situated as mentioned hereafter, shall be considered to be permanent preservation:

a. Along rivers and other water currents, throughout marginal strips, the minimum width of which shall

---

[1] Source: Beattie (1975). This Forest Code is currently undergoing revision, and the new version will be effective in 1982.

be:

1. Five meters of rivers less than ten meters wide.
2. Equal to half the width of rivers measuring from ten to 200 meters from margin to margin.
3. 100 meters for any rivers more than 200 meters in width.

b. Around natural or artificial lagoons, lakes and reservoirs.

c. Around springs, even those called "olho d' agua" whatever their topographic situation.

d. At the summit of rises, hills, mountains and ridges.

e. On slopes, or parts thereof, with more than 45 degree declivity, equivalent to 100 percent along the line of steeper declivity.

f. On shores, as dune holders or swamp stabilizers.

g. On plateau ridges.

h. At altitudes over 1800 meter, on natural or artificial fields, native forests and field vegetation.

Article 3: Forests and other forms of natural vegetation shall also be qualified as permanent preservation property, when so declared by an Act of the Public Powers and when intended to:

a. attenuate erosion;

b. hold dunes;

c. form protection barriers along roads and railways;

d. help in the defense of the national territory, as decided by the military authorities;

e. protect sites of exceptional beauty or of scientific or historical value;

f. be used as habitat for fauna and flora species threatened with extinction;

g. preserve the environment necessary for ensuring public well-being conditions.

Paragraph 1: The total or partial suppression of permanent preservation forests shall be possible only with the previous authorization from the Federal Executive Power, when necessary for the carrying out of work plans, activities, or projects of public utility or social interest.

Paragraph 2: Forests integrating the "Patrimonio Indigena" (Indian Reservations) are hereby made subject to permanent preservation (letter g).

Article 4: Actions of "public interest" are defined as follows:

a. the limitations and control of herds in certain areas, in order to permit proper conservation and propagation of forest vegetation;

b. practices aiming at preventing or eradicating pests and diseases that could affect forest vegetation;

c. divulgence and adoption of technological methods that will increase the economical and useful life of timber and its utilization in all phases of handling and transformation.

Article 5: The Public Power shall form:

a. National, state and municipal parks, as well as biological reserves, specifically to protect exceptional qualities of nature, harmonizing full protection of flora, fauna, and natural beauties with their use for educational, entertainment and scientific purposes;

b. National, state and municipal forests for economical, technical, and social purposes, and choose so far unforested areas to be reserved for that purpose.

Sole paragraph: Any form of exploitation of the natural resources of the national, state and municipal parks is, as of now prohibited.

Article 6: The owner of the non-preserved forest, according to the terms of this law, can pledge it to perpetuity providing it is qualified as being of public interest by the forest authorities. The bond shall be the object of a document signed before the local forestry authority and legalized on the margin of its registration with the real estate registrar.

Article 7: Any tree may be declared immune to felling by an act of the Public Powers, for reason of its location, rarity, beauty and seed bearing qualities.

Article 8: Permanent preservation forested areas mentioned in this law, or the forests necessary to the local or national supply of timber and other products, can be included in the distribution of land intended for agricultural purposes in any settlement or agricultural reform plan.

Article 9: Privately owned forests, adjacent to the others that are subject to a special regime, shall be subordinated to the laws ruling same.

Article 10: The felling of trees is not permitted in areas with an inclination of between 25 degrees and 45 degrees, where the withdrawal of logs will only be tolerated when done rationally and for permanent income purposes.

Article 11: Charcoal or mineral coal can be used as fuel only when the precautions have been taken to avoid the diffusion of sparks that may cause fires in the adjacent forest or other form of vegetation.

Article 12: The expoitation of firewood and other forestry products, as well as the manufacture of charcoal, can be done freely in planted forests not considered to be of permanent preservation. In forests other than these mentioned, such exploitation shall be governed by rules to be established by an act of the State or Federal Power, based on the best practices dictated by technology and local peculiarities.

Article 13: Marketing of live plants, originating from forests, shall require a license to be issued by the qualified authorities.

Article 14: To further the general precepts that shall rule the utilization of forests, the State or Federal Public Power may:

a. lay down other rules, as applicable to the local peculiarities;

b. forbid or limit the cutting of vegetable species in danger of extinction, by issuing an act that will demarcate the area, in which the cutting of other species shall depend on the previous obtention of authorization;

c. prorogate the registration of natural or judicial persons dealing in the extraction industry and commerce of forest products or by-products.

Article 15: Haphazard exploitation of the native forests of the Amazon basin is as of now prohibited. These forests shall henceforth be exploited only within the technical practices of management to be established, within one year, by an Act of the Public Powers.

Article 16: Private forests, which are not subject to a regime of limited utilization, and are not considered to be of permanent preservation as foreseen under Article 2 and 3 thereof can be exploited within the following restrictions:

a. In the east-meridional, southern and central-west regions, the latter in its southern portion, felling of native, primitive or regenerated forests will be permissible only when a minimum limit of 20 percent of the forested area is respected, depending on decision of the competent authority;

b. In the above mentioned regions, in the already settled areas previously demarcated by the qualified authorities, the felling of primitive forests for transformation into agriculture or pasture land is hereby prohibited, tree fellings being permitted only for the production of timber. In the yet wild and still unsettled areas, the felling of primitive forests will be tolerated only up to a maximum of 50 percent of the total property and insofar as required for the installation of new agricultural properties;

c. in the southern region, in areas where Araucaria angustifolia occurs, forest exploitation may not be done in such a way as may bring about the species permanent elimination. In these areas, exploitation will be tolerated only insofar as a rational management, as dictated by technique, will guarantee perpetuation of the woods in good condition for developmemt and production.

d. in the northeastern and septentrional eastern regions including the state of Maranhao and Piaui, the felling of trees and forest exploitation will be permitted only when done in accordance with technical rules to be laid down by an Act of Public Power, as foreseen under Article 15.

Sole Paragraph: In rural properties, falling under sub-section "a" of this Article totalling between 20 to 50 hectares, woods, be they of fruit, ornamental, or industrial trees, shall be taken into account, in addition to the forest coverage of any nature, for the purposes of stipulating the limits.

Article 17: In the case of division of rural properties into plots, the area intended to complete the limit stipulated under letter "a" of the preceeding Article, may be grouped into one single parcel to the jointly owned by the purchasers of the plots.

Article 18: Whenever permanent preservation forestation or reforestation needs to be done on privately owned land, the Federal Public Power may do it without dispossessing the land should the proprietor not do it himself.

Paragraph 1: Should such areas be in use, in agricultural activities, the proprietor shall be compensated for the loss thereof.

Paragraph 2: No taxes shall be levied on areas thus used by the Federal Public Power.

Article 19: In order to allow an economical exploitation, proprietors of heterogenous forests may transform them into homogeneous forests, in which case the felling may be done in one or successive operations, provided, before commencement of the work, they sign a commitment in which they bind themselves to replace the trees felled and to follow good crop practices.

Article 20: Industrial enterprises that use large quantities of forest raw material, shall be obliged to maintain within a distance deemed economically convenient for exploitation and transportation, an organized service insuring the planting of new areas, on land of their own or belonging to third parties, the production of which should correspond to their needs.

Sole Paragraph: Non-compliance with the above shall subject infractors further to the penalties foreseen in this code, to the payment of a fine corresponding to 10 percent of the commercial value of the native forest raw material used up beyond their production.

Article 21: Any industries requiring vegetable raw material for their operation, such as metallurgies, brick plants, transporatation companies and the like, shall necessarily have to rationally maintain forests of their own, or form forests, directly or through undertakings in which they participate, in order to keep themselves supplied with the required raw materials (such as firewood or charcoal).

Sole Paragraph: The competent authorities shall determine a period of time, not to exceed 5 to 10 years, in which each of such companies shall have to be organized in order to comply with these regulations.

Article 22: The Federal government shall supervise the enforcement of these rules directly through the specific departments of the Ministry of Agriculture, or through agreements with state and municipal governments, or through agencies that it may organize for this specific purpose.

<u>Article 23</u>: Government inspection and safeguard of forests does not exclude private police action.

<u>Article 24</u>: Government rangers or forest employees shall be permitted to carry firearms, in the same capacity as agents of social security.

<u>Article 25</u>: In the event of rural fire that cannot be extinguished by the usual means, the forestry agent or any other public authority may request the material means and the men as may be needed to control it.

<u>Article 26</u>: The following violations shall be punishable with 1 to 3 years of imprisonment or the fine of one to one hundred times the minimum salaries in force in the location and on the date the infringment occurred, or both penalties cumulatively:

a. destruction of, or damage to any permanent preservation forest, even when it is still being formed or utilization thereof in disrespect of the rules established in this law;

b. unauthorized cutting of trees in any permanent preservation forest;

c. without proper license issued by qualified authorities, to enter permanent preservation forest carrying weapons, substances or instruments for illegal hunting or exploitation of forest products or by-products;

d. to damage in any way national, state or municipal parks or biological reserves;

e. in any way to light fires, inside forests or in the vicinity of other forms of vegetation, without taking proper precautions;

f. make, sell, transport or fly "baloes' (paper balloons raised by the buoyancy of air heated by a fire in the lower part, commonly flown in Brazil mid-May to mid-July to commemorate St. Paul and St. Peter festivities) that may set forests and other forms of vegetation afire;

g. to prevent or hinder the natural vegetation of forests and other forms of vegetation;

h. to accept wood, firewood, charcoal, or other forest products without checking whether the seller has required license to deal in such products, and without taking out the document that must accompany the product until the final processing;

i. to convey or store timber, firewood, charcoal, and other forest products without the properly issued license, covering all the period required for transporatation or storage;

j. to refrain from returning to the authorities such licenses as are no longer needed, either because their validity has elapsed or because the products have have already been delivered to the consumer;

l. to use forest products as fuel without taking the necessary precautions to prevent sparks from starting fires;

m. to allow privately owned animals to enter forests subjected to special regime;

n. in any way to kill, damage, or ill-treat ornamental plants in public parks or private properties belonging to third parties, or in any way to tamper with the trees immune to cutting;

o. to remove from publicly owned forests, or from permanent preservation forests stones, sand, lime, or any other minerals.

p. vetoed.

Article 27: The use of fire is forbidden in forests or other forms of vegetation.

Sole Paragraph: Should local or regional peculiarities justify the use of fire in forestry or agriculture practices, permission therefore shall be given through an Act of the Public Power which shall also specify the area covered by the permission and as well as precautionary steps to be taken.

Article 28: Besides the penalties established in the preceeding Article infractors shall be further subjected to the laws governing violations and crimes as ruled in the Penal Code (Criminal Code).

Article 29: Such penalties shall apply to all infractors, be they:

a. direct infractors;

b. tenants, partners, leaseholders, managers, administrators or owners of forest areas, whether the violations have been practiced by themselves, on their orders or by other subordinates;

c. any government agents who, by omission or illegal consent become co-participants of such actions;

Article 30: Unless otherwise specifically provided for in this law the penalties applicable shall be those of the Criminal Code and of the Law of Violation Penalties.

Article 31: Besides those foreseen in the Criminal Code and in the Law of Penalties, there will be the following aggravating circumstances:

a. to commit the infraction at the time of seed-shedding at night, on Sundays or holidays, at times of drought or floods;

b. to commit the infraction against permanent preservation forests or materials originating therefrom.

Article 32: Penal action shall be exercised whether or not there has been a complaint to motivate it, including when private properties are involved, whenever violations occurred against forests and other forms of vegetation work instruments or tools, documents and actions related to forest protection as foreseen in this law.

Article 33: The following persons shall have authority to open, preside over, and effect inquests, serve warrants of arrest and to bring suit in all cases of crime against or violation to any of the provisions set forth in this law or in other laws dealing with forests and any forms of vegetation.

Sole Paragraph: In case various lawsuits have been brought simultaneously by various authorities for one and the same violation, the judge shall gather them in one case.

Article 35: The authority shall seize the products and instruments used in the violation and, in the event they cannot accompany the inquest because of their volume or nature, they shall be handed over to the local public depository, if existant, or to the one appointed by the judge if non-existant, later to be returned to the injured party. Should these items belong to the violator himself, they will be sold in public auction.

Article 36: The legal procedure shall be that of Law 1508, of December 19, 1951, when applicable.

Article 37: "Inter-vivos" or "cause-mortis" transfers of title shall not be registered with the real estate registrars without submission of a "negative certificate" proving that no debts burden the property as regards to fines applicable in view of this or any other law.

Article 38: Planted or natural forests are tax-exempted, and the land they are on cannot be increased in value for tax purposes.

Paragraph 1: Income arising from forest products obtained from planted forests shall not be considered taxable as regards the person(s) who planted them.

Paragraph 2: Money invested in forestation or reforestation shall be fully deducted from income tax and from the specific taxes connected with reforestation.

Article 39: Areas with permanent preservation forests and forests planted for timber exploitation shall be exempted from payment of the Rural Territorial Tax.

Sole Paragraph: Should the forest be native, exemption shall not exceed 50 percent of the tax levied on the taxable area.

Article 40: Vetoed.

Article 41: Official credit agencies shall give full priority to forestation and reforestation projects, or those for the purchase of mechanical equipment required for forestation or reforestation purposes, within the priority rates previously determined by law.

Sole Paragraph: The National Monetary Council, within its legal attributions and as the agency governing all credit operations in the country, shall establish compatible terms and rates of interest for forestry financings related to forestation and reforestation plans approved by the Federal Forestry Council.

Article 42: Two years after promulgation of this law, all school reading books shall compulsorily have to contain texts for forestry education, previously approved by the Federal Council of Education and competent forestry agencies.

Paragraph 1: Radio and television stations will compulsorily include special texts on forestry in their programs, previously approved by the competent agencies, for periods never less than 5 minutes per week, whether or not distributed among several days.

Paragraph 2: Public parks and forests shall compulsorily be marked on all official maps.

Paragraph 3: The Union and the states shall promote the creation and development of schools for forestry education, at various levels.

Article 43: The Forestry Week is hereby instituted, on dates to be determined by federal decree for the country's various regions; it shall compulsorily be commemorated in schools and public institutions, through objective programs where the value of forests is emphasized in view of their products and usefulness.

Sole Paragraph: Meetings, conferences, and other festivities shall be planned for the Forestry Week, with the purpose of identifying forests as a renewable natural resource of high economical and social value.

Article 44: In the North, and part of the northern Central-west region, as long as the Decree mentioned under Article 15 is not enacted, shallow (selective) cut exploitation will be permitted only if at least 50 percent of the original vegetation remains untouched in each property.

Article 45: All existing contracts, covenants, agreements, and concessions related to the forest exploitation in general, shall be reviewed by the Executive Power within 180 days in order to be adjusted to the specifications of this law.

Article 46: The Forestry Council, with headquartes in Brasilia, shall continue to be the consulting and normative agency for Brazilian forest policies.

Sole Paragraph: The composition and attributions of the Federal Forestry Council, to be composed of 12 members maximum, shall be stipulated by a decree of the Executive Power.

Article 47: The Executive Power shall set forth the regulations as will be necessary for the enforcement of this law.

Article 48: This law shall come into force 120 days after its publication, the Decree Number 23793, of the 23rd of January, 1934 (Forestry Code) and all other contrary provisions being hereby revoked.

Brasilia, 15th of September, 1965; 144th year of Independence; and 77th year of the Republic;

Signed: H. Castello Branco
Hugo Leme
Octavio Gouveia de Bulhoes
Flavio Lacerda

Published in the "Diario Oficial" on 16 September, 1965.
Corrected in the "Diario Oficial" on 28 September, 1965.

APPENDIX C

TREE SPECIES WITH POTENTIAL FOR ARTIFICIAL REGENERATION

COMMON NAME	SCIENTIFIC NAME
Amapa	Parahancornia Amapa
Andiroba*	Carapa Guianensis Aubl.
Angelim Rajado	Pitchecelobium Recemosum Ducke
Aroeira	Astronium Fraxinifolium Mattick
Castanheira do Para*	Bertholletia Excelsa HBK
Cedro Vermelho	Cedrela Odorata L.
Copaiba	Copaifera Duckei Dwyer
Cumaru	Dipteryx Odorata Ducke
Cupiuba	Goupia Glabra Aubl.
Envira	Guatteria Sp.
Freijo Branco*	Cordia Bicolor A.Dc.
Freijo Verdadeiro*	Cordia Goeldiana Huber.
Jacarebuba	Calophyllum Brasilience Camb.
Jacarana	Holopyxidium Jarana Ducke
Jutai-açu	Hymenaea Courbaril L.
Louro Amarelo	Aniba Bucherllii Kesterm
Louro Vermelho	Ocotea Rubra Mez.
Maçaranduba	Manilkara Huberi Puke
Mandioqueira	Qualea Albiflora Warm

Maparajuba	Manilkara Paraencis Ducke
Marupa*	Simaruba Amara Engl.
Moroto	Didymopanax Morototoni Marchal
Muiracatiara	Astronium Lecointei
Melancieira	Alexa Grandiflora, Ducke
Pau Rosa	Aniba Duckei Kostermans
Piquia*	Caryocar Villosum (Aubl.) Pers.
Quaruba Verdadeira	Vochysia Maxima Duke
Sucupira	Bowdichia Nitida Spruce
Sucupira	Diplotropis Purpurea
Sumauma	Ceiba Pentandra BAK
Tachi Branco*	Tachigalia Sp.
Tatajuba*	Bagassa Guianensis Aubl.
Ucuuba Vermelha*	Virola Sebifera Aubl.

* High growth rate species

APPENDIX D

"LINE-PLANTING"; a definition and principles for the technique on tropical high-forest land[1]

1. In the sense used here, line-planting is the establishment of a tree crop to be closed at rotation age, in lines spaced at intervals equal to or slightly greater than estimated final-crop crown-diameter.
2. There are five necessary conditions for line-planting in addition to the normal requirement of healthy plant establishment:
   1) there must be little or no demand for thinnings: if thinnings are required the method is unsuitable;
   2) the species planted must be fast-growing (152 cm of height per year is a minimum), naturally straight and self-pruning; i.e. generally of the colonizing or gap-filling light-demanding type;
   3) there must be no upper canopy; only clear-felled, clear-poisoned low "farm-bush" or recent secondary growth is suitable;

---

1 Source: Dawkins (1967) and FAO/IBDF (1980)

4) the regrowth between the planted lines, the "matrix", must be noninflammable;

5) browsing animals must be absent, scarce or of negligible effect on planted trees.

Provided all five conditions are met, the method can cut the cost of a final crop to less than a third of what would be incurred by close-planting. The technique then requires the following:

6) Planting lines should be spaced equal to or slightly more than - up to 20% more is reasonable - mean crown-diameter of healthy final-crop trees as estimated from studies of crown: bole-diameter graphs. The reason for this is to prevent any possibility of serious between-line crown competition before maturity, to save on establishment costs, and to give more scope for possibly superior quality species which may arise naturally between the lines;

7) plants should be spaced along the lines at approximately one fifth of the spacing between them, to allow a selection of about one-in-four for the final crop. If poisoned overwood is likely to be abundant, as in very lightly felled natural forest being planted, then up to 30% losses must be expected and spacing in the lines should be nearer 1/6th to 1/7th of spacing between lines. Only by

this means can good form of the final crop be assured;

8) planting lines must be well-cleared about 183 cm wide at first and made easy to move along, at least along one side of planted trees, by removal of most if not all woody branches and snags. Once planted the lines must be kept clean and no overhanging or threatening growth tolerated. Since this clearing work is confined to a very small fraction of the area labour costs are low and several cleanings (sometimes up to six or seven are necessary) can be afforded in the first twelve months;

9) plants must get away to a quick start. For most species this means using potted stock; stumps or striplings are not likely to be suitable.
Cedrela has shown itself capable of starting from direct seed but this is exceptional;

10) planting must follow immediately on clearing the planting lines; clearing in the early dry season and planting three to five months later in the early rains is thoroughly bad technique and will result in at least two more clearings than otherwise. Poisoning of the upper canopy also should be timed to let in the light at time of planting, not before. It is recognised however that this is not a precise possibility;

11) trees arising between the lines, unless superior in value to the planted species, must be cut or poisoned immediately they "threaten" the plants, i.e. before they overshadow them.

12) thinning along the lines is a matter of selecting the stems of superior form and height. (Unless the disparity in size is very great, form and height should both be regarded as more important than girth). The first thinning will generally be at three to four years by which time the trees should be well above the shrub and climber regrowth. It will probably require about 50% culling of crop;

13) lines should be orientated east-west, particularly where regrowth or persistent canopy between the lines may exceed the planted trees in height. To some extent this injunction is necessary only if numbers 2, 3, 9, 10 and 11 are in any way vitiated by circumstances. It may be considered an insurance though in no way permitting the relaxing of the five cited paragraphs.

The above five principles and eight technical guides must be taken very seriously. Line-planting has very commonly failed and has a bad reputation among English-speaking tropical foresters because one or other of the principles has been flouted. If all the above are followed for a sensibly chosen species the technique has a very high chance of success in tropical forest conditions.

APPENDIX E

TAPAFOR USER'S MANUAL

This manual provides details regarding input information necessary to run TAPAFOR (TAPAjos FORest management model) by using a time-sharing computer system.

Print Out	Input Options	I/R*	Meaning
1. Option	1	R	Periodic output
	0	R	Annual output
	(Default=0.)		
2. Area probability	1	R	Yes
	2	R	No
	(Default=1.)		
3. Stand area	....	R	Stand area
	(any number)		
4. Treatment	1	I	Natural regener.
	2	I	Enrich. plant.
	3	I	Line plant.
	4	I	Close plant.
5. Cutting intensity	....	R	Intensity of cut
	(from 0. to 1.)		

6. Interest rate	....	R	Discounted rate
	(from 0. to 1.)		
7. Desired output	1	R	Detailed output
	2	R	General output
	(Default=no Out.)		
8. Silviculture desired	1	R	Yes
	0	R	No
	(Default=1.)		
9. Log desired (harvesting)	1	I	Yes
	0	I	No
	2	I	Out of system
	(Default=1.)		
10. Clearcut	1	R	Yes
	0	R	No
	(Default=0.)		

*I=integer

R=real

TAPAFOR under option 1 (periodic output) will request the year (real variable) for the next output from the user. At the beginning of the simulation run, the user will provide the storage for each DBH class (a real variable) for each species group:

-exportable trees,

-local commercial,

-non commercial.

Harvesting and silvicultural treatment can be prescribed by the user at any time after the third year after initial disturbance and treatment.

APPENDIX F

SOURCE LISTING FOR TAPAFOR

```
list.
C
C
C
C PROGRAM NAME= THE  TAPAJOS  NATIONAL  FOREST  SIMULATION  MODEL
C
C *************************** T A P A F O R ***************************
C
C PROGRAM ELABORATED BY - JORGE PALADINO CORREA DE LIMA
C
C
C**********************************************************************
C THIS PROGRAM SIMULATES THE BEHAVIOR(GROWTH AND YIELD) OF A TROPICAL
C NATIONAL FOREST(TAPAJOS-BRAZIL)  AFTER LOG BASED ON A SPECIFIED
C SILVICULTURAL TREATMENT
C**********************************************************************
C
C
      PROGRAM TAPAFOR(INPUT,OUTPUT)
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
C STRG=STORAGE BY EACH DBH CLASS AND TREATMENT
C K=STAGES IN A DELAY PROCESS FOR EACH DBH CLASS AND TREATMENT
C R=INTERMEDIATE RATES OF K STAGES
C BA=AVERAGE BASAL AREA FOR EACH DBH CLASS AND TREATMENT
C CLASS=DBH CLASS
C VRA=ACCUMULATE REMOVED VOLUME
C
      COMMON/RONN/LOS,A(7,15),B(7,15),PLR(15),AREA,VAL(41)
C LOS=CLASS OF LOSS
C A=MINIMUM VALUE FOR PROPORTION OF LOSS
C B=MAXIMUM VALUE FOR PROPORTION OF LOSS
C PLR=PROPORTIONAL LOSS RATE
C AREA=STAND AREA
C VAL=NORMAL DISTRIBUTION VALUES
C
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
C ALI=AVERAGE LOG INTENSITY
C TMOR=TOTAL MORTALITY PER HECTARE
C XBA1=TOTAL BASAL AREA BEFORE GROWTH PER HECTARE
C XBA2=TOTAL BASAL AREA AFTER GROWTH PER HECTARE
C YEAR=YEAR AFTER THE FIRST DISTURBANCE
C CL=FLAG IF CLEARCUT OR CLOSE PLANTATION IS EXECUTED
C IFLAG=FLAG AFTER TREATMENT
C ITR=TREATMENT
C
      COMMON/LENN/DEL(6,15),DELP(6,15),DT,DAL(6,15),DIL(6,15),TLOSS,I,J,
     +RIN,ROUT
C DEL=DELAY FOR EACH DBH CLASS(15) AND  TREATMENT(6)
C DELP=PREVIOUS DELAY FOR EACH DBH CLASS AND TREATMENT
C DAL=ADJUSTED DELAY FOR EACH DBH CLASS AND TREATMENT
C DIL=DELAY IN THE GROWTH SUBROUTINE IF NOT OVER DENSITY
C TLOSS=TOTAL LOSS FROM EACH DELAY PROCESS
C I=TRETMENT CLASS
C J=DBH CLASS
C RIN=INPUT FOR EACH DELAY PROCESS
C ROUT=OUTPUT FROM EACH DELAY PROCESS
C
      COMMON/TERR/V1,V2,CI,AV(15),TP,TH,SILV,PNW,XL,RSV
C V1=REMOVED VOLUME OF EXPORTABLE AND ARTIFICIAL REGENERATE TREES
C V2=REMOVED VOLUME OF LOCAL COMERCIAL TREES
C CI=CUTTING INTENSITY FROM .1 TO 1.0
C AV=AVERAGE  VOLUME BY DBH CLASS
C TP=TOTAL PLANTED TREES
C TH=FLAG IF THINNING WAS EXECUTED
C SILV=FLAG IF SILVICULTURE IS DESIRED
C PNW=PRESENT NET WORTH
```

```
C XL=INTEREST RATE
C RSV=RESIDUAL STAND VALUE
C
      COMMON/VERDE/BAC,BEC,BIC
C BAC=NUMBER OF TREES FOR ENRICHMENT PLANTING
C BEC=NUMBER OF TREES FOR LINE PLANTING
C BIC=NUMBER OF TREES FOR CLOSE PLANTING
C
      DATA V1/0.0/
      DATA V2/0.0/
      DATA CI/1.0/
      DATA AV/.0799,.3268,.6489,1.0768,1.6105,2.250,2.9953,3.8464,4.8033
     +,5.866,7.0345,8.3088,9.6889,11.1748,12.76665/
      DATA TP/0.0/
      DATA TH/0.0/
      DATA SILV/0.0/
      DATA PNW/0.0/
      DATA XL/0.1/
      DATA RSV/0.0/
      DATA ROUT/0.0/
      DATA RIN/0.0/
      DATA TLOSS/0.0/
      DATA DIL/90*(0.0)/
      DATA DT/1.0/
      DATA DAL/90*(0.0)/
      DATA DELP/12.,10.0,10.9,7.6,8.0,8.0,8.3,9.3,10.1,4.9,5.2,6.0,9.1,8
     +.5,20.8,5.1,5.1,6.0,9.3,9.0,25.5,5.0,5.0,6.0,8.7,10.0,29.8,5.5,4.9
     +,6.5,8.8,10.0,30.0,7.6,7.1,8.0,9.2,11.0,30.7,7.2,6.8,8.2,10.3,11.0
     +,33.1,8.7,8.2,10.9,10.4,12.0,34.2,9.1,9.8,10.0,10.6,14.0,35.0,9.5,
     +9.7,10.6,5*(12.0,14.0,35.0,9.0,9.0,10.0)/
      DATA DEL/12.0,10.0,10.9,7.6,8.0,8.0,8.3,9.3,10.1,4.9,5.2,6.0,9.1,8
     +.5,20.8,5.1,5.1,6.0,9.3,9.0,25.5,5.0,5.0,6.0,8.7,10.0,29.8,5.5,4.9
     +,6.5,8.8,10.0,30.0,7.6,7.1,8.0,9.2,11.0,30.7,7.2,6.8,8.2,10.3,11.0
     +,33.1,8.7,8.2,10.9,10.4,12.0,34.2,9.1,9.8,10.0,10.6,14.0,35.0,9.5,
     +9.7,10.6,5*(12.0,14.0,35.0,9.0,9.0,10.0)/
      DATA ITR/0/
      DATA IFLAG/0/
      DATA CL/0.0/
      DATA YEAR/0.0/
      DATA XBA1/0.0/
      DATA XBA2/0.0/
      DATA I/6/
      DATA J/15/
      DATA ALI/0.0/
      DATA AREA/0.0/
      DATA TMOR/0.0/
      DATA VAL/-3.5,-1.96,-1.645,-1.439,-1.281,-1.150,-1.037,-0.925,-0.8
     +41,-0.7455,-0.674,-0.598,-0.524,-0.454,-0.386,-0.312,-0.253,-0.189
     +,-0.126,-0.056,0.0,0.056,0.126,0.189,0.253,0.312,0.386,0.454,0.524
     +,0.598,0.674,0.755,0.841,0.925,1.037,1.150,1.281,1.439,1.645,1.960
     +,3.5/
      DATA PLR/15*(0.0)/
      DATA LOS/0/
      DATA A/.7,.6,.5,.7,.8,.7,.008,.05,.02,.01,.02,.10,0.01,.0001,.009,
     +.001,.002,.001,.005,.001,.0001,.0006,.0008,.0001,.0001,.0001,.0001
     +,.00005,11*(.0005,.0007,.0001,.0001,.0001,.00009,.00005)/
      DATA B/.95,.72,.63,.95,.95,.80,.08,.30,.10,.08,.10,.4,.09,.009,.10
     +,.07,.06,.05,.20,.009,.0009,.09,.06,.04,.08,.01,.005,.0005,11*(.08
     +,.05,.03,.07,.05,.0002,.00008)/
      DATA VRA/0.0/
      DATA CLASS /10HSEEDLINGS ,10H15-24.9   ,10H25-34.9   ,10H35-44.9
     + ,10H45-54.9   ,10H55-64.9   ,10H65-74.9   ,10H75-84.9   ,10H85-94
     +.9    ,10H95-104.9  ,10H105-114.9 ,10H115-124.9 ,10H125-134.9 ,10H1
     +35-144.9 ,10H145 AND + /
      DATA BA/.01,.03,.07,.13,.20,.28,.38,.50,.64,.79,.95,1.13,1.33,1.54
```

```
     +,1.77/
      DATA K/12,12,12,20,18,22,14*(15,15,15,22,20,25)/
      DATA R/2250*(0.0)/
      DATA STRG/90*(0.0)/
      BAC=0.0
      BEC=0.0
      BIC=0.0
      SOC=0.0
      OUT=0.0
      PRINT 1
    1 FORMAT(*1*,//,15X,*------------- T A P A F O R -------------*,//)
C READ INPUT DATA
C
      CALL SCREEN
      IF(ITR.EQ.4)SOC=1.0
C CYCLE CUTTING
C
      TOM=0.0
      PRINT*,'OPTION? ='
      READ*,OPT
      DO 4 IPO=1,100
C EXECUT LOG
C
   15 CALL REMOVE
      PRINT 2, V1,YEAR
    2 FORMAT(*0*,2X,*EXPORTABLE VOLUME REMOVED= *,F10.3,*CUBIC METER*,2X
     +,*AT YEAR*,F6.2)
      PRINT 3, V2,YEAR
    3 FORMAT(*0*,2X,*LOCAL COMERCIAL VOLUME REMOVED= *,F10.3,*CUBIC METE
     +R*,2X,*AT YEAR*,F6.2,/)
C
      DO 5 JOR=1,99
      TATU=0.
C CALCULATE PRESENT NET WORTH
C
      CALL NETVAL
      IF(OPT.NE.1.)GO TO 99
      IF(YEAR.EQ.TOM)GO TO 99
      GO TO 100
   99 CONTINUE
      PRINT*,'DESIRED OUTPUT= '
C OUTPUT FORMAT AT YEAR N
C
      READ*,OUT
      IF(OUT.EQ.1.)CALL OUTPUT1
      IF(OUT.EQ.2.0)CALL OUTPUT2
  100 CONTINUE
      YEAR=YEAR+1.0
      IF(OPT.NE.1.)GO TO 101
      IF(YEAR.LE.TOM)GO TO 101
      PRINT*,'NEW YEAR FOR OUTPUT= '
      READ*,TOM
C
  101 CONTINUE
      IF(ITR.EQ.4)GO TO 20
      IF(SOC.EQ.1.)GO TO 20
      IF(CL.EQ.1.0)GO TO 20
C STAND GROWTH
C
      CALL GROWTH1
      GO TO 30
   20 CALL GROWTH2
   30 IF(YEAR.LE.3.)GO TO 87
      IF(OPT.NE.1.)GO TO 102
      IF(YEAR.EQ.TOM)GO TO 102
      SIL=0.0
      GO TO 87
```

```
  102 CONTINUE
      PRINT*,'SILVICULTURE DESIRED? '
C READ IF TREATMENT IS DESIRED
C
      READ*,SILV
      IF(SILV.EQ.0.0)GO TO 87
      PRINT*,'TREATMENT=  '
      READ*,ITR
C SILVICULTURE TIME
C
      TATU=1.0
   87 CALL PRESCR
      IF(YEAR.LE.3.)GO TO 5
      IF(TATU.EQ.1.0)GO TO 5
C READ IF LOG IS DESIRED OR IF YOU WANT OUT OF THIS SYSTEM
C
      IF(OPT.NE.1.)GO TO 103
      IF(YEAR.EQ.TOM)GO TO 103
      LOG=0.
      GO TO 5
  103 CONTINUE
      PRINT*,'LOG DESIRED? '
      READ*,LOG
      IF(LOG.EQ.0.)GO TO 5
      IF(LOG.EQ.2.0)GO TO 11
C ASK IF CLEARCUT WHEN LOG IS DESIRED
C
      PRINT*,'CLEARCUT? '
      READ*,CL
      IF(CL.EQ.1.0)GO TO 15
C ASK FOR CUTTING INTENSITY IF CLEARCUT IS NOT THE CASE
C
      PRINT*,'CUTTING INTENSITY= '
      READ*,CI
      GO TO 15
    5 CONTINUE
    4 CONTINUE
C OUT OF SYSTEM
C
   11 CONTINUE
      END
C
C
C
      SUBROUTINE SCREEN
C THIS SUBROUTINE READ THE INPUT VALUES
C
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
      COMMON/TERR/V1,V2,CI,AV(15),TP,TH,SILV,PNW,XL,RSV
      COMMON/LENN/DEL(6,15),DELP(6,15),DT,DAL(6,15),DIL(6,15),TLOSS,I,J,
     +RIN,ROUT
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
      COMMON/RONN/LOS,A(7,15),B(7,15),PLR(15),AREA,VAL(41)
C CI=DESIRED CUTTING INTENSITY
C XL=DESIRED INTEREST RATE
C ITR=DESIRED TREATMENT
C AREA=STAND AREA
C
      PRINT*,'*** *** *** *** *** ***  ORIGINAL STAND *** *** *** ***  '
      PRINT*,'-EXPORTABLE TREES-'
C READ STORAGE BY DBH CLASS OF EXPORTABLE TREES
C
      DO 10 JR=1,15
      N=K(1,JR)
      PRINT 1,CLASS(JR)
    1 FORMAT(*0*,1X,A10,* = *)
```

```
      READ*,STRG(1,JR)
      DO 54 IB=1,N
      R(IB,1,JR)=STRG(1,JR)/DEL(1,JR)
   54 CONTINUE
   10 CONTINUE
      PRINT*,'-LOCAL COMERCIAL TREES-'
C READ STORAGE BY DBH CLASS OF LOCAL COMERCIAL TREES
C
      DO 11 JS=1,15
      N=K(2,JS)
      PRINT 1,CLASS(JS)
      READ*,STRG(2,JS)
      DO 55 IC=1,N
      R(IC,2,JS)=STRG(2,JS)/DEL(2,JS)
   55 CONTINUE
   11 CONTINUE
      PRINT*,'-NON COMERCIAL TREES-'
C READ STORAGE BY DBH CLASS OF NON COMERCIAL TREES
C
      DO 13 JT=1,15
      N=K(3,JT)
      PRINT 1,CLASS(JT)
      READ*,STRG(3,JT)
      DO 56 ID=1,N
      R(ID,3,JT)=STRG(3,JT)/DEL(3,JT)
   56 CONTINUE
   13 CONTINUE
      PRINT*,'*** *** *** *** *** *** *** *** *** *** *** *** *** ***  '
C CALCULATE THE AREA OF STAND IF PROBABILISTIC
C
      PRINT 88
   88 FORMAT(*0*,/,1X,*IS AREA PROBABILITY DESIRED? *)
      READ*,ANS
      IF(ANS.EQ.2.0)GO TO 70
      CALL COVER
      PRINT 81,AREA
   81 FORMAT(*0*,1X,*AREA BASED ON PROBABILITY=*,F10.3,2X,*HECTARES*,/)
      GO TO 71
   70 PRINT*,'-STAND AREA(HECTARES)= '
      READ*,AREA
C READ TREATMENT , CUTTING INTENSITY  AND  RATE  OF  INTEREST
C
   71 PRINT*,'-TREATMENT= '
      READ*,ITR
      IF(ITR.EQ.4)GO TO 73
      PRINT*,'-CUTTING INTENSITY= '
      READ*,CI
   73 PRINT*,'-INTEREST RATE= '
      READ*,XL
      RETURN
      END
C
C
C
      SUBROUTINE COVER
      COMMON/RONN/LOS,A(7,15),B(7,15),PLR(15),AREA,VAL(41)
C
C THIS SUBROUTINE GENERATE AREA OF STAND BASED ON  A NORMAL DISTRIBUTION
C OF RANDOM NUMBERS
      MEAN=10.
      SD=1.5
      R=RANF(-1)
      Y=TABLIE(VAL,0.,.025,40,R)
C
C AREA BASED ON TABLIE FUNCTION
C
```

```
      AREA=SD*Y+MEAN
C CALCULATE THE NEW AREA WITHOUT NON-PRODUCTIVE FOREST
C
      SAC=(.20-.0001)*RANF(-1)+.0001
      SIC=AREA*SAC
      PRINT 1,AREA,SIC
    1 FORMAT(*0*,1X,*TOTAL AREA=*,F10.3,1X,*HECTARES*,7X,*NON-PRODUCTIVE
     + FOREST=*,F10.3,1X,*HECTARES*)
      AREA=AREA*(1.0-SAC)
      RETURN
      END
C
C
C
C
      SUBROUTINE REMOVE
C THIS SUBROUTINE CUT THE STAND ACCORDING TO TREATMENT AND INTENSITY
C
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
      COMMON/TERR/V1,V2,CI,AV(15),TP,TH,SILV,PNW,XL,RSV
C V1=VOLUME REMOVED FROM EXPORTABLE CLASS IN NR,AND IN ARTIFICIAL REGEN
C V2=VOLUME REMOVED FROM LOCAL COMERCIAL TREES - NR PROCESS
C AV=AVERAGE VOLUME BY DBH CLASS
C
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
      TBA1=0.
      TOTAL=0.
      TV=0.
      VOL=0.
      TBA2=0.
C CALCULATE TOTAL BASAL AREA OF STAND BEFORE LOG
C
      DO 19 I=1,6
      DO 8 J=2,15
      TBA1=TBA1+STRG(I,J)*BA(J)
    8 CONTINUE
   19 CONTINUE
C CHECK IF CLEARCUT IS TO BE EXECUTED
C
      IF(CL.EQ.1.0)GO TO 80
      IF(YEAR.GT.0.)GO TO 2
      IF(ITR.EQ.4)GO TO 80
C CALCULATE COMERCIAL TREES WITH DBH GREATER THAN 45 CM
C
    2 DO 4 I=1,6
      IF(I.EQ.3)GO TO 4
      DO 3 J=5,15
      TOTAL =TOTAL + STRG(I,J)
    3 CONTINUE
    4 CONTINUE
      IF(TOTAL.GT.0.)GO TO 7
      PRINT*,'* * * * * * *  NO LOG EXECUTED-NO ALLOWABLE COMERCIAL TREE
     +S * * * * * * * * '
C NO COMERCIAL TREES WITH DBH GREATER THAN 45 CM
C
      GO TO 30
C SET FLAG FOR LOG
C
    7 IFLAG=1
C NUMBER OF TREES TO CUT
C
      CUT=TOTAL*CI
C CUT THE STAND
C
      DO 14 I=1,6
      IF(I.EQ.3)GO TO 12
      J=15
```

```
C
   10 N=K(I,J)
C ACTUAL REMOVED TREES
C
   50 VOL=VOL+STRG(I,J)
      IF(VOL.GT.CUT)GO TO 9
C TOTAL BASAL AREA REMOVED
C
      TBA2=TBA2+STRG(I,J)*BA(J)
C REMOVED VOLUME
C
      IF(I.EQ.2)V2=V2+STRG(I,J)*AV(J)
      IF(I.NE.2)V1=V1+STRG(I,J)*AV(J)
C NEW STORAGE
C
      STRG(I,J)=0.0
      DO 13 KK=1,N
C N=STAGES  IN THE ACTUAL DBH CLASS
C
      R(KK,I,J)=0.0
   13 CONTINUE
      J=J-1
      IF(J.LT.5)GO TO 12
      GO TO 10
   12 CONTINUE
   14 CONTINUE
      GO TO 20
    9 VOL=VOL-STRG(I,J)
      IF(CUT.LT.VOL)GO TO 50
      IF(CUT.EQ.VOL)GO TO 20
      TV=CUT-VOL
      AJA=1. - TV/STRG(I,J)
      STRG(I,J)=STRG(I,J)*AJA
      DO 72 II=1,N
      R(II,I,J)=R(II,I,J)*AJA
   72 CONTINUE
      TBA2=TBA2+TV*BA(J)
      IF(I.EQ.2)V2=V2+TV*AV(J)
      IF(I.NE.2)V1=V1+TV*AV(J)
      GO TO 20
C CLEAR WILL BE EXECUTED
C SET FLAG FOR LOG
C
   80 IFLAG=1
      DO 81 I=1,6
      IF(I.EQ.3)GO TO 81
      DO 82 J=2,15
      IF(I.EQ.2)V2=V2+STRG(I,J)*AV(J)
      IF(I.NE.2)V1=V1+STRG(I,J)*AV(J)
   82 CONTINUE
   81 CONTINUE
CC STAND WILL BE WITH ZERO DENSITY
C
      DO 83 I=1,6
      DO 84 J=1,15
      N=K(I,J)
      DO 85 KK=1,N
      R(KK,I,J)=0.0
   85 CONTINUE
      STRG(I,J)=0.0
   84 CONTINUE
   83 CONTINUE
      ALI=100.
      GO TO 30
C LOG INTENSITY
```

```
C
   20 ALI=(TBA2/TBA1)*100.
      PRINT 44,ALI
   44 FORMAT(*0*,/,1X,*AVERAGE LOG INTENSITY= *,F6.2)
   30 RETURN
      END
C
C
C
C
      SUBROUTINE NETVAL
C THIS SUBROUTINE CALCULATE THE NET PRESENT VALUE BASED ON COST AND
C REVENUE OF SAWLOG AS FINAL PRODUCT
C
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
      COMMON/TERR/V1,V2,CI,AV(15),TP,TH,SILV,PNW,XL,RSV
C TP=TOTAL TREES PLANTED
C V1=VOLUME OF EXPORTABLE OR ARTIFICIAL PLANTATION
C V2=VOLUME OF LOCAL COMERCIAL TREES
C PNW=PRESENT NET WORTH BASED ON SAWLOG AS FINAL PRODUCT
C XL=RATE OF INTEREST
C RSV=RESIDUAL STAND PRESENT VALUE
C
      B1=0.
      B2=0.
      RSV=0.
C CHECK IF THINNING OF NON COMERCIAL TREES WAS EXECUTED
C
      IF(TH.NE.1.)GO TO 10
      TE=1200.0/((1.0+XL)**YEAR)
C PRESENT VALUE OVER CYCLE
C
      PNW=PNW-TE
      TH=0.0
      GO TO 80
C CHECK LOG AND SILVICULTURE
C
   10 IF(IFLAG.EQ.0)GO TO 70
      IF(IFLAG-2)7,8,9
C LOG WAS EXECUTED,VALUE OF SAWLOG AS FINAL PRODUCT
C
    7 EXPOR=(V1*1./2.)*10000.
      XLOC=(V2*1./2.)*7000.
C PRESENT VALUE
C
      AREV=(XLOC+EXPOR)/((1.+XL)**YEAR)
C COST FOR SAWLOG AS FINAL PRODUCT
      DESP=(V1+V2)*(1./2.)*3540.
C PRESENT VALUE OF COST FOR FINAL PRODUCT
      ADESP=(DESP)/((1.+XL)**YEAR)
C TOTAL PRESENT VALUE
C
      PNW=PNW+AREV-ADESP
      GO TO 80
C ENRICHMENT PLANTING WAS EXECUTED - COST
C
    8 EP=(TP*24.5)/((1.+XL)**YEAR)
C PRESENT VALUE
C
      PNW=PNW-EP
      GO TO 80
C LINE PLANTATION WAS EXECUTED - COST
C
    9 XP=(TP*26.0)/((1.+XL)**YEAR)
C PRESENT VALUE
C
```

```
      PNW=PNW-XP
      GO TO 80
C CLOSE PLANTATION CHECK
   70 IF(CL.NE.1.0)GO TO 75
C CLOSE PLANTATION COST
C
      CP=(TP*30.)/((1.0+XL)**YEAR)
C PRESENT VALUE
C
      PNW=PNW-CP
      GO TO 80
C NO OPERATION EXECUTED, COST FOR MAINTENANCE
C
   75 CONTR=580./((1.+XL)**YEAR)
C PRESENT VALUE
C
      PNW=PNW - CONTR
C VALUE OF RESIDUAL STAND  HAVING SAWLOG AS FINAL PRODUCT
C
   80 DO 82 I=1,6
      IF(I.EQ.3)GO TO 82
      DO 83 J=2,15
      IF(I.EQ.2)B2=B2+STRG(I,J)*AV(J)
      IF(I.NE.2)B1=B1+STRG(I,J)*AV(J)
   83 CONTINUE
   82 CONTINUE
C REVENUE OF RESIDUAL STAND FOR SAWLOG
C
      Z1=(B1*1./2.)*10000.
      Z2=(B2*1./2.)*7000.
      AZ=(Z1+Z2)/((1.+XL)**YEAR)
C COST OF RESIDUAL STAND FOR SAWLOG OPERATION
C
      C1=(B1+B2)*(1./2.)*3540.0
C PRESENT VALUE OF RESIDUAL STAND IN CRUZEIROS PER HECTARE
C
      RSV=AZ-(C1/((1.+XL)**YEAR))
      RETURN
      END
C
C
C
C
      SUBROUTINE OUTPUT1
C THIS SUBROUTINE PROVIDE A DETAILED OUTPUT OF STAND BY YEAR
C
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
      COMMON/TERR/V1,V2,CI,AV(15),TP,TH,SILV,PNW,XL,RSV
C CALCULATE ACCUMULATE REMOVED VOLUME
C
      VRA=VRA+V1+V2
      PRINT*,'*** *** *** *** *** *** *** *** *** *** *** *** *** ***  '
C PRINT YEAR
C
      PRINT1,YEAR
    1 FORMAT(*0*,2X,*RESIDUAL STAND AFTER YEAR *,F3.0)
      IF(YEAR.LE.1.0)GO TO 79
C PRINT BASAL AREA BEFORE GROWTH AND AFTER GROWTH
C
      PRINT 2,XBA1
    2 FORMAT(*0*,2X,*TOTAL BASAL AREA BEFORE GROWTH= *,F10.3,1X,*SQUARE
     +METER P/HECTARE*)
      PRINT 3,XBA2
    3 FORMAT(*0*,2X,*TOTAL BASAL AREA AFTER GROWTH= *,F10.3,1X,*SQUARE M
```

```
     +ETER P/HECTARE*)
C PRINT MORTALITY
C
      PRINT 4,TMOR
    4 FORMAT(*0*,2X,*TOTAL MORTALITY= *,F10.3,1X,*P/HECTARE*)
C PRINT PRESENT NET WORTH AND REMOVED VOLUME
C
   79 PRINT 5,PNW
    5 FORMAT(*0*,2X,*PRESENT NET WORTH= *,F15.3,1X,*CRUZEIROS P/HECTARE*
     +)
      PRINT 13,VRA
   13 FORMAT(*0*,2X,*ACCUMULATE REMOVED VOLUME= *,F15.3,1X,*CUBIC METER
     +P/HECTARE*)
C RESIDUAL STAND VALUE AS OUTPUT FOR SAWLOG
C
      PRINT 6,RSV
    6 FORMAT(*0*,2X,*RESIDUAL STAND PRESENT VALUE= *,F15.3,1X,*CRUZEIROS
     +P/HECTARE*)
      COK=RSV+PNW
      PRINT 777,COK
  777 FORMAT(*0*,2X,*TOTAL PRESENT VALUE= *,F15.3,1X,*CRUZEIROS P/HECTAR
     +E*)
C PRINT RESIDUAL STAND TABLE
C
      PRINT 7
    7 FORMAT(*0*,//,1X,*DBH CLASS*,22X,*TREATMENT*,/,14X,*EXPORTABLE*,2X
     +,*LOC.COM.*,2X,*NON-COM.*,2X,*LINE PL.*,2X,*ENRI.PL.*,2X,*CLOSE-PL
     +.*)
      DO 10 J=1,15
      PRINT 9, CLASS(J),(STRG(I,J),I=1,6)
    9 FORMAT(*0*,1X,A10,1X,6(F10.2))
   10 CONTINUE
      V1=0.
      V2=0.
      PRINT*,'*** *** *** *** *** *** *** *** *** *** *** *** *** ***  '
      RETURN
      END
C
C
C
C
      SUBROUTINE OUTPUT2
C THIS SUBROUTINE PROVIDES A GENERAL OUTPUT
C
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
      COMMON/TERR/V1,V2,CI,AV(15),TP,TH,SILV,PNW,XL,RSV
C CALCULATE ACCUMULATE REMOVED VOLUME
C
      VRA=VRA+V1+V2
      TOTAL=0.
      PRINT*,'*** *** *** *** *** *** *** *** *** *** *** *** *** ***  '
      PRINT 1,YEAR
    1 FORMAT(*0*,2X,*RESIDUAL STAND AFTER YEAR *,F3.0)
      PRINT 2,PNW
    2 FORMAT(*0*,2X,*PRESENT NET WORTH= *,F15.3,1X,*CRUZEIROS P/HECTARE*
     +)
      PRINT 3,RSV
    3 FORMAT(*0*,2X,*RESIDUAL STAND PRESENT VALUE= *,F15.3,1X,*CRUZEIROS
     +P/HECTARE*)
      COK=RSV + PNW
      PRINT 777,COK
  777 FORMAT(*0*,2X,*TOTAL PRESENT VALUE= *,F15.3,1X,*CRUZEIROS P/HECTAR
     +E*)
      DO 4 I=1,6
      DO 5 J=2,15
C CALCULATING TOTAL TREES WITH DBH OVER 15 CM
C
```

```
      TOTAL=TOTAL + STRG(I,J)
    5 CONTINUE
    4 CONTINUE
      PRINT 6, TOTAL
    6 FORMAT(*0*,2X,*TOTAL TREES W/MINIMUM 15 CM DBH= *,F10.2,2X,*P/HECT
     +ARE*)
      TOTAL=0.0
C CALCULATE COMERCIAL TREES WITH DBH GREATER THAN 15 CM
C
      DO 7 I=1,6
      IF(I.EQ.3)GO TO 7
      DO 8 J=2,15
      TOTAL=TOTAL + STRG(I,J)
    8 CONTINUE
    7 CONTINUE
      PRINT 9,TOTAL
    9 FORMAT(*0*,2X,*TOTAL COMERCIAL TREES W/MINIMUN 15 CM DBH= *,F10.2,
     +2X,*P/HECTARE*)
      TOTAL=0.
      DO 10 I=1,6
      IF(I.EQ.3)GO TO 10
C CALCULATING TOTAL COMERCIAL TREES WITH DBH GREATER THAN 45 CM
C
      DO 11 J=5,15
      TOTAL=TOTAL + STRG(I,J)
   11 CONTINUE
   10 CONTINUE
      PRINT 13, TOTAL
   13 FORMAT(*0*,2X,*TOTAL COMERCIAL TREES W/MINIMUN 45 CM DBH= *,F10.2,
     +2X,*P/HECTARE*)
      PRINT*,'*** *** *** *** *** *** *** *** *** *** *** *** *** ***  '
      V1=0.0
      V2=0.0
      RETURN
      END
C
C
C
C
      SUBROUTINE GROWTH1
C THIS SUBROUTINE EXECUTE  THE STAND GROWTH BASED ON DELAY PROCESS
C
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
C ALI=LOG INTENSITY
C TMOR=TOTAL MORTALITY
C TBA1=TOTAL BASAL AREA BEFORE GROWTH
C TBA2=TOTAL BASAL AREA AFTER GROWTH
C
      COMMON/RONN/LOS,A(7,15),B(7,15),PLR(15),AREA,VAL(41)
C PLR=PROPORTION OF LOSS(MORTALITY IS INCLUDED)
C
      COMMON/LENN/DEL(6,15),DELP(6,15),DT,DAL(6,15),DIL(6,15),TLOSS,I,J,
     +RIN,ROUT
C DEL=DELAY FOR GROWTH =DAL=DIL
C DELP=PREVIOUS DELAY
C I=TREATMENT CLASS
C J=DBH CLASS
C RIN=INPUT IN PRESENT DELAY
C ROUT=OUTPUT IN PRESENT DELAY
C
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
C STRG=STORAGE BY DBH CLASS
C BA=AVERAGE BASAL AREA BY DBH CLASS
C
```

```
      COMMON/VERDE/BAC,BEC,BIC
C BAC=NUMBER OF TREES FOR ENRICHMENT PLANTING
C BEC=NUMBER OF TREES FOR LINE PLANTING
C
      TREE=0.0
      TOTAL=0.0
      TMOR=0.0
      XBA1=0.0
      XBA2=0.0
C CALCULATE TOTAL NUMBER OF TREES AND TOTAL BASAL AREA BEFORE GROWTH
      DO 1 IA=1,5
      DO 2 JA=2,15
      TOTAL=TOTAL+STRG(IA,JA)
      XBA1=XBA1+STRG(IA,JA)*BA(JA)
    2 CONTINUE
    1 CONTINUE
      IF(TOTAL.GT.400.)GO TO 3
      IF(XBA1.GT.45.)GO TO 3
      GO TO 4
C DELAY CHANGE IF NUMBER OF TREES GREATER THAN 400 W/DBH MINIMUM 15 CM
C OR BASAL AREA GREATER THAN 45 SQUARE METER
C
    3 DO 5 IB=1,5
      DO 6 JB=1,2
      DAL(IB,JB)=DEL(IB,JB)/.5
    6 CONTINUE
    5 CONTINUE
C FLAG WHEN TREES GREATER THAN 400
C
      TREE=1.0
    4 DO 55 ID=1,5
      DO 66 JD=1,15
      DIL(ID,JD)=DEL(ID,JD)-.01
      DEL(ID,JD)=DIL(ID,JD)
   66 CONTINUE
      IF(TREE.EQ.1.0)DIL(ID,1)=DAL(ID,1)
      IF(TREE.EQ.1.0)DIL(ID,2)=DAL(ID,2)
   55 CONTINUE
      XIC=0.
      DO 115 II=4,5
      DO 116 JJ=5,15
      XIC=XIC+STRG(II,JJ)
  116 CONTINUE
  115 CONTINUE
      IF(IFLAG.EQ.0)GO TO 13
      IF(IFLAG-2)10,11,12
C IF LOG WAS EXECUTED,IFLAG=1,CALCULATE PROPORTION OF LOSS AFTER LOG
C ALI=LOG INTENSITY
C
   10 IF(ALI.GE.80.)LOS=1
      IF(ALI.GE.50..AND.ALI.LT.80.)LOS=2
      IF(ALI.LT.50.)LOS=3
      CALL LOSS
      DO 7 I=1,5
C NUMBER OF SEEDLINGS FOR NR
C
      XER=0.0
      DO 38 JW=5,15
      XER=XER + STRG(I,JW)
   38 CONTINUE
      RIO=RANF(NULL)
      Y=TABLIE(VAL,0.,.025,40,RIO)
      IF(XER.GT.0.)RIN=800. + Y*300.
      IF(XER.LE.0.)RIN=500. + Y*200.
      IF(RIN.LE.0.)RIN=100.
C INPUT FOR NATURAL REGENERATION FROM PLANTED TREES
```

```
C
      IF(I.GT.3)RIN=0.
C
      DO 8 J=1,15
      CALL DELICT
C CALCULATE TOTAL MORTALITY
C
      TMOR=TMOR+TLOSS
      RIN=ROUT
    8 CONTINUE
    7 CONTINUE
      GO TO 14
   11 LOS=4
C ENRICHMENT PLANTING WAS EXECUTED,CALCULATE PLR IN NATURAL STAND
C
      GO TO 30
   12 LOS=5
C LINE PLANTATION WAS EXECUTED, CALCULATE PLR
C
   30 CALL LOSS
      DO 20 I=1,5
C
C NUMBER OF SEEDLINGS FOR NATURAL REGENERATION
C
      XER=0.0
      DO 528 JY=5,15
      XER=XER + STRG(I,JY)
  528 CONTINUE
      RIO=RANF(NULL)
      Y=TABLIE(VAL,0.,.025,40,RIO)
      IF(XER.GT.0.)RIN=800. + Y*300.
      IF(XER.LE.0.)RIN=500. + Y*200.
      IF(RIN.LE.0.)RIN=100.
      IF(I.LE.3)GO TO 16
      RIN=0.0
      IF(I.EQ.4)RIN=RIN+BEC
      IF(I.EQ.5)RIN=RIN+BAC
      LOS=7
      CALL LOSS
      IF(RIN.NE.0.)GO TO 16
      IF(ITR.NE.3.AND.I.EQ.4)GO TO 16
      IF(ITR.NE.2.AND.I.EQ.5)GO TO 16
      IF(XIC.GT.10.)RIN=100.
      IF(XIC.GT.10.)PLR(1)=.85
   16 DO 21 J=1,15
      CALL DELICT
C TOTAL MORTALITY
C
      TMOR=TMOR+TLOSS
      RIN=ROUT
   21 CONTINUE
   20 CONTINUE
      GO TO 14
C NO REMOVE OR PRESCRIPTION EXECUTED
C
   13 LOS=6
      CALL LOSS
      DO 300 I=1,5
C
C SEEDLINGS FROM NATURAL REGENERATION
C
      XER=0.0
      DO 783 JG=5,15
      XER=XER + STRG(I,JG)
  783 CONTINUE
      RIO=RANF(NULL)
```

```
      Y=TABLIE(VAL,0.,.025,40,RIO)
      IF(XER.GT.0.)RIN=800. + Y*300.
      IF(XER.LE.0.)RIN=500. + Y*200.
      IF(RIN.LE.0.)RIN=100.
      IF(I.LE.3)GO TO 17
      RIN=0.0
      LOS=7
      CALL LOSS
      IF(ITR.NE.3 .AND.I.EQ.4)GO TO 17
      IF(ITR.NE.2 .AND.I.EQ.5)GO TO 17
      IF(XIC.GT.10.)RIN=100.
      IF(XIC.GT.10.)PLR(1)=.85
   17 DO 31 J=1,15
      CALL DELICT
      TMOR=TMOR+TLOSS
      RIN=ROUT
   31 CONTINUE
  300 CONTINUE
   14 IFLAG=0
      DO 40 IT=1,5
      DO 41 JT=2,15
      XBA2=XBA2+STRG(IT,JT)*BA(JT)
   41 CONTINUE
   40 CONTINUE
      RETURN
      END
C
C
C
C
      SUBROUTINE GROWTH2
C THIS SUBROUTINE CALCULATE GROWTH UNDER THE CLOSE PLANTATION OPTION
C ALLOWABLE PRESCRIPTIONS = CLOSE PLANTATION AND ITS NR
C
      COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
C YEAR=YEAR AFTER THE FIRST DISTURBANCE
C CL=FLAG IF CLEARCUT WAS EXECUTED
C
      COMMON/LENN/DEL(6,15),DELP(6,15),DT,DAL(6,15),DIL(6,15),TLOSS,I,J,
     +RIN,ROUT
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
      COMMON/RONN/LOS,A(7,15),B(7,15),PLR(15),AREA,VAL(41)
C I=TREATMENT CLASS
C J=DBH CLASS
C RIN=INPUT IN THE PRESENT DELAY
C ROUT =OUTPUT IN THE PRESENT DELAY
C
      COMMON/VERDE/BAC,BEC,BIC
C BIC=NUMBER OF TREES FOR CLOSE PLANTING
C
      TOTAL=0.
      XBA1=0.0
      TMOR=0.0
      XBA2=0.0
      TREE=0.0
      TOT1=0.0
      RIN=0.
C CALCULATE TOTAL BASAL AREA AND TOTAL TREE/HA BEFORE GROWTH
C
      DO 2 JO=2,15
      XBA1=XBA1+STRG(6,JO)*BA(JO)
      TOTAL=TOTAL+STRG(6,JO)
    2 CONTINUE
C IF FIRST YEAR AFTER CLEAR,PLANTATION YEAR,RETURN
      IF(YEAR.EQ.1.0)GO TO 20
      IF(CL.EQ.1.0)GO TO 20
      IF(TOTAL.GT.500.)GO TO 3
```

```
      IF(XBA1.GT.70.)GO TO 3
      GO TO 4
C CHANGE DELAY IF NUMBER OF TREES IS GREATER THAN 500
C OR BASAL AREA GREATER THAN 70 SQUARE METER
C
    3 DO 6 JP=1,2
      DAL(6,JP)=DEL(6,JP)/.5
    6 CONTINUE
C FLAG WHEN TREES GREATER THAN 500
      TREE=1.0
    4 DO 8 JL=1,15
      DIL(6,JL)=DEL(6,JL)-.01
      DEL(6,JL)=DIL(6,JL)
    8 CONTINUE
      IF(TREE.EQ.1.0)DIL(6,1)=DAL(6,1)
      IF(TREE.EQ.1.0)DIL(6,2)=DAL(6,2)
C CHECK NUMBER OF TREES WITH DBH GREATER THAN 45 CM
C
      DO 9 JR=4,15
      TOT1=TOT1+STRG(6,JR)
    9 CONTINUE
C INPUT FOR THE GROWTH PROCESS
C
      RIN=RIN+BIC
      IF(TOT1.GT.200.)RIN=100.
      IF(IFLAG.EQ.1)GO TO 7
      LOS=7
      CALL LOSS
      IF(TOT1.GT.200.)PLR(1)=.88
      GO TO 11
    7 IF(ALI.GE.80.)LOS=1
      IF(ALI.GE.50..AND.ALI.LT.80.)LOS=2
      IF(ALI.LT.50.)LOS=3
      CALL LOSS
      I=6
   11 DO 12 J=1,15
      CALL DELICT
      TMOR=TLOSS + TMOR
      RIN=ROUT
   12 CONTINUE
C TOTAL BASAL AREA AFTER GROWTH
C
      DO 30 JZ=2,15
      XBA2=XBA2+STRG(6,JZ)*BA(JZ)
   30 CONTINUE
   20 CONTINUE
      IFLAG=0
      CL=0.0
      RETURN
      END
C
C
C
C
      SUBROUTINE DELICT
C THIS SUBROUTINE CALCULATE THE DELAY PROCESS FOR EACH DBH CLASS AND
C TREATMENT BASED ON  SUBROUTINE DELLVF(DISTRIBUTED DELAY WITH STORAGE
C LOSSES AND VARIABLE DELAY TIME) FROM M. H. ABKIN  AND  C. WOLF
C (SCIENCE,1980)
C
      COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
      COMMON/RONN/LOS,A(7,15),B(7,15),PLR(15),AREA,VAL(41)
      COMMON/LENN/DEL(6,15),DELP(6,15),DT,DAL(6,15),DIL(6,15),TLOSS,I,J,
     +RIN,ROUT
C I=TREATMENT  CLASS
```

```
C J=DBH CLASS
C RIN=INPUT
C ROUT=OUTPUT
C
       N=K(I,J)
C STAGES IN TREATMENT I AND DBH CLASS J
C
       FK=FLOAT(N)
       G=1.+(DIL(I,J)-DELP(I,J))/(FK*DT)+PLR(J)*DELP(I,J)/FK
       IDT=1.+2.*DT*FK/DELP(I,J)*AMAX1(G,0.)
       C=FK*DT/(DELP(I,J)*FLOAT(IDT))
       DELP(I,J)=DIL(I,J)
       KM1=N-1
        DO 20 L=1,IDT
        DO 10 M=1,KM1
        R(M,I,J)=R(M,I,J)+C*(R(M+1,I,J)-G*R(M,I,J))
     10 CONTINUE
        R(N,I,J)=R(N,I,J)+C*(RIN-G*R(N,I,J))
     20 CONTINUE
        STRG(I,J)=0.0
        DO 30 M=1,N
        STRG(I,J)=STRG(I,J)+R(M,I,J)*DIL(I,J)/FK
     30 CONTINUE
        TLOSS=PLR(J)*STRG(I,J)
        ROUT=R(1,I,J)
        RETURN
        END
C
C
C
C
        SUBROUTINE PRESCR
C
C THIS SUBROUTINE EXECUTE SILVICULTURAL TREATMENT AS SPECIFIED
C
        COMMON/DIMY/ALI,TMOR,XBA1,XBA2,YEAR,CL,IFLAG,ITR
C ITR= NATURAL REGENERATION=1
C       ENRICHMENT PLANTING=2  - IFLAG=2
C       LINE PLANTATION=3 - IFLAG=3
C       CLOSE PLANTATION=4
C TOTAL=TREES WITH DBH GREATER THAN 15 CM
C
        COMMON/TERR/V1,V2,CI,AV(15),TP,TH,SILV,PNW,XL,RSV
C TP=TREES PLANTED
C TH=FLAG IF THINNING IS TO BE EXECUTED
C SILV=FLAG IF SILVICULTURE IS TO BE EXECUTED
C
        COMMON/KRISTY/STRG(6,15),R(25,6,15),K(6,15),BA(15),CLASS(15),VRA
        COMMON/VERDE/BAC,BEC,BIC
C BAC=NUMBER OF TREES FOR ENRICHMENT PLANTING
C BEC=NUMBER OF TREES FOR LINE PLANTING
C BIC=NUMBER OF TREES FOR CLOSE PLANTING
C
        BAC=0.0
        BEC=0.0
        BIC=0.0
        TH=0.
        TAC=0.
        TOTAL=0.
        DO 215 I=1,5
        IF(I.EQ.3)GO TO 215
        DO 216 J=2,15
        TOTAL=TOTAL + STRG(I,J)
    216 CONTINUE
    215 CONTINUE
        IF(YEAR.EQ.1.)GO TO 3
        IF(SILV.NE.1.)GO TO 5
      3 GO TO(7,8,9,10)ITR
C NATURAL REGENERATION
```

```
C
    7 SILV=0.
      GO TO 60
C ENRICHMENT PLANTING
C CHECK DENSITY OF STAND
C
    8 IF(TOTAL.GT.100.)GO TO 59
      IFLAG=2
C NUMBER OF TREES TO BE PLANTED
C
      BLUE=COS(TOTAL*2.0*3.14159265/360.0)
      TP=26.2666114 + 100.93310 * BLUE
      BAC=BAC+TP
      SILV=0.0
      GO TO 60
C LINE PLANTATION TO BE EXECUTED
C CHECK THE DENSITY
C
    9 IF(TOTAL.GT.100.)GO TO 59
      IFLAG=3
      BLUE=COS(TOTAL*2.0*3.14159265/360.0)
      TP=26.2666114 + 100.93310 * BLUE
      BEC=BEC+TP
      SILV=0.
      GO TO 60
C CLOSE PLANTATION
C
   10 TOTAL=0.0
      DO 46 IO=1,6
      DO 47 JO=1,15
      TOTAL=TOTAL+STRG(IO,JO)
   47 CONTINUE
   46 CONTINUE
      IF(TOTAL.GT.0.0)GO TO 48
      TP=400.
      BIC=BIC+TP
      SILV=0.0
      CL=0.0
      GO TO 60
   48 PRINT*,'* * *  NO CLOSE PLANTATION EXECUTED - CLEARCUT  FIRST  * *
     + *'
      SILV=0.0
      GO TO 60
    5 IF(ITR.EQ.4)GO TO 60
C YEAR OF NON-COMERCIAL THINNING CHECK
C
      IF(YEAR.LE.5.)GO TO 60
C DENSITY OF STAND FOR THINNING
C
      TOTAL=0.
      DO  99 IB=1,5
      DO 100 JB=2,15
      TOTAL=TOTAL + STRG(IB,JB)
  100 CONTINUE
   99 CONTINUE
      IF(TOTAL-300.)60,60,13
   13 TH=1.0
      PRINT*,'* * * NON-COMERCIAL THINNING EXECUTED * * *'
      TIC=TOTAL-300.
      J=15
   16 N=K(3,J)
   50 TAC=TAC + STRG(3,J)
      IF(TAC.GT.TIC)GO TO 17
```

```
      STRG(3,J)=0.0
      DO 15 KK=1,N
      R(KK,3,J)=0.0
   15 CONTINUE
      IF(J.EQ.1)GO TO 60
      J=J-1
      GO TO 16
   17 TAC=TAC-STRG(3,J)
      IF(TIC.LT.TAC)GO TO 50
      IF(TIC.EQ.TAC)GO TO 60
      TIV=TIC-TAC
      TEV=1. - TIV/STRG(3,J)
      STRG(3,J)=STRG(3,J)*TEV
      DO 78 IK=1,N
      R(IK,3,J)=R(IK,3,J)*TEV
   78 CONTINUE
      GO TO 60
   59 PRINT*,'* * *  NO SILVICULTURE EXECUTED-GOOD DENSITY OF COMERCIAL
     +TREES  * * *'
      SILV=0.0
   60 CONTINUE
      RETURN
      END
C
C
C
C
      SUBROUTINE LOSS
C THIS SUBROUTINE CALCULATE PROPORTION LOSS RATE - PLR - BASED ON
C NORMAL DISTRIBUTION
C
      COMMON/RONN/LOS,A(7,15),B(7,15),PLR(15),AREA,VAL(41)
C LOS=CLASS OF LOSS
C PLR=PROPORTIONATE LOSS RATE IN PROPORTION/UNIT TIME
C
      DO 3 JX=1,15
      XMEAN=(A(LOS,JX)+B(LOS,JX))/2.
      IF(JX.GT.5)GO TO 15
      GO TO(10,11,12,13,14)JX
   10 SD=XMEAN/40.
      GO TO 17
   11 SD=XMEAN/35.
      GO TO 17
   12 SD=XMEAN/30.
      GO TO 17
   13 SD=XMEAN/25.
      GO TO 17
   14 SD=XMEAN/20.
      GO TO 17
   15 SD=XMEAN/10.
C GENERATE RANDOM NUMBER BETWEEN  ZERO AND ONE
C
   17 RIO=RANF(NULL)
      Y=TABLIE(VAL,0.,.025,40,RIO)
C RANDOM PLR BASED ON NORMAL DISTRIBUTION
C
      PLR(JX)=SD*Y+XMEAN
    3 CONTINUE
      RETURN
      END
C
C
C
C
```

```
      SUBROUTINE   TABLIE(VAL,SMALL,DIFF,K,DUMMY)
C
C THIS FUNCTION INTERPOLATE NUMBERS WITH EQUAL INCREMENT
C FROM ROBERT W. LLEWELLYN - 'FORDYN'
C 'AN INDUSTRIAL DYNAMICS SIMULATOR'(1965)
C
      DIMENSION VAL(1)
      DUM=AMIN1(AMAX1(DUMMY-SMALL,0.0),FLOAT(K)*DIFF)
      I=1.0+DUM/DIFF
      IF(I.EQ.K+1)I=K
      TABLIE=(VAL(I+1)-VAL(I))*(DUM-FLOAT(I-1)*DIFF)/DIFF+VAL(I)
      RETURN
      END

READY 19.12.05
```

APPENDIX G

SOURCE LISTING FOR OPTIMUM

```
LIST,
      PROGRAM OPTIMUM(INPUT,OUTPUT)
C THIS PROGRAM OPTMIZE THE PRESENT NET WORTH OF AN AREA WITH FOUR
C DIFFERENT STANDS AND 20 TREATMENTS EACH UNDER SPECIFIED CONSTRAINTS
C AND RESULTS FROM TAPAFOR PROGRAM
C
      DIMENSION XNVAL(4,20),TVR(4,20),RSV(4,20),BA(4,20)
C XNVAL=PRESENT NET WORTH
C TVR=TOTAL REMOVED VOLUME
C RSV=RESIDUAL STAND VALUE
C BA=BASAL AREA
C
   80 CONTINUE
C
C READ PRESENT NET WORTH VALUES
C
      PRINT 1
    1 FORMAT(*1*,10X,*ENTER VALUES OF PRESENT NET WORTH*)
      DO 2 J=1,4
      PRINT 3,J
    3 FORMAT(*0*,5X,*STAND NUMBER=*,I4)
      DO 4 JC=1,20
      PRINT 5,JC
    5 FORMAT(*0*,5X,I4,*=*)
      READ*,XNVAL(J,JC)
    4 CONTINUE
    2 CONTINUE
C
C READ TOTAL VOLUME REMOVED VALUES
C
      PRINT 7
    7 FORMAT(*0*,//,10X,*ENTER VALUES OF TOTAL REMOVED VOLUME*)
      DO 8 J=1,4
      PRINT 3,J
      DO 9 JC=1,20
      PRINT 5,JC
      READ*,TVR(J,JC)
    9 CONTINUE
    8 CONTINUE
C
C READ RESIDUAL STAND VALUE
C
      PRINT 10
   10 FORMAT(*0*,//,10X,*ENTER RESIDUAL STAND VALUE*)
      DO 11 J=1,4
      PRINT 3,J
      DO 12 JC=1,20
      PRINT 5,JC
      READ*,RSV(J,JC)
   12 CONTINUE
   11 CONTINUE
C
C READ BASAL AREA OF RESIDUAL STANDS
C
      PRINT 13
   13 FORMAT(*0*,//,10X,*ENTER RESIDUAL BASAL AREA*)
      DO 14 J=1,4
      PRINT 3,J
      DO 15 JC=1,20
```

```
      PRINT 5,JC
      READ*,BA(J,JC)
   15 CONTINUE
   14 CONTINUE
C
C READ AREA FOR EACH STAND
C
      PRINT 20
   20 FORMAT('0',//,10X,'ENTER AREA IN HECTARES FOR EACH STAND')
      PRINT*,"STAND 1="
      READ*,A
      PRINT*,"STAND 2="
      READ*,B
      PRINT*,"STAND 3="
      READ*,C
      PRINT*,"STAND 4="
      READ*,D
      AREA=A+B+C+D
   99 CONTINUE
C
C READ CONSTRAINTS
C
      PRINT 44
   44 FORMAT('0',//,10X,'ENTER CONSTRAINTS FOR AREA')
      PRINT*,"TOTAL NUMBER OF YEARS(CYCLE) OF SIMULATION= "
      READ*,YEAR
      PRINT*,"MINIMUM DESIRED VOLUME TO BE REMOVED BY YEAR(TOTAL)= "
      READ*,AVR1
      PRINT*,"MAXIMUM DESIRED VOLUME TO BE REMOVED BY YEAR(TOTAL)= "
      READ*,AVR2
      PRINT*,"MINIMUM DESIRED AVERAGE DISCOUNTED RESIDUAL VALUE/HA=
"
      READ*,ARSV
      PRINT*,"MINIMUM DESIRED AVERAGE RESIDUAL BASAL AREA/HA= "
      READ*,ABAT
C
C STARTING LOOP FOR BEST COMBINATION
C
      XNTO=0.
      DO 22 KI=1,20
      DO 23 KK=1,20
      DO 24 KL=1,20
      DO 25 KM=1,20
       XNTV=XNVAL(1,KI)*A + XNVAL(2,KK)*B + XNVAL(3,KL)*C + XNVAL(4,
KM)*D
       TVRT=TVR(1,KI)*A + TVR(2,KK)*B + TVR(3,KL)*C + TVR(4,KM)*D
       RSVT=RSV(1,KI)*A + RSV(2,KK)*B + RSV(3,KL)*C + RSV(4,KM)*D
       BAT=BA(1,KI)*A + BA(2,KK)*B + BA(3,KL)*C + BA(4,KM)*D
C
C CHECK THE BEST ALTERNATIVE  ACCORDING TO CONSTRAINTS
C
       IF(XNTO.GT.XNTV)GO TO 25
       IF(TVRT/YEAR.LT.AVR1)GO TO 25
       IF(TVRT/YEAR.GT.AVR2)GO TO 25
       IF(RSVT/AREA.LT.ARSV)GO TO 25
       IF(BAT/AREA.LT.ABAT)GO TO 25
       XNTO=XNTV
       BEST1=XNVAL(1,KI)
       BEST2=XNVAL(2,KK)
       BEST3=XNVAL(3,KL)
       BEST4=XNVAL(4,KM)
       N1=KI
       N2=KK
       N3=KL
       N4=KM
   25 CONTINUE
```

```
  24 CONTINUE
  23 CONTINUE
  22 CONTINUE
     PRINT 30, YEAR
  30 FORMAT(●0●,///,10≐,●BEST COMBINATION OVER THE PERIOD OF●,1X,F
6•2,1
    •X,●YEARS●)
     PRINT 31, N1,N2,N3,N4
  31 FORMAT(●0●,//,5≐,●STAND 1 TREATMENT= ●,I4,/,5≐,●STAND 2 TREAT
MENT=
    + ●,I4,/,5≐,●STAND 3 TREATMENT= ●,I4,/,5X,●STAND 4 TRATMENT= ●
,I4)
     PRINT 32, BEST1, BEST2, BEST3, BEST4
  32 FORMAT(●0●,//,10≐,● BEST PNW OVER CYCLE●,/,5X,●1=●,F20•3,/,5≐
,●2=●
    +,F20•3,/,5≐,●3=●,F20•3,/,5≐,●4=●,F20•3)
     PRINT 55
  55 FORMAT(●0●,///,10≐,●NEW CONSTRAINTS? ●)
     READ●,CONS
     IF(CONS•EO•1•)GO TO 90
     PRINT 66
  66 FORMAT(●0●,///,10≐,●NEW VALUES  TO BE OPTMIZED? ●)
     READ●,≐NEW
     IF(≐NEW•EO•1•)GO TO 80
     END

READY 15•21•29
```

APPENDIX H

BEST STAND AREA DISTRIBUTION IN THE TAPAJOS NATIONAL FOREST

This appendix presents a maximization process of PNW (present net worth) by using the COMPLEX algorithm to search area distribution along with routine OPTIMUM (Appendix G) that looks for the best treatment combinations. The basic approach will be the utilization of areas generated by COMPLEX in the OPTIMUM routine (FUNC subroutine of COMPLEX in the present process), based on specified constraints.

The COMPLEX algorithm presented by Kuester, et al. (1973) is based on the "COMPLEX" method of Box (1965). An initial set of points is randomly scattered throughout the feasible region and it will tend to find a global optimum.

To find the best stand area distribution and best treatment for the stands, the following criteria were established:

$$\text{Max PNW} = \sum_{i} \sum_{j} N_{ij} X_i$$

Where

i = stand number

j = treatment alternative

N_{ij} = present net worth when stand i is managed according to j

X_i = number of hectares of stand i

SUBJECT to:

a) COMPLEX

- explicitly constrains (available area for each stand):

$$80{,}000 \text{ hectares} > X_i > 0.$$

- implicitly constrains (total area to be utilized):

$$\sum X_i = 170{,}000 \text{ hectares}$$

b) OPTIMUM (= Subroutine FUNC of COMPLEX)

- volume removed by year by hectare according to i and j

$$(\sum_i \sum_j V_{ij} X_i)/\text{AREA} < 7 \text{ m}^3/\text{ha/year}$$

$$(\sum_i \sum_j V_{ij} X_i)/\text{AREA} > 4 \text{ m}^3/\text{ha/year}$$

- residual basal area in m^2/hectare according to i and j

$$(\sum_i \sum_j Ba_{ij} X_i)/\text{AREA} > 24 \text{ M}^2/\text{ha}$$

- stand discounted residual value/hectare according to i and j

$$(\sum_i \sum_j RSV_{ij} X_i)/\text{AREA} > \text{CR\$ } 7{,}000.00/\text{ha}$$

AREA = total area to be utilized

The COMPLEX will generate areas according to specified constraints. Its subroutine FUNC (OPTIMUM routine from TAPAFOR approach) will establish the best treatment combination according to its constraints and it will generate a best PNW for that area. This process will be repeated many times; then, the best area distribution will be that which will provide maximum PNW in treatment combinations.

Best stand area distribution as determined by COMPLEX, which gave a 20 percent improvement in PNW over that computed in Chapter 6 was:

Stand 1 = 56,897.61 ha

Stand 2 = 32,382.51 ha

Stand 3 = 12,401.73 ha

Stand 4 = 68,318.14 ha

The best treatment combinations for these stands were:[1]

a) Including Treatment 20:

Stand 1 and Stand 3 = Treatment 18

Stand 2 and Stand 4 = Treatment 20

b) Not considering Treatment 20:

Stand 1 and Stand 4 = Treatment 18

Stand 2 and Stand 3 = Treatment 17

This approach will be a useful one when avaibility of land for each stand is presented (i.e., as constraints established above).

----

[1] Treatment definitions are presented in Chapter VI.

APPENDIX I

TAPAFOR OUTPUT SAMPLE

```
EXEC BEGUN.19.14.43.

              ------------- T A P A F O R -------------

*** *** *** *** *** ***  ORIGINAL STAND *** *** *** ***
-EXPORTABLE TREES-

 SEEDLINGS   =100

 15-24.9     =10

 25-34.9     =2

 35-44.9     =1

 45-54.9     =2

 55-64.9     =1

 65-74.9     =1

 75-84.9     =.7

 85-94.9     =.9

 95-104.9    =2

 105-114.9   =0

 115-124.9   =0

 125-134.9   =0

 135-144.9   =0

 145 AND +   =0
-LOCAL COMERCIAL TREES-

 SEEDLINGS   =1100

 15-24.9     =10

 25-34.9     =1

 35-44.9     =1

 45-54.9     =1

 55-64.9     =3

 65-74.9     =1

 75-84.9     =0

 85-94.9     =0

 95-104.9    =0

 105-114.9   =0
```

```
 115-124.9  =0

 125-134.9  =0

 135-144.9  =0

 145 AND +  =0
-NON COMERCIAL TREES-

 SEEDLINGS  =20

 15-24.9    =15

 25-34.9    =3

 35-44.9    =2

 45-54.9    =1

 55-64.9    =2

 65-74.9    =1

 75-84.9    =1

 85-94.9    =1

 95-104.9   =0

 105-114.9  =0

 115-124.9  =.6

 125-134.9  =.2

 135-144.9  =0

 145 AND +  =.1
*** *** *** *** *** *** *** *** *** *** *** *** *** ***

IS AREA PROBABILITY DESIRED?1

 TOTAL AREA=    10.303 HECTARES       NON-PRODUCTIVE FOREST=     1.959 HECTARE

 AREA BASED ON PROBABILITY=     8.344  HECTARES

-TREATMENT=3
-CUTTING INTENSITY=.8
-INTEREST RATE=.1
OPTION? =1

AVERAGE LOG INTENSITY=  42.02

  EXPORTABLE VOLUME REMOVED=     27.214CUBIC METER  AT YEAR  0.00

  LOCAL COMERCIAL VOLUME REMOVED=      6.325CUBIC METER  AT YEAR  0.00

DESIRED OUTPUT=2
*** *** *** *** *** *** *** *** *** *** *** *** *** ***
```

*** *** *** *** *** *** *** *** *** *** *** *** *** ***

RESIDUAL STAND AFTER YEAR 0.

PRESENT NET WORTH= 98843.181 CRUZEIROS P/HECTARE

RESIDUAL STAND PRESENT VALUE= 35567.464 CRUZEIROSP/HECTARE

TOTAL PRESENT VALUE= 134410.646 CRUZEIROS P/HECTARE

TOTAL TREES W/MINIMUM 15 CM DBH= 54.42 P/HECTARE

TOTAL COMERCIAL TREES W/MINIMUN 15 CM DBH= 27.52 P/HECTARE

TOTAL COMERCIAL TREES W/MINIMUN 45 CM DBH= 2.52 P/HECTARE

*** *** *** *** *** *** *** *** *** *** *** *** *** ***

NEW YEAR FOR OUTPUT=20
SILVICULTURE DESIRED?0
LOG DESIRED?0
DESIRED OUTPUT=1

*** *** *** *** *** *** *** *** *** *** *** *** *** ***

RESIDUAL STAND AFTER YEAR 20.

TOTAL BASAL AREA BEFORE GROWTH= 21.328 SQUARE METER P/HECTARE

TOTAL BASAL AREA AFTER GROWTH= 22.582 SQUARE METER P/HECTARE

TOTAL MORTALITY= 2664.768 P/HECTARE

PRESENT NET WORTH= 93767.140 CRUZEIROS P/HECTARE

ACCUMULATE REMOVED VOLUME= 33.539 CUBIC METER P/HECTARE

RESIDUAL STAND PRESENT VALUE= 47544.528 CRUZEIROSP/HECTARE

TOTAL PRESENT VALUE= 141311.668 CRUZEIROS P/HECTARE

DBH CLASS	TREATMENT					
	EXPORTABLE	LOC.COM.	NON-COM.	LINE PL.	ENRI.PL.	CLOSE-PL.
SEEDLINGS	1219.77	1333.52	1084.09	.00	0.00	0.00
15-24.9	7.95	20.46	15.29	.00	0.00	0.00
25-34.9	5.48	21.77	11.97	1.51	0.00	0.00
35-44.9	7.28	47.66	4.27	15.73	0.00	0.00
45-54.9	3.71	4.99	1.84	4.96	0.00	0.00
55-64.9	1.24	1.08	1.29	.01	0.00	0.00
65-74.9	.42	1.14	1.61	.00	0.00	0.00
75-84.9	.01	1.27	1.00	.00	0.00	0.00
85-94.9	.00	.14	.97	0.00	0.00	0.00
95-104.9	.00	.00	.56	0.00	0.00	0.00
105-114.9	0.00	.00	.00	0.00	0.00	0.00
115-124.9	0.00	0.00	.24	0.00	0.00	0.00
125-134.9	0.00	0.00	.41	0.00	0.00	0.00
135-144.9	0.00	0.00	.11	0.00	0.00	0.00
145 AND +	0.00	0.00	.04	0.00	0.00	0.00

*** *** *** *** *** *** *** *** *** *** *** *** *** ***

```
*** *** *** *** *** *** *** *** *** *** *** *** *** ***
NEW YEAR FOR OUTPUT=35
SILVICULTURE DESIRED?0
LOG DESIRED?1
CLEARCUT?0
CUTTING INTENSITY=1.


AVERAGE LOG INTENSITY=  70.82

  EXPORTABLE VOLUME REMOVED=    101.450CUBIC METER  AT YEAR 35.00

  LOCAL COMERCIAL VOLUME REMOVED=    156.194CUBIC METER  AT YEAR 35.00

DESIRED OUTPUT=2
*** *** *** *** *** *** *** *** *** *** *** *** *** ***

  RESIDUAL STAND AFTER YEAR 35.

  PRESENT NET WORTH=      114407.719 CRUZEIROS P/HECTARE

  RESIDUAL STAND PRESENT VALUE=        3836.531 CRUZEIROSP/HECTARE

  TOTAL PRESENT VALUE=      118244.251 CRUZEIROS P/HECTARE

  TOTAL TREES W/MINIMUM 15 CM DBH=     129.49  P/HECTARE

  TOTAL COMERCIAL TREES W/MINIMUN 15 CM DBH=      74.14  P/HECTARE

  TOTAL COMERCIAL TREES W/MINIMUN 45 CM DBH=        .00  P/HECTARE
*** *** *** *** *** *** *** *** *** *** *** *** *** ***
NEW YEAR FOR OUTPUT=40
SILVICULTURE DESIRED?0
LOG DESIRED?2
      END  TAPAFOR
     026700   FINAL EXECUTION FL.
       .731 CP SECONDS EXECUTION TIME.

READY 19.19.28
```

VITA

VITA

JORGE PALADINO CORREA de LIMA

Ph.D. Dissertation: A Proposed Management Model for Brazil's Tapajos National Forest

Final Examination: July 21, 1981

Biographical Items:

Born: November 03, 1949, Rio de Janeiro, RJ, Brazil

Undergraduate Studies:

University Rural of Rio de Janeiro, 1969-1972; B.S. 1972 - Forest Engineer

Graduate Studies:

University Federal of Rio de Janeiro- 1974-1975; specialization in engineering economics, 1975.
University of Brasilia, 1976; specialization in statistics and probability, 1976.
Michigan State University - Department of Forestry, 1977-1981; M.S., June, 1979; Ph.D., Sep., 1981.

Experience: Aero-photo interpretation, Bahia State Government, Brazil, 1973.
Biometrician, Project PNUD/FAO/IBDF/BRA-45, 1974-1976. RIO, MG, SP, Mato Grosso.
Head of statistics team for planning, COPLAN-IBDF, 1977. Brasilia.

Member: Sigma Xi
Xi Sigma Pi
Society of American Foresters
Conselho Regional de Engenharia e Arquitetura, RJ, Brazil.