Working Paper

Data and Models Used for French Forests in the Context of the IIASA Forest Study

Francois Houllier

WP-92-40
June 1992

IIASA
International Institute for Applied Systems Analysis ☐ A-2361 Laxenburg Austria
Telephone: +43 2236 715210 ☐ Telex: 079137 iiasa a ☐ Telefax: +43 2236 71313

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Foreword

The IIASA Forest Study has the objective to;

- gain an objective view of potential future developments of the European forest resources, and
- build a number of alternative and consistent scenarios about potential future developments and their effects on the forest sector, international trade and society in general.

The basic approach was to assemble detailed country-by-country databases of European forest resources, and link them to a matrix-type simulation model. As a result of different forest structures among European countries, we employed three different model concepts, namely; the Area-Based Approach, the Diameter Distribution Approach and the Simplified Approach.

The diameter distribution models are briefly described in the literature. Therefore, we feel it is important to publish the model concept on diameter distributions employed by the Forest Study. The concept has been developed by Dr. Francois Houllier through his work at IIASA.

Abstract

The paper describes the basic data collected by the French National Inventory Service and how this data has been aggregated to match the models employed by the IIASA Forest Study. A major part of the paper discusses model approaches which are suitable for the available French data and model concepts suitable for even-aged and uneven-aged forests.

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Data and Models Used for French Forests in the Context of the IIASA Forest Study

Francois Houllier

1. Introduction

This paper reports about the contribution of the French National Forest Inventory Service (NFIS) to the IIASA's Forest Study. This contribution began in 1986 and was carried out in three successive phases:

I. The first phase took place in France and consisted:

- I:1 In analyzing IIASA's request for aggregated data about French forest resources;
- I:2 And in generating the required data by using the database managed by NFIS Computer Center in Nancy.

II. The second phase took place at IIASA during a one-month-stage in Laxenburg with two main aspects:

- II:1 Further data processing was carried out in order to elaborate aggregated statistics for whole France and large subregions;
- II:2 Two dynamic models were conceived and implemented in order to simulate the global evolution of forest resources. The first model was dedicated to regular (even-aged) stands and the second to irregular (uneven-aged) stands.

III. The third phase took place in Sweden, at IIASA and in France. It consisted:

- III:1 In defining global management schedules compatible with the structure of the two dynamic models;
- III:2 In running these models to get simulations for the future wood resources and wood available cuts;
- III:3 And in checking the consistency of the results of these simulations.

This paper is composed of three sections. The first is dealing with point (I:2): it describes the data which were provided to IIASA, their origin and their meaning. The second part is concerning the point (II:1): it explains how the data were processed to get global estimates of French wood resources. The third section is dealing with point (II:2): it describes the structure of the two dynamic models.

This report does not provide any information about the third phase which should be described by the appropriate IIASA publications (it does not contain any result about the future French resources). The main aim of this paper is *to provide an explicit description of the data and methods* which were used for French forests in the context of the Forest Study, so that *anyone can appreciate the strengths, the limits and the weaknesses of the ensuing results.*

2. Description of the Data Provided by NFIS to IIASA

The data provided by NFIS to IIASA for its Forest Study are described in this section. These data were designed and processed by NFIS in order to meet the requirements developed in the context of this study (high level of aggregation, for example).

However, the structure of the data had to be modified (in Laxenburg) so that it could best fit with the general frame of the study. These modifications are described in the third section.

2.1 General information about the data

2.1.1 About French forests

Some important aspects of the data provided by NFIS are due to some characteristics of the French forests.

o Types of forests and wood resource

As in most countries, the utilization of forests in France are multiple and may be classified according to three main types: wood and biomass production, environmental uses and social uses (ie. recreation, landscape, etc.).

These uses are not necessarily exclusive (at least in most situations); however, they determine three forest types.

- The *production forests* whose aim is mainly the wood production. Small forest areas (which are often owned by farmers) have a great extent in some parts of France and they are usually aggregated with the production forests.

- The *protection forests* which are mainly located in the mountains.

- The *recreational forests* (parks and gardens may, for example, contain some forest areas).

In fact, all forest areas, except those which are exclusively dedicated to environmental or social uses and those that cannot be exploited, are considered as production forests by NFIS (but the level of their wood production and the intensity of their management may differ according to the relative weight of their different uses and functions).

Since the Forest Study is dealing with the sole wood resources and their possible decline due to forest damages, *the data provided to IIASA concern the sole production forests* (which represent the largest part of French forests). This does not mean that protection or recreational forests do not provide valuable resources, nor that these resources cannot be affected by damages and decline. It only means that these forest types have to be studied in another context and with other data and methods.

Although they are surveyed by NFIS, two other important types of wood resources were neglected in this study:

- the *poplar plantations*, which have a relatively small extent but a rather high productivity;
- the *hedges* and *tree alignments*: in some departments (especially in the western part of France) they may contain as much wood resource as the production forests themselves.

These resources were neglected because their dynamics (both natural growth and management patterns) are quite different from the dynamics of the production forests: poplar rotation varies from 12 to 25 years and poplar management is nearer to agriculture than to traditional silviculture; hedges are by no means forests stands and their "management" is heavily related to agriculture.

o Ownership

There are three main types of ownership in France:

- *state forests* which cover about 11% of the total area of production forests;
- *other public forests* (generally owned by local administrations and especially by municipalities) which represent about 16% of the total area of production forests;
- and *private forests* which represent the largest part of the forest area (73%). It should be noted that the average extent of private forest per owner is quite small (about 4 ha) and that the proportion of forest owned by industries is very low.

Of course, these proportions vary according to the different regions. They are also more or less correlated with the forest stand types (for example, most of the coppices are located in private forests, some are in communal forests, but only very few are in state forests).

The quality and intensity of management and silviculture is highly variable in private forests, ranging from very intensive silvicultural treatments (including fertilization and pruning, for example) to a total lack of management.

The management of the public forests is carried out by the same organization (Office National des Forêts) and is, therefore, more homogeneous, although the objectives for communal forests may differ from those for state forests.

o Forest stand types

An important feature of French forests is that a quite large area is covered by irregular stands which may be:

- either uneven-aged high forests, especially frequent with coniferous species in mountain ranges (6% of the area of production forests),
- or coppice-with-standards (33% of the area).

In these stands, the concept of stand age is meaningless for at least two reasons:

- their treatment is (or used to be) deliberately oriented towards irregular structures (although there have been some recent efforts to convert coppice-with-standards to regular high forests);
- it is impossible to define and to measure any stand age since the trees may have very different ages within such stands (in coppice-with-standards, it is only possible to measure the age of the coppice and to estimate the age of the oldest standards).

The consequence of this situation is that it was by no means possible to provide age classes for these stands. Therefore, another option had to be proposed for both the structure of the (static) data (see 2.2, 2.3 and 3.3.2) and the modelling of their dynamics (see 3.4.3).

Another important feature of French forests is the great diversity of tree species (compared to Scandinavian countries, for example), which is mainly due to the wide variability of the ecological conditions. Quite a large proportion of the stands are hence, more or less, *mixed stands*.

It seemed therefore necessary to distinguish the volume and the increment of the predominant species from the volume and the increment of the other species (see 2.2 and 2.3).

These aspects (the relatively high number of species, the existence of irregular stands) are not specific to French forests and they may be encountered in several other European countries (Switzerland and Italy, for example). Although they explain why the frame initially planned by IIASA on a more or less "nordic basis" could not be fully applied to France.

2.1.2 About the National Forest Inventory Service

The aim of this section is to point out some important features of the NFIS methods and data in the context of the "Forest Case Study" [for a more detailed presentation, see IFN (1985)].

o General overview

The national survey of French forests and wood resources is carried out by a specialized service (the NFIS), which belongs to the Ministry of Agriculture. The NFIS is not at all involved in forest management.

The inventory is carried out using a theoretical *10-years cycle*. Each year, one-tenth of the country is surveyed, the basic inventory unit being the department (this is an administrative unit and France contains 96 metropolitan departments, meaning that 9 to 10 departments are surveyed each year).

In February 1987 (when the data were sent to IIASA), the entire country had been surveyed at least once (the oldest department was 14 years "old"), about 50 departments had been inventoried twice, and some were going to be surveyed for the third time during that year.

As a consequence of that organization, no national statistics can be produced for a fixed reference year. This is generally not a big problem (since forest changes are quite slow in most cases when compared to the 10-years cycle), except for:

- the forests submitted to strong and rapid fluctuations (this may be the case of the poplar plantations which are outside the scope of this study);
- some peculiar events like storms (for example, some departments that were heavily affected by a storm in November 1982 had been surveyed some years before, while the others were surveyed just after). The aggregation of data or results concerning different departments may, therefore, be hazardous in some cases.

o Sampling design

The NFIS sampling design is schematically a two-phase stratified one:

- The first phase consists in the *interpretation of aerial photographs* (it provides area estimates and allows further stratification);
- The second phase corresponds to the *field verification* of the first phase and to the *field sampling operations* (stand and plot description, tree measurements) according to a random stratified multi-stage sampling design.

This general framework has been applied for all the departments, since the beginning of the national inventory in the late 50s and early 60s. But some aspects have been modified according to successive methodological improvements.

NFIS basic data concern some 150 000 field plots and about 1.5 million measured trees for a whole survey cycle in France. After field work and control, all the data are centralized by the Computer Center (in Nancy). They are structured as a database, which then allows various types of sorting and other data processing treatments similar to IIASA's database.

o Growth and change data

Until now, NFIS has not been using permanent plots (except for some preliminary test studies). But, for several years about half of the plots have been marked so that it will be possible to remeasure them in the future. (The first remeasurements began in 1987 in one department.)

Consequences of that situation are that growth, mortality and harvesting data have to be assessed:

- by *measuring the past increment of the living trees* (5-years core increments for the diameter at breast height, 5-years increments estimated from the ground for the total tree height);

- by *recording the dead trees* (which died during the 5-years period preceding the field inventory) and by measuring their diameter at breast height (or at the stump level);

- by *recording the stumps* (of the trees that were harvested during the 5-years period preceding the field inventory) and by measuring their girth.

These measurements have some drawbacks:

- Short period growth measurements are, of course, subject to climatic variations (there have been some heavy droughts in France during the last decade) and the volume increments should, therefore, be used cautiously;

- Height increment cannot be well estimated in some cases (mainly with broadleaves and dense or old conifers). In that case, it is often considered as a missing measurement and it generally leads to an underestimation of the true volume increment;

- The estimates of thinning and clearcut volume are quite poor (some stumps may have disappeared, their age is not fairly well evaluated, the growth measurements are not very accurate,...).

Since the procedure used to estimate the (past) cut volume and area changed in the last years, it is not possible to generate consistent figures at the regional and national levels.

o About volume classes

Another major feature (common to many countries) is that the field inventory plots are quite small (from 0.01 to 0.07 ha according to the diameter of the trees), so that each plot cannot be considered as fully representative of a true stand or even of a "piece of stand" (see section 4).

A consequence of that fact is that it may be meaningless to define volume classes, to aggregate the plots according to these classes, and to simulate the management of these classes as though they were stand volume classes. The situation would be slightly (but still not totally) different if permanent plots were available to build up the dynamic model (see section 4).

2.2 Logical organization of the data

This paragraph deals with the logical structure and the meaning of the data provided to IIASA. (It must be noticed that these "data" are not the basic raw NFIS data, but that they are actually highly aggregated results.)

o Basic structure of the data

The data were basically structured according to the following criteria:

- The (administrative) *region*: this unit was chosen (1) because it is much larger than the department unit (there are 22 regions in France), (2) because it provides a rough division in geographically and climatically homogeneous zones, (3) and because it is consistent with the aggregated approach of IIASA's Forest Study. However, as earlier mentioned, the rough summation of the results of different departments belonging to the same region may be seen as some unrealistic operation in come cases (see 2.1.2).

- The kind of *ownership* with 3 possibilities: state forests, communal (other public) forests and private forests.

- The *forest structure* (appreciated around each field inventory plot) with 5 possibilities:

    - regular high forests,
    - irregular (uneven-aged) high forests,
    - coppice with broadleaf standards,
    - coppice with coniferous standards,
    - (simple) coppices (supposed to be regular).

- The *predominant species* (appreciated around each field inventory plot) with 9 different groups of species (4 for broadleaf species and 5 for conifers, see 2.3.3).

The different combinations of these criteria determined the *basic forest stand types* which were used in this study. This lead to a fairly large amount of basic types that had to be further aggregated (see 3.2).

o Distinction between regular and irregular stands

Since it was impossible (for both the theoretical and practical reasons mentioned in 2.1.2 to provide an age-class distribution for each stand type), two different situations were distinguished:

- *The case of regular stands*, which may be either true even-aged stands or regular approximatively even-aged stands and which concerned the two following forest structures: regular high forest and (simple) coppice. These stands were described according to a stand-age classification (the age is always the age of the predominant species; see 2.3.1).

- *The case of irregular stands* (which are always uneven-aged stands) which concerned coppice-with-standards and irregular high forests. These stands were described according to a *tree-diameter classification* (see 2.3.2).

o Area, volume and volume increment data

The first purpose of the data was to provide information about the forest *area* of each basic forest stand type:

- for regular stands, area was computed according to the stand-age classification,

- for irregular stands, it did not make sense to attribute any area to the various tree-diameter classes, so that the area was provided globally for each basic stand type.

This information was completed by the *number of sampled field plots*. This number gives a qualitative idea of the reliability of the information (area, volume, increment) associated to each basic stand type (or to each age class within regular stand types).

The second purpose was to provide information about the standing volume and the volume increment. These data were structured according to the following scheme:

- Variables were:
    - the mean *standing volume* per ha,
    - the mean *sawtimber volume* per ha,
    - the mean *current volume increment* per ha (see 2.3.3 for the exact definition).

- Species subclassification was done by distinguishing:
    - the *predominant species*
    - the *other broadleaf species*,
    - the *other conifers*.

For the irregular stands, these data were completed by the *numbers of living and dead trees* in each diameter class and for each of the three groups of species defined above.

2.3 Physical organization of the data

The data provided to IIASA were stored in two files on a magnetic tape. The first file, called **PARAB**, contained two kinds of information: (1) the global data concerning every basic forest stand type and (2) the detailed data (based on the stand-age classification) for the sole regular stand types.

The second file, called **PCRAB**, contained the detailed data (based on the tree-diameter classification) which concerned the irregular stands.

Listings were also provided. The information contained in these listings differed slightly from the data of the files:

- For the regular stands, the PARAB file contained the mean volume per ha and the mean current increment per year and per ha while the listing contained the total volume (in m^3) and the total increment (in $m^3 \cdot yr^{-1}$);
- The PARAB and PCRAB files contained only the basic information for each basic forest stand type, while the listings also contained some intermediate summaries of all (either stand-age or tree-diameter) classes at some different levels determined by the successive aggregation of the criteria mentioned in section 2.2.

2.3.1 The file PARAB

This file contained:

- all the information relative to forest area,
- all the information relative to volume and increment in each age class for the regular stand types,
- the global figures relative to volume and increment for the irregular stand types.

The recorded length was 72. There were 4810 records sorted according to the following criteria:

- region,
- ownership,
- structure,
- species,
- age class.

One record represented one age class in a basic type of stand. When an age class of a basic type did not include any field plot, it was omitted in the file.

Item	Unit	Columns
'B' value	none	1
Administrative region	none	2-3
Forest structure	none	5
Predominant species	none	6
Age class	none	7-8
Area	ha	9-16
Number of plots	number	17-21
Standing volume of predominant species	m^3/ha/100	22-27
Sawtimber volume	m^3/ha/100	28-33
Volume increment	m^3/ha/yr/100	34-38
Standing volume of other broadleaf species	m^3/ha/100	39-44
Sawtimber volume	m^3/ha/100	45-50
Volume increment	m^3/ha/yr/100	51-55
Standing volume of other coniferous species	m^3/ha/100	56-61
Sawtimber volume	m^3/ha/100	62-67
Volume increment	m^3/ha/yr/100	68-72

2.3.2 The file PCRAB

This file contained the data for the sole irregular stands. These data were structured according to tree diameter classes.

The record length was 140. There were 6207 records sorted according to the following criteria:

- region,
- ownership,
- structure,
- species,
- diameter class.

One record represented one diameter class in a basic stand type. When a diameter class of a basic stand type did not include any tree, it was omitted in the file.

Item	Unit	Columns
'A' value	none	1
Administrative region	none	2-3
Ownership	none	4
Forest structure	none	5
Predominant species	none	6
Diameter class (center of the class)	cm	7-8
Number of living trees of predominant species	number	9-18
Number of dead trees	number	19-27
Standing volume of predominant species	m^3	28-36
Sawtimber volume	m^3	36-45
Volume increment	m^3/yr	46-52
Number of living trees of other broadleaf species	number	53-62
Number of dead trees	number	63-71
Standing volume of other broadleaf species	m^3	72-80
Sawtimber volume	m^3	81-89
Volume increment	m^3/yr	90-96
Number of living trees of other coniferous sp.	number	97-106
Number of dead trees	number	107-115
Standing volume of other coniferous species	m^3	116-124
Sawtimber volume	m^3	124-133
Volume increment	m^3/yr	134-140

2.3.3 Signification of the codes

o (Administrative) regions

The codes of the 22 metropolitan regions were provided on a separate listing.

Ownership

A = (1) = state forests
B = (2) = other public forests (mainly communal forests)
C = (3) = private forests

Forest structure

1 = regular high forests
2 = irregular (uneven-aged) high forests
3 = coppice with broadleaf standards
4 = coppice with coniferous standards

Predominant species

A = (1) = oak (Q. pendunculata and Q. sessiliflora)
B = (2) = beech
C = (3) = sweet chestnut
D = (4) = other broadleaf species
E = (5) = maritime pine
F = (6) = other pines (especially important is scots pine)
G = (7) = norway spruce and white fir
H = (8) = douglas fir
I = (9) = other coniferous species.

Age classes

Age always refers to the age of the predominant species.

There are three age classifications. This fact is due both to:

- the difficulty of age measurements in some stands;

- the fact that regular high forest is not always composed of strictly speaking even-aged stands (this is especially true for naturally regenerated stands).

These three classifications are:

- *lack of age measurement*: it is seldom (some hundred of hectares) and is generally due to omitted measurements.

- *true measured ages* in true even-aged stands: a basic 20-years step was chosen (except for older stands).

- *estimated ages* (in true and approximatively even-aged stands): the width of classes is much more irregular in that case.

Generally, age of conifers is measured (and rarely estimated). The situation is quite different for the broadleaves.

1 = no age (either uneven-aged stands or even-aged stands with no measurement of age; this last case is rare).

Measured ages

2 = from 0 to 19 years
3 = from 20 to 39 years
4 = from 40 to 59 years
5 = from 60 to 79 years
6 = from 80 to 99 years
7 = from 100 to 119 years
8 = from 120 to 139 years
9 = from 140 to 159 years
10 = from 160 to 179 years
11 = from 180 to 199 years
12 = from 200 to 239 years

Estimated ages

13 = from 0 to 29 years
14 = from 30 to 59 years
15 = from 60 to 99 years
16 = from 100 to 159 years
17 = from 160 to 239 years
18 = over 240 years

Diameter classes

Diameter is diameter at breast height; it is rounded to the nearest centimeter.

10 = from 8 to 12 cm
15 = from 13 to 17 cm
20 = from 18 to 22 cm
25 = from 23 to 27 cm
30 = from 28 to 32 cm
35 = from 33 to 37 cm
40 = from 38 to 42 cm
45 = from 43 to 47 cm
50 = from 48 to 52 cm
55 = from 53 to 57 cm
60 = over 58 cm

Area

Area does not include the area of the temporarily bare land forest areas (which have been recently clearcut and not yet regenerated).

o Standing volume

NFIS data are dealing with the overbark volume of the sole stem (excluding branches, even if they are large) from the stump to an upper limit, which is defined either by the point where the stem diameter equals 7 cm (over bark) or by the point where the stem "vanishes" in branches.

o Sawtimber volume

This volume is not really measured by NFIS field teams. They estimate it for each sampled tree as a percentage of its total volume.

o Volume increment

Volume increment is estimated by using the 5 years diameter and height increments measured in the field. It is therefore subject to climatic variations. Since the height increment has not always been measured for broadleaf and old conifers, volume estimates may be an underestimation of the true volume increment (bias may reach 30%, but it is likely to be smaller in the average: around 10%).

Volume increment provided by NFIS to IIASA is the total increment of the trees living at the date of the survey:

- in the PARAB file, it includes the increment of the trees which died or were thinned during the last 5 years (just before the survey);

- in the PCRAB file, it does not include the increment of the trees which died or were thinned during the last 5 years.

The data do not include any information about recruitment (trees which reached the minimum diameter of 7.5 cm in the last five years).

Consequently, it is difficult to build a yield model by using these sole data (see section 3).

DATA PROCESSING:

3. From the Basic NFIS Files to the IIASA Database

Since the basic data did not fit exactly to the general frame defined by IIASA, they had to be processed further before being utilized in any kind of dynamic model. This was done with three different objectives:

- in order to put the data in such a form that they could be imported into a PC for *a better presentation of the French wood resources* in 1987 (static point of view);

- in order to further aggregate the data, with the aim of *defining large domains* (or global forest stand types) associated to different dynamic models or to different management schedules;

- and in order to put the data in such a form that they could be *introduced in the dynamic models.*

This section is therefore dealing with these intermediate data processing steps[1] (intermediate between the basic data described in section 1 and the dynamic modelling approach which is presented in section 4).

3.1 Presentation of the 1987 forest resource

This presentation was done at two main levels of aggregation: the regional level and the national level.

3.1.1 Regional level

A Fortran program called "resume.f" was written in order:

- to aggregate the different age classes for each basic type of stand in the selected region,

- and to provide area, mean standing volume, ...information (see below).

The input file was a subfile of PARAB (previously extracted by using some standard software). This subfile contained the sole data related to the selected region.

The output file was named by the user and had the following structure:

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[1] It must be stressed that all the programs that were developed at IIASA were written during a very short period in order to fulfill immediate objectives and should not be considered as final products, but as temporary tools adapted to specific objectives.

Item	Unit	Columns
Administative region	none	1-2
Ownership	none	3-4
Forest structure	none	5-6
Predominant species	none	7-8
Area	ha	9-17
Number of plots	number	18-23
Standing volume of predominant species	m^3/ha	24-30
Sawtimber volume	m^3/ha	31-37
Volume increment	m^3/ha/yr	38-43
Standing volume of other broadleaf sp.	m^3/ha	44-50
Sawtimber volume	m^3/ha	51-57
Volume increment	m^3/ha/yr	58-63
Standing volume of other coniferous sp.	m^3/ha	64-70
Sawtimber vollume	m^3/ha	71-77
Volume increment	m^3/ha/yr	78-83

The codes were those given in section 1.3.1, except that alphanumeric codes for ownership and species were replaced by numeric ones.

The regional output files were called SUMMARY.xx where "xx" denoted the code of there region.

These files were then sent to the PC (using Kermit) and imported under Lotus-123 to better present the results.

3.1.2 National level

A Fortran program called "resumf.f" was written in order:

- to aggregate the different age classes for each basic type of stand in France,
- and to provide area, mean standing volume, ...(see below).

Input file was PARAB.

Output files were:

- SUMMARY.FRANCE with the same structure as the one described in previous paragraph for regions (the sole change was that code of region was replaced by "00");

- SUMMAR2.FRANCE with the following structure:

Item	Unit	Columns
"00"	none	1-2
Ownership	none	3-4
Forest structure	none	5-6
Predominant species	none	7-8
Area	ha	9-17
Number of plots	number	18-23
Standing volume (all species)	m^3/ha	24-30
Sawtimber volume	m^3/ha	31-37
Volume increment	m^3/ha/yr	38-43

The codes were those given in section 1.3.1, except that alphanumeric codes for ownership and species were replaced by numeric ones.

The SUMMAR2.FRANCE file was then sent from VAX mainframe to the PC (using Kermit) and imported under Lotus-123 for better presentation of the results.

3.1.3 Comments

Since volumes, increments and areas referred to the same basic types of stands, the figures are consistent (area may be multiplied by mean volume per ha to get total volume in a basic type of stand).

- This would not have been the case if the area of predominant species had been computed apart from the total volume of the same group of species.

- This also means that it was impossible (by using these data) to know the total volume of a group of species at the regional or national level (one could only know the total volume of a group of species where it was predominant; in other stands these species were aggregated with either "other broadleaves" or "other conifers").

The number of field plots was maintained in these summaries as a qualitative indication of the reliability of the data for each basic type of stand (area, volume and increment figures based on only few plots had no strong statistical basis).

The absolute and relative distribution of species, structures and ownerships varied greatly from one region to another (chestnut is concentrated in southern regions, while maritime pine is the main species of Aquitaine region; communal forests are rare in the region around Paris, etc...).

These figures are, of course, interesting by themselves but:

- they mask some important features. For example, the mean increment of Douglas fir may seem to be quite poor compared to the one of maritime pine; but it must be recalled that large scale plantation of Douglas fir is quite recent and that stands are generally very young (which is not the case for maritime pine).

- they cannot be used (or only for a very rough approach), to assess directly the dynamic evolution of the forest stands.

3.2 Further aggregation of the data

3.2.1 Purpose

Forest dynamic models, like all models, are based upon some idealized view of the forest. This idealization is generally deduced by assumptions or hypotheses. Some of those are well known (independence of trees or of stands in Markov chain models, or silvicultural scenarios, for example). But one basic assumption (may be the most important) of the modeller is often omitted: it is the choice of the domain to be studied.

A domain may be viewed as some formal aggregate of stands and/or of trees. For the "Forestry Case Study" the domains were composed of one to several basic types of stands (see section 1) and were, therefore, also called (aggregated) types of stand.

Defining "good" domains is actually the first step in modeling forest dynamics. This step is crucial since it may have a deep influence:

- on the kind of model to be used (is the domain composed of regular high forest or of coppice with standard stands ?);

- on the value of the estimated parameters (or coefficients) of the model (growth figures of chestnut coppices are generally much higher than those of other coppices);

- on the simulated management (aggregation of young Douglas fir with old white fir stands may give the illusion that age classes are well distributed).

It must be noticed that NFIS data provided to IIASA did not include any information neither on site (and fertility), nor on altitude, although these two factors may sharply influence the growth and the management of the stands.

On the other side, it must be stated that the basic structure of these data lead to a maximum theoretical number of 22*3*(3*9+4)=2178 basic domains (a figure which was not compatible with the aggregated approach used by the IIASA Forest Study, so that it was necessary to perform some further aggregation of these domains.

3.2.2 The procedure used for aggregation

Criteria for carrying out the complementary aggregation of the data were:

- the homogeneity of the domain (on both static and dynamic points of view): it was empirically appreciated according to the general knowledge of French forests and to the rough results included in the summaries (see 3.1).
- the economical importance of the domain: for example, coppices were highly aggregated, although they cover a quite large area in France. On the contrary, more attention was paid to regular high forest whose products have a higher value and whose management is more intensive.
- the area of the domain: domains with an area less than 100 000 ha were avoided, when it was possible;
- the statistical reliability of the data was qualitatively appreciated by using the number of plots, which is actually highly correlated with the area (one plot represents a rough average of 100 hectares).

Some further general guidelines were used to perform this aggregation:

- concerning predominant species: broadleaves were always distinguished from conifers (it must be recalled that a stand with predominant white fir may contain some beech, for example).
- concerning structure: the four basic structures were always distinguished (coppice, regular high forest, irregular high forest, coppice with standards).
- concerning ownership: this criterion was neglected for coppice and uneven-aged high forest. For other structures, the main distinction was between public and private forest with an occasional further distinction between state and other public forests.
- concerning regions: a first aggregation, based on geographical proximity and rough similarity of forests, leads to 9 groups of regions, namely:

. north-west	11, 22, 23, 25, 31
. north-center	21, 26
. north-east	41, 42, 43
. center-west	24, 52, 53, 54
. Aquitaine	72
. Midi-Pyrenees	73
. south-east	91, 92, 93
. Rhone-Alpes	82
. center	74, 83

Finally a program called 'resumg.f' was used to provide a summary (same type as SUMMAR2.FRANCE) for any selected group of regions. The summaries of the nine groups of regions were inspected and lead to some further aggregation.

3.2.3 "Results": the domains

It must be stressed that the domains finally obtained are by no means "the best" and that their definition is highly empirical. These domains could, therefore, be modified for other types of study where necessary.

STRUCTURE	SPECIES	OWNER	REGIONS
1	5	private	Aquitaine
1	5	private	all except Aquitaine
1	5	public	all
1	8	all	all
1	9	all	all
1	7	all	north-east
1	7	all	center
1	7	all	Rhone-Alpes
1	7	all	North-west, north-center
1	7	all	center-west, Aquitaine
1	7	all	Midi-P... and south-east
1	6	all	north-east
1	6	all	center
1	6	all	Rhone-Alpes
1	6	all	north-west, north-center
1	6	all	center-west, Aquitaine
1	6	all	Midi-P... and south-east
1	1	public	north-east, center-north
1	1	public	north-west, center-west, Aquitaine, Midi-P..., center
1	1	private	north-east, center-north
1	1	private	north-west, center-west, Aquitaine, Midi-P..., center
1	2	public	north-east, center-north
1	2	public	north-west, center-west
1	2	public	Aquitaine, Midi-P..., center
1	2	private	north-east, center-north
1	2	private	north-west, center-west
1	2	private	Aquitaine, Midi-P..., center
1	1,2	all	south-east
1	1,2	all	Rhone-Alpes
1	3,4	public	all
1	3,4	private	all

2	1	all	all
2	2,3,4	all	all
2	7	all	all
2	5,6,8,9	all	all
3	1	state	all
3	1	other public	all
3	1	private	north-west, center-west
3	1	private	north-center, north-east
3	1	private	Aquitaine
3	1	private	Midi-Pyrenees
3	1	private	center
3	1	private	Rhone-Alpes, south-east
3	2	public	all
3	2	private	all
3	3,4	public	all
3	3,4	private	all
3	5	all	all
3	6	all	south-east
3	6	all	all except south-east
3	7,8,9	all	all
4	1	all	all
4	2	all	all
4	3	all	all
4	4,(5,6,7,8,9)	all	all

3.3 Data for dynamic models

Since at least two types of models are necessary to simulate the evolution of French forest resource supply (one for the even-aged stands and one for the uneven-aged stands), two basic types of data were defined.

These data were then used in modelling for two different purposes (see 3.3.1 and 3.3.2):

- for estimating the parameters of the models,

- and as input for the simulations (initial state of forest resource).

3.3.1 Data for regular stands

Two Fortran programs called "evenal.f" and "tabage.f" were written to generate a full age table which could be used by the model developed by IIASA (see Attebring et al, 1989).

3.3.1.1 Program "evenal.f"

The aim of "evenal.f" was:

- to retrieve in PARAB the data relative to a specified domain;
- to aggregate these data according to the 3 basic age classifications (see section 2).
- to generate the age classes which are empty and to fill them with zeros.

Input file is either PARAB.S1 or PARAB.S4 which are subfiles from PARAB (extracted by using "egrep" Vax-Unix command). They contain respectively the sole regular high forest and coppice stands.

The user is asked to define the domain under study by giving the selected regions, owners, structures and species.

Output file is an age table with the following structure:

Item	**Unit**	**Columns**
Lower bound of age class	yr	1-4
Upper bound of age class	yr	5-8
Medium age of age class	yr	9-12
Area	ha	13-21
Number of plots	number	23-28
Standing volume (all species)	m3/ha	29-35
Sawtimber volume	m3/ha	36-42
Volume increment	m3/ha/yr	43-48

Each record corresponds to an age class. There are 18 age classes ordered as in section 2.3.3. Four final records are used to recall the selection of the user (regions, structure, ownership and species).

3.3.1.2 The program "tabage.f"

The aim of program 'tabage.f' was:

- to generate a complete age table based on a sole age classification (remember that NFIS data contain 3 types of age classes);
- to complete this age table with information about bare land waiting for regeneration (forest areas which have been recently clearcut and not yet regenerated or planted);
- to complete this age table with recruitment figures.

Final (output) age classes are essentially similar to the measured age classes with two differences:

- a "bare land class" with age 0 is added to account for areas waiting for regeneration,
- the last class of estimated ages is added (over 240 years).

There are therefore 13 final (or output) age classes:

- bare land,
- 0- 19 yrs,
- 20- 39 yrs,
- ...
- 180-199 yrs,
- 200-239 yrs,
- 240 yrs and over.

The weakest point of this program is the procedure adopted for mixing the input age classifications issuing from PARAB and 'evenal.f':

- input measured age classes are simply attributed to the correspondent output classes, since their definition is similar;
- input estimated age classes (and also the class with omitted age) are distributed according to their relative overlay with the output classes. For example, the area, volume and increment of estimated age class (0-29 years) are divided in:
  . 2/3 for final age class (0-19),
  . 1/3 for final age class (20-29).

This procedure can easily be accepted for area distribution (it may be founded on the "reasonable" assumption of uniform area distribution within each initial age class). This is not the case for volume and increment, since it would mean that these variables do not depend on age within the initial age classes (this assumption is not "reasonable").

This procedure must, therefore, be considered as some rough and empirical smoothing of the initial data. Actually, it can hardly be improved unless the data themselves are improved (but the conditions of age measurement must be recalled, see section 2.1.1).

Moreover, since both bare land and recruitment data are not included in the data provided to IIASA, these data have to be assumed (using other published results of NFIS or according to yield tables).

Input file is an output file of 'evenal.f'. The user is also asked to provide:

- the bare land area (as a proportion of stocked forest area),
- and the recruitment figures for the different age classes.

Output file has the following structure:

Item	**Unit**	**Columns**
Area	ha	1-8
Standing volume (all species)	m3/ha	9-15
Sawtimber volume	m3/ha	16-22
Volume increment	m3/ha/yr	23-29
Recruitment	m3/ha/yr	30-36

In total, there are 13 records with each record corresponding to an age class.

3.3.2 Data for irregular stands

The program "uneven.f" was written to generate a basic diameter class table. Since this program also performs some steps directly related to the estimation of the parameters of the dynamic uneven-aged stands model, it is discussed in more detail in section 4.3.

Input file of "uneven.f" is either PCRAB or some extracted subfile from PCRAB. The tasks performed by this program are:

- retrieving the data in PCRAB file (or subfile) the data which correspond to the domain selected by the user;

- and creating a complete diameter class table with:

  . the limits of the classes,
  . the number of living and dead trees in each class,
  . the mean volume of trees in each class,
  . the mean sawtimber volume of trees in each class,
  . the mean volume increment (mean current increment during the 5-years period preceding the
  survey) of the trees in each class; and
  . some coefficients relevant to the model (see section 4).

(Diameter classes are those described in section 2.)

3.4 Comments

The procedures described in this section (especially those of 3.2) are based on very simple data management operations. Nearly all of them could, therefore, be realized more easily by using a rational data base management system. This would provide a much greater flexibility for the definition of domains to be modelled and it could help in improving their quality (see the criteria listed in section 3.2.2).

4. Dynamic Models for the French Forests

This section deals with the dynamic models conceived for French forests in the context of the IIASA "Forest Study". These models use the data presented in section 2 and further processed in section 3.

Since the irregular stands represent a fairly large area in France (respectively 33% and 6% of the total area of production forests for coppice with standards and irregular high forest), and cannot be described in terms of age classes, a specific model (different from the "area concept developed by Sallnäs, 1989) had to be created (see section 4.3).

Moreover, applying the area concept model for regular stands needed some modifications and intermediate steps which are described in sections 3.2 and 3.3.1.

4.1 Introduction

4.1.1 General structure of the study: links between domains and models

As explained in section 2, the French forest area was divided into several domains (excluding poplar plantations, hedges and protection forests), which may be grouped into 2 broad categories:

- the domains composed of even-aged (or so-called regular) stands (i.e. coppice or even-aged high forest), for which stand age is meaningful: they were studied by using the area concept (which considers the transition of areas between age-classes as the core of the model);
- the domains composed of uneven-aged (or so-called irregular) stands (coppice with standards, uneven-aged high forest), for which stand age classification is practically impossible and theoretically meaningless: they were studied at a more aggregated level (all stands brought together), and the core of the model is constituted by the flow of trees between tree diameter classes.

This division of global forest area in different domains separately modelled is a fairly strong assumption, meaning that:

- the management and natural dynamics of these domains are independent (although wood demand may be actually addressed simultaneously to several domains);
- there will not be any transfer of area from domains to others in the future: this assumption is unrealistic, since, for example, a large area of coppice-with-standards should be converted or transformed to (broadleaf or coniferous) high forest in the future.

A second important point is that this general structure does not take into account the possible (and likely) variations of global forest area (especially the links between forest and agricultural areas).

This is not actually a major drawback since this evolution could be simulated, at least roughly; expected evolution is indeed a transfer from agricultural lands to forest areas, so that the major part of new stands should be even-aged and could therefore be "injected" in the area concept model.

4.1.2 Links between data and models

These links exist at two different levels:

- first, to get an estimate of the parameters of the model or even to design the model itself (form of the functions);
- second, to define the initial state of wood resource in the domains (the two models act as growth discrete-time recurrent models).

In a certain sense, the models which were used (and especially the uneven-aged stands model) should be termed "data-oriented" models, meaning that they have been designed to fit in with the structure of the data (division of forest area in domains, characterization of each domain by either a standwise (age,volume) area distribution or by an aggregated treewise diameter distribution, existence of increment data which provide estimates of the dynamics).

4.2 The model for the regular (even-aged) stands

4.2.1 The model

4.2.1.1 The principles

• Static description of each domain

At a date t, the domain is described as an age table, i.e. as a vector AREA(t), whose elements AREA(class,t) are the area in different (age, volume) classes. These classes are arbitrarily chosen, and are defined as:

$$[age(i),age(i+1)[\ \times [vol(vc),vol(vc+1)],$$

with age(i) and vol(vc) being the limits of the classes (volume classes are noted vc).

Age classes are those previously defined (see section 3.3.1), except that an age class is added to account for the case of "forest bare land" (forest areas which have been recently clearcut and are going to be regenerated in the near future). This leads to a total number of 13 age classes.

Similarly, a special volume class was introduced for "bare land" (with volume equal to zero !). Other volume classes are described below (see section 4.2.2).

This static description of the wood resource in a domain is based on a double discretization relative to both age and volume. It may be completed by some further variables like:

- the mean sawtimber volume in each class: SAW(age,vc,t).
- the mean annual volume increment in each class over the past 5 years: GRO(age,vc,t).

• Description of dynamics

Forest dynamics is viewed as transitions between the different (age,volume) classes. During the basic time step, i.e. between dates t and t+1, it is assumed to be represented by:

$$AREA(t+1) = INC(t) * (I - CUT(t)) * AREA(t)$$

where:

- CUT(t) is a cutting transition matrix accounting for clearcuttings and thinnings between t and t+1;
- I is the identity matrix;
- INC(t) is an increment transition matrix accounting for natural growth of stands between t and t+1.

This method of representing the dynamics is quite simple and is based on some form of direct analysis of what happens between 2 successive dates. It also implies a time discretization which is commonly accepted for forest dynamics (time step will usually be 5 years).

• Restrictions to the model

Some restrictions were imposed to the model (actually to the matrices INC(t) and CUT(t)) to ensure that the parameters of the model can be estimated by using the NFIS data sent to IIASA (these restrictions could be avoided - at least some of them - if more detailed data were available, see section 4.2.1). The trajectory of a stand is assumed to be the following:

- First, at the beginning of the time step, stands may:
  - either be clearcut: i.e. they move from their current (age,vc) class to the bare land class (0,0);
  - or be thinned down to the neighboring lower volume class (from (age,vc) down to (age,vc-1): their age does not change);
  - or remain in the same (age,vc) class.

Mortality due to any reason (pest, air pollution, storms, drought,...) could be introduced at this stage.

- Second, they are matured (by the model) and may:

- either move to the next volume class or remain in the same volume class;
- either move to the next age class or remain in the same age class;
- be regenerated in the case of bare land (i.e. the stands move from bare land -i.e. class (0,0)- to 1st age class and 1st volume class -i.e. class (1,1)-).

Growth reducers like air pollution effects, climatic cycles, etc... could be introduced at this point.

It is further assumed that volume transition is independent from age transition. This is a strong and unrealistic hypothesis since age-class width is superior or equal to 20 years and the time step is only 5 years, so that the oldest stands of an age class (those which are going to move to next age class at next time step) are probably among those which have the highest volume and increment in the age class.

4.2.1.2 Comments

- **About the the hypothesis of stationarity**

At this point, the model does not contain any hypothesis about the stationarity of CUT(t) and INC(t). These matrices are simply assumed to depend on time. The assumptions of **growth stationarity** (i.e. that INC(t) is constant over time) and of **independence of growth and cutting level** (i.e. INC(t) is not affected by the value of CUT(t) and reciprocally) are introduced later (see section 4.2.3) in order to "enable" the extrapolation of past growth to future.

In the current version of the programs, CUT(t) cannot be modified from one time step to another during the course of a simulation. This could easily be changed. However, the lack of detail would prevent any attempt to model the feed-back relationship between growth and harvesting level.

- **About the sense of classes: the "stand/plot problem"**

The definition of the classes may be an illusion, since it is well known that classes assessed according to plot or to stand characteristics have not the same meaning (see Hagglund, 1983, for a discussion of this topic).

This criticism does not concern the age classification because it is both a stand and plotwise classification (due to the definition of even-aged stands).

But it concerns the volume classification. Since forest management is organized at the stand level, the volume classes should be standwise classes. But, since NFIS is using small plots, the data put into AREA(t) are actually plotwise data. For this reason, the assessment of sivicultural treatments according to plotwise volume classification may not correspond to the intentions of the modeller.

- **About the stochastic nature of the model**

This model may either be viewed as deterministic (in that case the values in INC(t) and CUT(t) are just ratios) or as stochastic (in that case the parameters in INC(t) and CUT(t) are probabilities).

Following the trajectory of a stand (or a plot) from one state to another, leads to the probabilistic point of view. But, considering the different classes as global compartments linked by flows of stands leads to the deterministic point of view.

These two conceptions are not independent: the deterministic point of view may be deduced from the probabilistic description by using mathematical expectations conditional to the initial state. But it must be stressed that the basic foundations are stochastic (the construction of the model refers basically to the trajectory of a theoretical stand).

The stochastic nature of the model combined with the discrepancy between time step and the width of the age classes leads to some problems due to the fact that age transition is basically a deterministic dynamic process.

> Example: let us take a stand in the first age class in 1987: in 20 years, it will be in the second age class; but according to the model, its age will "range" from age class 1 (0-19 years) to age class 5 (80-99 years) with different probabilities and an expected age-class equal to age class 2.

This difficulty could be simply reduced or even avoided by decreasing the age-class width to 10 or even 5 years (this could be possible for true even-aged stands with age measured by using the basic data measured on the field; but this would be a pure illusion for the regular stands which are more or less uneven-aged with an estimated age; see section 2).

- **About the restrictions to the model**

The assumptions concerning the possibility for a stand to make only small moves (only one volume-class jumps, except for regeneration) could be avoided (at least partly) if permanent plots data were available, or if the past history of each stand or plot were reconstructed (to carry out this last possibility, it would be necessary to go back to the basic data - around 100000 plots for even-aged stands in France).

- **About the way of representing clearcuttings**

Another major drawback of the model is that the way of simulating clear-cuttings is not fully consistent with the traditionnal way of regenerating the broadleaf stands (i.e. several successive cuttings with a short time interval over a 10 to 20 years period).

- **About volume discretization**

The traduction of volume discretization may have (at least) two forms, which indicate a lack of consistency of the model:

- either all the stands (or plots) of the same volume class are assumed to have the same volume, equal to the mid-volume of the class: this form is used to get estimates of transition probabilities (see section 4.2.3).
- or these stands are assumed to have a uniform volume distribution, within each volume class: this form is used to get estimates of the coefficient of variation of volume distribution within each age class (see 4.2.3).

- **About the separation of cuttings and growth**

The division of time step into two logical sub steps ([1] cuttings, [2] growth) may be considered as a further time discretization of the model.

4.2.2 Volume classes, initial state and growth function

4.2.2.1 Introduction

To apply the model (for future simulations), it is necessary to define the initial (or present) state of wood resource. As shown in the two first sections, this state is well-defined for age classes (although discretization may be regarded as too rough for fast growing species and as not fully consistent with the 5-years time step). But, since the data provided to IIASA did not include volume classification, there were two possibilities:

- either making a more aggregated model with only one large volume class,
- or defining various volume classes and dispatching the age classes in the different (age,volume) classes.

This second possibility was chosen and performed by writing the program 'tabag2.f' which also deals with the growth function.

4.2.2.2 Definition of volume classes

- **Preliminary remark**

First, it must be stated that the limits of the volume classes (i.e. their number and their fixed or variable width) are always arbitrary and that they actually depend on:

- the roughness of the discretization accepted by the modeller (more classes mean a better description of the dynamics in terms of continuity). They must also be as compatible as possible with both age-class width and time step.
- the constraints imposed to the model: the volume classes must be broad enough to ensure that stands cannot jump more than 1 class ahead (growth) or down (thinning). This

means that the total growth during one time step should not exceed the width of volume classes (see section 4.2.3).

- the reasonable maximum value of volume in a stand or, better, in a plot (since the model is based on plotwise data rather than on standwise data).

- **Practical procedure**

The procedure used to generate the volume classes uses two parameters:

- the upper limit of the first non-zero volume class, noted vol(2);
- a constant, **r**, which expresses the ratio between the width of two successive volume classes.

It leads to the following formula:

vol(0) = 0 (bare land waiting for regeneration)
vol(1) = 0 (young forest with no trees over 7.5 cm diameter)
$1<j$: vol(j+1) = vol(j) + r * (vol(j)-vol(j-1))

where: vol(j) is the upper limit of the volume class j.

Let then mvol(j) = 0.5 * (vol(j+1)-vol(j)) be the mean volume of the jth class. All the stands in this volume class are assumed to have the same volume equal to mvol(j) (see section 4.2.12).

4.2.2.3 Estimate of the initial present state

- **The problem**

Since the NFIS data did not contain any information about volume classification, except the average volume for each age class, it was impossible to provide a "good" (age,volume) distribution: this distribution had to be arbitrarily guessed (see &2.21) by dispatching the area of each age class between the various volume classes.

If the (within-age-classes) coefficient of variation (CV) had been available, it would have been possible to generate a (within-age-class) volume distribution by using some kind of theoretical assumptions about the form of this (within-age-class) volume distribution. This was not the case, so that the procedure, which was finally chosen, is totally exterior to the data.

- **The procedure**

For any given age class (noted age), area is dispatched between 4 adjacent volume classes (v1,v2,v3,v4)grouped around the average volume of the age class (noted vol(age)):

$$\mathrm{mvol}(v1) \le \mathrm{mvol}(v2) \le \mathrm{vol}(age) \le \mathrm{mvol}(v3) \le \mathrm{mvol}(v4).$$

These classes are then grouped by pairs: (v1,v4) and (v2,v3). Age-class area is dispatched between the 2 pairs according to a parameter x fixed by the user (x is between 0 and 1):

$$\begin{aligned}\mathrm{AREA}(v2,v3) &= x * \mathrm{AREA}(age)\\ \mathrm{AREA}(v1,v4) &= (1-x) * \mathrm{AREA}(age)\end{aligned}$$

The area is then divided within each pair of volume classes by applying the constraint for volume consistency, which leads to:

$$\begin{aligned}\mathrm{vol}(age)\ \mathrm{AREA}(v2,v3) &= \mathrm{AREA}(age,v2)\ \mathrm{mvol}(v2) + \mathrm{AREA}(age,v3)\ \mathrm{mvol}(v3)\\ \mathrm{AREA}(v2,v3) &= \mathrm{AREA}(age,v2) + \mathrm{AREA}(age,v3)\end{aligned}$$

(same for v1 and v4).

- **Comment about the link between x and coefficient of variation**

The CV of the simulated (within-age-class) volume distribution may be computed a posteriori by assuming that within-volume-class distribution is uniform. Under this hypothesis, it is possible to estimate the variance of the simulated volume distribution within each age-class by adding:

- the between-volume-classes variance, which is equal to:
  $\mathrm{SUM}\ [\mathrm{AREA}(age,vi)\ (\mathrm{mvol}(vi)-\mathrm{vol}(age))**2]\ /\ \mathrm{AREA}(age)$

- the sum of the 4 within-volume-class variances, which is equal to:
  $\mathrm{SUM}\ [\mathrm{AREA}(age,vi)\ (\mathrm{mvol}(vi)-\mathrm{mvol}(vi-1))**2]\ /\ (12\ \mathrm{AREA}(age))$

It may be proven easily that decreasing x increases the CV of the simulated distribution, so that x could generally be empirically adjusted until the simulated CV fits some reasonable CV value (known or guessed by other means).

4.2.2.4 Estimation of underlying growth function

- **Reasons for introducing a growth function**

The NFIS data processed through section 2 provided an aggregated growth figure for each age class, GRO(age), without any distinction between (within-age-class) volume classes. It was necessary, however, to have some form of growth estimate for each possible (age,volume) class: this growth estimate is used to compute the growth parameters of the model (i.e. the probabilities for a plot or a stand to grow from one volume class to the next; see section 4.2.3).

This can be done by carrying out at least one of the three following procedures:

- either by assuming that volume does not influence the growth within each age-class;

- or by modelling the response of growth to standing volume within each age-class;
- or by modelling the response of growth to both standing volume and age.

These three possibilities can of course be viewed as some peculiar types of a general model formed as:

"growth = f(age,volume)".

Since the data did not allow any test of these three hypothesis, the choice had to be arbitrary.

- **Growth function**

The second possibility was chosen (see above) with a growth function of the following form:

GRO(age,vc)= inc(age) * f(vc) where

GRO(age,vc) = mean growth of a stand in class (age,vc)
inc(age) = a parameter dependent of age
f(vc) = a function.

The function chosen for f was (it could be changed easily by modifying one line in 'tabag2.f'):

f(vc) = mvol(vc)**0.5 (mvol(vc) = mean volume of class vc)

The value of inc(age) is determined by the constraint of consistency of growth figures:

AREA(age) * GRO(age) = SUM [AREA(age,vc) * inc(age) * f(vc)] where

GRO(age) = mean growth of stands in age class "age"
and AREA(age) = area of the age class "age".

- **Comments**

The introduction of the growth function is due to two reasons:

- the lack of volume-class data (combined with the choice of an age-volume class model);
- the fact, that even if the data had contained volume classes, the model would have required a growth function to extrapolate the growth figures out of the range of the observed ages and volumes.

This modelling step could obviously be improved:

- either, by improving the data (by including volume classes): this would certainly be the best way;

- or by improving the growth function: this is anyway submitted to the improvment of the data.

4.2.2.5 Using 'tabag2.f'

- **Input file**

It is an output file of 'tabage.f' (i.e. an age table containing the area, the mean volume, the mean sawtimber volume and mean growth of each age class).

- **Questions to the user**

They are relative to the definition of the volume classes and the distribution of area between volume classes within an age class:

- vol(2), the upper limit of the 2nd volume class (1st non-zero volume class) in m3/ha; values of vol(2) should range between 20 and 60 m3/ha.

- r, the ratio between the width of successive volume-classes (without any unit); values of r should range between 0.9 and 1.2.

  Remark: vol(2) and r may be modified until the user is satisfied with the generated volume classes.

- x, the parameter responsible for the volume distribution within age-classes (without any unit): values of x should range between 0.8 (high CV) and 1.0 (low CV).

- **Output file**

The first record contains the mean volume (mvol(j)) of all volume classes. The other records are all relative to age classes (one record for each age class); each record contains:

- the value of the parameter inc(age),
- the distribution of areas between volume classes, within the age class: AREA(age,vc) (vc=1,12).

4.2.3 Estimation of the parameters and simulation

Both the estimation of the model parameters (transition probabilities) and the simulation of dynamics are carried out by the program 'tabag3.f'. It is recalled that, during one time step, the stands are first thinned and clearcut (this is matrix CUT(t),) and then grown (this is matrix INC(t)).

4.2.3.1 Assessment of silvicultural parameters

- **Clearcuttings**

They are simulated by introducing 3 parameters:

- the "normal" revolution of stands, **agerev**: i.e. the age class, where regeneration fellings begin;
- the probability for a stand older than agerev to be cut during one time step: this quantity can be related to the mean duration of regeneration fellings and to the variation between the shortest and the longest revolutions; this parameter is fixed to 0.5 in 'tabag3.f', but it could easily be changed.
- the maximum age of stands, **agemax**: stands older than agemax will be clearcut with a probability equal to 1.

The probability for a stand to be clearcut is therefore:

if age < agerev:	pcc(age,vc) = 0
if agerev <= age < agemax:	pcc(age,vc) = 0.5
if agemax <= age:	pcc(age,vc) = 1.0

- **Thinnings**

They are simply simulated by assuming that thinnings are proportional to growth. The user must, therefore, determine the ratio, **thin**, between thinning and increment. This ratio is assumed to be independent of age (but this could be modified).

Then the probability for a stand to be thinned (from the volume class vc down to vc-1) during one time step is equal to:

if vc > 2:
pth(age,vc)= thin time-step gro(age,vc) / (mvol(vc)-mvol(vc-1))

if vc = 2:
pth(age,2) = thin time-step gro(age,2) / (mvol(3) -mvol(2))

The special formula for vc=2 is introduced to avoid that a stand returns to vc=1 (volume=0). Thinnings of stands in volume class vc=2 are therefore simulated as reductors of growth (see section 4.2.2.4).

4.2.3.2 Estimation of growth parameters

- **A complementary assumption: independency of age and volume transition probabilities**

Since no data were available to test the likely interaction between age and volume transitions, it was assumed that they were independent.

Let us take a stand in class (age,vc) (vc is a volume class). This assumption means that the stand may:

- move to the next age class with a probability: qa(age),
  or remain in the same class with a probability: 1-qa(age).

- move to the volume class vc+1 with a probability: qv(age,vc),
  or remain in its volume class, with a probability: 1-qv(age,vc);

and that:

- probability for moving to (age+1,vc+1)=qa(age) qv(age,vc)
- probability for moving to (age+1,vc)=qa(age) (1-qv(age,vc))
- probability for moving to (age,vc+1)=(1-qa(age)) qv(age,vc)
- probability for staying in (age,vc)=(1-qa(age)) (1-qv(age,vc))

- **Age transition probabilities**

They are simply estimated by using the formula:

qa(age) = (time-step) / (width of age class)

As previously stated, the discrepancy between the time step and the width of age classes may lead to some abnormal dynamics, when the initial age distribution is not uniform (which is the common case). These anomalies are due to the fact that age transition is basically a deterministic process.

- **Volume transition probabilities**

They are estimated by using the growth function introduced in 4.2.2.4.The probability qv(age,vc) to move from class (age,vc) to either (age,vc+1) or (age+1,vc+1) during one time step is equal to:

qv(age,vc) = GRO(age,vc) time-step / (mvol(vc+1)-mvol(vc))

As previously stated, this imposes us to define volume classes which are broad enough. The representation of growth associated to this formula considers that growth is totally due to transitions between volume classes (i.e. there is no growth within volume classes; see section 4.2.1.2).

This formula is slightly altered for the second volume class (due to thinnings, see &2.312):

qv(age,2) = GRO(age,2) (1-thin) time-step / (mvol(3)-mvol(2))

- **Recruitment**

Since no data were available for recruitment, it was chosen to introduce recruitment figures as external data for each age class, noted **rec(age)**, without any effect of volume (these external data may be based either on other NFIS data or on some general assumptions or figures like those deduced from yield tables).

- **Regeneration**

Regeneration is represented in the model by transitions between the bare land class (0,0) and the first forest class (1,1) (let recall that volume class vc=1 is a zero volume class). It is represented by a fixed coefficient, **rege**, (given by user) which simulates the rapidity of regeneration after clearcuttings.

The data provided to IIASA do not contain any information about regeneration delays. These can be indirectly estimated by considering the proportion of bare land in each domain.

4.2.3.3 Simulation

The user is asked to provide the number of time steps which should be run by the model. Simulation is then simply carried out by iterating the model. For each time step:

i - at the first step, the initial state is the present one defined in section 4.2.2.3,for other steps the simulator uses the updated initial state (see iv);

ii - cuttings are first performed and cut volume is computed (sawtimber volume is also estimated, by considering that the proportion of sawtimber volume is the same for cut trees as for standing trees);

iii - then the stands are grown and regenerated;

iv - former initial state is replaced by the final state.

Remark: as previously explained, the dissociation of cuttings and growth is not respected for the second volume-class.

4.2.3.4 Using 'tabag3.f'

- **Input file**

It is an output file of 'tabag2.f', i.e. a file containing the mid-volume of the volume-classes and the initial state of the domain (area in (age,volume) classes) completed by the parameter used in the growth function (see section 4.2.2.4).

- **Questions to the user**

They concern:

- the assessment of silviculture: values of "agerev","agemax" and "thin" (see section 4.2.3.1);
- the recruitment figures for the first four age-classes (from 0 to 79 years); it is assumed that further recruitment is equal to 0 or may be neglected.
- the turn-over of bare land to regenerated forest areas: value of "rege";
- and "niter" the number of time steps (the duration of the simulation is then 5*niter (in years)).

- **Output file**

It contains:

- the estimated values of growth and cuttings transition probabilities;
- the simulated values of:
  - . final state after each time step;
  - . the total cut volume.

Remark: this last part has to be added to the present 'tabag3.f' program.

4.3 The model for the irregular (uneven-aged stands)

4.3.1 The model

4.3.1.1 The principles

- **The problem**

The decision to conceive a different model for the irregular stand types was due to the fact that the "Swedish" model described in section 3.2 could not be adapted to these stands, since both stand age and stand volume could not be regarded as relevant characteristics of the dynamics of uneven-aged stands.

For such stands, it is generally accepted that standwise **tree-diameter distributions** (or histograms) provide a more satisfactory description and that their dynamics may be simulated by using **stand table projection techniques** (at least, for short-term periods). The model developed for irregular stands was, therefore, based on that type of stand characterization. (Some slightly different descriptions of the model may be found in the literature; see Usher (1969), Pitard (1978), Houllier (1986).)

However, it must be stated that the level of description (in this study) was neither the stand, nor the sampling plot, but a fairly **large aggregate of stands** (i.e. the whole domain). This choice was partially due to the fact that data were not available at the plot or stand level. But, even if data were available at the plot level (and this could be possible by using the detailed database stored in France), plotwise tree-diameter distributions would be meaningless in irregular stands unless the plots are fairly large (i.e. a small plot cannot be viewed as representative of the surrounding stand when it is irregular).

- **Static description**

The static description of the domain at a date t has the form of a <u>stand table</u> (i.e. a diameter histogram), L(t), whose elements L(diam,t) are the number of living trees at t in diameter class diam.

Diameter classes are those described in sections 1 and 2, completed by the class 0-7 cm (which contains the young trees smaller than the minimum diameter adopted by NFIS for tree measurement). Data provided to IIASA did not contain any information about this classes.

This description has the same nature as the one used for even-aged stands:

- regular stands are put in discrete stand- (or plot-)wise (age, volume) classes;
- while trees are put in discrete diameter classes.

- **Dynamic model**

The dynamic model is also a discrete-time growth model, based on the study of <u>the trajectory of a tree when time passes</u>. Between t and t+1, a tree may:

- either be cut and replaced (by natural or artificial means): this is regeneration and it occurs generally only for large trees or for coppice;

- or be cut and not replaced: this is thinning;

- or die (in that case replacement of the tree by seedlings may also occur).

- or survive and remain in the same diameter class;

- or grow and move to another diameter class: it must be clear that growth within diameter class actually exists in reality, but that it cannot be represented by the model, which only accounts for changes of diameter classes.

This dynamic description can be translated into a matrix model:

$$L(t+1) = USH(t)\ L(t)$$

where USH(t) is a square matrix containing the transition and regeneration coefficients.

- **Further restrictions imposed to the model**

They are due to the estimation procedure described in sectopm section 3.3.3.and to the lack of permanent plots.

- The time step is divided into 2 basic (logical) steps:
  - . first, the trees may be cut, with a probability **c(diam)** which may be split into 2 parts:
  - . **ct(diam)** = probability of being thinned;
  - . **cc(diam)** = probability of being clearcut (either for standard or coppice); so that c(diam) = cc(diam)+ct(diam);
  - . then, they may:
  - . die, with a probability **m(diam)**;
  - . survive, with a probability **s(diam)**;
  - . or new trees may replace the cut ones, with an apparent fecundity **f(diam)**.

- During a time step, a surviving tree can only:
  - . remain in the same class, with a probability **p(diam)**;
  - . or move to the next upper class (jumps over one class are not allowed, although they could actually happen with some fast-growing species), with a probability **q(diam)**; so that: s(diam) = p(diam)+q(diam) = 1-m(diam)

USH(t) has then the following form:

- $USH(i,i) = (1-c(i))\ p(i)$
- $USH(i+1,i) = (1-c(i))\ q(i)$
- $USH(1,i) = f(i)$
- Other values of USH(i,j) are all equal to 0.

4.3.1.2 Comments

- **Where is my tree ? Where is my stand ?**

The first and probably most important comment is that the high level of aggregation makes it impossible to know:

- whether a tree belonging to class 30 (i.e. its diameter is between 28 and 32 cm) is the biggest or the smallest in its stand, whether it is dominant or dominated;

- and whether it is a conifer or a broadleaf (although many irregular stands are mixed).

The second major comment is that the stands also cannot be retrieved in the aggregate of trees. This must be kept in mind when dealing with silvicultural assumptions which are usually stated at the stand level and should be stated here at the aggregate level (see section 4.3.3.2).

- **Is the model stochastic or deterministic ?**

The comments done in section 4.2.1.2 are still relevant for this model (with replacement of stand by tree and (age,volume) class by diameter class): the model may either be regarded as stochastic or as deterministic.

Although it is basically constructed by using the stochastic point of view, only its deterministic version will be used in this study.

- **About the hypothesis of stationarity and independence of growth and cuttings**

These very strong and doubtful hypothesis are added to the model to enable the extrapolation of past growth into future. These assumptions are even more dramatic for that model than for the former one (see section 4.2.1.2):

- There is no equivalent of the "area constraint" of the "Swedish model" for even-aged stands (i.e. for even-aged stands, the total forest area is fixed and is distributed over (age,volume) classes). The lack of such a constraint and the linearity of the model lead to an exponential asymptotic behaviour of stand table, which is generally totally unrealistic (see section 4.3.3.3 for further discussion).

- While there are some empirical laws relative to stand growth, (which state that stand growth does not depend on silvicultural treatments within a large range of silvicultures, no such law does exist for tree growth, on the contrary (one of the aims of silviculture is to modify the individual growth of the trees).

- **Regeneration and recruitment**

One difficult point with those type of models always occurs with the regeneration. Since the model excludes any stand area statement (there is only one global area statement for the whole domain), it is difficult to estimate the fecundity of trees.

Moreover, it must be noticed that regeneration appears more like a replacement of removed trees than that of a biological regeneration, so that the estimated fecundity is more apparent than real.

- **Alternative silvicultural scenarios**

As mentionned earlier (see section 4.3.1.2), the hypothesis of independence of growth and cuttings is added to ensure further extrapolation of the model. This assumption is in fact mainly due to the lack of data (the model used here may be regarded as a data-oriented model), and that this major drawback and weakness of the model could be reduced only by further experiments or by data improvment.

This means especially that, although it seems quite easy to modify the silvicultural treatments by changing the cutting probabilities, this type of parameter manipulation is highly doubtful: changing the level of thinnings should modify the transition probabilities and the apparent fecundity of trees.

- **About the mixture of species**

The mixing of species which may reach different maximum diameters and whose growth may vary is also a difficult topic.

It is easy to simulate growth and cuttings with specific models (one matrix for each group of species). But, again the regeneration poses some heavy problems (species may be replaced by others, for example). So that each domain is generally simulated as a whole, without any (within-domain) species distinction.

Nevertheless, the definition of domains includes the predominant species (see section 3) and is, therefore, a partial answer to that problem.

4.3.2 The initial present state

The initial (present) state for simulation was obtained by applying the program 'uneven.f' (already mentioned in section 3) to the PCRAB file. It was characterized by a (diameter) stand table, completed by:

- **vol(diam),** the mean volume of trees in each diameter class: this volume is assumed to be constant, though it can vary (for example, according to within-diameter class distribution);
- **saw(diam),** the mean percentage of sawtimber volume in each diameter class.

Other variables useful for parameter estimation, like the number of dead trees, **D(diam),** or the mean past growth (during the last 5 years), **gro(diam),** were also computed for each class.

Remark: let us recall that volume increment estimates have some drawbacks (see section 2).

The hypothesis of stationarity means that gro(diam), vol(diam) and saw(diam) are supposed to be constant over time.

Since the data provided to IIASA did not contain any information on the first diameter class, the number of trees in this class had to be estimated.

4.3.3 Estimation of the parameters

4.3.3.1 Survival probabilities

- **Preliminary remarks**

There are several possibilities to estimate the growth and death parameters in the last 5 years, according to the available data:

- if permanent plot data with individually located trees exist, the solution is quite easy (see Houllier, 1986);

- if diameter increment data exist for all trees, it is possible to reconstruct an estimate of the state of each tree 5 years back in the past and to apply the same kind of procedure as the one developed for permanent plots (except for cutting probabilities);

- if only the mean diameter increment in each diameter class is available, it is possible to define the mean duration of state for a tree in a diameter class and to estimate then the transitional probabilities;

- if only the mean volume increment in each diameter class is available, it is necessary:
  - either to define volume classes associated to diameter classes (see then the procedure described above);
  - or to assume that there is no within-diameter-class volume variation and that the observed growth is only due to the trees which moved from one diameter class to the next.

Considering the data provided to IIASA, one of the last two possibilities had to be chosen. The last was finally chosen, not because it was the most realistic, but because it was much easier to implement during a short period.

This choice required us to, at first, reconstruct an estimate of the past stand table of the domain (before growth and after cuttings: let us recall that direct estimation of cuttings was not possible by using the NFIS data, see section I). Let:

- L be the current state (given in file PCRAB),
- L' be the state 5 years earlier (after cuttings; see section 4.3.1.1),
- L" be the state 5 years earlier (before cuttings).

- **Estimate of past state**

Assuming that the growth is only due to transitions between diameter classes, one gets:

- if $2 < diam < 11$:
$L'(diam) = L(diam) + D(diam)$
$+ L(diam+1)\ gro(diam+1)\ /\ (vol(diam+1)-vol(diam))$
$- L(diam)\ gro(diam)\ /\ (vol(diam)-vol(diam-1))u$

- if $diam = 2$, a special formula has to be used due to recruitment:
$L'(2) = L(2) + D(2) + L(3)\ gro(3)\ /\ (vol(3)-vol(2))$
$- L(2)\ gro(2)\ /\ (vol(2)-vpf))$

Remark: $vpf = vol(2)\ (7/10)**2$ is an estimate of the mean volume of trees when they pass the recruitment diameter.

- $L'(12) = L(12) + D(12) - L(12)\ gro(12)\ /\ (vol(12)-vol(11))$

Remark: this formula is not applied since the mean volume of last diameter class is generally too high, because this class contains very big trees (with a diameter greater than 62 cm). A complementary assumption is therefore introduced (see section 3.3.1).

- $L'(1)$ cannot be estimated without complementary assumptions since $L(1)$ and $D(1)$ are unknown.

The basic assumption made above may be regarded as consistent with volume discretization, except for the last class (see the remark above).

- **Growth and death transition parameters**

They are obtained by using the following formula:

If $1 < diam < 11$:
$m(diam)\ L'(diam) = D(diam)$
$q(diam)\ L'(diam)\ (vol(diam+1)-vol(diam)) = L(diam+1)\ gro(diam+1)$
$p(diam) + q(diam) + m(diam) = 1$

$q(12) = 0$
$q(11) = q(10)$: this a complementary assumption due to the problems associated with the last diameter class (see above).

$p(12)\ L'(12) + q(11)\ L'(11) = L(12)$
$m(12)\ L'(12) = D(12)$
$p(12) + m(12) = 1$

These 3 formulas provide an a posteriori estimate of $L'(12)$.

The case of the first diameter class obliges us to complete the 2 following formulas:

- $m(1)\ L'(1) = D(1)$
- $p(1) + q(1) + m(1) = 1$

by some further assumptions:

- $q(1) = (2/3)\ q(2)$
- if $m(2) > m(3)$: $m(1) = 2\ m(2) - m(3)$
  if $m(2) <= m(3)$: $m(1) = m(2)$

$p(2)\ L'(2) + q(1)\ L'(1) = L(2)$ provides an estimate of $L'(1)$.

4.3.3.2 Cutting probabilities

- **Distinction between coppice and standards**

For coppice with standards domains (forest structure = 3, see section 2), the case of coppice should be partly separated from, and partly aggregated with, the case of standards.

- It should be separated because the treatment of coppice is quite different (no thinnings but a clearcut every 20 to 40 years).

- It should be aggregated for two reasons:
  - . a theoretical reason relative to silviculture: the stands are managed as a whole (some coppice trees are allowed to become future standards);
  - . a practical reason relative to data: in the data provided to IIASA, there was no distinction between coppice and standards, so that any separation would be an illusion.

- **High forest and standards clearcuttings**

These are defined by 3 parameters:

- the "normal diameter" of harvested trees (those which will be replaced by offspring), **icc**;

- the level of clearcutting, **clear**, expressed as a percentage of living trees;

- the "maximum diameter" of trees, **imax**, which is used to "accelerate" the cuttings of large trees.

The probability for a tree to be clearcut is then arbitrarily fixed by the following formula, which provide a certain smoothing of clearcutting probability, **cc(diam)**:

if diam < icc-1: cc(diam) = 0
if diam > = imax: cc(diam) = (3 clear + 1) / 4
if icc < = diam < imax: cc(diam) = clear
else (diam=icc-1): cc(diam) = clear / 2

For coppice with standards, this probability should normally be conditional to the fact that the tree is belonging to standards (and not to coppice). Since the trees are not distinguished in the data sent to IIASA, this is not the case.

- **The case of coppice**

2 parameters were introduced to account for coppice cuttings:

- the diameter of clearcut coppice, **icccop**;
- the level of coppice cuttings, **clearc**, expressed as a percentage of the number of living trees (this parameter contains implicitly both the proportion of coppice trees in the diameter class and the cutting probability of these trees).

The probability for a tree to be clearcut is then assumed to be equal to:

if diam < icccop-1: cc(diam) does not change (see &3.322)
if diam > icccop+1: cc(diam) does not change (see &3.322)
if diam = icccop: cc(icccop) = cc(icccop) + clearc
else (i.e. /icccop-diam/ = 1): cc(diam) = cc(diam) + clearc / 2

- **Thinnings**

They are defined by a sole parameter, **thin**, the level of thinnings expressed as a percentage of growth (this could be refined by modifying this parameter according to diameter classes). The probability of being thinned is therefore:

ct(diam) = thin (1-cc(diam)) (GRO(diam)/vol(diam))

Complementary assumptions were done for the first diameter class:

c(1) = ct(1) = c(2).

4.3.3.3 Regeneration

- **Theoretical form of regeneration parameters**

The following form was assumed for f(diam), the apparent fecundity parameters:

f(diam) = alpha diam**2 cc(diam)

where:

- alpha is a constant to be determined (see below);
- cc(diam) is the clearcutting probability (let us recall that regeneration must be regarded as a replacement);
- diam**2 is introduced empirically to account for the fact that large trees cover and that they should therefore be replaced by a large number of offspring.

The data provided to IIASA did not contain any information about regeneration so that neither the form proposed above nor the coefficient alpha could be estimated without further assumptions. It must however be noticed that this situation is not unusual in forest surveys, since regeneration cannot be easily measured.

- **The long term stability assumption**

As previously mentioned (see section 4.3.1.2), this model has an expontentially asymptotic behaviour, which is not compatible with long term forest dynamics, except if the largest positive eigenvalue of the matrix USH is equal to 1 (in that case, the stand table becomes stable on the long term).

This statement is usually used to check the consistency of the model:

- if the estimated largest positive eigenvalue is significantly different from 1, this means that the past observed growth is not compatible with the stationary hypothesis, so that the predictive power of the model is likely to be poor except for short term extrapolations;
- if this eigenvalue is not significantly different from 1, nothing can be said (i.e. the model cannot be rejected).

Here, the long term behaviour of the model was used as a constraint to determine the unknown coefficient alpha: alpha was adjusted so that the largest eigenvalue was equal to 1. This again constitutes a very strong hypothesis meaning that:

- the observed past growth will not change (hypothesis of stationarity; see section 4.3.1.2);
- the apparent fecundity will adapt to the simulated silvicultural treatment.

- **The procedure**

The procedure used to determine alpha is iterative:

i) a default value of alpha is given to the program;

ii) then, the largest eigenvalue is computed by iterating the model 200 times;

iii) if this eigenvalue is different from 1, the user is asked to provide a new value of alpha and the program performs again the step ii).

It is known that the procedure used to estimate the eigenvalue always converges except if there are complex eigenvalues with the same modulus as the largest positive eigenvalue (which is a rare case).

It is also known that the largest eigenvalue is a monotonous increasing function of alpha going from 0 to infinity when alpha goes from 0 to infinity (except in some rare cases), so that the whole procedure converges to an alpha value.

- **Estimation of the present initial state**

To perform simulations the present stand table must be known. In fact, it was known (or better, estimated) for all diameter classes, but the first. The present number of trees in the first diameter class was therefore estimated by using the estimated coefficients of the model.

L"(diam) = L'(diam) / (1 - c(diam))

and L(1) = p(1) L'(1) + SUM [f(diam) L"(diam)]

4.3.4 Programs

4.3.4.1 Using 'uneven.f'

The input file must be PCRAB or some PCRAB subfile (see section 2).

The questions to the user are relative to the selection criteria (i.e. administrative regions, forest structure, species, and ownership).

The output file contains:

- the lower and upper limits and mid-value of each diameter class (for the last class upper limit and mid-value are meaningless);
- the present number of living trees (without any distinction between species);

- the former number of living trees (before growth and after cuttings as estimated in section 4.3.3.1);

- the present number of dead trees;

- the mean volume, sawtimber volume and past annual growth (in the 5 years preceding the survey);

- the estimated transition probabilities: p, q, m.

There is one record for each diameter class. The first record contains some zeros (it deals with the smallest trees). 4 final records recall the selection done by user (regions, ownership, structure, species).

4.3.4.2 Using 'uneve2.f'

The input file is an output file of 'uneven.f'.

The questions to the user deal with:

- the definition of the silvicultural treatments:
  - the level of thinning expressed as a growth ratio;
  - the minimum diameter class of clearcut trees and the clearcutting level expressed as a ratio relative to the number of living trees;
  - the maximum diameter class of clearcut trees;
  - the characteristics of coppice cuttings: diameter class and level expressed as a ratio relative to the number of living trees.

- the alpha parameter which is involved in regeneration (see section 4.3.3.3):usual values of alpha will range from 0.1 to 0.5.

The output file contains 24 records.

- The first 12 records describe the present state of wood resource in the domain; there is one record for each diameter class. Each record contains:
  - the mid-diameter of each diameter class;
  - the present number of living and dead trees;
  - the mean volume, sawtimber volume and volume increment;
  - the transition probabilities: p, q, m, ct and cc.

- The other 12 records contain USH, the matrix of the model.

4.3.5 Simulation

Simulations may be performed by running the 'uneve3.f' program. The input file is an output file of 'uneve2.f'. The sole question to the user is the number of iterations of the simulator.

The output file contains:

- the transition probabilities (p, q, m, c) followed by the estimated USH matrix,
- and for each iteration:
  - the simulated future wood resource (estimated number of trees at the end of each time step),
  - the number of thinned and clearcut trees in each diameter class;
  - and finally the total harvested volume and sawtimber volume.

4.4 General comments

The main interest of models is probably their methodological fecundity. First, they provide a way of gathering the current knowledge, of testing its consistency.

Second, they oblige to search for better data, either to test the validity of the models, or to enable practical estimation of their parameters.

4.4.1 About the sense of the models

The sense of the models depends basically on their objectives. Hence, the goal of models is not to be as realistic, but to meet some requirements and some objectives which should be a priori assigned by the user. The level of aggregation in the Forestry Study approach constitutes both an objective and a constraint. At this level, reasonable objectives cannot be to simulate the growth of a stand but to simulate the global evolution of wood resource in large domains.

The sense of the models is also obviously related to the underlying hypothesis and to their adequacy with forest reality and to their own consistency. One major aim of this technical note was to point out these assumptions, to discuss them and even to propose refinements which could lessen these assumptions and improve the adequacy of the models to the reality.

It was especially important to focus on the constraints due to the weaknesses of the data: these constraints may transform progressively what should be a goal-oriented model into a data-oriented model mainly or even exclusively designed to fit the structure of the data provided to IIASA.

It must be stated that building and implementing more "realistic" models (i.e. models which are established on milder assumptions and better quantitative data) is heavily dependent on both:

- the kind of available data: more refined model, based on stand or even on tree units, can theoretically be created; but their practical implementation can only be performed with individual stand and/or tree data;
- the availability of knowledge relative to management or silvicultural rules:
  - defined at the unit level (stand and/or tree),

- compatible with the general level of the study.

4.4.2 About the direct use of the models

The models developed here should be regarded as tactical rather than strategical models. They do not tell the user which general strategy he should use to adapt management to changing environments. It only draws a rough picture of what may happen conditionally to extrapolation of some past estimates and to some numerous assumptions.

The quantity of assumptions introduced at the various steps of the modelling process (especially for unevenaged stands) should indicate to potential users that applying these models is not only a matter of running programs. The case of the uneven-aged stands model is certainly the most critical.

4.4.2.1 Wood supply

The models developed here are obviously wood-supply models. Their integration into a broader quantitative or even qualitative approach would actually be difficult:

- because of the models themselves: as mentioned in the core of the text, the feedback of growth to variations in silvicultural treatments is not taken into account, so that fluctuations in harvesting level (due to demand, to price variations or to natural dramatic events) cannot be described by the model;

- but also because of the general structure of the study dividing the forest area into non-overlapping domains is a quite simple way of dealing with forest resource and constitutes a reductive temptation common to many forest modellers. The wood demand may nevertheless be addressed simultaneously to several domains and/or to several parts of domains (both geographical and species substitutions may happen for example).

The link of these models with wood demand is, therefore, a problem of disaggregation of data, and a problem of definition of domains according more to an economic point of view than to the sole silvicultural point of view.

4.4.2.2 The link with forest decline

One of the primary goals of the Forestry Study is to provide some insights in the future evolution of forest sector according to air pollution damages.

As such, the models presented in this paper do not deal at all with the impacts of forest decline. Some possibilities were, however, pointed out. But it must be stressed that they constitute rather formal suggestions than practical ones. To be implemented these suggestions should be based upon quantitative observations and further data analysis.

The problem seems therefore to be rather a problem of data linkage (it is necessary to have at the same geographic and temporal scales both dynamic data - increment - and forest damage data) than a problem of model availability.

5. References

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