Future Forest Resources of Western and Eastern Europe

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Foreword

National timber-assessment studies based on dynamic models are well developed in several European countries. However, consistent and dynamic timber assessments for all of Europe are rare and those that exist are not based on formal quantitative models. Because of this lack, a first objective of the IIASA Forest Study was to develop a consistent and formal dynamic model for European forests. Such a model is crucial for formulating relevant forest policies throughout Europe, as well as for calculating long-term timber balances for the region.

One important external factor influencing the forest policies in individual countries in Europe is the effect of air pollutants, which have affected Europe's forests since the onset of the Industrial Revolution. The first scientific warnings came in the 1850s, when German researchers reported damage to trees near industrial sites. A century later, scientists began warning that all of Europe was awash in a basin of polluted air, and that pollution was damaging vast stretches of forest. Although there is a considerable body of knowledge concerning air pollution and forest decline, this information has never been employed in Europewide site studies. One major objective of the IIASA Forest Study has been to try to quantify the effects of air pollutants on European forests in a consistent way, using the best available knowledge.

Finding solutions to the air-pollution problem is not easy. Those who design and implement solutions to the problem must coordinate local actions to achieve regional, national, and international goals. We hope that the results of the IIASA Forest Study will play a role in this process.

The Forest Study was initiated by IIASA in 1986 but has been carried out in close collaboration with the Swedish University of Agricultural Sciences, Garpenberg, where much of the work was done. We are also indebted to approximately 120 collaborating organizations throughout Europe that assisted in the work.

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Preface

In 1986 the IIASA Forest Study began to address the question of the long-term development of the European forest resources. Objectives of the study are:

(1) To gain an objective view of potential developments of forest resources of Europe.
(2) To build a number of alternative and consistent scenarios about potential future developments.
(3) To illustrate the effects of forest decline caused by air pollutants.
(4) To identify meaningful policy options.

A detailed country-by-country database of European forest resources has been assembled by the Forest Study and linked to a matrix-type simulation model. The model generates projections of growing-stock and timber-harvest volumes over time by country, species group, and age, making it possible to undertake a general timber-supply assessment.

The forest-decline effects caused by air pollutants have been simulated in the model by taking into account depositions, critical loads for air pollutants (sensitivity to air pollutants), and resulting damage cycles and growth losses.

The following results can be highlighted concerning Western and Eastern Europe:

- By comparing the 100-year average harvests from the Forest Study with actual removals in 1987, it can be shown that there is a potential to increase long-term sustainable harvests by about 110 million cubic meters per year. This calculation does *not* take into account any effects of air pollutants.
- The Nordic countries and the original EEC countries (EEC-9) have the highest potential to strengthen their role as wood suppliers.
- The loss of potential harvest caused by air pollutants expected to be emitted in Europe up to the years 2000 and 2005 is estimated to be about

16 percent of the total potential in the no-decline situation (assuming no pollution-induced decline). This corresponds to a loss of about 85 million cubic meters per year averaged over 100 years.

- The regions most affected by forest decline attributed to air pollutants are the Eastern and Central (Austria and Switzerland) regions, followed by the EEC-9.
- The anticipated expansion of forest land in Europe will generate an increase in the total timber-harvest potential of some 25 million cubic meters per year, averaged over 100 years.
- About 70 percent of this increase will take place in the EEC-9 region.
- Even in the case of no future decline attributed to air pollutants, the Continent may face an annual roundwood deficit of some 40 million cubic meters per year by 2010.
- If decline caused by air pollutants is taken into account, the deficit amounts to about 130 million cubic meters per year.
- Even full success in controlling major damaging air pollutants will not be enough to remove all signs of stress in European forests. Inadequate implementation of good silvicultural practices has also contributed to the decline visible today.
- Improvements in implementing basic forest management are required.
- Immediate reductions of air pollutants in Europe are required.
- Unfortunately, pollutant emissions are unlikely to be controlled as rapidly and comprehensively as desired.

The information generated by the study is intended for use by policymakers in governments, international organizations, industry, and special interest groups. This is an introductory volume to a series of books on the timber assessment of the Forest Study. Volume I deals with the background of the Forest Study and results for Western and Eastern Europe, not including the Soviet Union. Volume II presents details on the forest-resources databases and models used in our analyses. Volume III describes the background and results for the European part of the Soviet Union.

Contents

Chapter 1

Introduction

1.1 Background

The forests of the world are one of humanity's most important resources. Trees are necessary components of the ecological processes that make the Earth inhabitable for human beings. Trees store energy and oxygen, and their root systems bind soil particles and raise the soil's capacity to absorb and store water.

From an economic point of view, trees are valuable. They are the raw material needed for the production of timber, paper, and lumber, and are an important part of the chemical industry. In developing countries, firewood is the dominant source of energy and accounts for more than 80 percent of total wood consumption.

The forests of the world are also tremendous genetic reservoirs – especially the flora and fauna of tropical forests, the riches of which are not yet fully appreciated. Today, nature is the most important venue for recreation. Undisturbed areas of virgin forest are becoming increasingly attractive to those living in urban centers.

Because the forests of Europe are so important in many different ways, forest decline attributed to air pollution became a major concern of European society in the 1980s. Although the phenomenon is by no means a new one (researchers have noted forest damage from air pollutants on a local scale for more than a century), the simultaneous appearance recently of visible stress symptoms in trees in many areas of Europe and North America has raised the issue to one of great significance. There is widespread concern within the scientific, industrial, labor, economic, regulatory, and public sectors of

European society that a continuation of recent trends in forest decline may lead to a plethora of undesirable consequences. These include: disturbances in trade patterns for wood products, leading to wide fluctuations in prices of both raw materials and finished products; increased costs for silviculture and forest protection (e.g., due to increased incidence of insect outbreaks); loss of recreation forests; and loss of the protective functions of forests with respect to soil and water, especially in mountain regions.

While the scope of the phenomenon is international (i.e., there are declining forests throughout the European continent), the scale of each instance of decline is local to regional. There are two major reasons for this: (a) the forests themselves differ from region to region (because of ecological and silvicultural differences), making them differentially susceptible to air pollution and other stressors, and (b) the spectrum of air pollutants differs from region to region. While strategies to combat undesirable impacts of forest decline must be fitted to specific local or regional factors, they also must be set firmly in an international context to take into account, for example, transboundary air pollution and trade in raw materials.

Most of those who recognize the gravity of the problem are calling for immediate mitigative actions. However, it is clear that actions taken in one country for its own benefit may undesirably affect other countries and that actions taken by one sector of Europe's economy may undesirably affect other sectors. Thus there is a urgent call for international and regional cooperation in efforts to combat the consequences expected of continued forest decline in Europe.

There is, in relative terms, a considerable body of knowledge on what actions should be pursued on a local scale in response to decline. However, the systems whose future we are most concerned about are regional (e.g., forest-management units administered by governments or companies), national (national economies), and international systems (e.g., European Economic Community). Therefore, those who design and implement solutions to the problem of forest decline must grapple with the difficulties of coordinating local actions to achieve regional goals, regional actions to achieve national goals, and national actions to achieve international goals. This is a central dilemma of management, ***think globally, act locally.***

The same kind of difficulty arises when considering the temporal dimensions of forest decline. Forests are, in relative terms, slowly evolving systems. Actions taken in the European forests over the past several centuries have given us the forests we have today. Any actions taken over the next decade will play a large part in determining the nature of the forests and forest economy several decades into the future. Therefore, those who design and implement solutions to the problem of forest decline must coordinate actions for the near term to achieve longer-term objectives for the systems under management. This is another central dilemma of management, *think long-term, act now.*

A third dilemma of trying to cope with the forest-decline problem in a broad-scale, long-term context is that the range of affected persons and decision makers is extremely broad, heterogeneous, and very difficult to bound. If the repercussions of continued forest decline become as far-reaching as the partial list above suggests, then the number of societal parties and sectors that would want to be involved in the design and implementation of solutions is large. In this situation, the challenge is to find ways of accommodating the myriad of competing interests, of various strengths, in the search for equitable problem resolution.

1.2 The IIASA Forest Study

Within IIASA's Environment Program, the Biosphere Dynamics Project examines long-term, large-scale interactions between the world's economy and its environment. The Project conducts its work through a variety of basic research efforts and applied case studies. One such study, the Forest Study, has been under way since March 1986, addressing the social, economic, and ecological consequences of forest decline. The immediate focus is on the future development of forest resources in Europe. Objectives of the Forest Study are:

(1) To gain an objective view of potential future developments of the forest resources of Europe.
(2) To build alternative and consistent scenarios about the potential future developments and their effects on the forest sector, international trade, and society in general.
(3) To illustrate the effects of forest decline caused by air pollutants, existing and changed silvicultural strategies, and expansion of the forest landbase.
(4) To identify meaningful policy options, including institutional, technological, and research/monitoring responses that should be pursued to deal with these effects.

A matrix-type simulation model has been developed to forecast various scenarios of the development of forest resources and wood supply under different assumptions about future forest-decline rates, silvicultural practices, and forest-land expansion policies in Europe. A detailed country-by-country database on the forest resources in Europe has been developed by the Forest Study and linked to the simulation model. The model generates forecasts of wood volume over time by country (and subregions of a country), species group, and age, making it possible to undertake a general timber-supply assessment for Europe.

Another major activity of the Forest Study has been to generate information and knowledge about different topics connected to timber assessment. Of special concern is forest decline attributed to air pollutants. Examples of topics related to this issue are forest-decline patterns, monitoring of forest decline, future demand for forest products, future trade in forest products, industrial structure, restoration of declining forests, and social consequences of decline.

The third activity of the Forest Study is to examine strategic policy options for coping with the consequences of the future development of forest resources in Europe by generating a set of *future history* scenarios. A new approach to policy analysis, the *policy exercise*, has been developed and tested. A policy exercise is a flexible process designed as an interface between analysts and policymakers. It consists of one or more structured workshops where the policymakers formulate responses to a basic scenario or situation context, and the scientists simulate the impact of the policy responses and update the world accordingly by introducing constraints on policy options. The basic objective of the work is to set priorities for near-term policy initiatives to help cope with potential undesirable consequences of forest decline.

1.3 Policy Issues Concerning European Forest Resources and Forest Management

One of the most important features of European forests is their economic function as a source of raw materials for the forest-products industry. The forests generate employment opportunities which contribute to rural development by maintaining populations and improving standards of living. More and more attention is now being paid to the importance of forests in environmental conservation and the protection of water, soil, fauna, and flora. The social and recreational functions of the forests are also becoming more significant. Therefore, an increased awareness in European society of the importance of maintaining diversity in the landscape is foreseen.

For several years, European forestry interests have, in general, been overshadowed by agricultural policies; forestry has thus been a matter of relatively minor concern. Recently, there have been some changes in agricultural policies, and the role of forestry has increased. Moreover, large areas of the European forests are subject to serious damage from pollution, fire, disease, and storms. They have been under strong pressure from environmental changes, particularly with regard to the quality of the air. Since the early 1980s, several alarming reports have been released, and the studies have generated major concerns within industry, governments, international organizations, and society in general.

Forest decline is a common phenomenon in Europe. Currently, about 20 percent of the growing stock of Europe's forests is in some state of decline. Bearing in mind the current situation and the growth of forest decline, the Ninth World Forestry Congress appealed to all people and nations to recognize the importance of forest resources for the biosphere and the survival of humanity. The SILVA International Conference on Trees and Forests, held in Paris in 1986, concluded that policymakers have a responsibility to formulate policies for the sound management of the forest resource as a vital component of the biosphere. Individual governments have already adopted measures based on international agreements against forest decline, including restoration. However, the measures taken so far will not be effective in avoiding serious forest decline in Europe in the future (see, for example, InterAction Council, 1989).

When formulating comprehensive forest policies throughout Europe, forest decline must be taken into consideration. Forest policies must be nationally or regionally based, because quite different natural conditions for forest growth exist from country to country throughout the Continent. Recently, the Food and Agriculture Organization (FAO) of the United Nations (FAO, 1988) and the Commission of the European Communities (CEC, 1988a and 1988b) published the forest policies of many countries in Europe. Nilsson (1989b) aggregated the individual national policies expressed in these three publications, and although the aggregation is rough it does indicate how different policy issues vary in importance throughout Europe (see *Table 1.1*).

A comprehensive quantitative forest-resource assessment should be undertaken as a basis for developing forest policies in Europe. However, it is not possible to do this in one comprehensive study mainly because there is a lack of basic data (see Nilsson, 1989b). Among the issues shown in *Table 1.1*, the only aspects which could be dealt with satisfactorily today are:

Table 1.1. Overview of forest-policy issues in Europe.

Policy issues	Number of countries expressing concern
Sustain yield; increase harvest; improve growing stock	15
Better utilization of wood resources (less waste)	2
Increase productivity; expand forest area; transform forests with low productivity; and transform coppice into high forests	8
Establish a natural equilibrium; improve the functions of protection, water supply, and landscape; improve social values of forestry, amenity, and recreation	26
Avoid forest decline caused by air pollutants	6
Improve profitability, economic conditions, and competitiveness of the forest sector	16
Produce high-quality and high-value-added timber	2
Convert marginal agricultural land	6
Prevent forest fires	6
Stimulate rural development	5
Improve structure among private forest owners	3
Control levels of game animals	2

Source: Nilsson (1989b).

- The potential wood supply from a biological point of view.
- The potential effects of forest decline caused by air pollutants.
- The potential effects of future expansions of forest land on future wood supply.

The results presented in this book deal with the long-term potential wood supply in closed forests from a biological point of view. Because of the lack of basic information, it is not possible to carry out quantitative analyses of economic wood supply.

Chapter 2

The Forest Study Timber Assessment

2.1 Introduction

National timber-assessment studies based on dynamic models are well developed in several European countries including Bulgaria, Finland, the former GDR, Sweden, and the United Kingdom (see Evju, 1979). However, consistent and dynamic timber assessments for all of Europe are sparse. The existing comprehensive studies are not based on formal quantitative models. The ECE Timber Committee has carried out four European timber trends studies (ETTS), the first of which was published in 1953 and the latest in 1986 (UN, 1986). So far, these studies have been based on an approach in which the member countries of the organizations are invited to provide forest-resources forecasts for removals and growing stock based on domestic conditions and future plans. The ECE Timber Committee Secretariat analyzes the replies and compiles the results in a consistent way. One advantage of this approach is that knowledge about forest policies in the individual countries will automatically be built into the analyses.

However, there are several drawbacks to this approach. Different methods are used from country to country in data collection and forecasting. Some countries use advanced analytical tools, others use simple methods, while others do not use formal forecasting tools at all. The basic forecasts for the various countries are produced by different people with a wide range of reference frames. Therefore, there are bound to be inconsistencies in the results of these efforts. Countries that use simple forecasting tools, or no formal tools at all, are usually just projecting historical conditions into the future. Without formal forecasting tools, countries cannot describe the dynamic behavior of their forest resources.

Kuusela (1985) presented scenarios of future wood-supply possibilities in Europe based on analyses of individual countries. While Kuusela did not use a formal forest-dynamics forecasting model, he has followed the development of forest resources around Europe for decades and has produced a consistent set of forecasts based on his own experience and knowledge, and on published forecasts from various countries. An advantage of this approach, compared with the ETTS series, is that the analyses have been carried out by one scientist with a consistent method for all countries. A potential disadvantage, the implications of which are largely unexplored, is the possibility for error due to investigator bias or inappropriate methods.

In the IIASA Forest Study, the goal has been to try to simulate the development of the European forests using a formal dynamic model. When discussing the choice of model concept, some general features of forest-resource studies should be explained. One basic distinction is that between a timber-supply prediction and a timber-assessment study. The former aims at forecasting probable wood supply, taking into account forest structure and dynamics as well as timber growers' expected harvest and silvicultural activities. By timber-assessment analyses, we mean wood-supply scenario development based on forest structure and dynamics and a wide range of achievable harvest and silvicultural strategies. Thus, these studies, of which our timber assessment is an example, should be regarded as illustrating possibilities in and implications from the present forest state and structure without aiming at predicting most-probable forest development.

Alig *et al.* (1984) identified four components of timber-supply and timber-assessment modeling: land allocation, progression of the timber inventory, harvest flows, and long-term investments in forest-management strategies. Changes in land allocation can be incorporated as either restrictions on activities or results of specific activities. Harvest flows can be regarded as the outcome of activities for a given period of time in a specific forest state.

A dynamic forest model that recognizes intertemporal dependencies demands an explicit description of the forest. This description should encompass both the initial conditions (or state) and a means of depicting the dynamics of the forest. Three components can be distinguished: a forest-state description, a projection tool, and a set of allowed activities. The state development is dynamically simulated by the projection tool under the control of a specific set of activities.

When classifying forest-projection models, a common distinction is that between forest and stand models. Many authors refer to their models as stand models; however, both Brooks (1987) and Binkley (1987) found surprisingly little in the literature about approaches suitable for large area analysis. From a technical point of view, there is no sharp distinction between stand- and forest-level models. The distinction must be made based on the intended use of the model and on the data used for estimating the model. From a modeling point of view, a stand can be regarded as a physically coherent area on which tree development is biologically dependent and in which the tree community is relatively homogeneous across space. A forest, however, refers to a heterogeneous region in which there are many (perhaps thousands) spatial units – for example, stands – that may be considered biologically independent.

Forest models can be formulated in different ways relating to the basic entities constituting the forest-state description. The most aggregated way is to describe the whole forest area under study as one entity described by some average values for certain parameters (Lönnstedt, 1986). In such cases, the forest, in principle, takes the form of a macroproduction function. Another way is to differentiate the forest state explicitly into a number of entities – stands, age classes, plots, etc. – where the biological developments of the entities are independent of each other (Bengtsson, 1984; Nilsson, 1982). An interesting recent development in multientity models is that entities represent not only a forest area but also a specific geographical location. For example, the PEMU model developed in Berlin represents forests in a grid system, coupling the development of the forest to a transfer model for airborne pollutants (Bellmann and Lasch, 1988).

Activities encompassing all external factors affecting forest development constitute the controlling part of the forest model. The most important activities are forest-management treatments such as thinning, final felling, and regeneration. Landbase changes are seldom incorporated, probably owing to the long time horizon of timber-supply projections. Exceptions are, of course, countries where new areas are afforested with fast-growing species. A significant problem with respect to forest area is the potential for land withdrawal from timber production due to the increasing interest in the non-wood benefits of the forests (UN, 1986).

The degree of sophistication among timber-assessment models can be quite wide-ranging, as the following list of variables from increasingly more sophisticated models shows:

(1) Future growing stock.
(2) Future growing stock and biological-potential harvest levels.
(3) Future growing stock, biological-potential harvest levels, and future distributions of assortments and qualities of wood available.
(4) All of the above plus economically available wood supply.
(5) All of the above plus future flows of non-timber forest benefits, contribution to regional development, etc.

The degree of sophistication is heavily dependent on the quantity and quality of data about forest resources and their uses. Sophisticated models require detailed, high-quality data. Two major classes of models can be used in the forecasting of forest resources: simulation and optimization. Examples of advanced simulation models include HUGIN, which was developed in and for Sweden (Hägglund 1981; Bengtsson, 1984), and that described in Williams and Gasson (1986) and Williams (1987) for projecting the economic wood supply in British Columbia, Canada. Examples of optimization models include TIMBER-RAM in the USA (Navon, 1971) and some dynamic programming models developed in Finland by Kilkki and Pökölö (1975) and Kilkki (1982).

2.2 Conditions for a Timber Assessment for Europe and Data Accessibility

In selecting an appropriate model structure for a European timber assessment, actual forest-resource conditions and data availability must be taken into account. There are large variations and differences among European countries along several dimensions of forestry. These include:

- The natural potential for forest production.
- Forest-management and silvicultural traditions.
- Economic importance of forest resources.
- Ownership patterns and objectives of owners.

Throughout Europe the environmental and social benefits of forests are increasing in importance compared with industrial benefits. Unfortunately, the non-timber benefits of forests are difficult to measure and model quantitatively. The threats from air pollutants, climate change, and fire may increase and pose great uncertainties in analyzing forest-resource futures. In addition, public involvement in setting forest policies is increasing. Along with the expected large-scale conversions of agricultural land to forests in the coming decades, these factors suggest that forestry in the near future will be characterized by major political complications.

Nevertheless, the most important factor in designing a consistent, dynamic, timber-assessment model for all of Europe is the availability of forest-resources data. Data quantity, quality, and accessibility must be added to the list of features of European forestry for which there is large variability among countries (*Table 2.1*). In general, most countries collect huge amounts of data about their forests. However, such data-collection programs are seldom driven by a strong link to quantitative dynamic analyses of future forest resources. These analyses make strong demands on the choice of variables that need to be measured in the forest, variables that are often different from those usually measured to obtain a simple static description of current resources. Timber-assessment analyses require structural variables and information on site quality and growth rates (for example, data on areas, growing stocks, and growth rates for different stand types, age classes, and site classes).

While some countries have rather well-suited databases for timber-assessment studies (e.g., Finland and Poland), others lack basic information (e.g., Germany and Luxembourg). In general, there are some fairly widespread data problems regarding European forests and their management:

- Insufficient data on young forests and forests made up of uneven-aged stands.
- Inconsistent definitions of forest land.
- Insufficient information about the dynamics of potential forest land.
- Sparse documentation on silviculture programs.
- Outdated inventories.
- Insufficient economic information about the forests.

Clearly, the only kind of timber assessment that can be carried out for all Europe in a consistent and dynamic way is one that projects future development of growing stocks and biological harvest potentials. Thus, at this stage, it is not possible to undertake Europewide, quantitative assessments of such aspects as future economic wood supply, future non-timber benefits, and potential contribution of forests to regional development.

Besides forest-resource data quality and availability, there are other important criteria to take into account in choosing and designing a model structure:

Table 2.1. Distribution of basic data used in the study for key forest-inventory variables in European countries.

Country	Regions within country	Owner	Species	Age or diameter class	Site class	Standing volume	Growth
Nordic							
Finland	x	x	x	x	x	x	x
Norway				x	x	x	x
Sweden	x	x	x	x	x	x	x
EEC-9							
Belgium	x	x	(x)	x		(x)	
Denmark			x	x	(x)		
France	x	x	x	x		x	x
FRG[a]			x	x		x	
Ireland	x		x	x	x		
Italy			x	x		x	x
Luxembourg			x	x			
Netherlands			x	x	x	(x)	(x)
UK	x	x	x	x	x	x	
Central							
Austria	x	x		x		x	x
Switzerland	x		x	x	x	x	
Southern							
Greece			x	(x)		(x)	(x)
Portugal	x	x	x	x	x	x	
Spain	x		x	(x)		x	x
Turkey			x	(x)		(x)	(x)
Yugoslavia	(x)		(x)	(x)		x	(x)
Eastern							
Bulgaria			x	x		x	
CSFR	x		x	x	x	x	
GDR[a]			x	x		x	x
Hungary			x	x	x	x	x
Poland	x	x	x	x	x	x	x
Romania			x	x	x		
USSR (Europe)	x		x	x	x	x	x

x = satisfactorily represented in inventory.
(x) = partially represented in inventory.
[a]Prior to German unification.

- The model structure must be appropriate for all countries included in the assessment.
- The model structure must be equally adaptable to both high-quality and low-quality databases.
- The model must be easy to calibrate and to understand.
- Results from the model must be easy to explain.

These criteria require highly aggregated forest-resources data. In Section 2.3, we describe the model structure chosen for our timber assessment for Europe.

2.3 Modeling Approaches

The basic demand on a timber-assessment simulation model is that it must depict the dynamics of the forest under different, exogenously determined, management regimes. The model must represent forest growth in a proper way, react to changes in management programs, react to changes in the environment, and cope with changes in the landbase allocated to forest production.

Since we are dealing with different forest structures, there is a need for different model concepts, founded on different assumptions. The two model concepts we used are the unit area and its characteristics (area-based approach) and the tree and its characteristics (diameter-distribution approach).

2.3.1 Area-based approach

Specific forest types in the study are described by age and standing volume. A matrix defined by 10 intervals for the volume dimension and 6–15 intervals for the age dimension is defined. The forest state is then depicted by an area distribution over this matrix. Dynamics of volume increment are expressed as transitions of areas between specific fixed states in the matrix (*Figure 2.1*).

Harvest and regeneration activities are introduced through controlled transitions. Thinnings are expressed as the fraction of the area residing in a cell of the age-volume matrix that is thinned. This area is moved one step down in the volume dimension, thus simulating the harvest of the difference in volume between the cells, whereupon the area grows in a normal way. An area unit that is clear-cut is moved to a bare-land class, the transitions out of which are controlled by a "young forest" coefficient. This coefficient can then

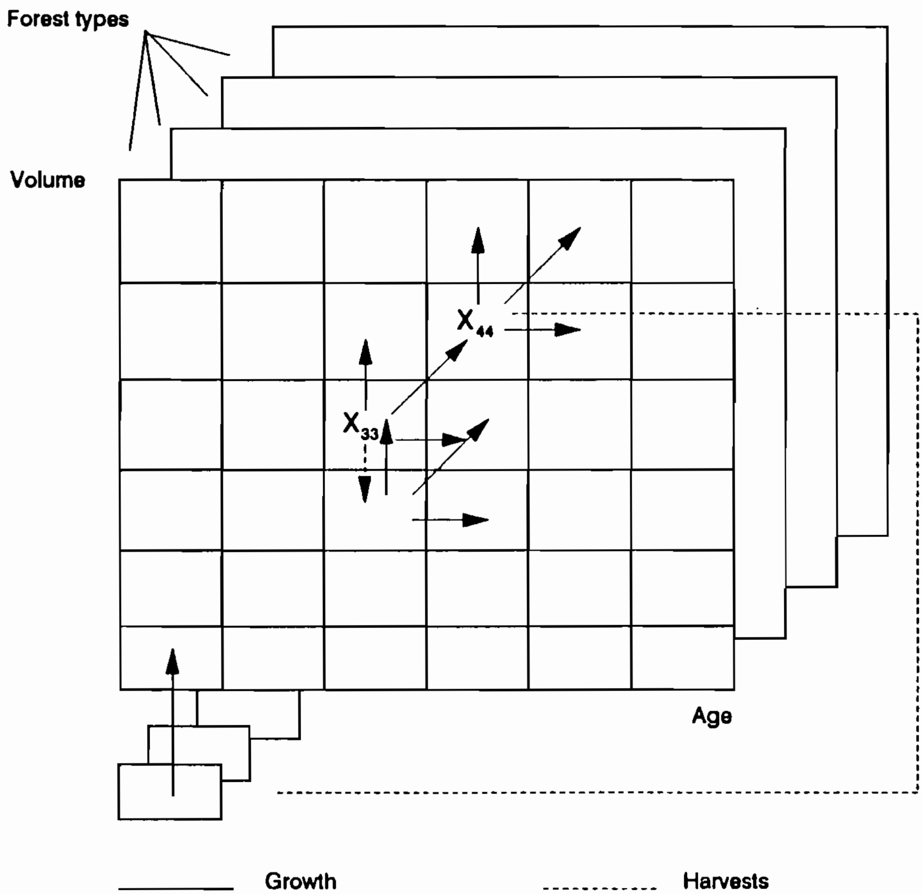

Figure 2.1. Transitions in the area-based model.

be regarded as expressing the intensity and quality of regeneration efforts. A more extensive discussion of the area-matrix model and its characteristics is found in Sallnäs (1990).

Forest Types

An age-volume matrix is established for every forest type. Here, the concept of forest type is used for a stratum that can be defined by country, geography, owner, forest structure (high forest, coppice), site class, and species. The level of aggregation into forest types is of course dependent on available data.

The number of forest types used in our study ranges from 2 to 130 for an individual country. A forest type is distinguished if proper data can be found to provide the state-descriptive parameters for the forest type. A minimum demand is that the total area of the forest type must be separable into age classes for which areas and standing volumes are available.

Estimation of the Growth Model

Three sets of parameters must be estimated or given for the model:

(1) Parameters describing the volume distribution of forest state, such as area and standing volume, including data about the external changes to the initial conditions, such as changes in the forest landbase.
(2) Parameters describing the biological dynamics, such as growth and site quality.
(3) Parameters describing management activities and external factors influencing the dynamics.

Volume distribution. The forest-type definitions imply that only figures for area and standing volume are available at the age-class level. This means that to be able to use the model, a procedure has to be applied to produce a distribution of area over volume for each age class. When advancing this procedure, two assumptions are made:

(1) The standard deviation in relation to the mean volume per hectare for different areas with similar types of forest is approximately the same. Values for the coefficient of variation that were available for some countries were extrapolated to other countries.
(2) The variance in volume per hectare increases with age. The relation between the variance and age must be established.

When the area distribution over volume classes is calculated, three variables are used: (a) the mean volume per hectare, (b) the coefficient of variation in volume per hectare, and (c) the correlation between volume per hectare and age or transformations of age. The calculation is performed in four steps. Calculate the variance in volume per hectare, using mean volume per hectare and the coefficient of variation:

$$s^2 = (mv \times cv)^2 \ ,$$

where cv is the coefficient of variation, mv is the mean volume per hectare, and s^2 is the variance in volume per hectare. Calculate the conditional variance given mean age:

$$s_{ma}^2 = (1 - r^2) \times s^2 ,$$

where s_{ma}^2 is the variance in volume per hectare given mean age and r is the coefficient of correlation between age and volume per hectare. Calculate the ratio of variance to age, and use this ratio to calculate the variance in each age class:

$$k = s_{ma}^2 / ma .$$

The variance in age class i is then

$$s_i^2 = k \times ma_1 .$$

The class limits for the volume classes are calculated using the largest volume per hectare plus three times the largest standard deviation as the class limit for the largest volume class. This span is then divided into a sequence of volume classes of increasing width. The distribution of area over the volume classes is calculated using the mean deviation and the standard deviation of volume in each age class and a modified normal distribution. After analyzing the available data it was decided to use ln (age) as a transformation of age in the calculations involving the correlation between age and volume.

Biological dynamics. The percent volume increment is estimated with functions of the following type:

$$I_v = a_0 + \frac{a_1}{T} + \frac{a_2}{T^2} ,$$

where I_v is the five-year volume increment in percent of the standing volume, T is the total stand age in years, and a_0, a_1, a_2 are coefficients.

The functions are estimated from data on age and percent volume increment. The percent volume increment is calculated from data on volume increment and standing volume (cubic meters per hectare). This means that each function is associated with a series of standing volume over age. Using this method, a distribution over volume classes is created in the matrix. Consequently, the mean volume in an age-volume cell will deviate from the mean volume series. Accordingly, the percent volume increment will also deviate from the value given by the function, which means that some correction must be made. The correction is made according to

$$I_{va} = I_{vf} \times \left(\frac{V_m}{V_a}\right)^{\beta} \quad ,$$

where I_{va} is the five-year percent volume increment for actual standing volume, I_{vf} is the five-year percent volume increment given by the function, V_a is the actual standing volume (cubic meters per hectare), and V_m is the standing volume (cubic meters per hectare) from the mean volume series. The relationship between the relative standing volume and the relative volume increment is described by the parameter β. From studies of this relationship in yield tables and data available for this study, the value of the parameter ranges from 0.25 to 0.45, depending on species, site classification, and the type of data used to construct the yield tables.

Management activities. Management is controlled in two levels in the model. First, a basic management program is defined for each forest type. In this program the activities thinning, final felling, and regeneration are included. Thinnings are expressed as a percent of growth in each forecast period. This percentage of growth is then converted in the forecasting model to percentage of the area in a cell to be thinned. The thinning percentages are extracted mainly from yield tables and vary with age, species, and site.

Thinning programs can be expressed in the model by the algorithm

$$A_t = a + b \times \left(\frac{L}{c}\right)^{d} \quad ,$$

where A_t is the proportion of the volume increment that is thinned, L denotes the number of the age class, and a, b, c, d are parameters that can be changed.

The final felling in forests with even-aged stands is performed using stand age as a criterion for harvest. First, an age is set when final felling can occur. Then, the felling profile for the age classes above this age limit is defined. The amount of final felling in each forecast period (usually five years) is expressed as a proportion of the area in each cell. The following algorithm is used:

$$L \succeq c; A_t = a + b \times (L - c) \quad ,$$

where A_t is the portion of area that will be felled in one forecast period, L is age class number, c is the first age class where final felling is performed, and a and b are coefficients. The coefficients a and b vary depending on species, site class, and other information about silviculture regimes.

The regeneration intensity is expressed by a coefficient controlling the transition rate from the bare-land class to the ordinary matrix. The values used range from 0.4 to 0.9 depending on region and species.

These expressions correspond to an ideal management program. If these programs are applied at an aggregated level, the resulting cutting profiles over time will be quite uncontrolled, since in many cases the present forest state does not correspond to ideal management. Therefore, a second level for defining management programs is introduced. Here, a total harvest level, differentiated by species groups and type of harvests (e.g., thinning, final felling), can be prescribed. In each period, the activity structure defined by the handbook (or ideal) program is shifted upward or downward to meet the prescribed cutting levels.

2.3.2 Diameter-distribution approach

In the diameter-distribution model, the basic entity on which the description of the forest is based is the individual tree instead of the forest area. The state of the forests belonging to a forest type is described by the distribution of stems over a set of diameter classes. In turn, each diameter class is associated with a figure for mean volume per stem. Dynamics are introduced via transitions of stems between the diameter classes (see *Figure 2.2*). In this case the different forest types are defined by country, region, owner, forest structure (e.g., high forest, coppice), and species. The use of site class as an additional separating variable was not possible because supporting data were not available.

The estimation of the model is generally quite straightforward. For every diameter class in the basic data sets, data on number of stems, total volume, and total growth are available. Thus, the transition probability between two subsequent classes can be calculated as

$$P_{i,i+1} = \frac{g_i}{v_{i+1} - v_i} \quad ,$$

where $P_{i,i+1}$ is the probability for a stem to move from diameter class i to $i+1$, and g_i and v_i are the growth and volume per stem, respectively, in diameter class i.

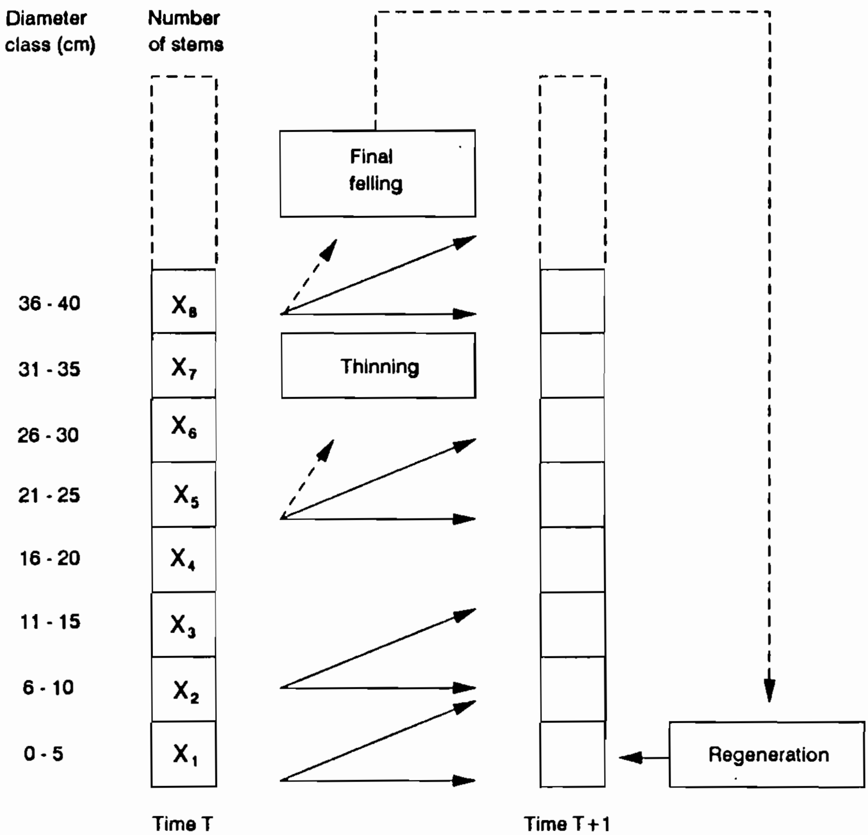

Figure 2.2. Structure of the diameter-distribution model.

One major problem in estimating a model of this kind is the lack of information about regeneration rates. Regeneration in such models must result from the final felling of one stem in a specific diameter class. Since regeneration coefficients are crucial to the properties of such a model, we decided to establish the coefficients in a way that assures stability of model results. This was accomplished by using coefficients that, together with the basic transition probabilities and the management program defined, yield a transition matrix in which the largest eigenvalue equals 1.0. For a more detailed discussion, see Houllier (1986 and 1989).

2.3.3 Simple approach

We tried to use the same basic model structures for all countries in Europe. However, due to data problems this was not possible for some countries. The forest inventory of Greece and parts of Yugoslavia is described in terms of diameter-class distributions. Unfortunately, the data encompass only a narrow range of diameter classes, with no information about corresponding growth rates and standing volumes. For Turkey, standing-volume information did not match the reported forest areas. Thus, in these forests, it was not possible to use either an area-matrix approach or a proper diameter-distribution approach, so the analyses were made in a very approximate way. Potential harvests were determined as a percentage of standing volume and growth rates as initial growth percentages multiplied by a factor that depends on the relations between actual volume and initial volume, according to the formula

$$IV_t = IV_0 \left(\frac{V_t}{V_0}\right)^{\alpha} ,$$

where IV_t and IV_0 are growth percentages at time t and 0, respectively; V_t and V_0 are standing volumes at time t and 0, respectively; and α is a coefficient differentiating species groups and countries.

In the simulation runs using this model, two basic objectives were pursued: a steady harvest level over time and an increasing growing stock over time. As a result, for Greece, Turkey, and Yugoslavia we produced only one basic simulation (instead of three as for all the other countries) of the future wood supply as affected by silviculture and timber harvest.

2.4 Forest Structures

Three different forest structures can be distinguished in the forest-resource data sets: (a) even-aged high forests; (b) uneven-aged high forests; and (c) coppice. Coppice is regarded here as a forest structure more than a regeneration form. There are several different forms of coppice; for example, in the Italian national inventory (Anon, 1988b) four different types are distinguished: simple coppice, composed coppice, coppice with standards, and transition forest which is an intermediate form between coppice and high forest.

To model the development of these different structures, the following basic criteria were used for allocating different forests to the different model

Table 2.2. Type of model used in different European countries.

Country	Area approach	Diameter approach	Simple approach
Nordic			
Finland	x		
Norway	x		
Sweden	x		
EEC-9			
Belgium	x		
Denmark	x		
France	x	x	
FRG	x		
Ireland	x		
Italy	x	x	
Luxembourg	x		
Netherlands	x		
UK	x		
Central			
Austria	x		
Switzerland	x		
Southern			
Greece			x
Portugal	x		
Spain		x	
Turkey			x
Yugoslavia	x		x
Eastern			
Bulgaria	x		
CSFR	x		
GDR	x		
Hungary	x		
Poland	x		
Romania	x		

concepts. In those rare cases where both a diameter-distribution approach and an area approach would have been possible, we regard simple coppice as even-aged forest, consequently modeled with the area approach, while other coppice types are regarded as uneven-aged forest, and consequently modeled with the diameter-distribution approach. As noted above, the forests of certain countries or parts thereof are described in a way that make it more or less impossible to model a more sophisticated simulation. For these cases, the so-called simple model has been used. For most countries in Europe, however, an area-based modeling approach was used (*Table 2.2*).

Chapter 3

Current Condition of European Forest Resources

The latest published information about the current forest resources throughout Europe comes from the United Nations (UN, 1985 and 1986). Data for these publications were gathered from agencies in each participating country during the early 1980s. Thus, the primary forest inventories serving as a basis for these data are from 1980 at the latest, and many are inventories collected during the 1960s and the 1970s. The data collected by the Forest Study from 1986 to 1989 from various agencies throughout Europe often reflect updated inventories describing forest-resource conditions in the mid-1980s. To set the stage for later discussions about potential futures for the forest resources of Europe, under a suite of no-decline and decline scenarios, we first summarize the current status of the forests, drawing upon both the UN documents and the Forest Study databases (*Table 3.1*). There are two major differences between the UN sources and the Forest Study databases. The Forest Study looks at exploitable closed forests, but the UN data refer to all closed forests (*Table 3.1*). In addition, the Forest Study has obtained and used very detailed national inventory databases, while the UN documents aggregate all coniferous species and all nonconiferous species together. A key similarity, by design, is that the Forest Study has used the same country aggregations as those used in the UN studies (*Figure 3.1*).

In the majority of cases, the closed forest areas reported by the UN are slightly larger than the exploitable closed forest areas in the Forest Study databases (*Table 3.1*). This occurs because there are some nonexploitable forest areas (such as park and protected forests) included in the UN database,

Table 3.1. Current condition of European forest resources.

Country Region	Closed forest area (1,000 ha) Source: UN[a]	Exploitable closed forest area (1,000 ha) Source: Forest Study	Growing stock exploitable closed forests (m^3/ha) Source: Forest Study	Volume increment closed forests (m^3/ha/yr) Source: UN[a]
Finland	19,885	19,335	86	3.2
Norway	7,635	5,184	83	2.6
Sweden	24,400	23,365	101	3.0
Nordic	51,920	47,884	93	3.0
Belgium	600	584	148	7.5
Denmark	427	434	141	7.7
France	13,875	13,231	120	4.0
FRG	6,989	7,477	224	5.7
Ireland	347	271	102	7.3
Italy	6,363	4,787	154	3.1
Luxembourg	82	34	249	4.1
Netherlands	294	221	103	4.2
UK	2,027	1,924	108	5.6
EEC-9	31,004	28,963	152	4.5
Austria	3,754	2,831	274	6.2
Switzerland	1,124	1,092	364	5.6
Central	4,878	3,923	298	6.0
Greece	2,512	1,947	73	1.8
Portugal	505	1,475	90	4.4
Spain	3,600 (6,906)[b]	5,605	68	4.3
Turkey	8,830	15,877	58	2.9
Yugoslavia	9,100	8,028	138	3.5
Southern	24,547 (27,853)[b]	32,932	82	3.3
Bulgaria	3,800	3,196	106	1.8
CSFR	4,435	4,159	207	5.4
GDR	2,700	2,461	190	5.8
Hungary	1,612	1,503	182	6.1
Poland	8,588	7,938	163	3.4
Romania	5,940	6,207	178	5.5
Eastern	27,075	25,464	168	4.4
Europe	139,424	139,166	122	

[a]UN (1985 and 1986).
[b]According to Spanish inventory data.

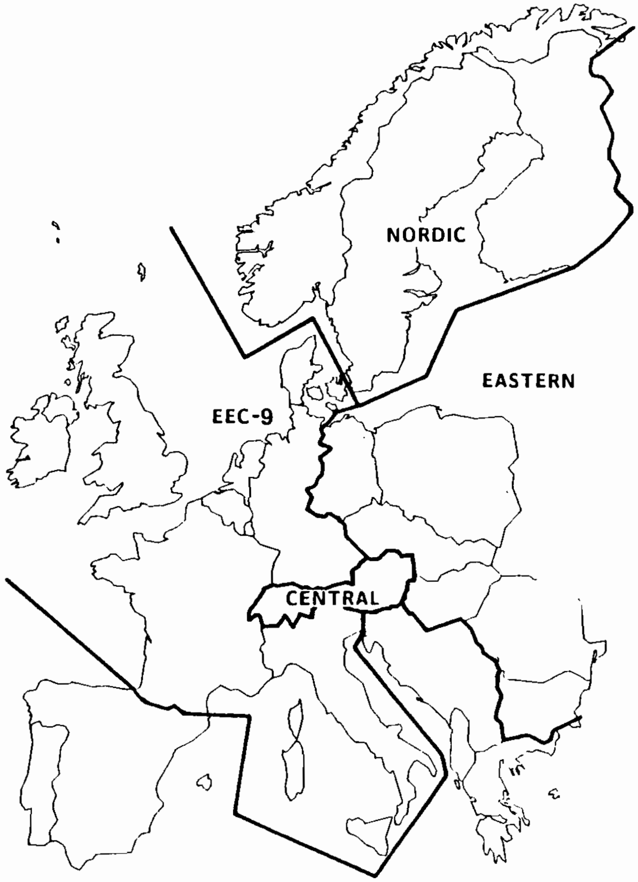

Figure 3.1. Aggregation of countries into regions.

and the Forest Study has in many cases been able to acquire updated inventories compared with those on which the UN compilations are based. Moreover, the ECE Timber Committee Secretariat has, in some cases, had to estimate forest area for lack of credible data from specific countries. One exception is the Southern region. In this region, new inventory information released since the UN compilation shows an increase of the forest landbase in comparison with the UN data.

Table 3.2. Distribution of forest areas and growing stock by species groups and regions.

	Coniferous		Deciduous		Coppice	
Region	Area (1,000 ha)	Growing stock (m^3/ha)	Area (1,000 ha)	Growing stock (m^3/ha)	Area (1,000 ha)	Growing stock (m^3/ha)
Nordic	44,019	94	3,855	82	–	–
EEC-9	13,012	181	10,822	179	5,129	95
Central[a]						
Southern	12,862	99	7,566	143	12,504	27
Eastern	14,183	185	10,206	158	1,075	97

[a]The basic data for the Central region do not allow differentiation into types.
Source: Forest Study.

The volume increment figures given in *Table 3.1* are those of the UN rather than those of the Forest Study. The latter were developed to apply over long future periods; those from the UN database reflect current conditions.

The distribution of growing stocks per unit area across Europe varies: from a high of 364 cubic meters per hectare in Switzerland to a low of 58 cubic meters per hectare in Turkey (*Table 3.1*). In general, the countries of Central Europe have high standing volumes per unit area, mainly because the age-class structures of the forests in this region are biased with large proportions of mature and overmature stands.

In the Nordic and Central regions, coniferous species dominate (UN, 1986). Even in the other regions, coniferous areas exceed the deciduous areas (*Table 3.2*). It is notable that more than one third of the forests in the Southern region are of coppice type. Coppice is also important in the EEC-9 region (*Table 3.2*). Even if large areas of coppice exist, the growing stock per unit area of this group is much smaller than the growing stocks of coniferous and deciduous types. In the Nordic and EEC-9 regions, the growing stock per unit area is roughly the same for both coniferous and deciduous types. In the Eastern region, the growing stock is higher for coniferous than for deciduous species, whereas in the Southern region the conditions are the opposite. We use the term *deciduous* to refer to nonconiferous, broad-leaved species of trees in Europe.

Chapter 4

Future Wood Supply as Affected by Silviculture and Harvest Levels: The Basic Scenarios

4.1 Major Assumptions and Modeling Approach

In this section we outline the major assumptions underlying analyses of three no-decline scenarios: handbook silviculture; harvest levels according to European timber trend study (ETTS-IV; UN, 1986); and Forest Study estimates of reasonable future silviculture and harvest levels.

For all scenarios, and for each species or group of species in each country or region within a country, specific silviculture and management programs are defined. These programs are based mostly on the recommended practices in each region or country. Where no documentation on silviculture programs could be obtained, existing yield tables were used to infer silviculture, with adjustments for existing practices known through unpublished sources. In any scenario the major component of a silviculture program is harvest, disaggregated into thinnings and final fellings. Thinnings are defined as harvested volume as a percentage of current growth for each five-year period. Final fellings are expressed as harvested percentage of area by age class.

The three basic scenarios, with the assumption of no forest decline, are intended to show how growing stock and potential wood supply can evolve under different silviculture programs. Of course, since the silviculture programs in each scenario are expressed mainly as intensities of thinnings and final cuttings, the potential wood supply under each is different from the other two.

It is very important to remember that we are projecting biological potential wood supplies. In reality several factors can restrict actual harvests, such as roundwood prices, behavior of forest owners, and restrictions for non-timber benefits. These factors have not been taken into consideration in our scenarios.

All the simulations have a time horizon of 100 years, with 1985 as the starting point. The forest areas presented in *Table 3.1* are used in all basic simulations. This presents a further discrepancy between our results and those of ETTS-IV, because harvest-level projections given by ETTS-IV actually incorporate some changes in land area. We deal with the issue of a changing forest landbase in our scenario of future forest-land expansion, the results of which are presented in Chapter 6.

Three scenarios have been constructed based on the information about forest resources and silviculture programs provided by our collaborators. The collaborators have reviewed the results from our first simulations for their respective countries. Based on their review, we have rerun all the scenarios to generate the results presented in Section 4.3.

4.1.1 Basic Handbook Scenario

In the scenario we call the Basic Handbook Scenario, the forests of each country are treated strictly in accordance with the silviculture programs that have been defined as ideal at the stand level. These silvicultural programs have been developed mainly by government and academic forestry research institutions, and have been published in textbooks, manuals, and guidebooks. Handbook silviculture means the ideal silvicultural programs (i.e., regeneration, tending, thinning, rotation) that analysts and researchers claim should be practiced under normal conditions in the forests of each country. In our implementation of this scenario, we apply the handbook silviculture rules strictly, beginning in the first five-year period, regardless of the degree to which they were actually applied in each country. Results from using this approach show the degree to which the actual forest structure in each country matches an "ideal" structure (that is, if ideal silviculture had been applied for a long time previously), which in turn indicates the degree to which forest policies incorporating ideal silviculture have been implemented in the various countries.

4.1.2 Basic ETTS-IV Scenario

In the scenario we refer to as the Basic ETTS-IV Scenario, we have constrained total wood supply taken from the forests at the levels of the high ETTS-IV scenarios up to the year 2020 (UN, 1986). The ETTS-IV harvest level of 2020 is used for the remainder of the simulation period (i.e., up to 2085). We use this scenario to explore the forest-dynamics effects of implementing the harvest levels of ETTS-IV, which are official estimates from the contributing countries.

Our approach in this scenario was to implement handbook silviculture to the extent possible under the harvest constraints imposed. The inability to implement handbook rotation periods is evident through comparison of the harvest patterns in the first few periods of the Basic Handbook Scenario and the Basic ETTS-IV Scenario. The former often results in huge increases in final cuttings when the large areas of overmature stands, which have been accumulating in the forests under conditions of not implementing handbook silviculture for several decades, are rapidly cut. Thus, implementation of ETTS-IV harvest levels often means letting many forest stands get beyond handbook rotation age.

4.1.3 Basic Forest Study Scenario

The objective in the scenario we call the Basic Forest Study Scenario is to strive for consistently high levels of both growing stock and harvest levels over the simulation horizon of 100 years. Handbook silviculture is implemented to the extent possible under these new harvest constraints.

4.2 Guide to the Results

In this book, we focus on simulation results at the regional and country levels. The five regions (Nordic, EEC-9, Central, Southern, and Eastern) are defined according to the UN convention in ETTS-IV (see *Figure 3.1*). For each region, and for Europe as a whole, we present one table and three sets of diagrams. The tables and diagrams convey information from all three scenarios. *Tables 4.1* to *4.6* present selected projection data on growing stock and annual harvest volumes at the beginning of the simulation and at specific points during the simulation. These data are also contained in the diagrams, but are provided in tabular form for convenient numerical comparison. The growing stock and potential harvest level is expressed in cubic meters over bark. Bar charts on projected development of annual growing stock and annual harvest levels for each five-year period are given for total forests (*Figures 4.1, 4.4, 4.7, 4.10, 4.13, 4.16*), coniferous forests (*Figures 4.2, 4.5, 4.8, 4.11, 4.14, 4.17*), and deciduous (i.e., nonconiferous) forests (*Figures 4.3, 4.6, 4.9, 4.12, 4.15, 4.18*). The results for individual countries are presented in Appendix B.

4.3 Discussion

4.3.1 Nordic region (Table 4.1 and Figures 4.1 to 4.3)

Results for the total forests using the Basic Handbook Scenario indicate that the forests of the Nordic region do not currently have a structure corresponding to an implementation of ideal silviculture programs. This is evident from the characteristic large pulse in the harvest level in the first five-year period of the simulation. In applying ideal handbook silviculture immediately, the move toward a more balanced age-class structure is rapid, but this can only come with concomitant, unrealistically large harvest levels over some 15–20 years, especially in the first five years. The overall forest age-class structure is responsible for this phenomenon – the distribution is strongly weighted by substantial areas of mature and overmature coniferous forest (see Appendix B for age-class structures for individual Nordic countries: Sweden, Finland, and Norway), much of which is harvested immediately when handbook silviculture is applied.

The Basic ETTS-IV Scenario suggests that there are no forest-structure constraints on meeting the harvest levels prescribed. Indeed, it shows that harvests could potentially be even higher, since growing stock climbs steadily throughout the simulation period. This is confirmed by the Basic Forest

Table 4.1. Selected data on potential harvest and growing stock in the Nordic region under the basic scenarios.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	93–154	93–147	93–147
Fellings (mill. m^3 o.b./yr)			
Year 1	312.2	123.8	124.4
Year 40	119.3	154.7	158.3
Year 80	166.5	155.4	161.9
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	94–156	94–154	94–150
Fellings (mill. m^3 o.b./yr)			
Year 1	289.2	106.2	113.4
Year 40	107.5	141.7	145.3
Year 80	151.8	141.6	147.6
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	82–127	82–66	82–115
Fellings (mill. m^3 o.b./yr)			
Year 1	23.0	17.6	11.0
Year 40	11.8	13.0	13.0
Year 80	14.7	13.8	14.3

Study Scenario in which a total of 3 to 6 million cubic meters more per year is removed over the 100-year period compared with ETTS-IV harvests. The Basic Forest Study Scenario is based on handbook silviculture but is adjusted to account for the actual forest structure at the beginning of the simulation, thus preventing massive harvests in the first periods and keeping them at realistic levels.

In all three scenarios, both coniferous and deciduous growing stocks increase overall, in some cases dramatically, from an average of some 90 cubic meters per hectare initially to 147 to 154 cubic meters per hectare in 100 years. The strongest growing-stock increases occur in coniferous forests, by roughly 60 percent (absolute increase of about 55 to 60 cubic meters per hectare). This development indicates that the structure of Nordic forest resources is relatively good – potential harvest levels could be even higher than the Basic Forest Study Scenario predicts without apparently compromising long-term sustainability of the harvests and the forest resources.

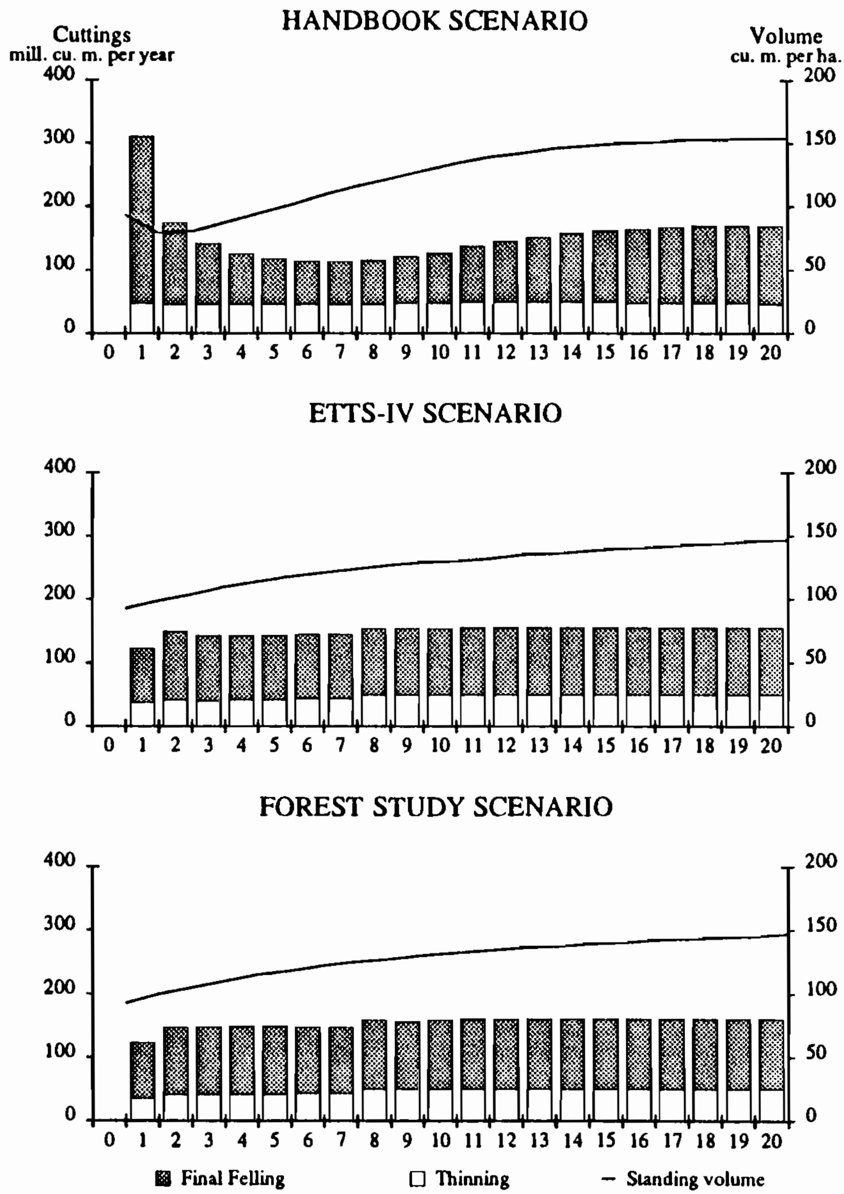

Figure 4.1. Projections for total potential harvest and growing stock in the Nordic region under the basic scenarios.

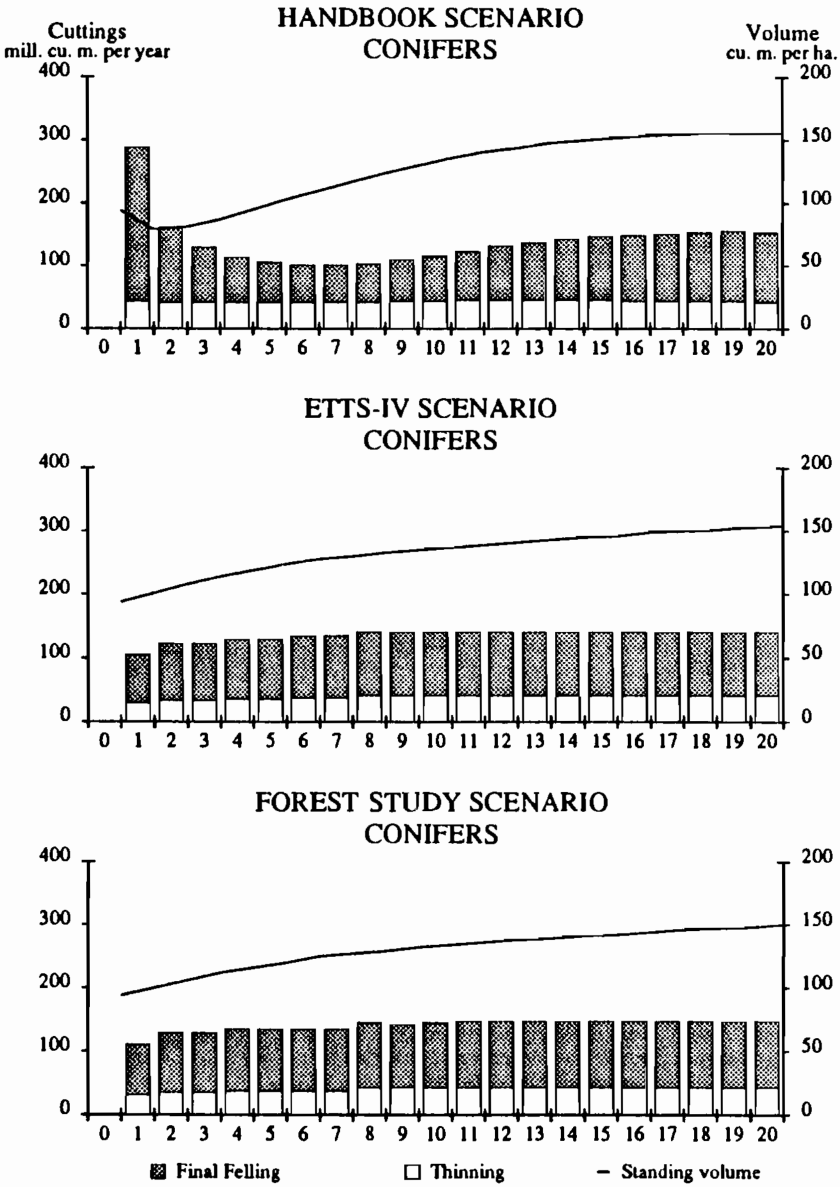

Figure 4.2. Projections for potential harvest and growing stock of coniferous forests in the Nordic region under the basic scenarios.

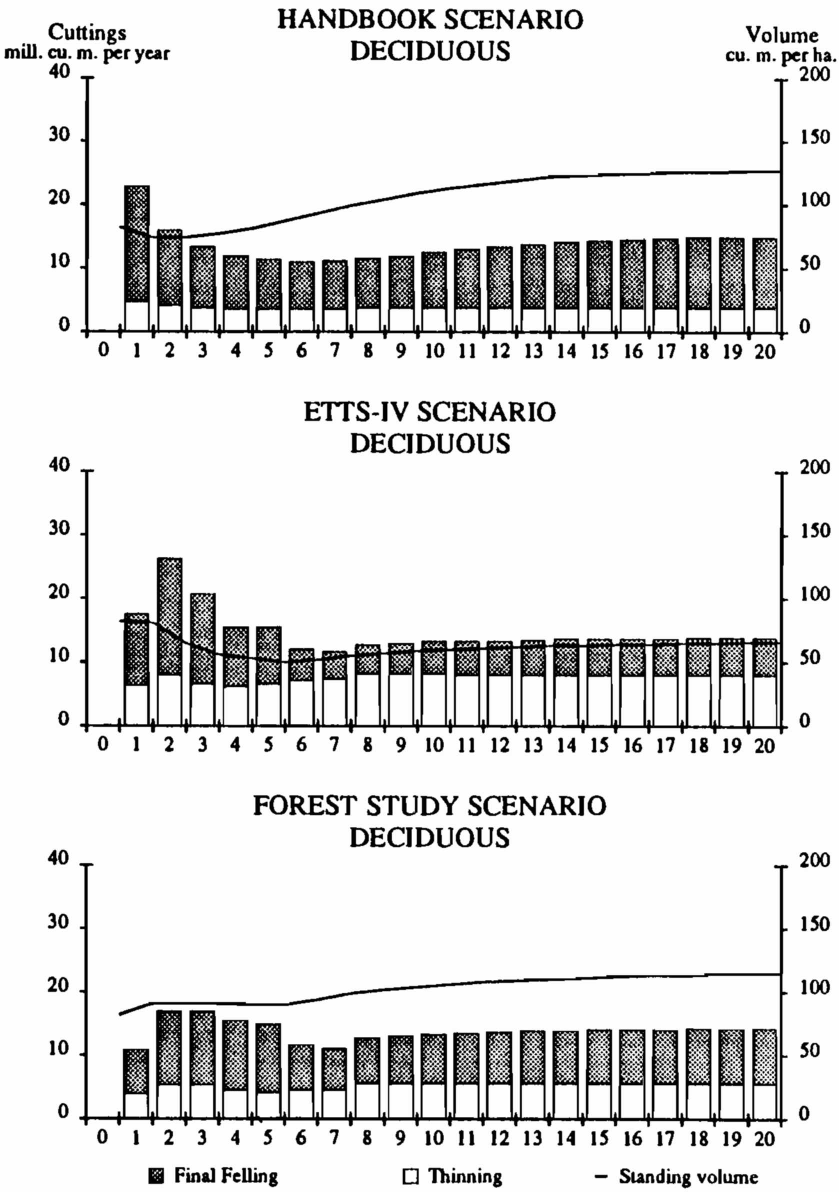

Figure 4.3. Projections for potential harvest and growing stock of deciduous forests in the Nordic region under the basic scenarios.

Table 4.2. Selected data on potential harvest and growing stock in the EEC-9 region under the basic scenarios.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	152–184	152–222	152–185
Fellings (mill. m^3 o.b./yr)			
Year 1	229.9	102.6	126.9
Year 40	154.2	141.4	157.1
Year 80	161.8	127.9	150.8
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	181–244	181–264	181–229
Fellings (mill. m^3 o.b./yr)			
Year 1	112.4	57.9	76.7
Year 40	91.0	92.8	95.4
Year 80	95.1	82.9	95.1
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	179–187	179–262	179–189
Fellings (mill. m^3 o.b./yr)			
Year 1	70.4	32.0	33.5
Year 40	33.7	33.7	39.9
Year 80	36.0	28.3	35.5
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	95–100	95–137	95–121
Fellings (mill. m^3 o.b./yr)			
Year 1	47.1	12.7	16.7
Year 40	29.5	14.9	21.8
Year 80	30.7	16.7	20.2

4.3.2 EEC-9 region (Table 4.2 and Figures 4.4 to 4.6)

The EEC-9 region also has an overall discord between the initial structure of the forest resources and the structure that would have developed if handbook silviculture had been implemented. This is evident from the early harvest pulse in the results of the Basic Handbook Scenario. The overall growing stock of the region increases with time under this scenario. The ETTS-IV harvest levels for the entire region are attainable for a while, but not beyond 40 years, especially for deciduous types. In the long term, they must be reduced somewhat to hold growing stock stable. The Basic Forest Study Scenario invokes a more gradual increase in harvest in the near term than

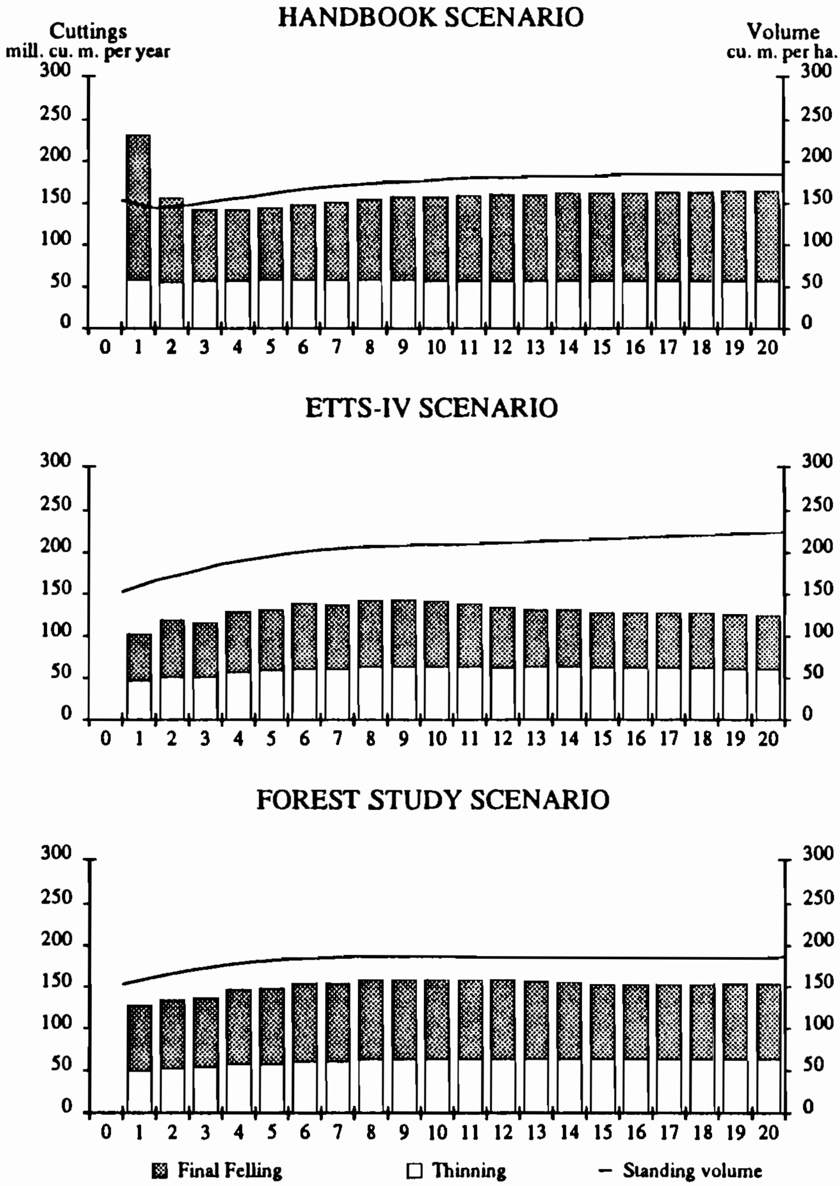

Figure 4.4. Projections for total potential harvest and growing stock in the EEC-9 region under the basic scenarios.

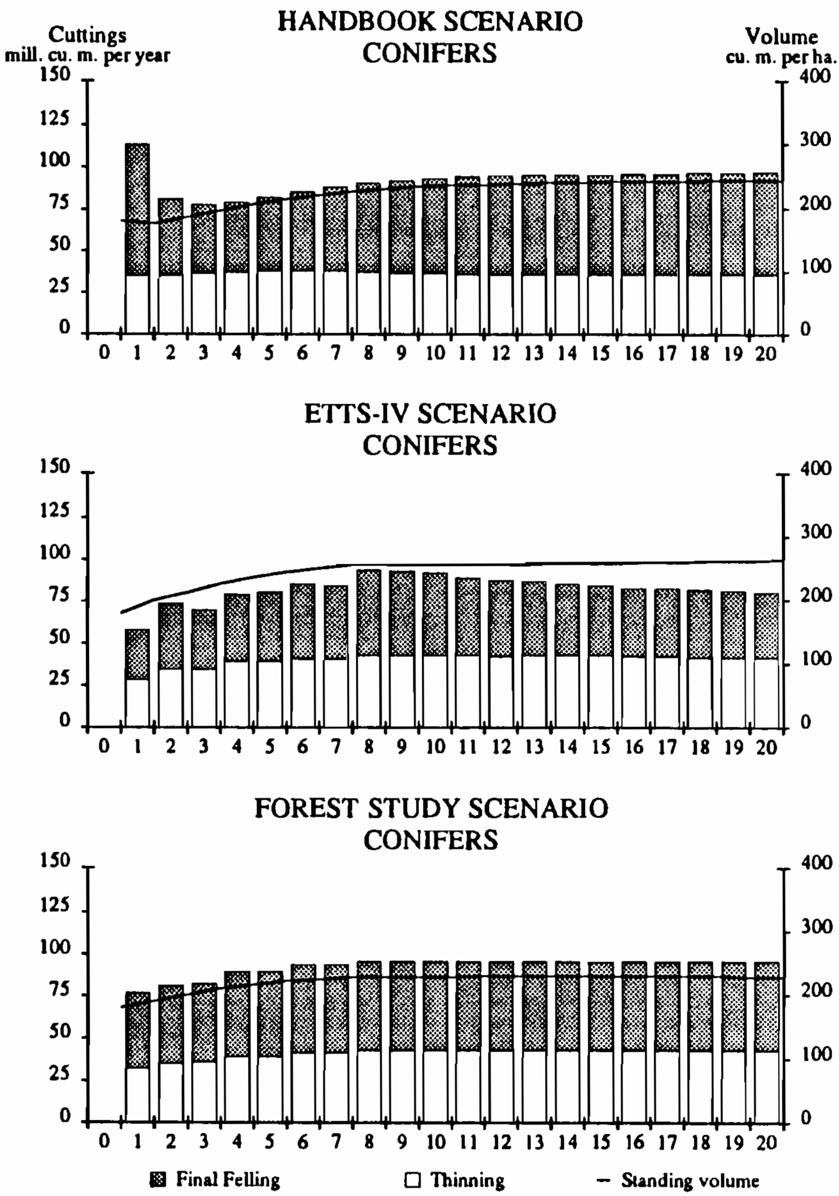

Figure 4.5. Projections for potential harvest and growing stock of coniferous forests in the EEC-9 region under the basic scenarios.

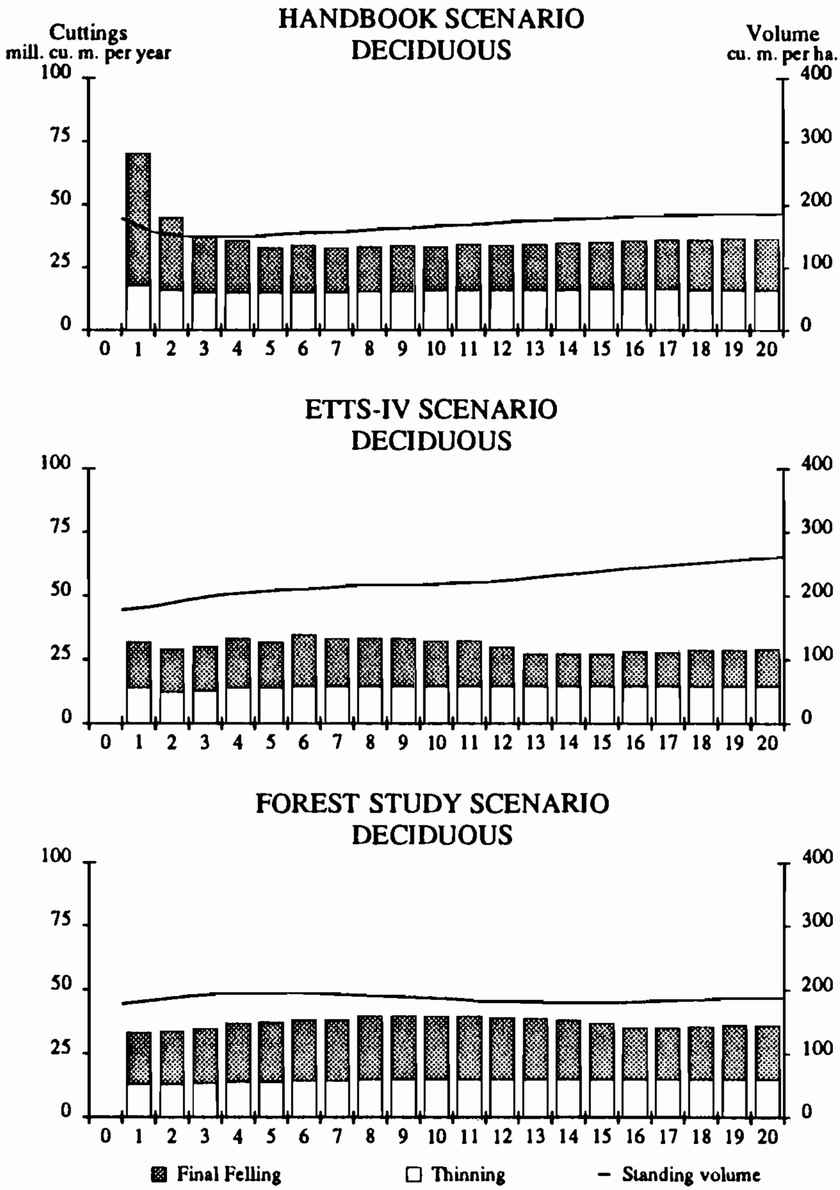

Figure 4.6. Projections for potential harvest and growing stock of deciduous forests in the EEC-9 region under the basic scenarios.

Table 4.3. Selected data on potential harvest and growing stock in the Central region under the basic scenarios.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	298–342	298–315	298–350
Fellings (mill. m^3 o.b./yr)			
Year 1	48.2	20.0	23.0
Year 40	24.7	26.1	25.1
Year 80	26.5	26.1	25.1
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	301–343	301–312	301–345
Fellings (mill. m^3 o.b./yr)			
Year 1	46.6	18.6	21.6
Year 40	23.0	24.4	23.6
Year 80	24.6	24.4	23.6
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	260–334	260–348	260–408
Fellings (mill. m^3 o.b./yr)			
Year 1	1.6	1.4	1.4
Year 40	1.7	1.7	1.5
Year 80	1.9	1.7	1.5

does the Basic ETTS-IV Scenario, arriving at a higher overall harvest level in the long term with a similar, stable, high growing stock. More than half of the coniferous harvest in the EEC-9, which dominates the region's harvest, comes from final cuttings.

4.3.3 Central region (Table 4.3 and Figures 4.7 to 4.9)

Because a distinction between coniferous and deciduous species has not been made for the Austrian data, all Austrian forests have been counted as coniferous for the Central region; thus deciduous forests in this summary are only those of Switzerland.

The pattern of harvest-level development in the Central region under the Basic Handbook Scenario is the same as that of the Nordic and Central regions. Thus, handbook silviculture has obviously not been implemented in recent decades. The ETTS-IV harvest levels can certainly be fulfilled (at least for conifers, which strongly dominate the total harvest), but not

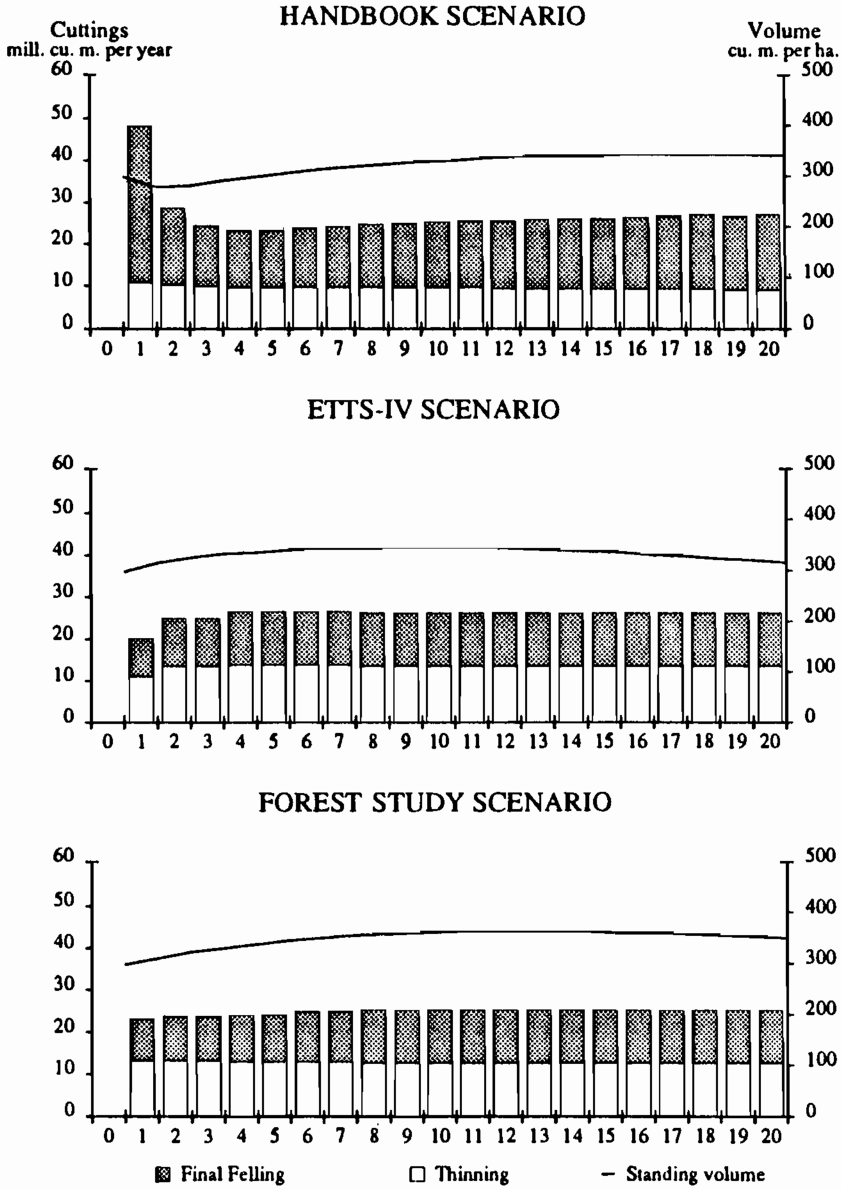

Figure 4.7. Projections for total potential harvest and growing stock in the Central region under the basic scenarios.

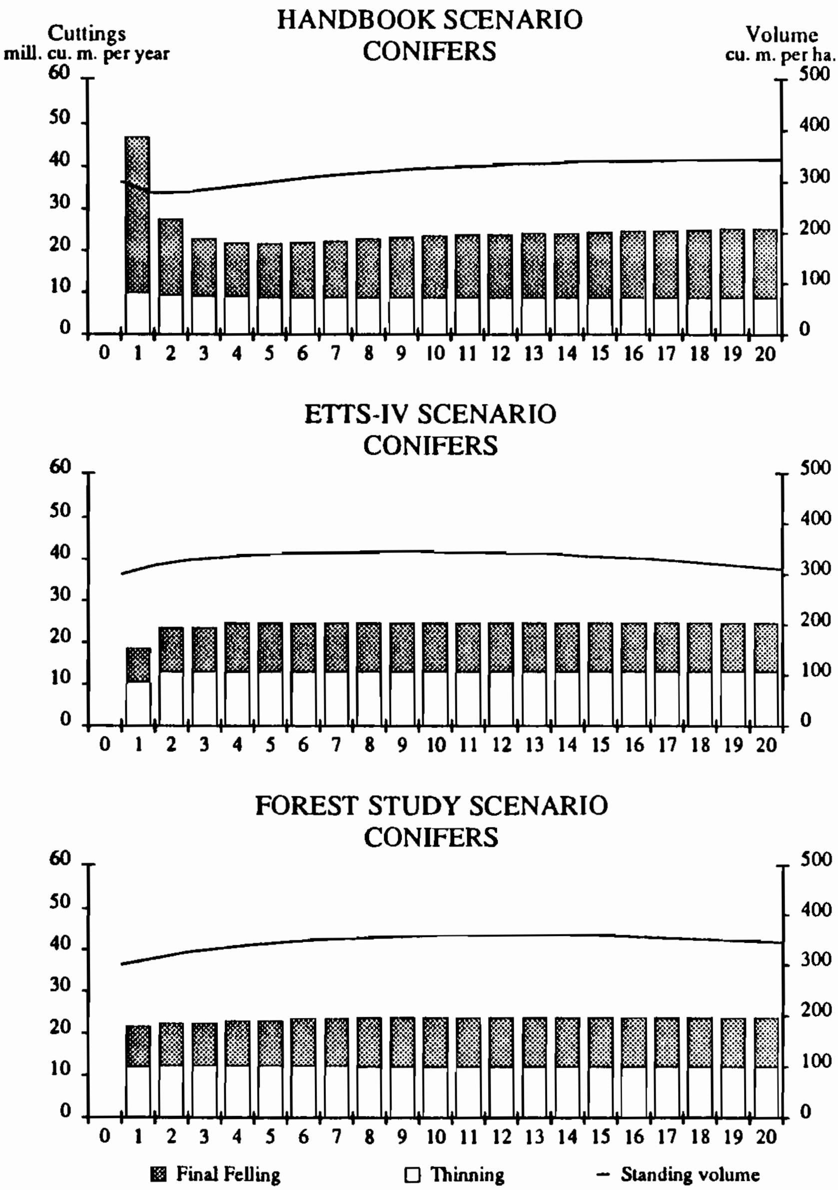

Figure 4.8. Projections for potential harvest and growing stock of coniferous forests in the Central region under the basic scenarios. Data for Austria include coniferous and deciduous species.

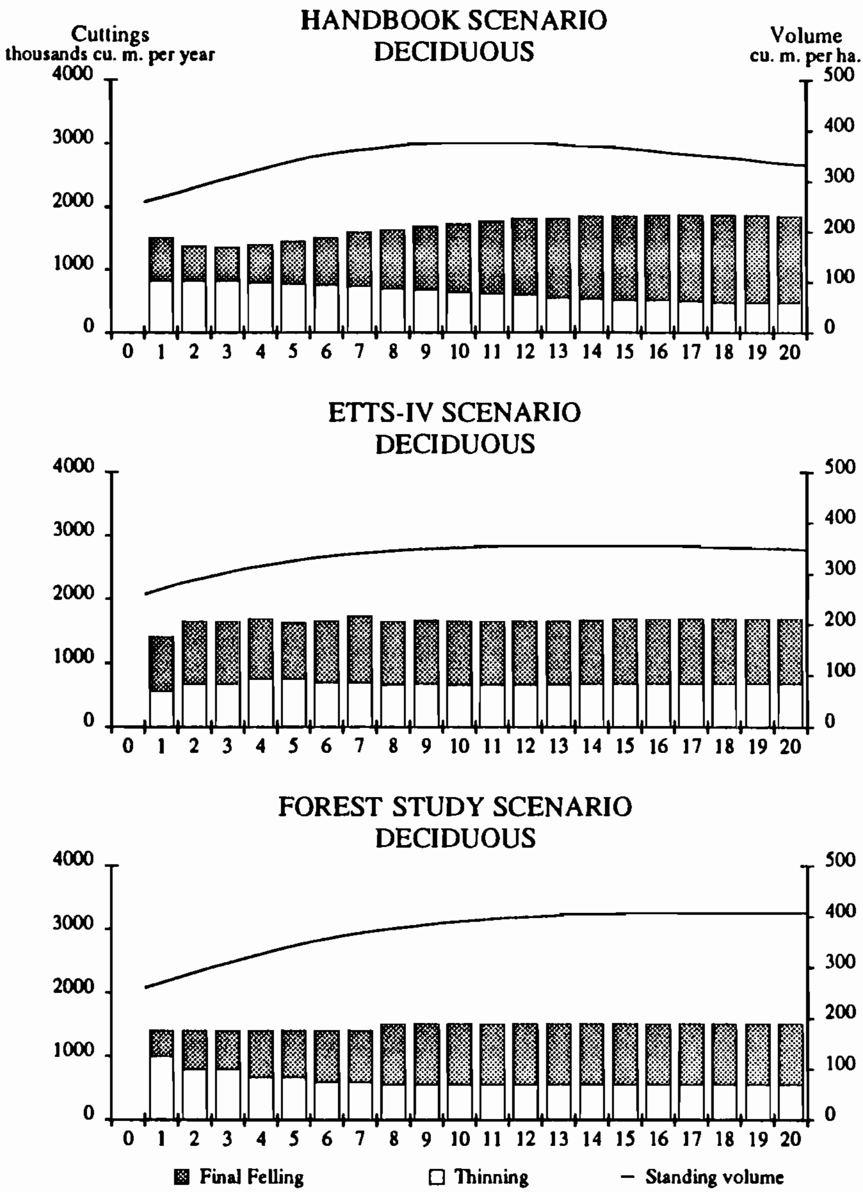

Figure 4.9. Projections for potential harvest and growing stock of deciduous forests in the Central region under the basic scenarios. Only Switzerland.

Table 4.4. Selected data on potential harvest and growing stock in the Southern region under the basic scenarios.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	82–124	82–122	82–127
Fellings (mill. m^3 o.b./yr)			
Year 1	77.8	71.4	69.8
Year 40	76.7	82.5	77.5
Year 80	84.5	84.0	83.0
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	99–159	99–158	99–164
Fellings (mill. m^3 o.b./yr)			
Year 1	29.0	32.0	28.4
Year 40	31.6	31.9	32.2
Year 80	36.5	36.5	35.6
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	143–219	143–214	143–222
Fellings (mill. m^3 o.b./yr)			
Year 1	27.2	25.4	25.4
Year 40	28.6	31.3	28.8
Year 80	31.3	30.4	30.9
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	27–28	27–27	27–29
Fellings (mill. m^3 o.b./yr)			
Year 1	21.6	14.0	16.0
Year 40	16.5	19.3	16.5
Year 80	16.7	17.1	16.5

without a slowly decreasing growing stock. In the Basic Forest Study Scenario, initial harvest levels are kept below those of ETTS-IV, leading to higher long-term sustainable harvests and fairly steady growing stocks for both coniferous and deciduous types (although deciduous stock reaches a higher level). In conifers, the proportion of thinnings in the total harvest is higher in the Forest Study Scenario than in the Handbook Scenario.

4.3.4 Southern region (Table 4.4 and Figures 4.10 to 4.12)

The analyses for the Southern region unfortunately do not have the same degree of consistency as the results for the other regions, for several reasons.

First, because of limitations in the basic inventory data for Spain, the total forest had to be analyzed using a diameter-distribution model rather than an area-based model. This must occur despite the fact that many of Spain's forests are managed on an area basis. Moreover, there are no possibilities to generate either a Basic Handbook Scenario or an Basic ETTS-IV Scenario.

We have not been able to produce a stable simulation over 100 years by invoking handbook silviculture, and we have not been able to determine a credible way of arranging the harvest rules in the diameter classes when the total harvest is set to ETTS-IV levels. Therefore, we present only one basic scenario for Spain, the Basic Forest Study Scenario which has a strong flavor of handbook silviculture. The harvests for Spain (see Appendix B) register entirely as thinnings. For Greece, Turkey, and parts of Yugoslavia the situation is somewhat similar. As the inventory databases for these countries are much simpler than our ideal database, we have had to employ a rudimentary model structure for the simulations (as discussed in Section 2.3.3). Again, we have invoked only one scenario, the Basic Forest Study Scenario, which closely resembles implementation of handbook silviculture.

In aggregating the results to the regional level, simulation output from the Basic Forest Study Scenario for Greece, Spain, and Turkey has been used for all three scenarios for the region. This causes a smoothing out of the regional results for the Basic Handbook and the Basic ETTS-IV Scenarios, especially since Spain and Turkey have large forest landbases. Thus, all three basic scenarios generate similar results for harvest levels and growing-stock development for total, coniferous, and deciduous forests. Total harvests are steady at about 75 million cubic meters per year, and growing stock increases slightly from about 80 to about 120 cubic meters per hectare. The apparently low growing stock is strongly influenced by the large areas of poorly stocked coppice forests. For both coniferous and deciduous types, the Basic Forest Study Scenario generates a slightly smaller harvest level than does the Basic ETTS-IV Scenario. However, the Basic Forest Study Scenario harvests are more even and stable over time, and the growing stock develops to a slightly higher level. Coniferous growing stock in this scenario rises from 100 to nearly 160 cubic meters per hectare, and deciduous stock from 150 to 215 cubic meters per hectare. The total harvest of some 75 million cubic meters per year is made up of about 30 million cubic meters per year each for coniferous and deciduous species, and roughly 15 million cubic meters per year for coppices.

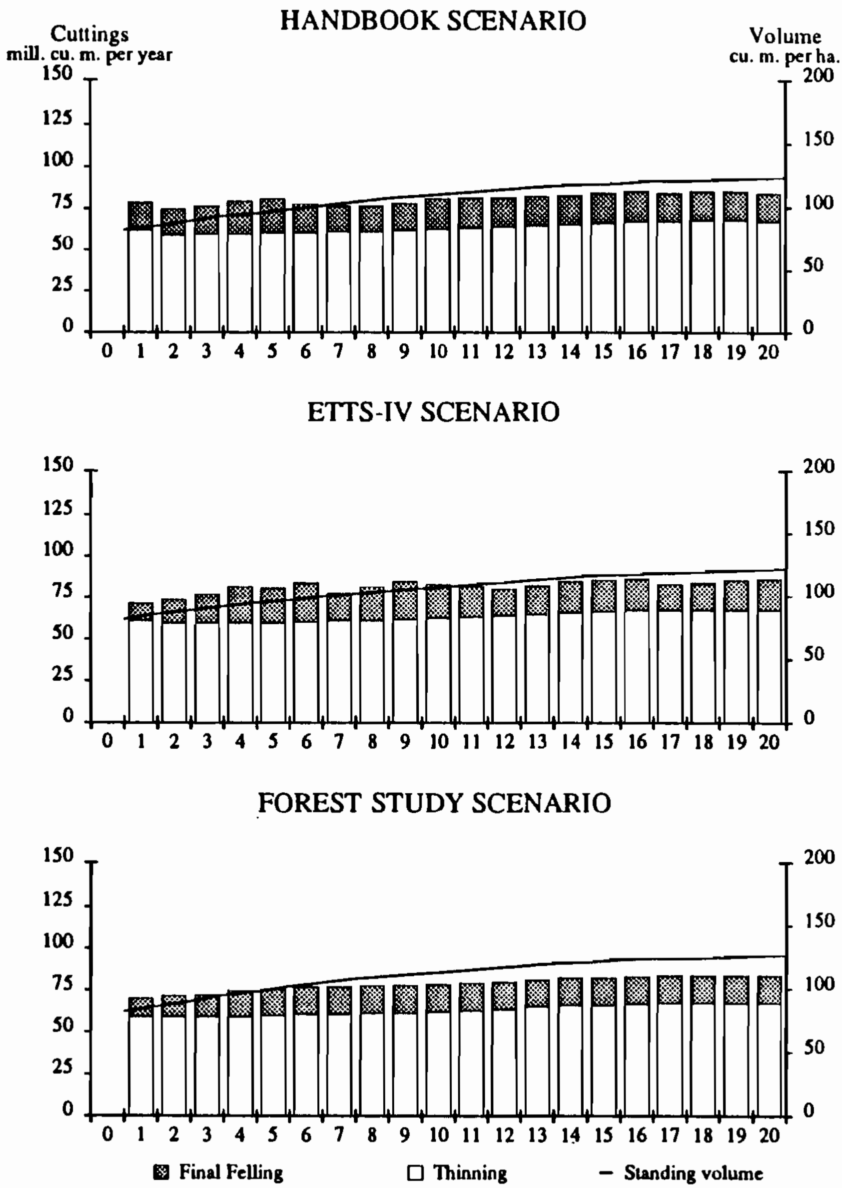

Figure 4.10. Projections for total potential harvest and growing stock in the Southern region under the basic scenarios.

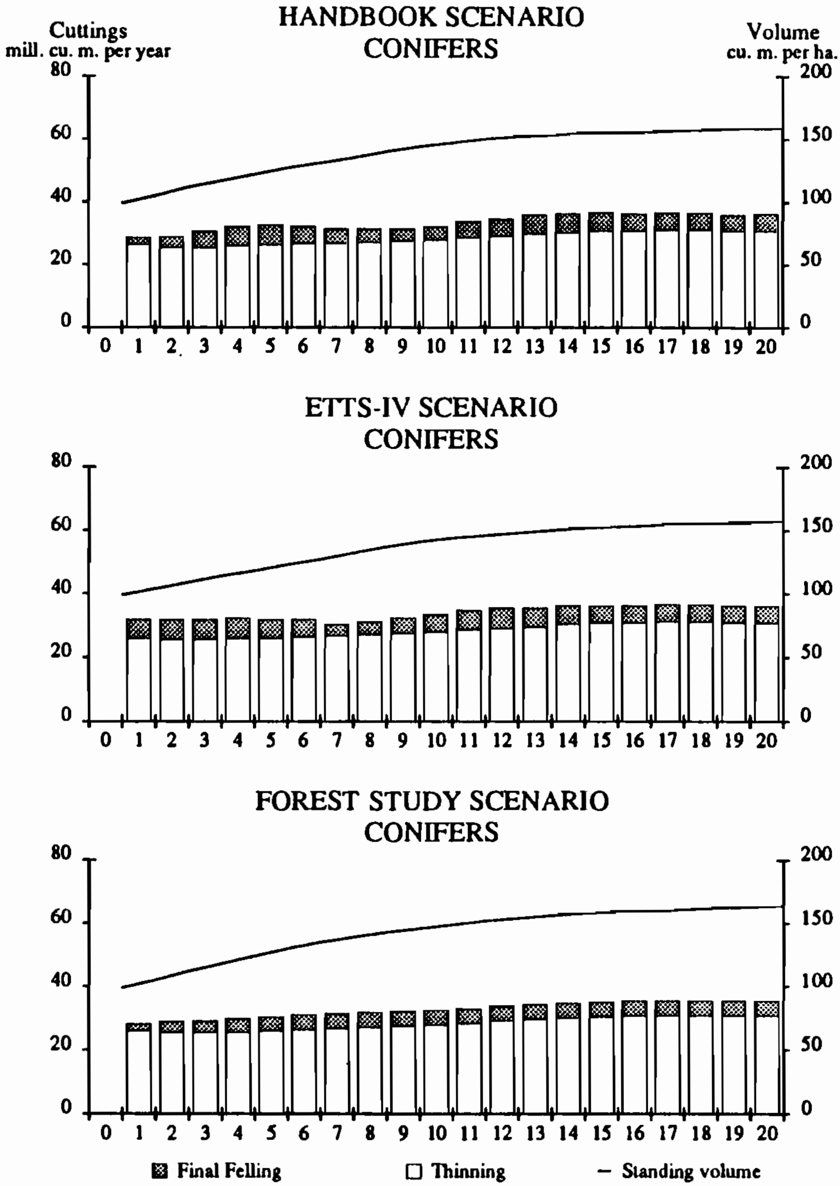

Figure 4.11. Projections for potential harvest and growing stock of coniferous forests in the Southern region under the basic scenarios.

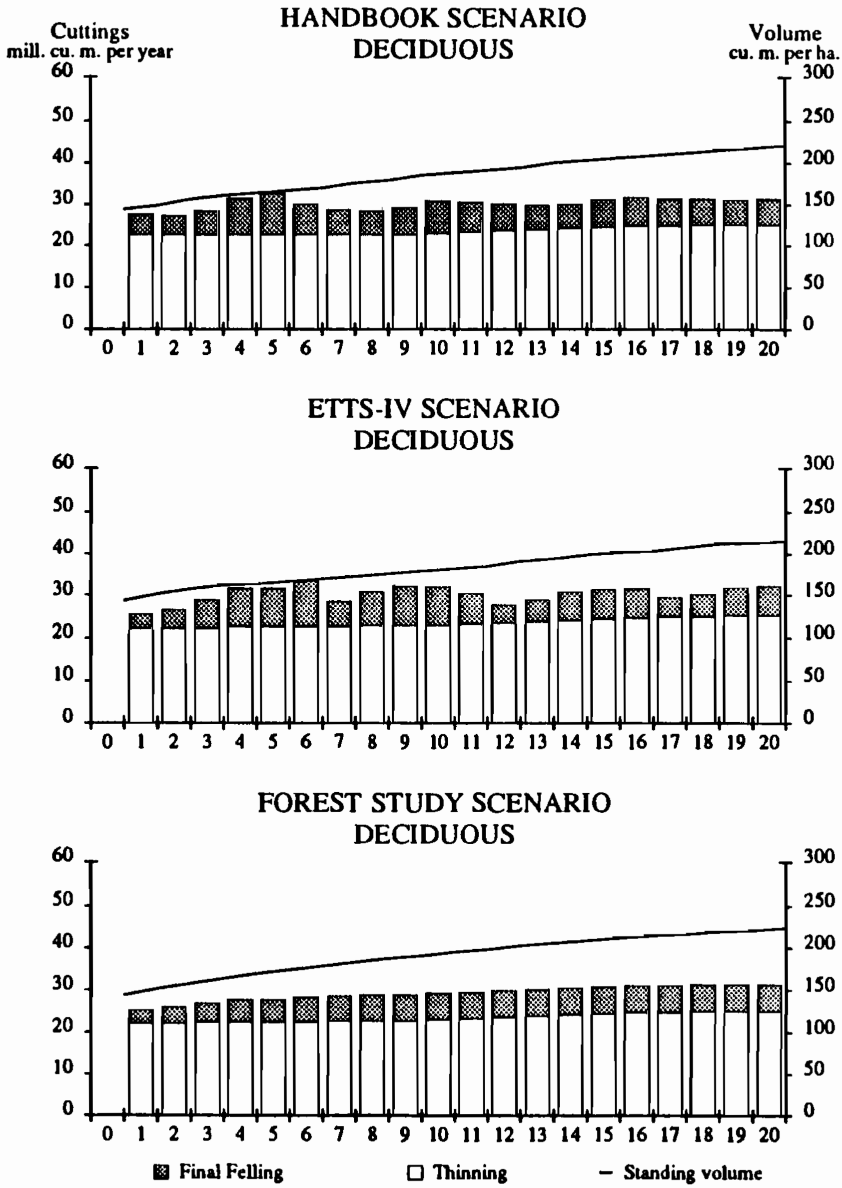

Figure 4.12. Projections for potential harvest and growing stock of deciduous forests in the Southern region under the basic scenarios.

Table 4.5. Selected data on potential harvest and growing stock in the Eastern region under the basic scenarios.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	169–202	169–246	169–206
Fellings (mill. m^3 o.b./yr)			
Year 1	207.3	93.1	116.2
Year 40	120.9	112.6	129.9
Year 80	130.1	112.5	127.5
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	185–234	185–276	185–235
Fellings (mill. m^3 o.b./yr)			
Year 1	108.1	56.3	68.6
Year 40	73.0	67.3	76.1
Year 80	79.5	67.2	76.1
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	158–174	158–224	158–174
Fellings (mill. m^3 o.b./yr)			
Year 1	92.6	34.4	45.4
Year 40	43.4	42.3	51.0
Year 80	46.7	42.3	48.6
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	97–93	97–119	97–130
Fellings (mill. m^3 o.b./yr)			
Year 1	6.6	2.4	2.2
Year 40	4.5	3.0	2.8
Year 80	3.9	3.0	2.8

4.3.5 Eastern region (Table 4.5 and Figures 4.13 to 4.15)

The same general pattern for harvest levels is apparent in the Eastern region under the Basic Handbook Scenario as in the Nordic, EEC-9, and Central regions. Thus, the early harvest pulses indicate weak correspondence between initial forest structure and implementation of handbook silviculture, although the pulse is not extreme in the Eastern region. The ETTS-IV harvest levels can be met over the whole simulation for deciduous species, but not for conifers despite a steady increase in growing stock. The Basic Forest Study Scenario manages to increase overall harvests by some 20 percent over the cumulative levels of the Basic ETTS-IV Scenario and still maintain

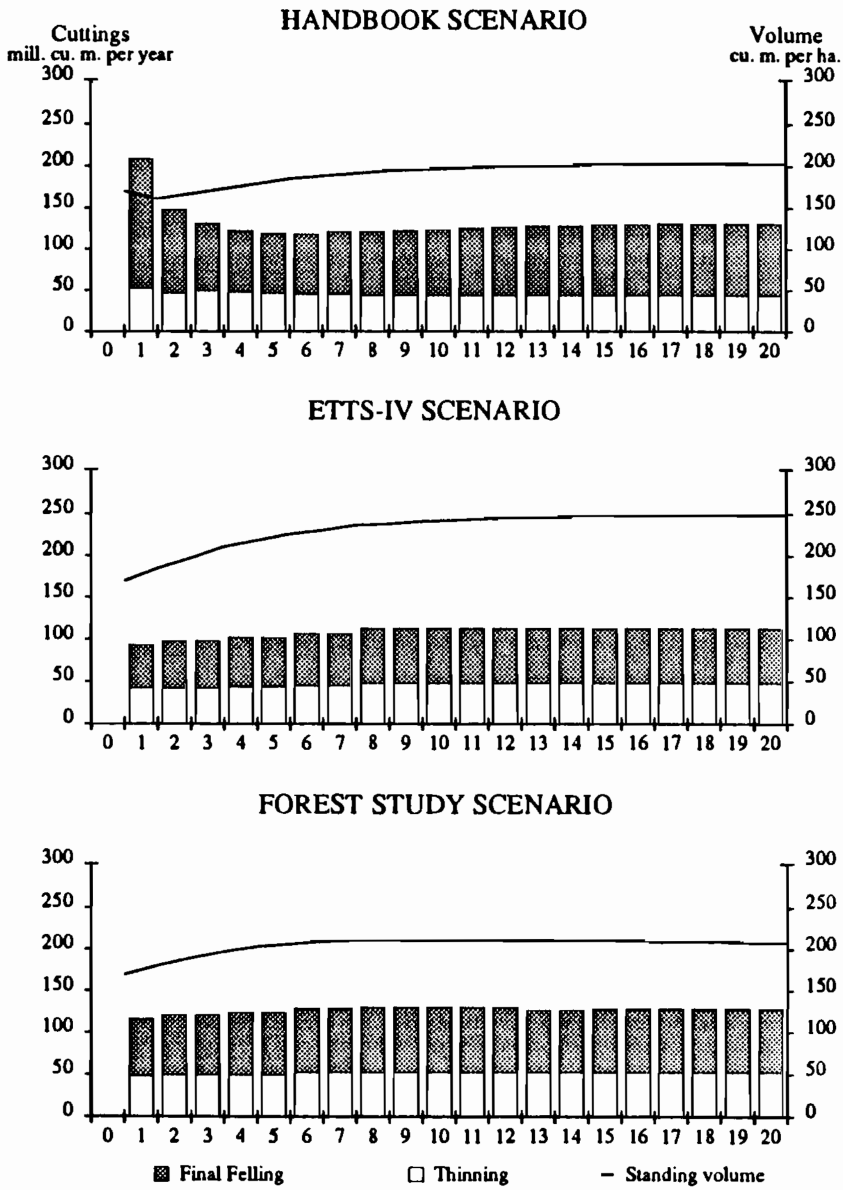

Figure 4.13. Projections for the total potential harvest and growing stock in the Eastern region under the basic scenarios.

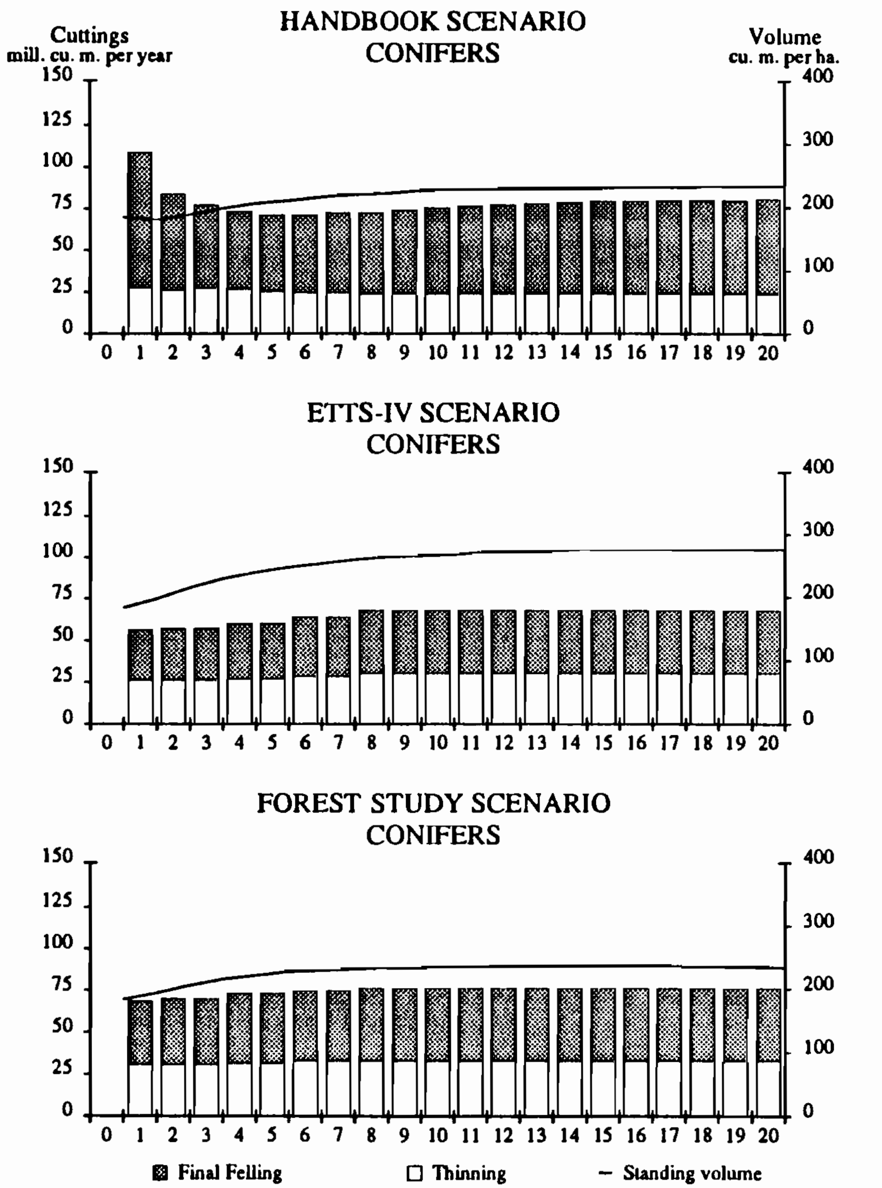

Figure 4.14. Projections for potential harvest and growing stock of coniferous forests in the Eastern region under the basic scenarios.

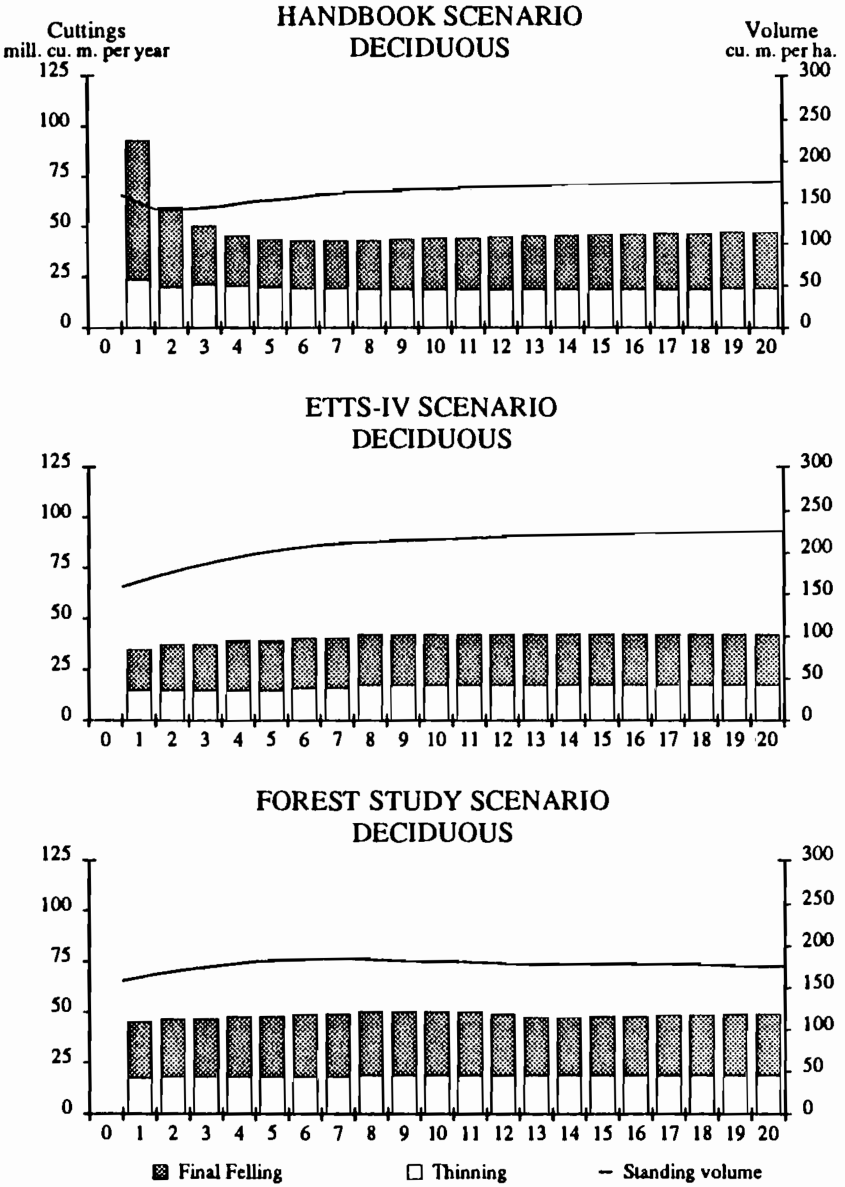

Figure 4.15. Projections for potential harvest and growing stock of deciduous forests in the Eastern region under the basic scenarios.

Table 4.6. Selected data on potential harvest and growing stock in Europe under the basic scenarios.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	122–167	122–180	122–166
Fellings (mill. m^3 o.b./yr)			
Year 1	875.2	410.9	460.0
Year 40	495.7	517.3	547.9
Year 80	569.5	505.9	548.4
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	131–190	131–197	131–185
Fellings (mill. m^3 o.b./yr)			
Year 1	585.1	271.1	308.5
Year 40	326.1	358.3	372.5
Year 80	387.6	352.5	378.0
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	150–184	150–210	150–185
Fellings (mill. m^3 o.b./yr)			
Year 1	214.8	110.7	116.5
Year 40	119.2	121.9	134.3
Year 80	130.6	116.5	130.8
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	58–61	58–77	58–72
Fellings (mill. m^3 o.b./yr)			
Year 1	75.3	29.1	35.0
Year 40	50.4	37.1	41.1
Year 80	51.3	36.9	39.6

growing stocks at reasonably steady and high levels. Most of the harvest in Eastern Europe is coniferous, with a dominance of final cuttings.

4.3.6 Europe (Table 4.6 and Figures 4.16 to 4.18)

For total Europe (not including the European USSR), there is low correspondence between initial forest structure and the implementation of handbook silviculture. This imbalance results in a strong harvest pulse during the first periods of the simulation. For Europe as a whole, the potential harvest level identified by ETTS-IV can be achieved without any reduction of the growing stock over time. With this actual harvest level there will also be a slight

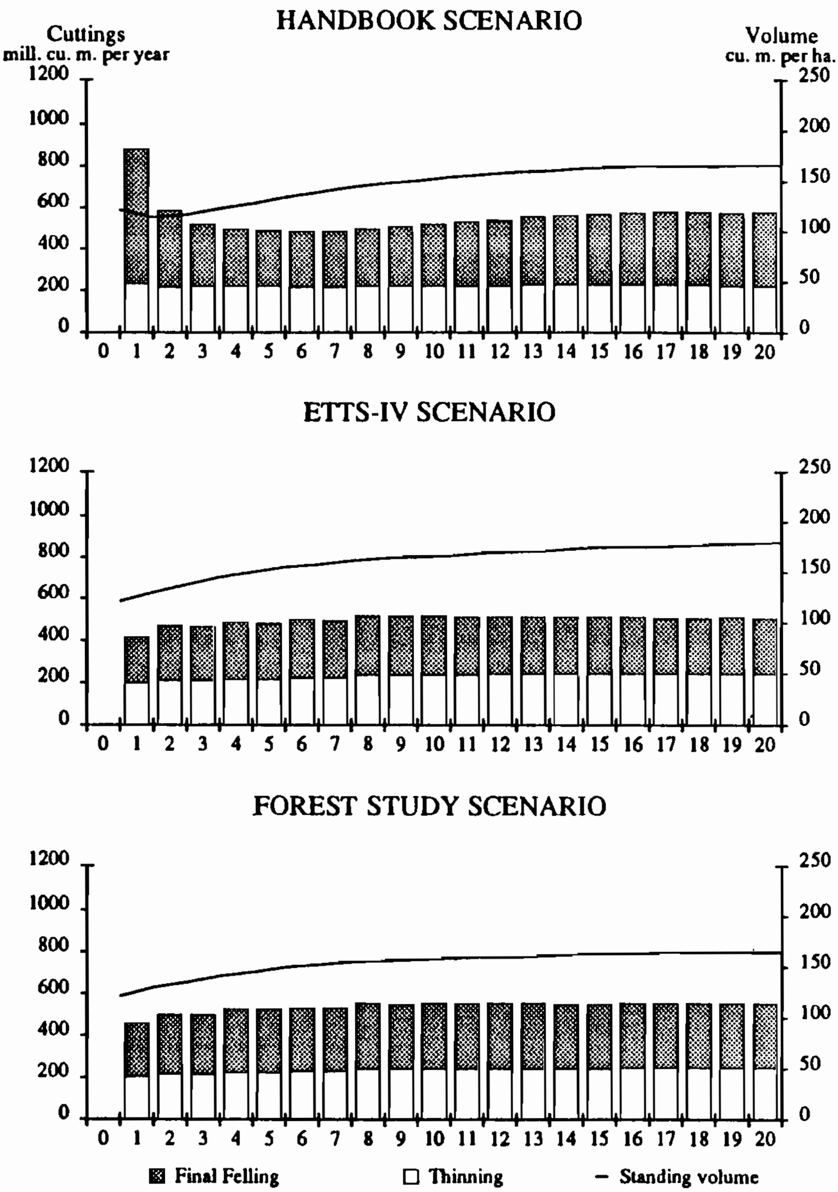

Figure 4.16. Projections for total potential harvest and growing stock in Europe under the basic scenarios.

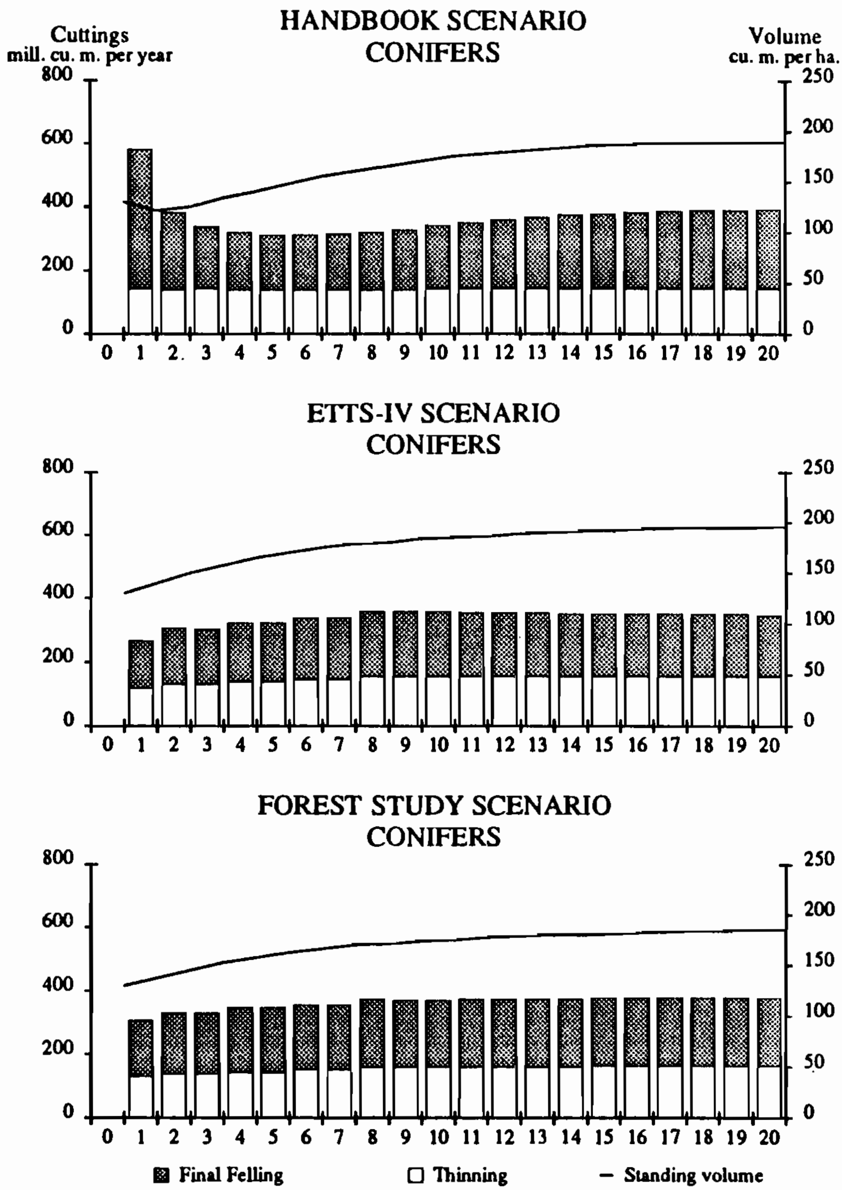

Figure 4.17. Projections for potential harvest and growing stock of coniferous forests in Europe under the basic scenarios.

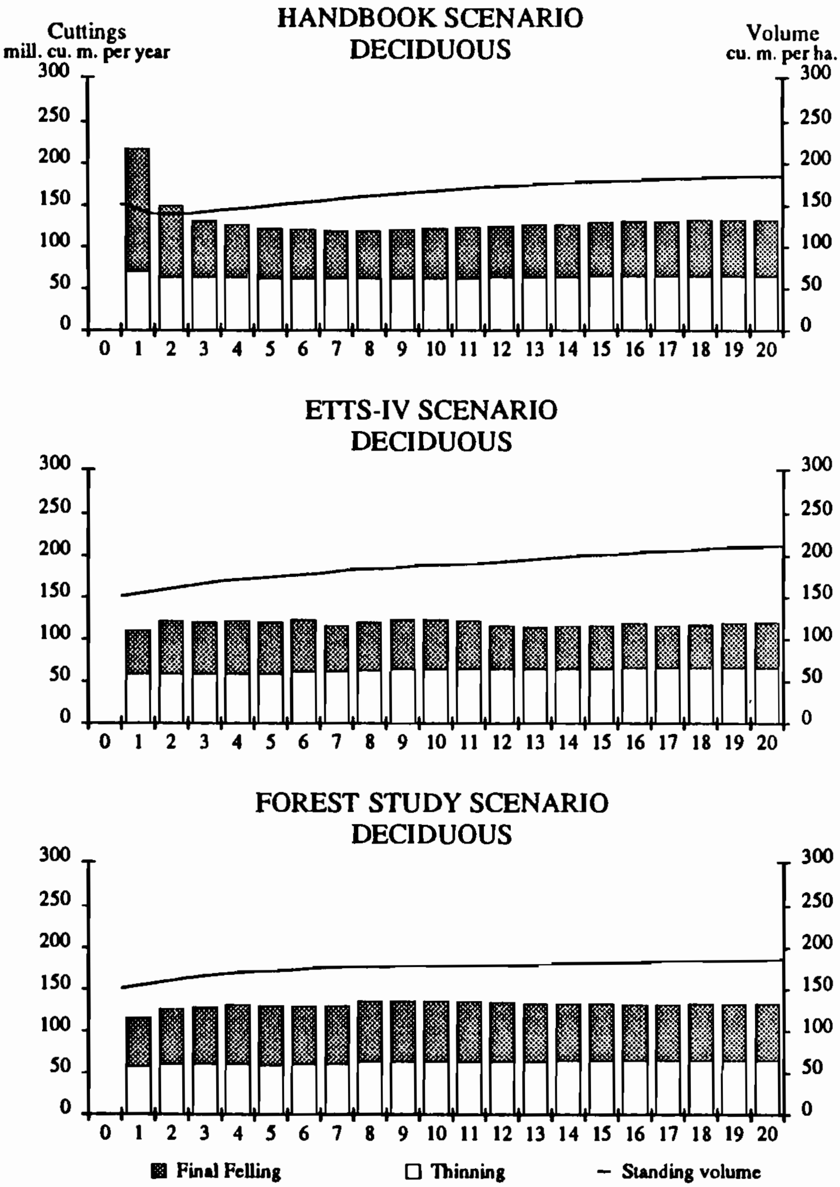

Figure 4.18. Projections for potential harvest and growing stock of deciduous forests in Europe under the basic scenarios.

increase of the total growing stock, indicating that the potential harvest levels suggested by ETTS-IV can be exceeded. This is confirmed by the Basic Forest Study Scenario, which identifies a higher potential harvest level in comparison with the Basic ETTS-IV Scenario. Even if the harvest level in the Basic Forest Study Scenario is higher than that of the Basic ETTS-IV Scenario, the development and level of the growing stock will be about the same in the two scenarios. About two-thirds of the potential harvest in Europe comes from coniferous species. The relative harvest level of coniferous, deciduous, and coppice types is very stable over the whole simulation period.

4.4 Conclusions

We have summarized the main trends from the simulation results under our basic scenarios in *Table 4.7*. We re-emphasize that the Basic Handbook Scenario is unrealistic, but it is the best way to discover the degree to which forest resources have been managed according to the silvicultural prescriptions in the forest-management handbooks of each country. We find that the forest structures of most European countries do not correspond with forest structures that would have been present under implementation of handbook silviculture. In fact, for regionally aggregated data, only the Southern region shows good correspondence, but this is partly an artifact of the rough nature of the analyses for many Southern countries. Country exceptions to this pattern include the CSFR, the Netherlands, Poland, and the United Kingdom. For these countries, the forest structures are apparently in line with handbook silviculture, although our simulations cannot discern whether handbook silviculture is actually being carried out. In those countries where implementation of the Basic Handbook Scenario resulted in large early harvest pulses, the major infractions of handbook silviculture include insufficient numbers, intensities of thinnings, and final fellings occurring too late (i.e., rotations too long). This indicates to us that, if handbook silviculture can be considered to be important in maintaining high forest vitality and high resistance to natural stress, then most countries in Europe are allowing their forest resources to be in a condition in which they are susceptible to stress factors, both natural and anthropogenic.

There is no overall pattern to the development of growing stocks in European countries under the Basic Handbook Scenario (*Table 4.7*). In the

Table 4.7. Summary of trends in the basic scenarios.

	Handbook Scenario		ETTS-IV Scenario		Forest Study Scenario	
Country Region	Balance of structure with handbook silv.	Development growing stock	Able to meet ETTS-IV harvest level?	Development growing stock	Exceed ETTS-IV harvest level?	Development growing stock
Finland	No	Increase	Yes	Stable	No	Increase
Norway	No	Increase	Yes	Increase	Yes	Increase
Sweden	No	Increase	Yes	Increase	Same	Increase
Nordic	No	Increase	Yes	Increase	Yes	Increase
Belgium	No	Stable	No	Up, Down	Yes	Stable
Denmark	No	Increase	Yes	Increase	Yes	Increase
France	No	Increase	No	Small decr.	No	Increase
FRG	No	Small incr.	Yes	Increase	Yes	Stable
Ireland	No	Decrease	No	Decrease	No	Increase
Italy	No	Stable	Yes	Increase	Yes	Small incr.
Luxembourg	No	Decrease	No	Decrease	No	Stable
Netherlands	Yes	Increase	Yes	Stable	No	Increase
UK	Yes	Increase	No	Increase	No	Increase
EEC-9	No	Small incr.	Yes	Small incr.	Yes	Small incr.
Austria	No	Increase	Yes	Decrease	No	Increase
Switzerland	No	Stable	Yes	Increase	Yes	Small decr.
Central	No	Stable	Yes	Small decr.	No	Stable
Greece[a]	Yes	Stable				Stable
Portugal	No	Increase	No	Increase	No	Increase
Spain[a]	Yes	Large incr.				Increase
Turkey[a]	Yes	Stable				Stable
Yugoslavia	No	Increase	Yes	Increase	No	Increase
Southern[a]	Yes	Small incr.	Yes	Small incr.	No	Increase
Bulgaria	No	Stable	Yes	Increase	Yes	Small incr.
CSFR	Yes	Stable	Yes	Increase	Yes	Small incr.
GDR	Yes	Increase	No	Stable	No	Small decr.
Hungary	No	Stable	Yes	Small decr.	No	Stable
Poland	Yes	Stable	Yes	Small incr.	Yes	Small incr.
Romania	No	Small incr.	Yes	Increase	Yes	Stable
Eastern	No	Stable	Yes	Increase	Yes	Small incr.
Europe	No	Small incr.	Yes	Increase	Yes	Increase

[a]The approach we needed to analyze the data of Greece, Spain, and Turkey damp out strong dynamics.

Nordic countries, and those of the Southern region where we could implement the Basic Handbook Scenario, we predict an increase in the development of growing stock, but in the EEC-9, Central, and Eastern countries there would be decreases, increases, and stability.

In the Basic ETTS-IV Scenario, we tried to implement the higher variant for harvest from ETTS-IV (UN, 1986), even beyond 2020 (the harvest-projection horizon in ETTS-IV). In *Table 4.7*, we indicate whether, for each

Table 4.8. Actual harvests in 1987 according to FAO (1989), expressed in million cubic meters.

Country	Removals under bark acc. to ETTS-IV	Removals over bark acc. to ETTS-IV	Conversion factor for bark	Harvest under bark in 1987 acc. to FAO	Calculated harvest over bark in 1987
Austria	12.17	14.60	1.20	14.12	16.94
Belgium	2.25	2.50	1.11	3.53	3.92
Bulgaria	4.34	4.94	1.14	4.44	5.06
CSFR	19.32	21.46	1.11	18.68	20.73
Denmark	1.89	2.10	1.11	2.20	2.44
Finland	44.89	51.18	1.14	41.66	47.49
France	32.32	37.60	1.16	40.90	47.44
FRG	32.88	36.16	1.10	33.74	37.11
GDR	9.99	11.47	1.15	10.83	12.45
Greece	2.30	2.70	1.17	2.94	3.44
Hungary	6.16	6.55	1.06	6.71	7.11
Ireland	0.53	0.65	1.23	1.24	1.53
Italy	7.33	7.71	1.05	9.12	9.58
Luxembourg[a]	0.29	0.33	1.14		
Netherlands	0.91	1.09	1.20	1.16	1.39
Norway	9.22	10.28	1.12	10.54	11.80
Poland	20.74	24.26	1.17	23.31	27.27
Portugal	8.42	10.29	1.22	9.42	11.49
Romania	18.42	20.07	1.09	24.63	26.85
Spain	10.57	13.21	1.25	17.54	21.93
Sweden	45.89	52.78	1.15	53.37	61.38
Switzerland	4.00	4.40	1.10	4.89	5.38
Turkey	17.52	19.30	1.10	16.17	17.79
UK	3.77	4.30	1.14	5.20	5.93
Yugoslavia	13.47	14.64	1.09	15.98	17.42
Total	329.59	374.57		372.32	423.87

[a]Luxembourg included in Belgium.

country and region, the ETTS-IV harvest levels for 2020 could be sustained to the end of our simulation period (an additional 65 years). For regionally aggregated data, all regions can meet ETTS-IV levels. At a disaggregated level, many countries can meet the ETTS-IV levels, except for Belgium, France, Ireland, Luxembourg, United Kingdom, Portugal, and the GDR.

In the Basic Forest Study Scenario, we have pursued two main objectives in forest-resource behavior over the simulation period: (a) stable or steadily increasing harvest levels and (b) stable or steadily increasing growing stock.

There are several classes of forest-resource behavior among countries. For some, the Basic Forest Study Scenario retreats from ETTS-IV harvest levels to maintain increasing growing stock (e.g., Finland, Netherlands, Austria, Portugal, Yugoslavia). In others, even with reduced harvest levels compared to ETTS-IV, growing stocks can only be maintained at a stable level (e.g., Luxembourg, Hungary) or allowed to decrease (e.g., GDR). In many countries ETTS-IV harvest levels can be exceeded, with growing stocks increasing (e.g., Norway, Denmark, Ireland, Italy, United Kingdom, Spain, Bulgaria, CSFR, and Poland), but in some cases the growing stocks are stable (e.g., Belgium, FRG, Greece, Turkey, and Romania) or even decreasing (e.g., Switzerland).

The potential harvest levels presented in *Tables 4.1* to *4.6* should be compared with actual harvests. The actual harvests for 1987 (*Table 4.8*) were calculated from basic information from ETTS-IV and statistics from FAO (1989). Actual harvest data in *Table 4.8* are given in volumes under bark. To compare these data with the Forest Study scenarios, the volumes must be calculated for over bark. Conversion factors for the bark calculations were derived from basic information from ETTS-IV.

The total harvest in 1987 was about 424 million cubic meters. Compared with the scenarios of potential harvests presented in *Tables 4.1* to *4.6*, actual harvests are seen to be far below the potentials. If the actual harvest is compared to long-term potentials in the Basic Forest Study Scenario, the difference is more than 120 million cubic meters per year.

Regional generalizations are dangerous when it comes to projecting forest-resource behavior in European countries under various silvicultural assumptions. However, in the long-term over all Europe, we conclude that the forest-resources situation could improve with respect to biological harvest potential and growing stocks if more careful silvicultural planning and implementation were carried out. We caution that our findings relate to biological potentials which cannot be exceeded but can certainly be impeded due to economic and technical conditions that might prevent implementation of better silviculture. We also point out that, for the entire simulation period of 100 years, environmental factors are held constant. A central theme of our study is that these factors – for example, the air-pollution situation and climate change – will not remain constant.

Chapter 5

Future Wood Supply as Affected by Forest Decline Attributed to Air Pollutants: The Decline Scenarios

5.1 Major Assumptions

Here we present the major assumptions underlying the analysis of three decline scenarios:

- Adjusted handbook silviculture (*Handbook Decline Scenario*).
- Harvest levels according to ETTS-IV (*ETTS-IV Decline Scenario*; UN, 1986).
- Forest Study estimates of reasonable future silviculture and harvest levels (*Forest Study Decline Scenario*).

In generating the input data for the models concerning forest decline attributed to air pollutants, we have been as quantitative as possible. The basic concepts used are *critical loads* and *target loads* of pollutants. The process of generating the information required for the decline scenarios has been described in detail by Nilsson and Posch (1989) and Nilsson (1989a). Below we give a short summary of this information to provide a general view

Table 5.1. Proportions of each country's forest area in three classes of site sensitivity to sulfur deposition. Data are percentages of total forest area.

	Coniferous forest area			Deciduous forest area		
Country	Low	Medium	High	Low	Medium	High
Albania	50	50	0	76	24	0
Austria	14	54	32	67	33	0
Belgium	0	100	0	23	73	4
Bulgaria	3	71	26	66	29	5
CSFR	20	45	35	71	29	0
Denmark	68	32	0	83	17	0
Finland	1	10	89	0	7	93
France	37	53	10	79	12	9
FRG	38	49	13	29	71	0
GDR	23	72	5	91	9	0
Greece	88	10	2	63	28	9
Hungary	100	0	0	100	0	0
Iceland	17	42	41	28	21	51
Italy	41	44	15	47	46	7
Luxembourg	0	100	0	47	53	0
Netherlands	79	21	0	100	0	0
Norway	0	11	89	0	9	91
Poland	37	61	2	38	62	0
Portugal	17	48	35	19	80	1
Romania	22	42	36	60	29	11
Spain	78	10	12	59	27	14
Sweden	1	16	83	2	17	81
Switzerland	18	66	16	23	20	57
Turkey	75	23	2	77	22	1
UK	20	15	65	75	12	13
Yugoslavia	24	61	15	36	57	7
USSR	58	24	18	77	16	7

of how forest decline attributed to air pollutants is treated in the decline scenarios.

Our first task was to calculate the distribution of the forests of each country over several sensitivity classes with respect to sulfur deposition (*Table 5.1*). The sensitivity classes are based on the capabilities of forest soils to buffer against acidification resulting from the deposition of sulfur and nitrogen compounds. Highly sensitive sites have low buffering capacity, and low sensitivity sites have high buffering capacity. Specific *critical loads* and *target loads* of sulfur and nitrogen depositions have been assigned to the

Table 5.2. Target loads for sulfur and nitrogen deposition for the site sensitivity classes used in the forest decline scenarios. Data are grams of substance per square meter per year.

	Coniferous			Deciduous		
Substance	Low	Medium	High	Low	Medium	High
Sulfur[a]	2.0	1.0	0.5	4.0	2.0	1.0
Nitrogen[b]	1.5	1.0	0.3	2.0	1.2	0.5

[a]Target loads set by Chadwick and Kuylenstierna (1988) based on critical loads set by UN-ECE (1988a).
[b]Target loads for nitrogen are the same as critical loads set by UN-ECE (1988a).

individual sensitivity classes. Schulze *et al.* (1988) defined the difference between critical and target loads in the following way:

> Critical loads are quantitative estimates of an exposure to one or more pollutants, below which significant harmful effects on specified sensitive elements of the environment do not occur, according to our present knowledge. The quantity is different from that of target load – while critical load is not an inherent property of an ecosystem, the term target load is less restrictive and also implies other factors, such as economic or emotional considerations.

For now, critical load can be said to mean a "quantitative estimate of the exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfeldt, 1988). Target levels are based on the critical loads and will be developed in the light of possible legal, technical, ecological, economic, and political concerns. Target levels may be set lower or higher than the critical loads depending on actual conditions. The basic idea in setting target levels is that they will form the basis for negotiating internationally accepted emissions reduction strategies.

The critical loads have been defined by Nilsson and Grennfelt (1988) and UN-ECE (1988a) and the target loads for sulfur (based on the ECE critical loads) by Chadwick and Kuylenstierna (1988). In this case the target loads for sulfur are higher than the associated critical loads. The target loads used for nitrogen are the same as the critical loads for nitrogen set by the UN-ECE (1988a). The target loads defined and used in the analyses are presented in *Table 5.2*.

The critical deposition rates given for acidity and nitrogen are in agreement with Ulrich's conclusions based on balance equations for acidity and nitrogen in continental Europe (Ulrich, 1988b and 1990). Rosén (1990) has

Table 5.3. Extent of forest area with depositions exceeding target loads for sulfur. The extent is expressed as a percentage of total forest area for coniferous and deciduous species.

		Coniferous				Deciduous			
Country	Year	Low 2.0 g S m^{-2}	Medium 1.0 g S m^{-2}	High 0.5 g S m^{-2}	Total in %	Low 4.0 g S m^{-2}	Medium 2.0 g S m^{-2}	High 1.0 g S m^{-2}	Total in %
Austria	1985	14	54	32	100	–	33	–	33
	2000	13	54	32	99	–	31	–	31
Belgium	1985	–	100	–	100	4	73	4	81
	2000	–	100	–	100	–	73	4	77
Bulgaria	1985	3	71	–	74	–	29	5	34
	2000	1	71	–	72	–	29	5	34
CSFR	1985	20	45	35	100	46	29	–	75
	2000	20	45	35	100	42	29	–	71
Denmark	1985	24	32	–	56	–	6	–	6
	2000	–	32	–	32	–	–	–	–
Finland	1985	–	2	77	79	–	–	17	17
	2000	–	–	53	53	–	–	3	3
France	1985	7	52	10	69	–	2	9	11
	2000	2	44	10	56	–	1	7	8
FRG	1985	38	49	13	100	8	71	–	79
	2000	27	49	13	89	–	50	–	50
GDR	1985	23	72	5	100	75	9	–	84
	2000	23	72	5	100	55		–	64
Greece	1985	4	8	2	14	–	1	7	8
	2000	34	9	2	45	3	11	8	22
Hungary	1985	100	–	–	100	30	–	–	30
	2000	100	–	–	100	40	–	–	40
Italy	1985	41	44	15	100	9	24	6	39
	2000	24	37	15	76	2	27	7	36

Table 5.3. Continued.

		Coniferous				Deciduous			
Country	Year	Low $2.0\ g\ S\ m^{-2}$	Medium $1.0\ g\ S\ m^{-2}$	High $0.5\ g\ S\ m^{-2}$	Total in %	Low $4.0\ g\ S\ m^{-2}$	Medium $2.0\ g\ S\ m^{-2}$	High $1.0\ g\ S\ m^{-2}$	Total in %
Luxembourg	1985	–	100	–	100	–	53	–	53
	2000	–	98	–	98	–	52	–	52
Netherlands	1985	79	21	–	100	85	–	–	85
	2000	79	21	–	100	–	–	–	–
Norway	1985	–	3	58	61	–	–	23	23
	2000	–	1	49	50	–	–	7	7
Poland	1985	36	61	2	99	19	61	–	80
	2000	35	61	2	98	12	58	–	70
Portugal	1985	–	16	33	49	–	–	1	1
	2000	–	16	33	49	–	–	1	1
Romania	1985	21	42	36	99	–	27	11	38
	2000	22	42	36	100	6	28	11	45
Spain	1985	8	4	11	23	–	3	5	8
	2000	8	4	11	23	–	3	6	9
Sweden	1985	–	4	55	59	–	–	19	19
	2000	–	2	42	44	–	–	10	10
Switzerland	1985	11	66	16	93	1	12	57	70
	2000	7	66	16	89	–	8	57	65
Turkey[a]	1985	23	23	2	48	–	7	1	8
	2000	60	23	2	85	8	18	1	27
UK	1985	7	13	65	85	8	4	11	23
	2000	4	11	65	80	4	2	9	15
Yugoslavia	1985	8	61	15	84	–	18	7	25
	2000	19	61	15	95	4	46	7	57

[a]Estimation, based on the total emissions of SO_2.

analyzed the critical load levels for nitrogen in detail for Sweden. He concluded that the critical nitrogen nutrient load to managed forests ranged between 0.2 and 1.0 grams of nitrogen per square meter for each year (depending on the sustainability of the ecosystem). This result corresponds well with the target loads used in this study. By combining the Forest Study database, described in Section 2.2, and the IIASA RAINS model (Alcamo *et al.*, 1990), it was possible to estimate the extent of forest area with depositions exceeding target loads today and in the future. In the input data for our timber-assessment models, the deposition estimates generated by the RAINS model for year 2000 were used. These deposition estimates are based on current plans to reduce emissions of SO_2 and NO_x as announced officially by individual governments (in 1988). Basic calculations were carried out at the country level, and for sulfur are presented in *Table 5.3*. These results are used as input to our timber-assessment models.

Regionally aggregated results for sulfur show that forest areas with sulfur depositions exceeding target loads will increase in the Southern region, remain stable for Eastern region conifers, and decline modestly to significantly elsewhere (*Figure 5.1*). Taking Europe as a whole from 1985 to 2000, decreases in forest area under sulfur depositions exceeding target loads will be rather small. The same is also valid for nitrogen and ozone. This means that in the year 2000, the target loads for sulfur will be exceeded in 74 percent of all coniferous forests and in 36 percent of all deciduous forests in Europe. The corresponding figures for nitrogen are 79 percent and 45 percent, respectively (see Nilsson, 1991). These results are in line with the results and conclusions presented by Ulrich (1988a):

> The present situation of forest damage has a long history: more than 80 percent of the forest area in Central Europe is already heavily affected, even if this is not yet reflected in the symptom of crown thinning; and it may also take decades for the effect of countermeasures to result in significant changes of the present status of forest stands.

Researchers in Berlin have developed an elaborate analytical tool (PEMU) for analysis of cause-effect relations concerning air pollution and forest health (Bellmann *et al.*, 1988; Bellmann and Lasch, 1988). Data used in the PEMU system are from field observations made since the early 1960s at a set of test sites along deposition gradients. This analytical tool has been employed in estimating the decline effects on forests if depositions exceed target loads. So far, the cause-effect relations have been quantified using PEMU only for sulfur emissions with different background depositions of nitrogen on pine stands. A spruce decline model is under development

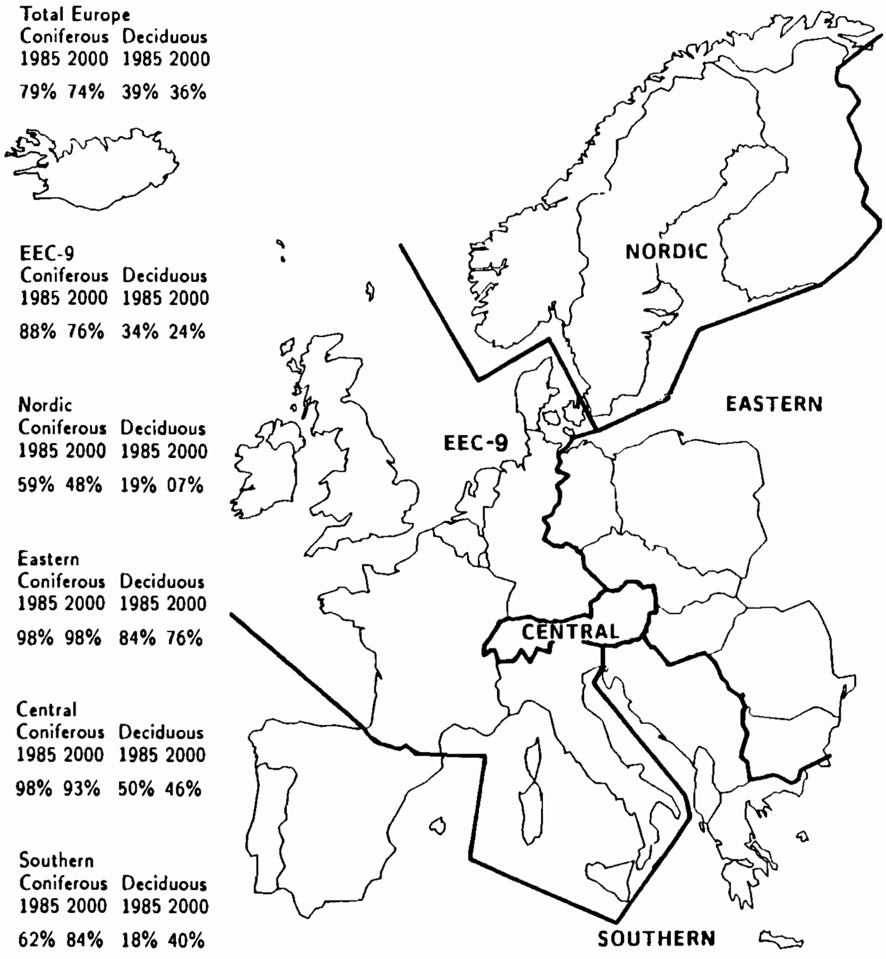

Figure 5.1. Percentage of existing forests with depositions exceeding the target loads for sulfur in different regions of Europe.

Table 5.4. Definition of decline classes attributed to air pollutants according to the UN-ECE (1986).

	Discoloration class		
Defoliation class	< 25%	26–60%	> 60%
0–10%	0	I	II
11–20 to 25%	I	II	II
20–25 to 60%	II	III	III
> 60%	III	III	III
Dead	IV	IV	IV

Decline classes: 0 = Healthy, I = Light, II = Moderate, III = Severe, IV = Dead.

(Thomasius *et al.*, 1989). Preliminary results from the spruce decline model indicate the same basic results as for pine. The PEMU system is described in Appendix A.

The link between the PEMU system and the critical/target load classification generated by the Beijer Institute is the characteristics of the sample plots employed by the German system. The criterion used for setting the target load in the German study is the productivity loss age, which means the age at which growth (increment) starts to decline. The target load in the German analyses is set in such a way that productivity loss is not allowed during an undisturbed rotation period. Undisturbed productivity is defined according to yield tables and as not being influenced by air pollutants. A comparison between target load set in this way and target loads set by the Beijer Institute shows a reasonably good correlation. For a further discussion on the linkage between the two systems, see Nilsson (1991).

Results from PEMU are expressed in terms of a damage cycle and growth losses. The expression *damage cycle* needs explanation. The international criterion used for monitoring forest decline attributed to air pollutants is loss of foliage (*Table 5.4*). Different degrees of foliage loss define different decline classes (UN-ECE, 1986). The damage cycle indicates how many years a forest stand of a particular sensitivity class stays in different defoliation classes at a specific rate of pollutant deposition. Based on the PEMU work, it has been possible to generate some quantitative estimates of damage cycles for middle-aged coniferous stands (*Table 5.5*). These results show clearly that the decline process is more rapid for sites with high sensitivity and with increasing depositions.

It should be emphasized that the damage cycle in *Table 5.5* uses sulfur deposition as the entry parameter. But the damage cycle is based on the

Table 5.5. Damage cycles for different depositions of sulfur on middle-aged coniferous stands. Values are years stands remain in each decline class, and are based on analyses using the PEMU system.

Decline class[a]	Deposition class (g S m^{-2} yr^{-1})					
Sensitivity class	0.5–0.99	1.0–1.99	2.0–3.99	4.0–5.99	6.0–7.99	> 8
0–10%						
Low sensitivity	[b]	60	30	6	1	p.t.
Medium	50	20	10	p.t.	p.t.	p.t.
High	40	10	p.t.	p.t.	p.t.	p.t.
10–25%						
Low sensitivity	[b]	20	12	5	3	1
Medium	25	20	8	3	2	p.t.
High	20	20	8	p.t.	p.t.	p.t.
25–60%						
Low sensitivity	[b]	25	13	12	8	7
Medium	25	20	12	7	5	4
High	20	20	12	5	1	p.t.
> 60%						
Low sensitivity	[b]	[b]	[b]	10	7	53
Medium	[b]	10	8	6	4	3
High	[b]	7	6	4	3	2
Number of years to death						
Low sensitivity	[b]	[b]	65	30	17	11
Medium	[b]	70	38	16	11	7
High	[b]	57	26	9	4	2

[a]Decline classes are delimited by defoliation percentages.
[b]Data do not allow any estimate.
p.t. = passed through this decline class.

combined effect of an excess of sulfur and nitrogen. The data in the PEMU system are based on sample plots where the target loads for both sulfur and nitrogen are exceeded. However, currently it is not possible to identify the individual dynamic effects of nitrogen in the damage cycle. Based on the discussions of the PEMU system in Appendix A it can be concluded that the damage cycle is probably also valid for sulfur pollution alone at high deposition rates (depositions above ~15 g S m^{-2} yr^{-1}). Under such conditions the decline effect seems to be dominated by sulfur.

Sensitivity analyses on the damage cycle were carried out for different ages, forest-site classes, and species groups. Nilsson and Posch (1989) and

Table 5.6. Decline classification used in the CSFR for coniferous stands according to Materna (1988).

Decline class	Percentage of heavily declining trees in a stand
1	< 5%
2	6–30%
3	31–50%
4	51–70%
5	71–100%
6	Dead

Nilsson (1989a) concluded from these analyses that no significant differences could be identified for different forest-site classes. However, significant differences were identified for different age classes and species groups.

There are limited possibilities to validate the damage cycle presented in *Table 5.5* owing to sparse investigations of this type. Researcher in the CSFR have been collecting field data on air pollution and studying its effect on forest decline since the 1960s. They have supplied the IIASA Forest Study with two sets of analyses which are in line with the concept of the damage cycle presented in *Table 5.5*.

Materna (1988) has summarized the total lifetime of stands in the CSFR under pollution stress mainly from sulfur with high background deposition of nitrogen. However, the decline classification in this case is different from that shown in *Table 5.4*. The classification criteria used in this case are based on the percentage of trees with heavy decline in a stand. Heavy decline is defined as a loss of foliage of 50 percent or more. The actual classification is presented in *Table 5.6*.

The corresponding estimate on the number of years it would take for complete disintegration of coniferous stands to occur is presented in *Table 5.7*. The results presented in this table describe an average situation and do not make any differentiation in sensitivity classes for the forest ecosystems or for the rate of sulfur deposition. However, the results confirm the length of the life cycle under stress from air pollutants presented in *Table 5.5*.

The second set of information on the damage cycle that the IIASA Forest Study obtained from the CSFR was produced by Ulrich and Cerny (1990). However, most of the basic field data collection and basic analysis were carried out by Lesproject in Brandys n.L. (Institute for Forest Management).

Table 5.7. Number of years for total disintegration of coniferous stands in the CSFR according to Materna (1988).

Decline class	Age class (years)			
Species	40–60	61–80	81–100	101–120
1 Norway spruce	50–70	40–50	30–40	30
Scots pine	60	50	40	40
2 Norway spruce	20–50	20–40	20–40	10–25
Scots pine	40–50	40	30	25
3 Norway spruce	15–20	15	10	5–10
Scots pine	20–30	20	20	20
4 Norway spruce	5–10	5	5	5
Scots pine	10	5	5	5

In this study an attempt was made to take into account the concentration of air pollutants and some of the ecological conditions. The concentration of air pollutants is expressed in $\mu g\ SO_2\ m^{-3}$ in the study. However, by using the RAINS model, it has been possible to translate the concentrations to depositions of sulfur in $g\ S\ m^{-2}\ yr^{-1}$. The results are presented in *Table 5.8*. The basic data stem from conditions with high pollution stress from sulfur in combination with high background deposition of nitrogen.

Again, there are difficulties in making direct comparisons between the results from the CSFR with the damage cycle employed by the IIASA Forest Study (*Table 5.5*). The general conclusion is, however, that the results from the CSFR support the damage cycle reported by the Forest Study.

Materna *et al.* (1989) have illustrated that there is a strong relationship between disintegration (lifetime) and SO_2 concentrations and altitude. The results demonstrate shorter life spans with higher altitude and higher SO_2 concentrations. Unfortunately, this information on life span and altitude could not be used by the Forest Study owing to lack of data on the distribution of forests over different altitudes.

The results presented thus far pertain only to coniferous species. Investigations of decline effects on deciduous species are more sparse in comparison with coniferous species. Statistics on the development of the extent of decline in individual countries suggest that the damage cycle is much faster for deciduous species (Nilsson, 1989a). This seems to be valid after the decline process has begun (a loss of foliage of over 10 percent). Until this stage has

Table 5.8. Relation of air pollution, ecological conditions, and decline effects.

Depositions	Ecological conditions	Decline effects
A >3.5 g S m^{-2} yr^{-1}	Exposed locations above 700 m.	Expected lifetime 20 years from start of intensive air pollution. Decline increases by 1 degree (see *Table 5.6*) per 5 years.
B >3.5 g S m^{-2} yr^{-1}	More favorable ecological conditions than A.	Expected lifetime 20–40 years from start of intensive air pollution. Decline increases by 1 degree (*Table 5.6*) per 5–10 years.
C 2.5–3.5 g S m^{-2} yr^{-1}	Favorable ecological conditions.	Expected lifetime 40–60 years. Decline increases by 1 degree (*Table 5.6*) per 10–15 years.
D 1–2 g S m^{-2} yr^{-1}	Exposed locations.	Expected lifetime 40–60 years. Decline increases by 1 degree (*Table 5.6*) per 10–15 years.
E 1–2 g S m^{-2} yr^{-1}	Protected locations.	Expected lifetime 60–80 years. Decline increases by 1 degree (*Table 5.6*) per 15–20 years.

Source: Ulrich and Cerny (1990).

been reached, the length of the damage cycle seems to be the same for both coniferous and deciduous species.

Hunziker *et al.* (1988) have made a rather detailed study of the decline process in Switzerland. They found several differences in the damage cycle between deciduous species and coniferous species. Two conclusions can be drawn from these investigations:

- In middle-aged and old deciduous stands the damage cycle runs about twice as fast as in coniferous species.
- In young deciduous stands, the decline is about 1.5 times as fast as in coniferous stands.

Ulrich (1989) has illustrated that deciduous stands react to the proton stress with shortened lifetimes for fine roots. Coniferous stands are not under the same proton stress.

It should be emphasized that the damage cycle employed for the whole of Europe by the Forest Study is only based on information from continental Europe. No studies of this kind were available from the Northern and

Southern regions. In reality there are many combinations of deposition mixtures. It has not been possible to treat all these combinations separately in the generalization of the decline cycle. The generalization is based on aggregated and averaged out deposition patterns generated by the RAINS model (Alcamo *et al.*, 1990).

Growth effects are linked to the loss of foliage (i.e., decline classes). We have estimated a set of growth effects expressed in relation to undisturbed growth according to yield tables for different damage classes (*Table 5.9*). Our results for middle-aged (50-year-old) coniferous stands show that growth effects occur only when defoliation exceeds 25 percent (*Table 5.9*). Sensitivity analyses show no significant differences among site classes, but there are strong relations between age classes and growth effects (Nilsson and Posch, 1989). A literature review reveals that there seems to be a consensus that the growth decline started several years before the damage was visible in the form of foliage loss (e.g., Kenk, 1987; Anon, 1988a and 1988b; Avemark and Schöpfer, 1988; Röhle, 1988; and Pretzsch, 1989). Researchers agree that the factors that caused visible damage during the early 1980s in the forests of continental Europe started to influence growth at least 10 to 20 years earlier. Nilsson and Posch (1989) also found that growth effects are stronger in deciduous species than they are in coniferous species.

It is important to try to validate the results generated by the PEMU system concerning the decline and growth effects. Many studies have been carried out on the relation between loss of foliage and growth losses. Nilsson (1986) made an extensive review of the studies that had been carried out up to 1985; the major conclusion was that a growth loss in coniferous species begins to occur when there is a foliage loss of 20 to 25 percent. This corresponds to the results generated by the PEMU system.

Attebring (1986) used the individual studies from Nilsson's literature review to carry out a statistical validity test of the different studies. The results of this test are presented in *Table 5.10* in the form of two scenarios concerning the effects of foliage loss on growth. In general, the results are in line with the results from the PEMU system; the only difference is that the PEMU system seems to give higher growth losses in cases where there is a loss of more than 60 percent. Since 1986 several new studies have been published. Most of them support the results presented by Attebring [e.g., UN-ECE (1988b), Lorenz and Eckstein (1988), Kramer (1986), Eichhorn (1986), Kenk (1987), Schöpfer (1986 and 1987), Röhle (1988), Pretzsch (1989), Pretzsch and Utschig (1989), and Eckmüller (1988)]. However, these newer studies

Table 5.9. Relative growth (current annual increment) in middle-aged coniferous stands in the different decline classes with different sulfur deposition. The relative growth is expressed in relation to undisturbed growth according to yield tables (= 100).

Decline class	Deposition class in g S m^{-2} yr^{-1}					
Sensitivity class	0.5–0.99	1.0–1.99	2.0–3.99	4.0–5.99	6.0–7.99	> 8.0
0–10%						
Low sensitivity	–	100	100	100	100	–
Medium	100	100	100	–	–	–
High	100	100	100	–	–	–
10–25%						
Low sensitivity	–	100	100	100	100	–
Medium	100	100	100	100	100	–
High	100	100	100	–	–	–
25–60%						
Low sensitivity	–	67	60	50	63	60
Medium	–	65	63	58	69	63
High	80	63	67	64	76	–
> 60%						
Low sensitivity	–	–	13	25	25	25
Medium	13	13	14	20	19	23
High	13	13	15	15	5	5

Table 5.10. Scenarios on the relationship between damage class (loss of foliage) and relative growth for coniferous species.

	Damage class (loss of foliage)			
Species	0–10%	10–25%	25–60%	> 60
Scenario 1				
Fir	100	100	60	40
Spruce	100	100	70	50
Scenario 2				
Fir	100	80	40	25
Spruce	100	90	50	30
Pine	100	100	60	40

Source: Attebring (1986).

Table 5.11. Increment losses in Norway spruce stands damaged by air pollution.

Decline class	Reduction of basal area increment A	B	C
I	30–40%	30–35%	5–10%
II	50–60%	50–60%	15–20%
III	75–90%	70–90%	
IV	75–100%	70–90%	

A: Very rapid development of injury, high level of air pollution, unfavorable ecological conditions.
B: Relatively slow progress of injury mostly due to a high pollution level but favorable ecological conditions.
C: Very slow development of injury under favorable growth conditions with a low pollution level.
Source: Materna (1989).

indicate that even a foliage loss of 10 to 25 percent would result in a loss of increment in sensitive coniferous species.

Materna (1989) has summarized the extensive studies of the last 30 years on decline and changes in increment in the CSFR. The results are presented in *Table 5.11.* The decline classes in *Table 5.11* are the same as those presented in *Table 5.4.* The results shown in the table illustrate the same kind of relationship between loss of increment and status of vitality, ecological conditions, and air-pollution load as the PEMU system and employed by the Forest Study. Ulrich and Cerny (1990) confirm the results presented by Materna. The newer studies also support the different reactions of increment to loss of foliage over age. This has been demonstrated by Dong and Kramer (1988) and Röhle (1988).

Since 1988 growth studies undertaken in the Nordic countries have been published. These studies are similar to the studies that had been carried out in continental Europe earlier. Eriksson (1988) has studied extensively the growth effects on spruce in southern Sweden. The results of this study indicate that with a foliage loss of 20 to 60 percent average growth loss is 9.4 percent and with 60 to 80 percent foliage loss the average growth loss increases to 28 percent.

Nöjd (1988) investigated conditions in Finland for spruce and pine; the study is based on material from decline monitoring conducted in 1986 and 1987 and includes more than 5,000 sample trees from the Finnish National Survey. The growth decline seems to start at a loss of about 20 percent foliage, and at this level growth decline is about 10 percent. The loss of increment at a foliage loss in the range of 25 to 50 percent foliage is about 20 percent. Based on the results of the Nordic studies there seems to be less growth reduction (at the same level of loss of foliage) in this region in comparison with continental Europe. We have not been able to obtain a similar study for the Southern European region. However, we expect the same pattern of decline in growth as discussed in *Table 5.9* in this region.

As emphasized earlier the damage cycles presented in *Table 5.5* and the growth losses presented in *Table 5.9* are mainly derived from calculations on sulfur deposition with high background deposition of nitrogen. But we know that nitrogen and ozone contribute to the decline effect individually and concurrently (with or without sulfur). Hällgren and Näsholm (1988) have identified that trees have different ways of responding to an increase in nitrogen:

- Increased growth.
- Accumulation of nitrogen.
- Discrimination against the uptake of nitrogen.
- Losses of nitrogen.

They conclude that there are no large decreases for nitrogen in forest ecosystems: "In the long run it is only by balancing input and removal that excess N in the ecosystem can be prevented." Agren and Bosatta (1988) support this conclusion. Houdijk (1988), Ellenberg (1985), Nihlgård (1985), and Andersen (1986) conclude that an increase in the nitrogen supply stimulates biomass production, which causes a relative shortage of other nutrients like magnesium, phosphorus, molybdenum, and boron. The authors also conclude that an excess of nitrogen deposition may cause a breakdown in the forest ecosystem. Ulrich (1990) emphasizes that "the nitrogen input by deposition can overcome the material problems of limited nitrogen supply on acid soils and thus lead temporarily to an increase in forest increment."

Hofmann *et al.* (1990) have studied the decline effects of nitrogen deposition in eastern Germany (the former GDR). They summarize the results in the following way:

(1) N deposition up to a critical level leads to a fertilizing effect resulting in increased growth.
(2) Excess N deposition, especially in poor soils, results in changes in the relationships of N:K, N:Ca, and N:Mg which may lead to a lack of K, Ca, and Mg.

(3) Excess N deposition results in decreased resistance to frost.
(4) Excess N deposition may lead to a release of Al^{+++} ions and a washing out of base cations.
(5) With an increase in N deposition the production of fine roots will decrease. This causes a decrease in the production of mycorrhiza, a result which has been confirmed by Boxman (1988).
(6) Factors (1) through (7) result in a decrease in vitality and hence decline.
(7) In the decline phase the growth rate decreases and eventually the death rate increases.

Hofmann *et al.* (1990) have illustrated the relationship between an increase in N deposition and growth rate (*Figure 5.2*). In the figure N deposition is reflected by the concentration of N in the needles, expressed as the percentage of N of dry needle weight.

The normal percentage of N of dry needle weight for the actual test stands is 1.4 to 1.5 percent. As seen in *Figure 5.2*, there will be an increase of about 30 percent in the volume increment if this amount increases from 1.4 percent to around 1.8 percent. With an N content of 1.8 percent to 2.35 percent the increment shows a plateau value and the instability of the stand increases. Therefore an N value of 1.8 percent is critical; when the N content is above 2.35 percent the decline phase begins.

Hofmann *et al.* (1990) have also tried to illustrate the capability of the test stands to carry different loads of N deposition. This is illustrated in *Figure 5.3*. The capability of the stand to cope with future loads of nitrogen depends on the existing sensitivity of the stand to nitrogen and the existing N load.

If the N value of 1.4 percent is chosen as a starting point, the stand can carry an excess load of 15 kg of N per year in about 25 years [*Figure 5.3(a)*]. *Figure 5.3(b)* shows the results of when the stand is starting at the critical N value of 1.8 percent and cannot absorb any excess N deposition. To illustrate the combination effect of sulfur and nitrogen depositions Bellmann *et al.* (1990) have extended the PEMU system. They have included the basic results from Hofmann *et al.* (1990) concerning the nitrogen effects in the PEMU system (see Appendix A).

The analysis of the combination effect is carried out for pine stands with the following characteristics:

- 40-year-old stands.
- Medium nutrient conditions.
- Medium site quality.

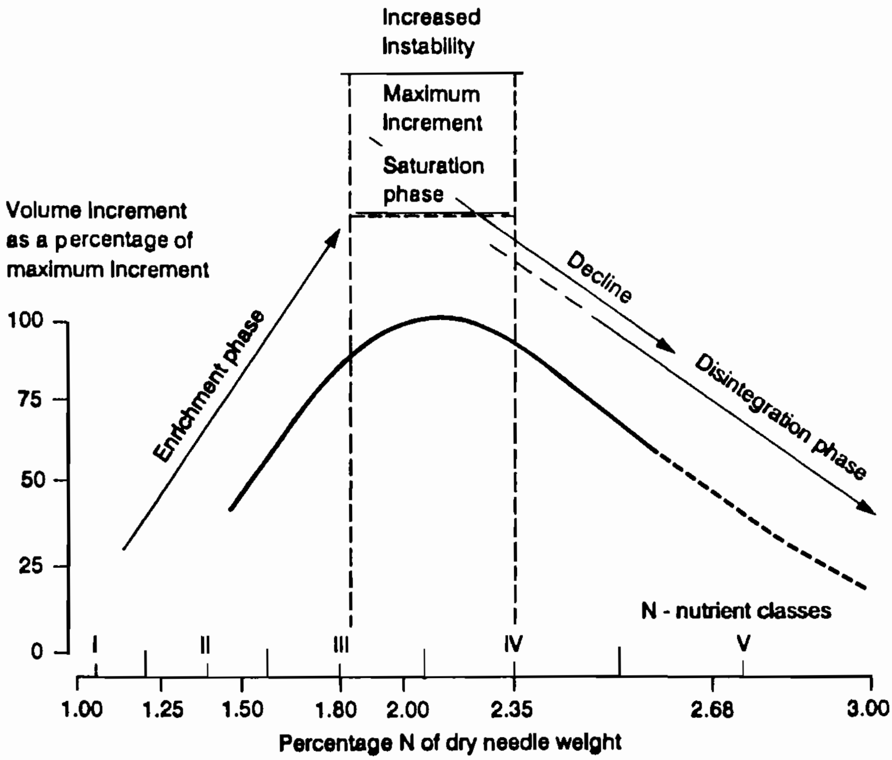

Figure 5.2. Relation between N nutrient conditions, increment, and development phases. Source: Hofmann *et al.* (1990).

- Normal rotation period according to yield tables of 100 years.
- Normal N content of dry needle weight of 1.4 percent.
- Average SO_2 concentration of 116 μg per cubic meters, which corresponds to 27 g of sulfur per square meter per year.

The results from one test area are presented in *Figure 5.4*. Simulations have been carried out for different loads of nitrogen at existing SO_2 concentration (116 μg per cubic meter). This is illustrated in *Figure 5.4(a)*. In *Figure 5.4(b)* the SO_2 concentration has been reduced by 50 percent.

From *Figure 5.4* we can conclude that when there is no reduction in S deposition the decline impact is dominated by nitrogen. In this case the stand is completely disintegrated after about 18 years, irrespective of the different N depositions studied. It can also be seen that nitrogen compensates for the

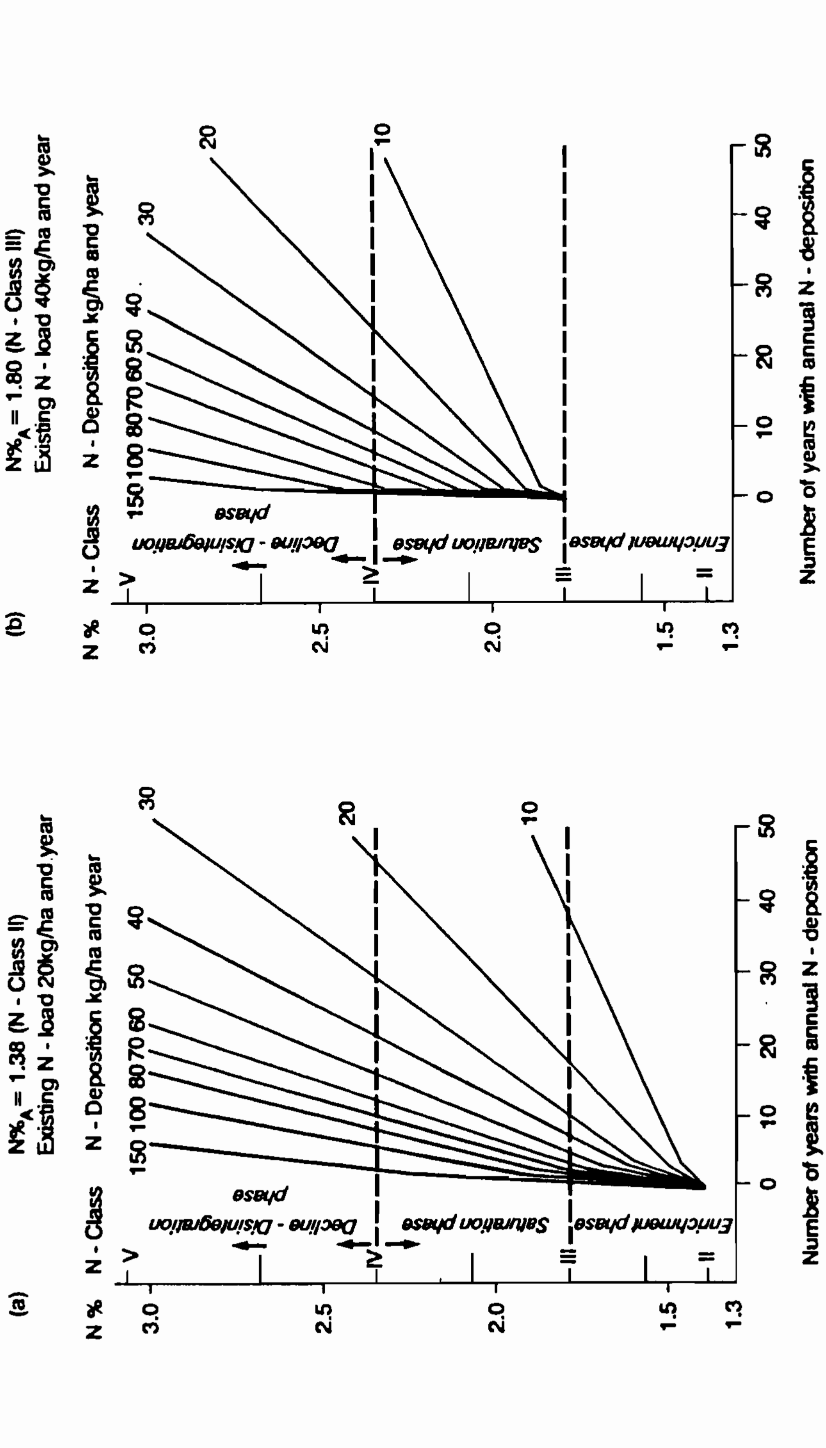

Figure 5.3. Combination effects of nitrogen and sulfur: (a) critical N value of 1.4 percent and (b) critical N value or 1.8 percent. Source: Bellmann *et al.* (1990).

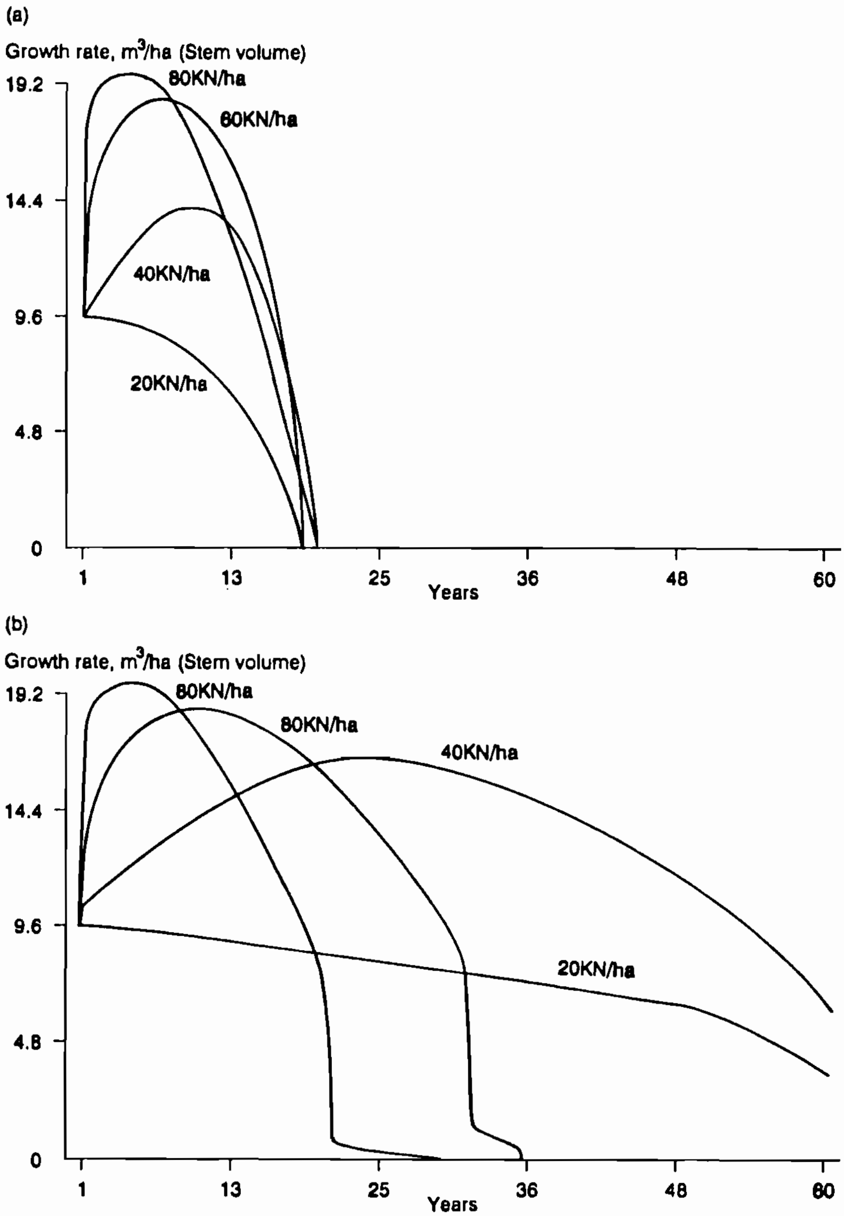

Figure 5.4. Long-term effects of different N depositions under (a) an actual S load of 116 μg per cubic meter, and (b) a 50 percent reduction of the S load. Source: Bellmann *et al.* (1990).

decline effect of S during the enrichment and saturation phases of nitrogen. During the decline phase (see *Figure 5.2*) the individual damage effects of S and N will be synergetic. This last conclusion can be drawn by comparing *Figure 5.4(a)* and *Figure 5.4(b)*.

From *Figure 5.4(b)* it can be seen that at a load of 20 to 40 kg of N per hectare per year, the S depositions have to be reduced by 50 percent to achieve a complete rotation period for the stands. At higher loads of N the stands will only live 20 to 25 years with a 50 percent reduction of S depositions. In this case the decline pattern is dominated by the N load. At a load above 20 kg of N per hectare, the lifetime of the stands depends on how much the S deposition is reduced.

The simulations from the other five test areas show similar results. Some findings from these simulations are important with regard to the damage cycle (*Table 5.5*) and growth decline (*Table 5.9*) used by the IIASA Forest Study. The findings are:

- During the enrichment and saturation phases for N deposition, nitrogen compensates the decline effects of sulfur.
- During the decline phase for nitrogen the individual damage effects of sulfur and nitrogen will be synergetic.
- Under certain conditions the decline effects of nitrogen dominate the effects of sulfur.

As a result of the compensation effect of nitrogen during the enrichment and saturation phases there could be a risk of overestimating the decline effects shown in *Tables 5.5* and *5.9*. However this is not the case here because at the test sites used for compiling the basic data for the PEMU system, there was a parallel build up of N and S depositions over time (see background data in Appendix A). This means that the compensation effects of nitrogen during the enrichment and saturation phases are taken into account in the construction of the damage cycle for sulfur in *Table 5.5* and for the growth losses in *Table 5.9*.

It was previously mentioned that during the decline phase for nitrogen the individual damage effects of sulfur and nitrogen will be synergetic. By studying the basic data for the test sites in Appendix A and the target loads for nitrogen (*Table 5.2*) it can be seen that not all test sites employed by the PEMU system have reached the decline phase for nitrogen. Therefore, the damage cycle takes into account those cases where the target loads are exceeded for both nitrogen and sulfur. Under certain conditions the decline effects of nitrogen dominate the decline effects of sulfur. It has not been possible to take this into account in *Tables 5.5* and *5.9*, which means that the real decline effects are probably underestimated.

As illustrated in *Figure 5.1* and listed in *Table 5.12*, by the year 2000 most of the European forests will to a large extent experience depositions of sulfur and nitrogen exceeding the target loads. The situation is even worse if the effects of future ozone concentrations are taken into account. The critical load for ozone concentrations for a whole vegetation period is set at 50 μg per cubic meter (see Nilsson 1989a). Grennfelt *et al.* (1988) present percentiles of the ozone concentrations during the vegetation period of 1986. The actual ozone concentrations frequently exceeded the critical load for most of Europe, and are expected to increase in the future (for example, see Nilsson, 1988). The conclusion drawn from this is that ozone concentrations frequently exceeding critical loads will cause damage to the forest canopy and slow down growth (see literature review by Nilsson, 1988).

Two conclusions can be drawn from the results presented in *Tables 5.3* and *5.12*. First, it can be seen that existing international agreements on reductions of emissions will not be effective; it is unlikely that the situation will improve very much for the European forest resources up to the years 2000 to 2005. New abatement policies must be developed and implemented immediately. Second, the damage cycle and growth effects used as input for modeling the decline component in our timber-assessment models will, in reality, probably occur much faster. The reason for the acceleration in this process is because the critical or target loads for sulfur, nitrogen, and ozone are all exceeded. The total combined effect of this on the damage cycle and growth has not been taken into account in the timber-assessment model and the decline scenarios.

To mitigate the negative effects of the decline process in forests, some silvicultural measures can be taken. The objectives of such silvicultural measures are to increase stand vitality, delay the decline process, and save commercial wood. Examples of such measures are intensified thinning, shortened rotation periods, and changed species composition. Several research organizations have been engaged by the Forest Study to formulate explicit silvicultural responses to the decline [see Nilsson and Posch (1989) for details]. The responses documented by the organizations are based on decline patterns caused mainly by depositions of sulfur. However, by using the loss of foliage as a link between deposition, decline, and silvicultural responses, there should be no substantial differences between the silvicultural responses to decline caused by other pollutants and decline caused by sulfur. Thus,

Table 5.12. Extent of forests exceeding critical loads for nitrogen from NO_x emissions for the period 1985 to 2000. The numbers in parentheses are estimates based on both NO_x and NH_3 emissions. The distribution is expressed as a percentage of total exploitable forest land.

	Coniferous				Deciduous			
Country	Low 1.5 g N m^{-2}	Medium 1.0 g N m^{-2}	High 0.3 g N m^{-2}	Total in %	Low 2.0 g N m^{-2}	Medium 1.2 g N m^{-2}	High 0.5 g N m^{-2}	Total in %
Austria	1	38	32	71 (100)	–	10	–	10 (83)
Belgium	–	100	–	100 (100)	–	69	4	73 (100)
Bulgaria	–	1	26	27 (27)	–	–	–	0 (5)
CSFR	–	37	35	72 (100)	–	11	–	11 (88)
Denmark	–	–	–	0 (22)	–	–	–	0 (6)
Finland	–	–	20	20 (73)	–	–	–	0 (46)
France	–	12	10	22 (76)	–	1	2	3 (46)
FRG	11	47	13	71 (98)	–	55	–	55 (90)
GDR	–	58	5	63 (88)	–	4	–	4 (53)
Greece	–	–	1	1 (2)	–	–	–	0 (5)
Hungary	–	–	–	0 (38)	–	–	–	0 (0)
Italy	–	3	15	18 (86)	–	–	5	5 (34)
Luxembourg	–	100	–	100 (100)	–	53	–	53 (100)
Netherlands	–	21	–	21 (100)	–	–	–	0 (100)
Norway	–	–	1	1 (78)	–	–	–	0 (56)
Poland	–	20	2	22 (86)	–	9	–	9 (61)
Portugal	–	–	–	0 (18)	–	–	–	0 (0)
Romania	–	–	36	36 (76)	–	–	9	9 (31)
Spain	–	–	5	5 (9)	–	–	–	0 (9)
Sweden	–	–	24	24 (76)	–	–	4	4 (56)
Switzerland	–	34	16	50 (100)	–	–	57	57 (95)
Turkey	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
UK	–	1	65	66 (76)	–	–	9	9 (26)
Yugoslavia	–	–	15	15 (63)	–	–	4	4 (36)

Table 5.13. Changed thinning regimes due to decline. The thinning is expressed as thinning percentage of standing volume in relative terms. Thinning according to yield tables = 100. Figures in parentheses indicate the number of years between thinnings within each age class.

Decline class[a]	Age class (years)						
Species	0–20	20–40	40–60	60–80	80–100	100–120	> 120
10–25%							
Pine	100(20)	100(10)	100(10)	100(10)	100(20)	100(10)	100(20)
Spruce/Fir	100(20)	100(10)	100(10)	100(10)	100(20)	100(10)	100(20)
Beech	100(10)	100(10)	100(10)	100(20)	100(20)	100(10)	100(20)
Oak	100(20)	100(10)	100(10)	100(20)	100(20)	100(10)	100(20)
25–60%							
Pine	267(20)	200(20)	200(20)				
Spruce/Fir	267(20)	200(20)	200(20)				
Beech	333(20)	200(20)	200(20)				
Oak	200(20)	235(20)	267(20)				
> 60%							
Pine	333(20)	250(20)					
Spruce/Fir	333(20)	250(20)					
Beech	417(20)	250(20)					
Oak	250(20)	294(20)					

[a]Decline classes are delimited by defoliation percentages.

the starting point for describing the quantitative silvicultural responses has been the decline class (degree of loss of foliage).

New thinning regimes to alleviate forest decline can be conveniently expressed in relative terms with respect to yield tables (*Table 5.13*). The new thinning regimes we have adopted in *Table 5.13* represent averages from several Central European countries. In our scheme, the thinning intensity should be strongly increased with declining stand vitality where defoliation exceeds 25 percent.

The expected time duration between stand establishment and final felling periods is expressed as an index compared to 100 for rotation periods in healthy stands (*Table 5.14*). The table is valid for stands with a stocking index of 0.7 to 1.0. For lower densities the cycle is faster. Our scheme for new rotation periods to reduce forest decline indicates much shorter rotations for stands with high levels of defoliation. Due to pollutant depositions, soils are expected to degenerate, resulting in delays in the regeneration of new stands. The measure we used is the number of years of delay after final

Table 5.14. Expected time duration before final felling. Data are expressed in terms relative to yield-table rotations for healthy stands.

	Age class (years)									
	40–60		60–80		80–100		100–120		> 120	
Decline class[a]	Site class									
Species	Low	High	Low	High	Low	High	Low	High	Low	High
10–25%										
Pine	100	83	50	75	–	100	–	100	–	–
Spruce/Fir	100	83	50	75	–	100	–	100	–	–
Beech	100	83	50	75	–	100	–	100	–	–
Oak	100	75	50	67	–	50	–	50	–	–
25–60%										
Pine	50	50	50	25	–	–	–	–	–	–
Spruce/Fir	50	50	50	25	–	–	–	–	–	–
Beech	50	50	50	25	–	–	–	–	–	–
Oak	50	50	50	33						
> 60%										
Pine	25	33	–	25	–	–	–	–	–	–
Spruce/Fir	25	33	–	25	–	–	–	–	–	–
Beech	25	33	–	25	–	–	–	–	–	–
Oak	25	38	–	17	–	–	–	–	–	–

[a]Decline classes are delimited by defoliation percentages.

felling until a growing stock of 50 cubic meters per hectare is achieved. Our scheme for building such delays into the timber-assessment model (*Table 5.15*) indicates larger regeneration delays for more severe defoliation and for low site qualities.

This information constitutes the basic platform of input data into the timber-assessment model concerning forest decline attributed to air pollutants. The vitality of the forests in each European country is used as a starting point for the decline scenarios. As a basis for this, the results of monitoring the current vitality according to the UN-ECE methodology (1986) have been employed. Nilsson (1989c) summarized these results on vitality conditions in 1988 (*Tables 5.16* to *5.18*). The data can be used as a starting point for the decline scenarios because the loss of foliage is used both as the main current vitality criterion and as a key parameter in the quantification of the effects attributed to air pollutants. The degree of defoliation also reflects the historical conditions concerning the stress of forests.

Table 5.15. Delay in regeneration time due to soil degradation caused by air pollutants.[a]

Decline class[b] Species	Regeneration delay (years) Site class Low	High
10–25%		
Pine	5 (18)	2 (13)
Spruce/Fir	4 (28)	2 (18)
Beech	2 (28)	1 (21)
Oak	3 (22)	2 (15)
25–60%		
Pine	10	5
Spruce/Fir	9	4
Beech	5	2
Oak	6	4
> 60%		
Pine	17	10
Spruce/Fir	15	7
Beech	8	3
Oak	11	6
Dead		
Pine	27	17
Spruce/Fir	22	12
Beech	12	4
Oak	18	10

[a]Data are expressed in the number of years of delay before a stand on a pollutant-distributed site reaches a growing-stock volume of 50 cubic meters per year, compared to stands on undisturbed sites (normal time in parentheses).
[b]Decline classes are delimited by defoliation percentages.

In *Tables 5.16* and *5.18*, a distinction is made for different amounts of coniferous needle loss (for a review, see Nilsson, 1986; and Nilsson and Posch, 1989). In the literature there is an indication that such losses may only be generated by natural stress factors without any influence from air pollutants, however. It should be emphasized that even the other decline classes are affected by natural stress, but air pollutants have undoubtedly played a crucial role. The corresponding decline information for deciduous species is presented in *Table 5.17*.

Table 5.16. Extent of slight forest decline in coniferous forests in Europe with light losses of foliage (loss of foliage of 10 to 20 or 25%). Vitality is expressed as trees with light losses of foliage as a percent of total number of monitored trees.

Country	1983	1984	1985	1986	1987	1988
Austria	–	24.0	33.4	32.0	29.1	24.3
Belgium (Flanders)	–	–	–	–	42.3	35.9
Belgium (Walloon)					21.0	24.0
Bulgaria	–	–	–	20.3	14.5	38.9
CSFR	–	–	–	32.8	36.7	44.0
Denmark	–	–	–		22.0[a]	14.0
Finland	–	–	n.a.	18.8	n.a.	22.5
France (Vosges)	26.7	33.0	33.6	33.4	29.5	n.a.
France	–	–	–	25.5	22.8	18.2
FRG[b]	30.5	33.2	31.9	33.3	32.7	35.4
GDR						33.1
Greece						43.3
Hungary	–	–	11.3[c]	15.0[c]	12.1	16.6
Ireland	–	–	–	–	4.1	25.3
Italy (Bolzano)		14.0	7.4	6.7	7.9	15.2
Italy (Sardinia)				–	39.1	
Italy (Tuscany)						21.0
Liechtenstein	–	–	–	38.0	38.0	35.0
Luxembourg	–	9.6	15.9	16.0	15.8	20.8
Netherlands	–	32.0	37.0	30.3	33.8	24.1
Norway	–	15.7	16.9	16.4[d]	18.1	29.5
Poland	5.4[c]	–	n.a.			33.4
Portugal						4.3
Spain	–	–	–	20.5	21.0	21.9
Sweden	–	n.a.	n.a.	n.a.	n.a.	31.9
Switzerland[b]	–	28.0	30.0	36.0	41.0	33.0
UK	–				34.0[e]	39.0
Yugoslavia	–	–	–	15.8[f]	30.5	28.0
USSR (Lithuania)					43.7	22.0
USSR (Estonia)						43.0

[a]Results from the joint European survey method were introduced in Denmark in 1987.
[b]The upper limit of this class of foliage loss in the Federal Republic of Germany and Switzerland is 25% and in the other countries 20%.
[c]Expressed as percentage of standing volume.
[d]Only two counties were surveyed in Norway in 1986.
[e]UK experts argue that only 1987 should be considered even if official reports about the decline are available since 1984.
[f]Based on a regional inventory for Slovenia.

Table 5.17. Vitality in deciduous forests in Europe. Vitality is expressed as trees with loss of foliage as a percent of total number of monitored trees. L = Light loss of foliage (10 to 20 or 25%), M = Moderate loss of foliage (20 or 25 to 60%), S = Severe loss of foliage (> 60% and dead), T = Total.

	1983				1984				1985				1986				1987				1988			
Country	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T	L	M	S	T
Austria									34.0	4.0	1.0	39.0	37.4	4.4	1.1	42.9	45.7	6.6	1.2	53.5	40.3	6.7	1.3	48.3
Belgium									n.a.	1.2	0.3	1.5	n.a.	n.a.	n.a.	n.a.								
(Flanders)																	30.2	15.1	0.9	46.2	35.7	8.4	1.6	45.7
Bulgaria													8.0	3.0	1.0	12.0	15.3	2.9	0.2	18.4	29.6	7.0	1.8	38.4
CSFR[a]													n.a.	n.a.	n.a.	3.8					39.4	23.5	5.6	68.5
Denmark[b]					n.a.	0.1		0.1	n.a.	0.1		0.1	n.a.	n.a.	n.a.	n.a.	61.0	19.0	1.0	81.0[c]	56.0	13.0	1.0	70.0
Finland													7.7	5.6	0.6	13.9	13.9	6.4	0.8	21.1	24.5	7.4	0.5	32.8[i]
France (Vosges)	14.0	5.8		19.8	9.5	2.7	1.1	13.3	11.5	1.1	0.5	13.1	16.6	5.3[j]		21.9	19.6	7.2[j]		26.8	n.a.	n.a.	n.a.	n.a.
France[e]									11.8	2.0	0.7	14.5	14.6	3.6	1.2	19.4	14.9	4.7	1.8	21.4	14.5	4.3	1.0	19.8
FRG	15.7	4.6	0.3	20.6	33.0	9.2	0.8	43.0	33.9	11.5	1.1	46.5	38.0	16.1	0.7	54.8	40.4	18.4	0.8	59.6	42.0	15.7	0.8	58.5
GDR																					24.1	9.0[j]		33.1
Greece																					51.7	27.1	1.4	80.2
Hungary[b]									8.7	0.9	0.3	9.9	12.0	8.0	4.0	24.0	8.5	5.0	3.1	16.6	13.6	3.7	3.3	20.6
Italy (Bolzano)													2.2	–	–	2.2	9.6	2.5	1.1	13.2[f]	8.6	2.5	0.4	11.5
Italy (Sardinia)																	23.0	13.7	1.6	38.3				
Italy (Tuscany)																					36.0	18.2	1.9	56.1
Liechtenstein													30.0	9.0	1.0	40.0	30.0	9.0	1.0	40.0	27.0	5.0[j]		32.0
Luxembourg[g]					18.2	3.3	0.7	22.2	19.1	3.2	1.0	23.3	24.6	4.4	1.2	30.2	32.9	8.9	1.2	43.0	36.5	10.2	2.1	48.8
Netherlands					28.3	3.7	1.0	33.0	32.0	12.0	3.0	47.0	33.8	10.8	2.4	47.0	40.6	20.1	6.4	67.1	35.4	21.0	8.2	64.6
Poland									3.9	1.4	1.7	7.0	n.a.	n.a.	n.a.	n.a.					13.4	5.2	1.9	20.5
Portugal																					5.3	0.0	0.8	6.1
Spain													1.6	2.4	0.2	4.2	28.3	13.1	0.6	42.0	27.0	5.8	1.0	33.8
Sweden[b]																					17.5	5.0	0.2	22.7
Switzerland					21.7	3.0	0.2	24.9	24.0	4.0	1.0	29.0	37.0	7.0	1.0	45.0	42.0	13.0	2.0	57.0	26.0	5.0	2.0	33.0
UK[h]																	35.0	19.0	1.0	55.0[d]	40.0	22.0	5.0	67.0
Yugoslavia																	18.6	5.4	2.1	26.1	21.3	6.7	2.3	30.3
USSR (Lithuania)																					9.0	1.0	–	10.0

[a]The vitality figures for deciduous come from the sanitary inventory for 1982 and not from the permanent plots for 1986. The actual information is not distributed on different damage classes, only the total figure exists and represents declining area expressed in percent.
[b]Monitored volume as percent of standing volume.
[c]Results from the joint European survey method were introduced in Denmark in 1987. Expressed as monitored trees in percent.
[d]The monitoring system was changed between 1986 and 1987 in the UK. UK experts argue that only the values for 1987 should be taken into consideration. The results cannot be compared with earlier years.
[e]During 1985, 1986, and 1987 monitoring in France was extended stepwise to cover most of the country.
[f]Bolzano only.
[g]Includes discoloration.
[h]Only beech for 1985 and 1986.
[i]The results cannot be compared with earlier years.
[j]Average for moderate and severe values. The breakdown is not available.

Table 5.18. Vitality of coniferous forests in Europe. Vitality is expressed as trees with loss of foliage as a percent of total number of monitored trees. M = Moderate loss of foliage (20 or 25 to 60%), S = Severe loss of foliage (> 60% and dead), T = Total.

	1983			1984			1985			1986			1987			1988		
Country	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T
Austria				3.8	1.6	5.4	3.6	0.8	4.4	4.0	0.5	4.5	3.0	0.5	3.5	2.7	0.6	3.3
Belgium							5.7	1.0	6.7									
(Flanders)													4.7	0.0	4.7	9.0	1.0	10.0
(Walloon)													5.0	4.0	9.0	7.0	4.0	11.0
Bulgaria										3.7	1.0	4.7	3.7	0.1	3.8	6.5	1.1	7.6
CSFR										12.1	4.3	16.4	10.5	5.1	15.6	21.6	5.4	27.0
Denmark[a]				n.a.	n.a.	4.6	n.a.	n.a.	4.1	1.5	0.0	1.5	1.4	0.0	1.4	–	–	–
													16.0	8.0	24.0[b]	14.0	7.0	21.0
Finland							11.3	1.0	12.3	7.7	1.0	8.7	n.a.	n.a.	n.a.[c]	14.9	2.1	17.0[d]
France (Vosges only)	16.6	3.0	19.6	18.7	2.8	21.5	17.6	2.3	19.9	n.a.	n.a.	17.9	n.a.	n.a.	17.9	n.a.	n.a.	17.1
France[e]				n.a.	n.a.	n.a.	12.0	1.6	13.6	10.3	2.0	12.3	9.8	2.2	12.0	8.0	1.1	9.1
FRG	11.2	1.2	12.4	20.2	1.9	22.1	20.5	2.8	23.3	18.2	1.3	19.5	14.9	1.0	15.9	13.2	0.8	14.0
GDR															37.0[f]	n.a.	n.a.	15.5
Greece																6.8	0.9	7.7
Hungary[g]				n.a.	n.a.	n.a.	0.6	0.1	0.7	7.0	2.0	9.0	5.5	0.0	5.5	7.3	2.1	9.4
Ireland													0.4	0.0	0.4	4.5	0.3	4.8
Italy (Bolzano)				2.5	0.5	3.0	0.7	0.1	0.8	0.7	0.1	0.8	1.5	0.3	1.8	4.6	0.6	5.2
Italy (Sardinia)													28.6	2.1	30.7	–	–	–
Italy (Tuscany)																13.5	1.9	15.4
Liechtenstein										18.0	4.0	22.0	18.0	4.0	22.0	n.a.	n.a.	23.0
Luxembourg				1.9	0.5	2.4	2.8	1.2	4.0	2.7	1.5	4.2	3.1	0.7	3.8	9.3	1.8	11.1
Netherlands				11.0	1.5	12.5	13.0	2.0	15.0	25.2	3.7	28.9	15.4	4.0	19.4	13.3	3.3	16.6
Norway[g]				10.7	2.8	13.5	11.2[h]	0.9	12.1	10.4	0.5	10.9[i]	16.6	1.2	17.8[j]	16.8	4.0	20.8
Poland	24.0	8.0	32.0	no monitoring			12.0	6.0	18.0	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	20.3	3.9	24.2
Portugal																1.5	0.2	1.7
Spain										14.1	4.1	18.2	9.9	0.8	10.7	6.2	1.1	7.3
Sweden[g]				26.2	1.2	27.4	21.0	0.7	21.7	16.4	0.3	16.7	8.5	0.3	8.8	10.9	1.4	12.3
Switzerland				8.2	1.4	9.6	7.0	2.0	9.0	13.0	3.0	16.0	11.0	3.0	14.0	12.0	3.0	15.0
UK[k]													18.0	5.0	23.0[l]	8.0	2.0	10.0
Yugoslavia										9.8	13.2	23.0[m]	12.9	5.4	18.3	14.0	3.5	17.5[n]
USSR (Lithuania)													10.9	3.9	14.8	3.0	0.0	3.0
USSR (Estonia)																8.0	1.0	9.0

[a]Monitored area in percent of forest area.
[b]Results from the joint European survey method were introduced in Denmark in 1987.
[c]Not able to report 1987 Finnish data due to difficulties in interpreting the results.
[d]In 1988 in Finland, the forest vitality results are only available from 450 sample plots on mineral soil sites. The results are not comparable with the results received in 1985–1986 from the survey on 3,009 permanent plots. However, results from the period 1986–1988 are available for the same 450 sample plots. This is illustrated below:

	1986	1987	1988
Pine			
M	4.1	4.6	7.1
S	0.0	0.3	0.3
T	4.1	4.9	7.4
Spruce			
M	18.2	22.5	26.8
S	1.6	4.8	4.0
T	19.8	27.3	30.8

[e]During 1985, 1986, and 1987 monitoring in France was extended stepwise to cover most of the country.
[f]All vitality classes.
[g]Monitored volume in percent of standing volume.
[h]Only six counties covered in 1984. There was a change in reported data from 1984 to 1985; from declining volume to percentage of trees damaged.
[i]Only two counties were surveyed in Norway in 1986.
[j]This covers four counties. Average for results in 1986 and 1987.
[k]For 1984 and 1985 vitality information was not collected for Norway spruce over 50 years old. For 1986 this information was collected. If this is taken into account, the results for 1986 are the following: Moderate 27.3%, Severe 1.3%, Total 28.6%.
[l]Even if the values for UK during the period 1984–1986 are based on official reports UK experts argue that only the values for 1987 should be considered. This is the year the monitoring technique according to the ECE manual was adopted.
[m]Only Slovenia.
[n]Based on a regional inventory for Yugoslavia.

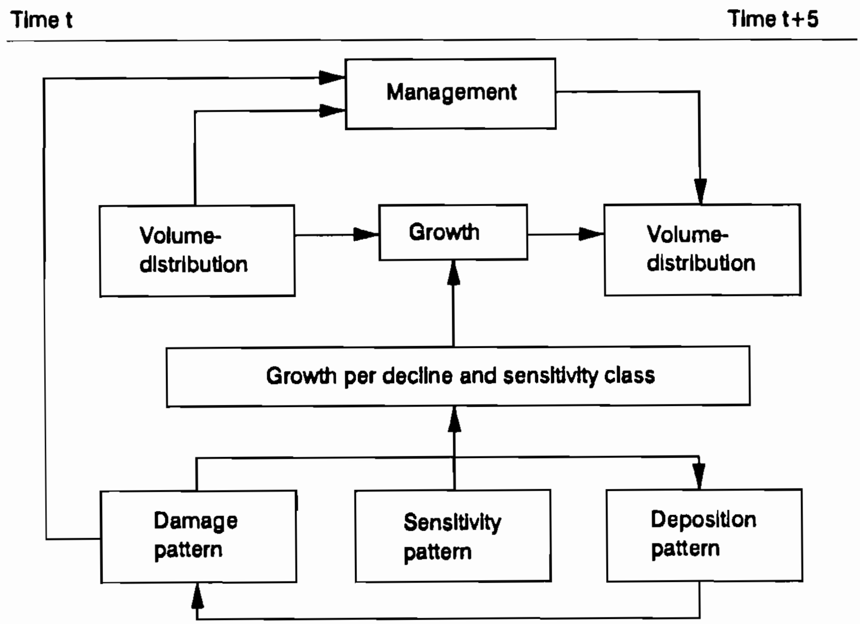

Figure 5.5. Schematic representation of the decline model.

5.2 Decline-modeling Approach

Two basic changes were made to the basic area-modeling concept to take forest decline into account. First, the basic state description scheme was expanded by two variables: decline class and sensitivity class. Second, the transition rates were made changeable over time. The decline model is schematically depicted in *Figure 5.5.*

5.2.1 State description

The state description scheme is expanded on two different levels: sensitivity classes are related to the state of the land or the site and decline classes refer to the stand of trees. Consequently, the distribution of the forest land over different sensitivity classes was regarded as a constant pattern, differentiated on a country-specific basis. This pattern was, however, separated over species groups since the target loads differ between these groups. Since there are no transitions between different species groups in the model, this means that even if the sensitivity dimension is included in the site description, the site can be regarded as stable over time. Three intervals, the definitions of which differ between coniferous and deciduous types, were used to express the sensitivity pattern (see *Tables 5.1* and *5.2*). The forest, in the decline context, is described not only by the age and the volume but also by the decline class. Four classes coinciding with internationally accepted definitions were used (see UN-ECE, 1986).

At present, there are no data available to correlate decline and sensitivity of the forests. Consequently, it was assumed that the distribution over decline classes is equal in all sensitivity classes. Using this assumption and the information in *Tables 5.13, 5.14, 5.15, 5.16*, and *5.18* the initial forest-state description was enhanced with the new variables.

5.2.2 Transition rates

Transition rates corresponding to volume growth should be related to the decline-class pattern and to depositions. In addition, new transitions between the decline classes must be implemented in the model. For every simulation period of five years, a distribution of the forest area of a specific country over six different deposition classes is calculated. Combined with the sensitivity structure, the growth-reduction scheme found in *Table 5.9*, and the damage cycles in *Table 5.5*, a new set of transition rates could be deduced for every forest state and every simulation period. Correspondingly, the transition rates between decline classes could be calculated.

5.2.3 Management

Management programs were altered in accordance with the data in *Tables 5.13, 5.14*, and *5.15*. Thus, earlier final fellings and higher thinning intensities were carried out with increasing damage class.

5.2.4 Regeneration

Regeneration was assumed to be at a slower rate if the forest area to be regenerated was found in the higher decline classes at the time of final felling. Therefore, the coefficients expressing transitions from the bare-land classes to the ordinary matrices were decreased for areas coming from the higher decline classes.

5.2.5 Summary

Our analytical implementation of the effects of air pollutants on forest resources is very conservative in two main respects:

- We have calculated decline effects based mainly on sulfur and nitrogen emissions and effects, without considering the full combination of effects from other pollutants.
- We assume no emissions of pollutants after 2005.

On the other hand, we have been able to implement only those kinds of silvicultural and management interventions that are already structured into our modeling framework, i.e., changed thinning regimes and rotations. Other means of silviculturally mitigating the effects of air pollutants, such as better matching of regenerated species with sites, genetic improvements in stock for regeneration, and fertilization, have not been incorporated or explored. However, considering our basic assumptions about air pollution, we feel that our overall results with respect to the possible impacts of air pollution on forest resources and potential wood supplies are conservative.

5.3 Decline Scenarios

All the simulations have a time horizon of 100 years, with 1985 as the starting point. The forest areas presented in *Table 3.1* are used throughout in all simulations. Although we are illustrating the effects of emissions only up to the year 2000, we know from the PEMU analyses (Bellmann *et al.*, 1988) that there are long lag effects of the depositions even if the emissions, contrary to expectations, should cease by the year 2000. Based on the PEMU analyses, we have considered the following lag effects in our decline scenarios:

- Full decline effects to the year 2005, after which growth rates will recover slowly over time.
- Recovery rates in the range of 10 to 40 years, depending on site conditions and historical deposition rates.

5.3.1 The Handbook Decline Scenario

In the Basic Handbook Scenario, the forests of each country are treated strictly in accordance with the silviculture programs that have been defined for each country as ideal under normal conditions. However, to keep the vitality of the forest as high as possible, the ideal silviculture programs in our analyses have to be adjusted. In this scenario, the handbook silvicultural programs have been used as a platform and adjusted in accordance with the assumptions presented in Section 5.1 – that is, shorter rotation, higher thinning intensity, and delayed regeneration in damaged forests. As in the Basic Handbook Scenario, no restrictions on the total harvest level have been imposed.

5.3.2 The ETTS-IV Decline Scenario

In the ETTS-IV Decline Scenario, we have followed the same principles as in the Basic ETTS-IV Scenario. Thus, harvests follow the high ETTS-IV scenarios, and the harvest levels of the year 2020 are used for the remainder of the simulation period. However, the silvicultural programs have been adjusted according to the decline responses discussed earlier.

5.3.3 The Forest Study Decline Scenario

In the Basic Forest Study Scenario, the objective is to strive for consistently high levels of both growing-stock and harvest levels over the simulation horizon. In the decline case, the silviculture programs employed in the basic scenario have been adjusted as in the other decline scenarios. In most cases in this scenario, there are no possibilities to achieve the high levels of both harvests and growing stock for the Basic Scenarios. In cases with conflicts between these two goals, the primary objective has been to keep the growing stock at a high and consistent level similar to that of the Basic Forest Study Scenario through the simulation period. Thus, in these cases, the effect of the decline will be illustrated by comparing potential harvest results with those of the Basic Forest Study Scenario.

5.4 Guide to the Results

Again we focus on simulation results at the regional level. For each region, and for Europe as a whole, we present one table and three sets of diagrams. Each table and diagram convey information from all three scenarios. The tables (*Tables 5.19* through *5.24*) present selected projection data on growing-stock and annual harvest volumes at the beginning of the simulation and at specific points in the simulation. These data are also contained in the

Table 5.19. Selected data on potential harvest and growing stock in the Nordic region under the decline scenarios.

Variable	Handbook Decline	ETTS-IV Decline	Forest Study Decline
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	93–126	93–125	93–140
Fellings (mill. m^3 o.b./yr)			
Year 1	382.2	123.8	106.8
Year 40	122.1	153.1	153.6
Year 80	161.1	152.6	152.2
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	94–130	94–132	94–144
Fellings (mill. m^3 o.b./yr)			
Year 1	357.0	106.2	99.6
Year 40	110.2	141.9	139.8
Year 80	150.0	141.6	139.7
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	82–74	82–44	82–87
Fellings (mill. m^3 o.b./yr)			
Year 1	25.2	17.6	7.2
Year 40	11.9	11.2	13.8
Year 80	11.1	11.0	12.5

diagrams, but are provided in tabular form for convenient numerical comparison. Bar charts on projected development of growing-stock and annual harvest levels for each five-year period are given for total forests (*Figures 5.6, 5.9, 5,12, 5.15, 5.18, 5.21*), coniferous forests (*Figures 5.7, 5.10, 5.13, 5.16, 5.19, 5.22*), and deciduous forests (*Figures 5.8, 5.11, 5.14, 5.17, 5.20, 5.23*). Results for individual countries are presented in Appendix B.

5.5 Discussion

5.5.1 Nordic region (Table 5.19 and Figures 5.6 to 5.8)

In the Basic Handbook Scenario, there was a rather strong harvest pulse during the first two periods of the simulation. In the Handbook Decline Scenario, the harvest pulse during the first period is even stronger. However, for the remainder of the simulation period, the total harvest is roughly the same in the two scenarios. Total growing stock is lower in the Handbook

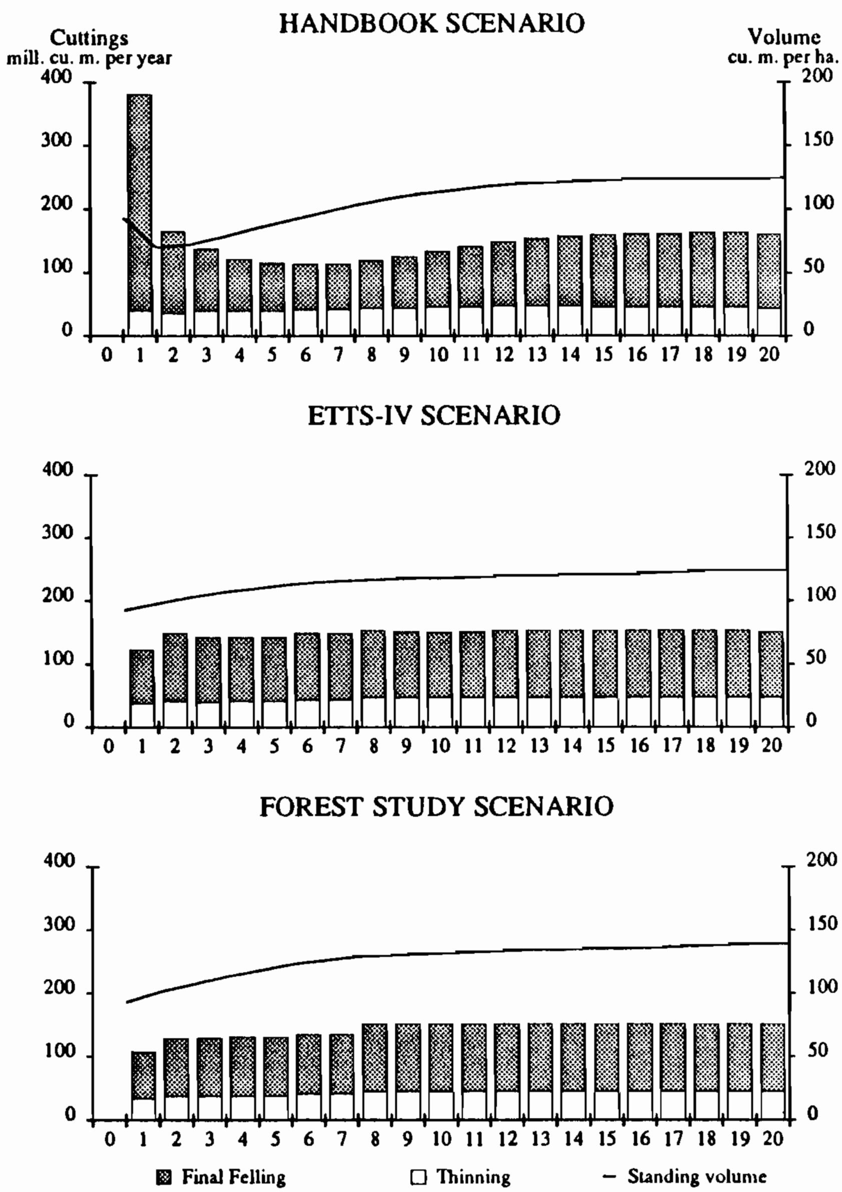

Figure 5.6. Projections for total potential harvest and growing stock in the Nordic region under the decline scenarios.

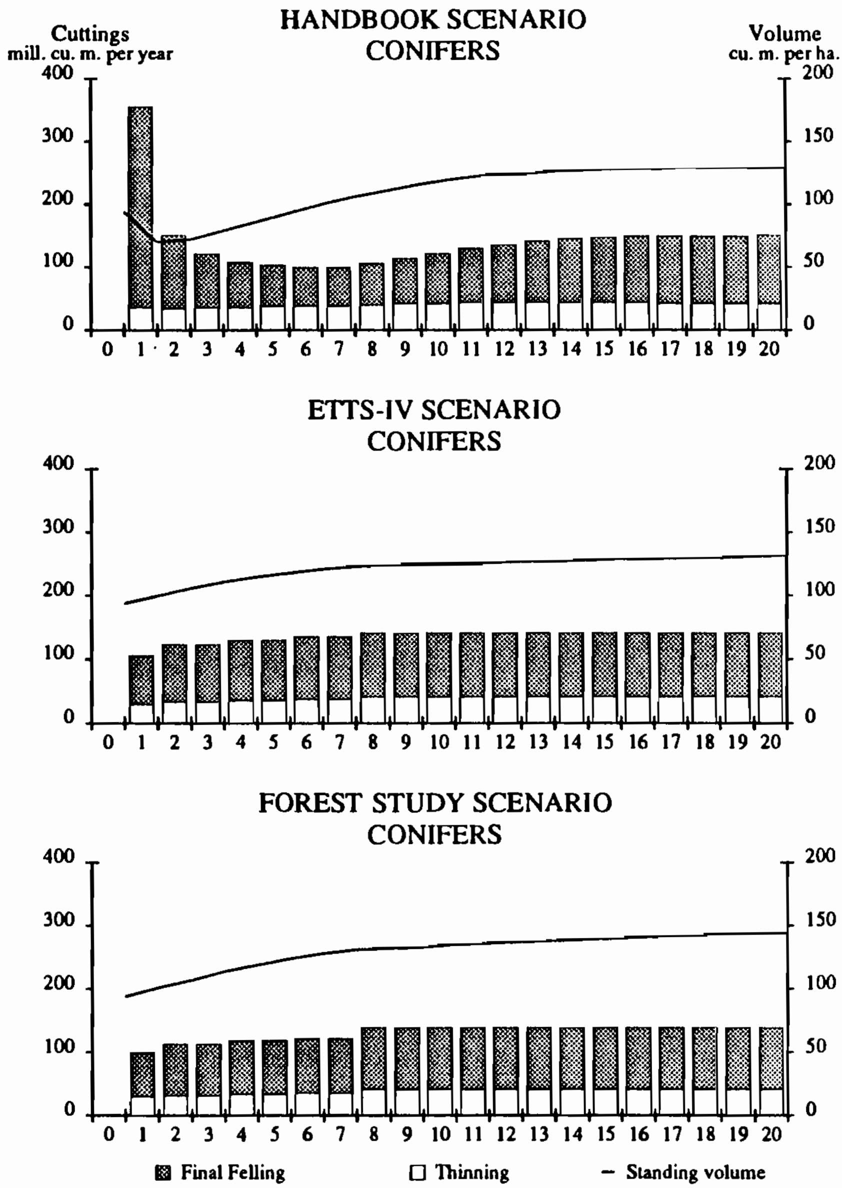

Figure 5.7. Projections for potential harvest and growing stock of coniferous forests in the Nordic region under the decline scenarios.

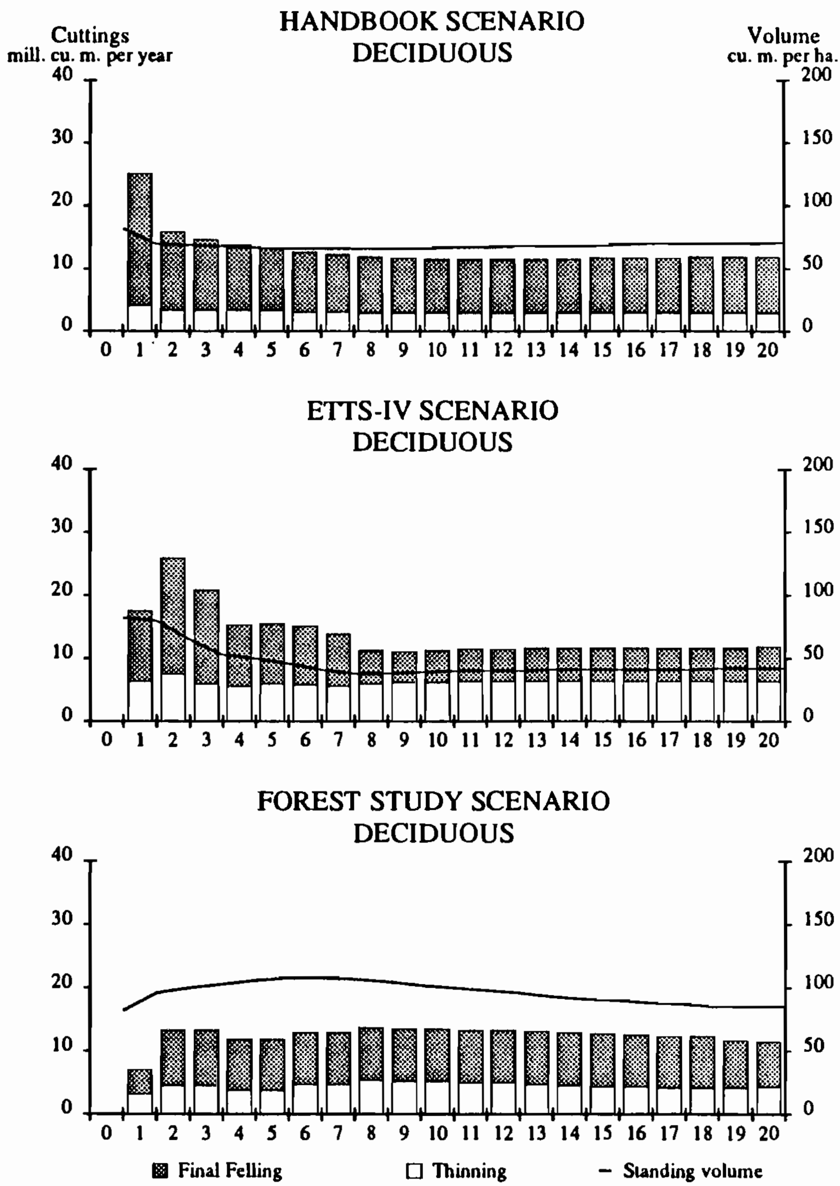

Figure 5.8. Projections for potential harvest and growing stock of deciduous forests in the Nordic region under the decline scenarios.

Decline Scenario than it is in the Basic Handbook Scenario throughout the simulation period.

In the ETTS-IV Decline Scenario, it is possible to keep the same total harvest level as in the Basic ETTS-IV Scenario during the first 40 years. After that, the potential harvest level is lower until the end of the simulation period. Growing stock is also lower through the whole period in comparison with the Basic ETTS-IV Scenario.

In the Forest Study Decline Scenario, growing-stock level and development is similar to that of the Basic Forest Study Scenario. However, the potential total harvest level is lower by some 10 million cubic meters per year throughout the simulation period.

The potential harvest of conifers is more seriously affected by the decline, in comparison with the Basic Forest Study Scenario, than the potential harvest of deciduous types. However, it is possible to keep the same growing-stock level of conifers in the decline case as in the basic scenario. Concerning deciduous species under decline, the potential harvest level decreases rather dramatically during the beginning of the simulation period, but later the potential deciduous harvest is the same in both the Basic Forest Study Scenario and the Forest Study Decline Scenario. At the end of the simulation period, the potential harvest decreases in the Forest Study Decline Scenario. After about 40 years into the simulation period, the deciduous growing stock decreases rather substantially in comparison with the Basic Forest Study Scenario.

5.5.2 EEC-9 region (Table 5.20 and Figures 5.9 to 5.11)

In the Basic Handbook Scenario, there was a harvest pulse during the first two periods of the simulation period. In the Handbook Decline Scenario, the pulse is stronger and longer, covering the first four periods of the simulation. After the harvest pulse, the potential harvest is lower throughout the simulation period in the decline scenario compared with the basic scenario. The total growing stock is also lower in the decline scenario, with a difference between the two scenarios of about 20 cubic meters per hectare at the end of the simulation period.

In the decline situation, it is not possible to reach ETTS-IV harvest levels. The potential harvest levels are lower throughout the whole simulation period. The total growing stock also decreases in the decline situation. The difference of the growing stock between the two scenarios is about 50 cubic meters per hectare.

Table 5.20. Selected data on potential harvest and growing stock in the EEC-9 region under the decline scenarios.

Variable	Handbook Decline	ETTS-IV Decline	Forest Study Decline
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	153–161	153–170	153–190
Fellings (mill. m^3 o.b./yr)			
Year 1	284.5	101.9	101.0
Year 40	127.6	136.2	129.3
Year 80	137.4	115.7	132.5
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	181–216	181–206	181–234
Fellings (mill. m^3 o.b./yr)			
Year 1	140.6	57.8	63.2
Year 40	76.7	86.5	81.0
Year 80	81.9	73.3	83.9
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	179–143	179–156	179–195
Fellings (mill. m^3 o.b./yr)			
Year 1	93.3	31.9	23.8
Year 40	25.9	33.9	29.3
Year 80	26.7	26.7	29.4
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	97–99	97–131	97–126
Fellings (mill. m^3 o.b./yr)			
Year 1	50.6	12.2	14.0
Year 40	25.0	15.8	19.0
Year 80	28.8	15.7	19.2

To reach the same growing stock in the Forest Study Decline Scenario as in the Basic Forest Study Scenario, the total potential harvest level must be forced down. The total harvest level is lower in the decline scenario throughout the whole simulation period than in the basic scenario. Based on the Forest Study Decline Scenario, it can be seen that coniferous and deciduous species are affected in similar ways concerning decreases of potential harvest levels. The coppice group is only slightly affected by the decline.

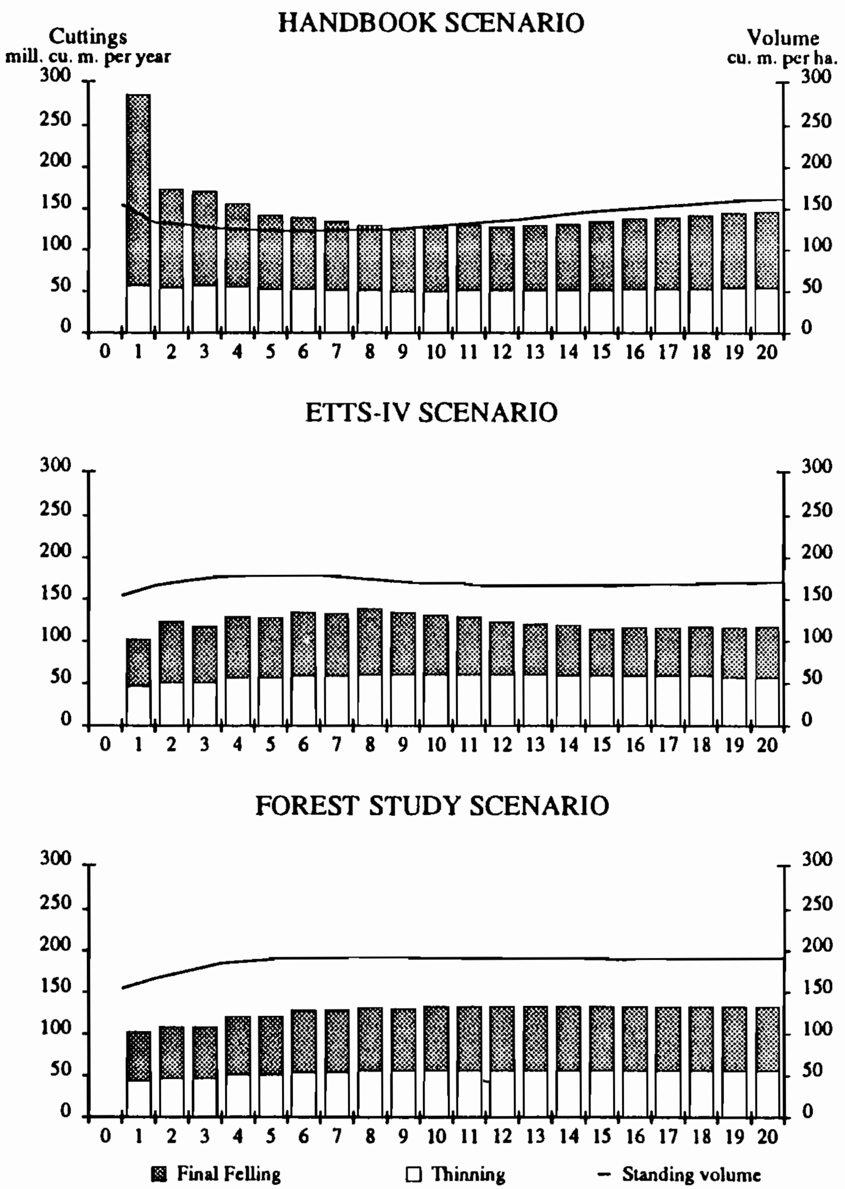

Figure 5.9. Projections for total potential harvest and growing stock in the EEC-9 region under the decline scenarios.

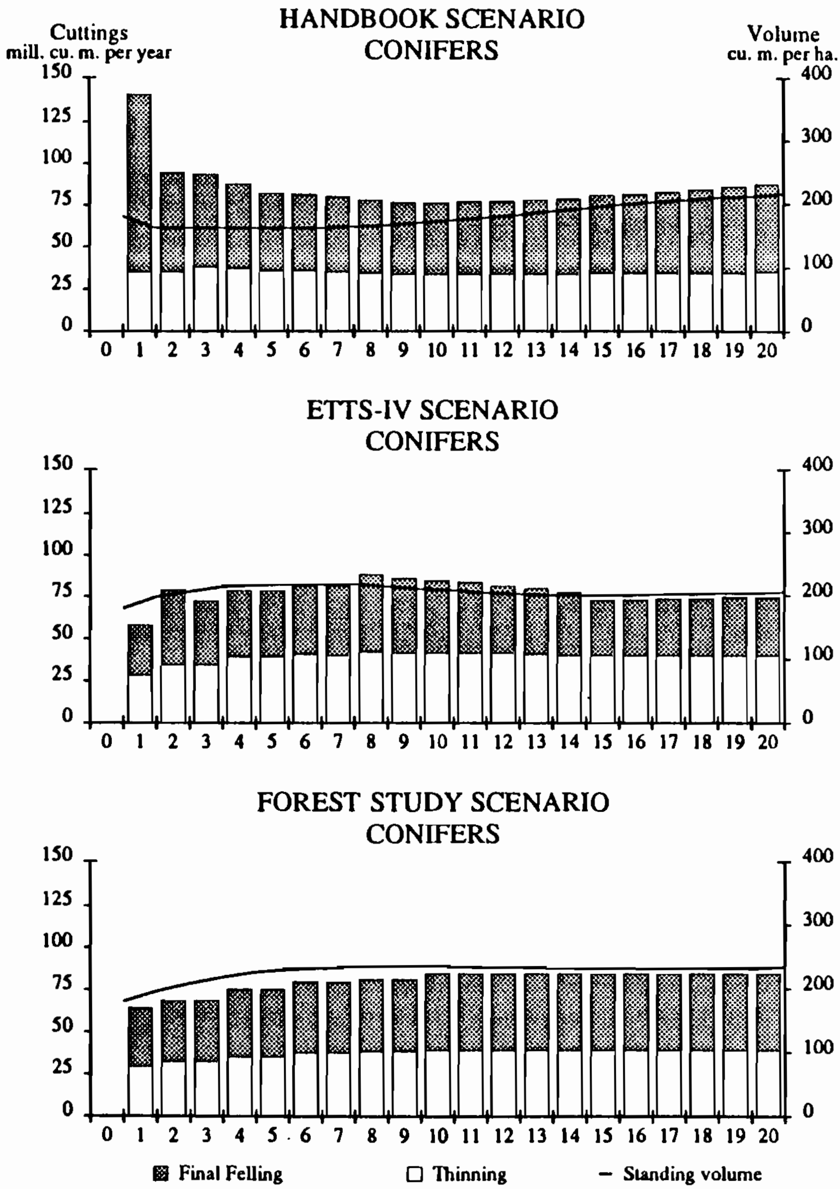

Figure 5.10. Projections for potential harvest and growing stock of coniferous forests in the EEC-9 region under the decline scenarios.

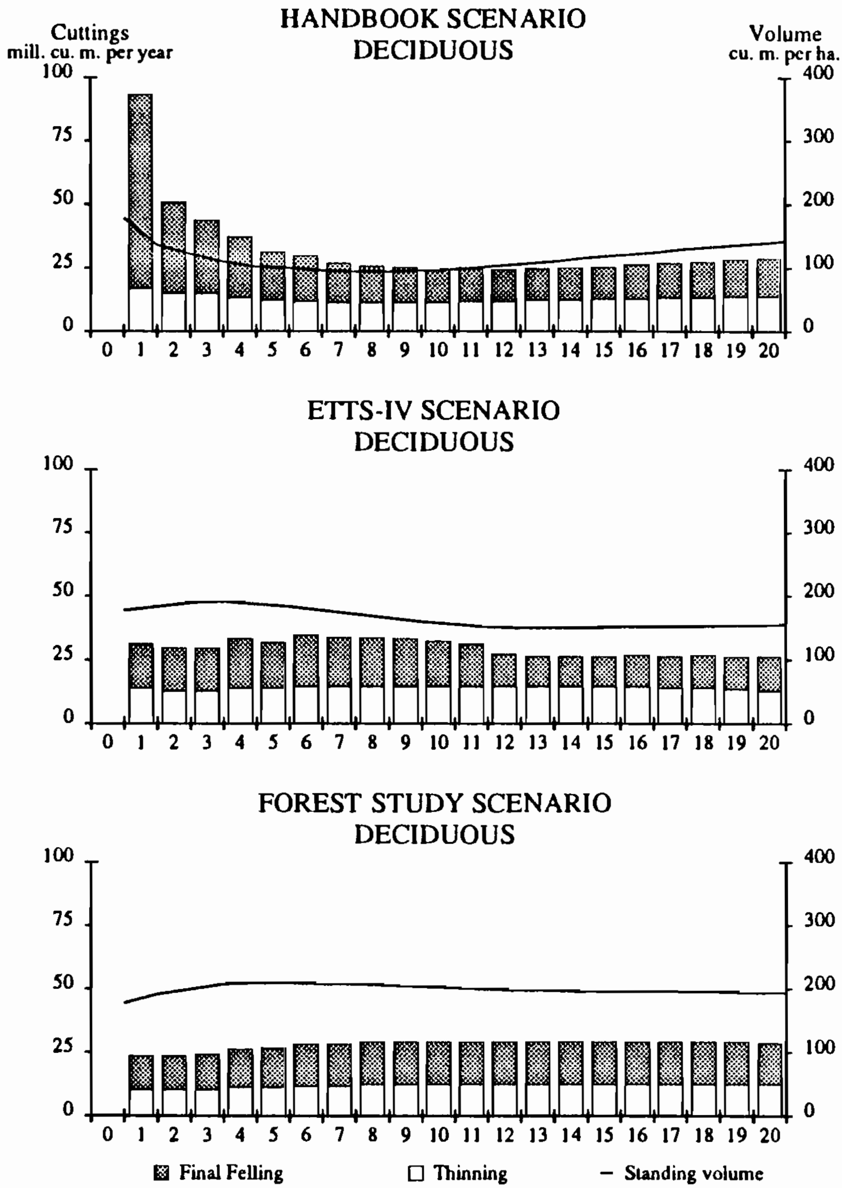

Figure 5.11. Projections for potential harvest and growing stock of deciduous forests in the EEC-9 region under the decline scenarios.

Table 5.21. Selected data on potential harvest and growing stock in the Central region under the decline scenarios.

Variable	Handbook Decline	ETTS-IV Decline	Forest Study Decline
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	298–215	298–179	298–369
Fellings (mill. m^3 o.b./yr)			
Year 1	55.1	20.0	17.3
Year 40	22.9	26.1	19.3
Year 80	19.3	26.2	19.3
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	301–221	301–184	301–372
Fellings (mill. m^3 o.b./yr)			
Year 1	53.0	18.6	16.3
Year 40	21.2	24.4	18.2
Year 80	18.1	24.5	18.2
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	260–144	260–125	260–343
Fellings (mill. m^3 o.b./yr)			
Year 1	2.1	1.4	1.0
Year 40	1.7	1.7	1.1
Year 80	1.2	1.7	1.1

5.5.3 Central region (Table 5.21 and Figures 5.12 to 5.14)

In the Basic Handbook Scenario, there was a harvest pulse during the first two periods of the simulation. In the Handbook Decline Scenario, decline leads to a stronger and longer pulse. After some 35 years, the total harvest level remains lower throughout the simulation period in the decline scenario in comparison with the basic scenario. The total growing stock is much lower in the decline scenario, by about 125 cubic meters per hectare at the end of the period, than in the basic scenario.

It is possible in the decline situation to keep the same harvest level as those in the Basic ETTS-IV Scenario. However, such a harvest level seriously harms the development of growing stock in the ETTS-IV Decline Scenario. At the end of the period, the growing stock will be nearly 150 cubic meters lower per hectare in the ETTS-IV Decline Scenario than in the Basic ETTS-IV Scenario.

To keep the same growing stock as in the Basic Forest Study Scenario, the total harvest level has to be strongly reduced in the Forest Study Decline

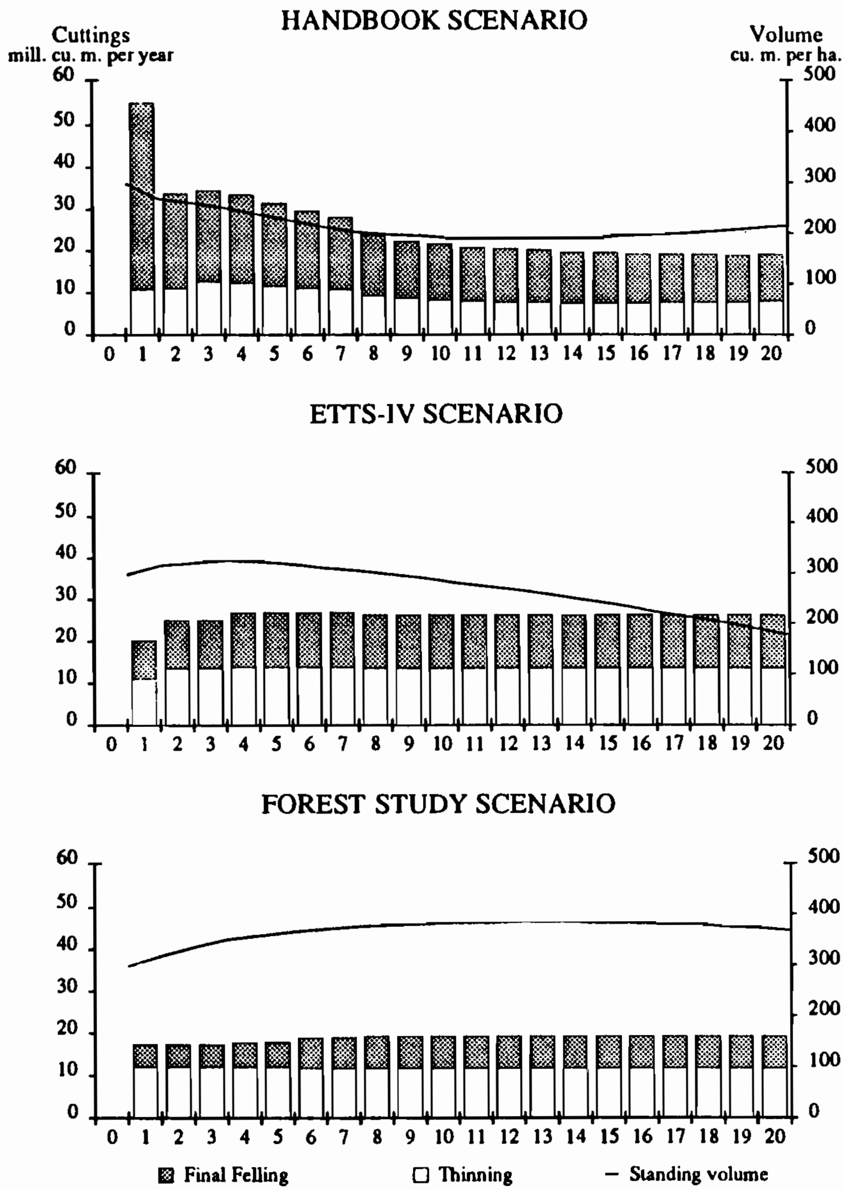

Figure 5.12. Projections for total potential harvest and growing stock in the Central region under the decline scenarios.

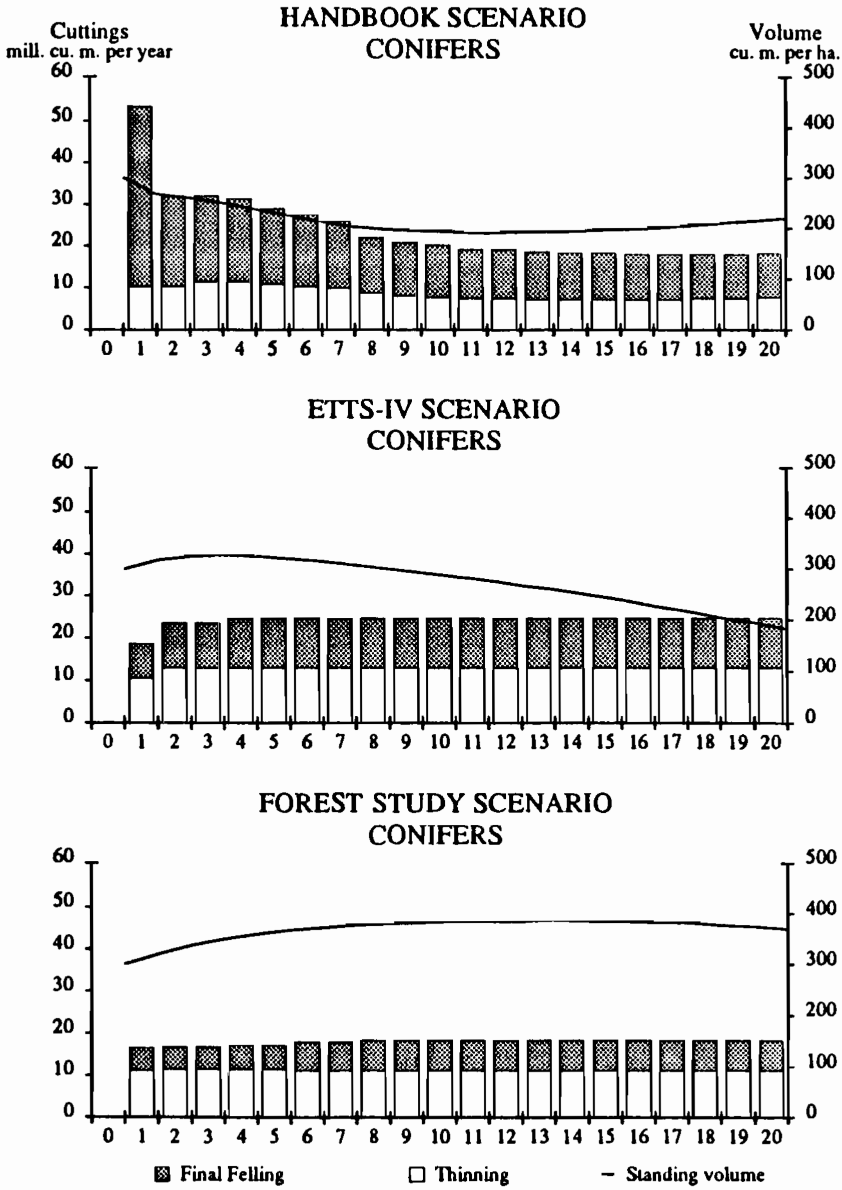

Figure 5.13. Projections for potential harvest and growing stock of coniferous forests in the Central region under the decline scenarios.

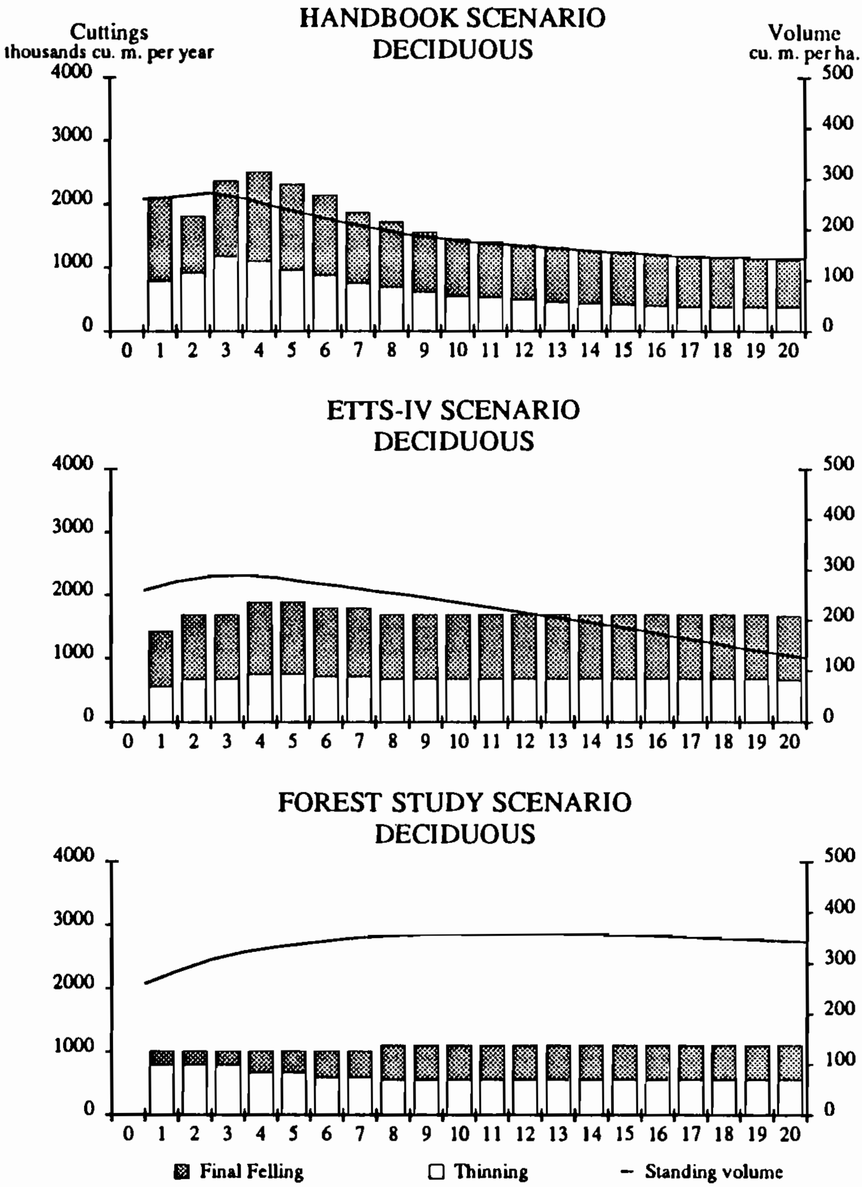

Figure 5.14. Projections for potential harvest and growing stock of deciduous forests in the Central region (in Switzerland only) under the decline scenarios.

Scenario throughout the simulation period. The total potential harvest level, averaged over the whole simulation period, is about 5.8 million cubic meters lower per year in the Forest Study Decline Scenario than in the Basic Forest Study Scenario.

Coniferous species are most affected by decline from a harvest point of view. In relative terms, coniferous and deciduous species (in Switzerland only) are affected to the same extent by the decline. The growing stock of both coniferous and deciduous types can be kept at the same level in the basic and decline scenarios.

5.5.4 Southern region (Table 5.22 and Figures 5.15 to 5.17)

For the Southern region, we can compare the Forest Study Decline Scenario only with the Basic Forest Study Scenario. In addition to a lack of an appropriate method to deal with the basic inventory data in three southern countries, there has been no possibility to quantify the effects of forest decline in Spain. Thus, the effects of forest decline attributed to air pollutants are underestimated for the Southern region.

In the Southern region, it is possible to reach the same growing-stock level in the decline situation as in the basic scenario. The potential harvest level is lower throughout the whole simulation period in the decline scenario. Coppice and deciduous species seem to be most affected by the decline. With regard to the development of the growing stock, it is possible to reach the same level in the decline situation as under the basic conditions for coniferous and deciduous species. However, for coppice the growing-stock level will be lower in the decline situation.

5.5.5 Eastern region (Table 5.23 and Figures 5.18 to 5.20)

In the Basic Handbook Scenario, there was a harvest pulse during the first periods of the simulation followed by an even harvest pattern for the remainder of the simulation. In the Handbook Decline Scenario, decline leads to a stronger harvest pulse during the first period. During the rest of the simulation, the total harvest decreases continuously, finally reaching a level about 35 million cubic meters lower per year than in the basic scenario. The growing-stock level is also lower in the decline scenario throughout the simulation period.

It is possible in the decline scenario to keep the harvest level identified in the Basic ETTS-IV Scenario for about 60 years. After that, the total

Table 5.22. Selected data on potential harvest and growing stock in the Southern region under the decline scenarios.

Variable	Handbook Decline	ETTS-IV Decline	Forest Study Decline
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	82–119	82–117	82–124
Fellings (mill. m^3 o.b./yr) Year 1	91.8	69.0	61.2
Year 40	73.7	81.1	70.8
Year 80	78.5	80.1	76.0
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	99–155	99–154	99–160
Fellings (mill. m^3 o.b./yr)			
Year 1	33.8	32.0	26.4
Year 40	32.8	33.0	31.8
Year 80	35.1	35.4	34.6
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	143–210	143–202	143–212
Fellings (mill. m^3 o.b./yr)			
Year 1	27.2	22.8	21.8
Year 40	26.3	29.4	25.4
Year 80	26.9	27.9	27.9
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	27–27	27–26	27–32
Fellings (mill. m^3 o.b./yr)			
Year 1	30.8	14.2	13.0
Year 40	14.6	18.7	13.6
Year 80	16.5	16.8	13.5

potential harvest will decrease in the decline scenario for the rest of the simulation period to a lower level than in the basic scenario. Even with this harvest level in the decline situation, there will be a strong reduction in the growing stock. The difference in the total growing stock at the end of the period between the basic and the decline scenarios is nearly 100 cubic meters per hectare.

In the Forest Study Decline Scenario, there are no possibilities to reach the same growing-stock level as in the Basic Forest Study Scenario. Indeed, the potential harvest level will also be much lower in the decline situation

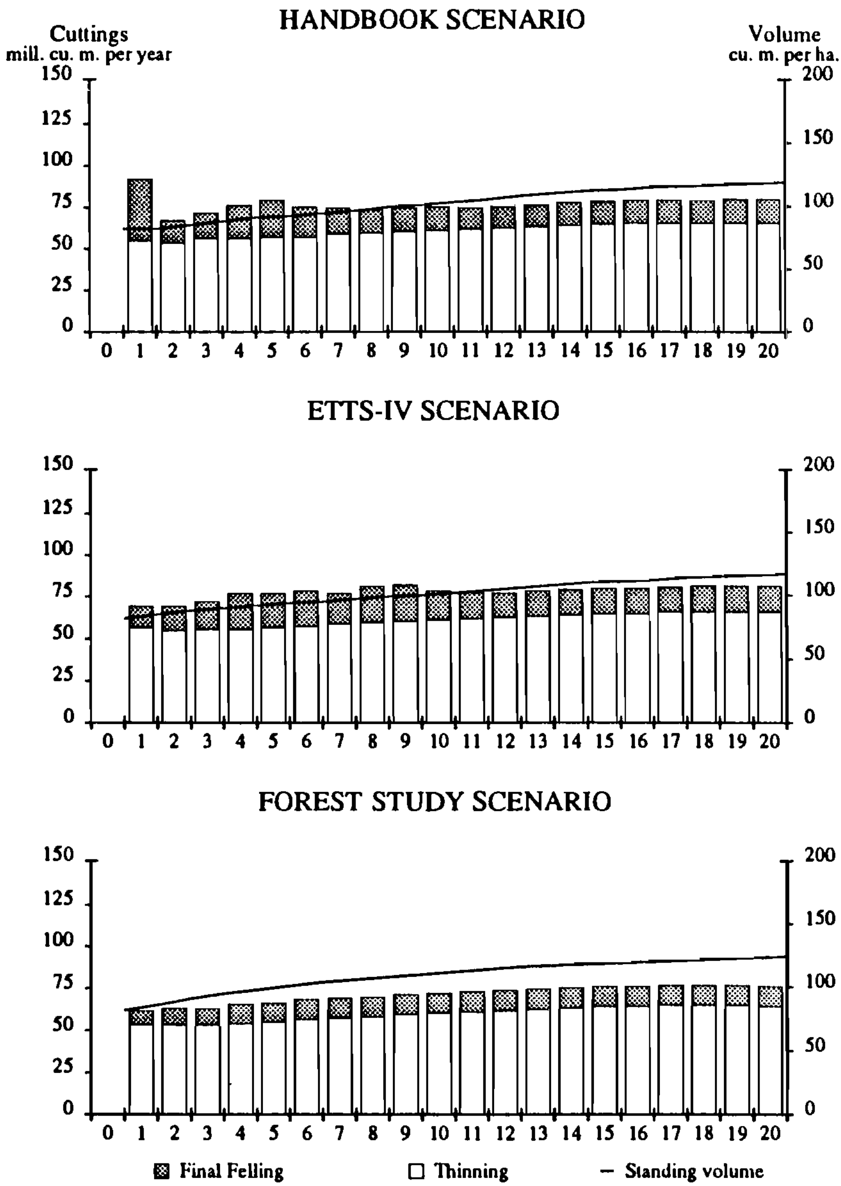

Figure 5.15. Projections for total potential harvest and growing stock in the Southern region under the decline scenarios.

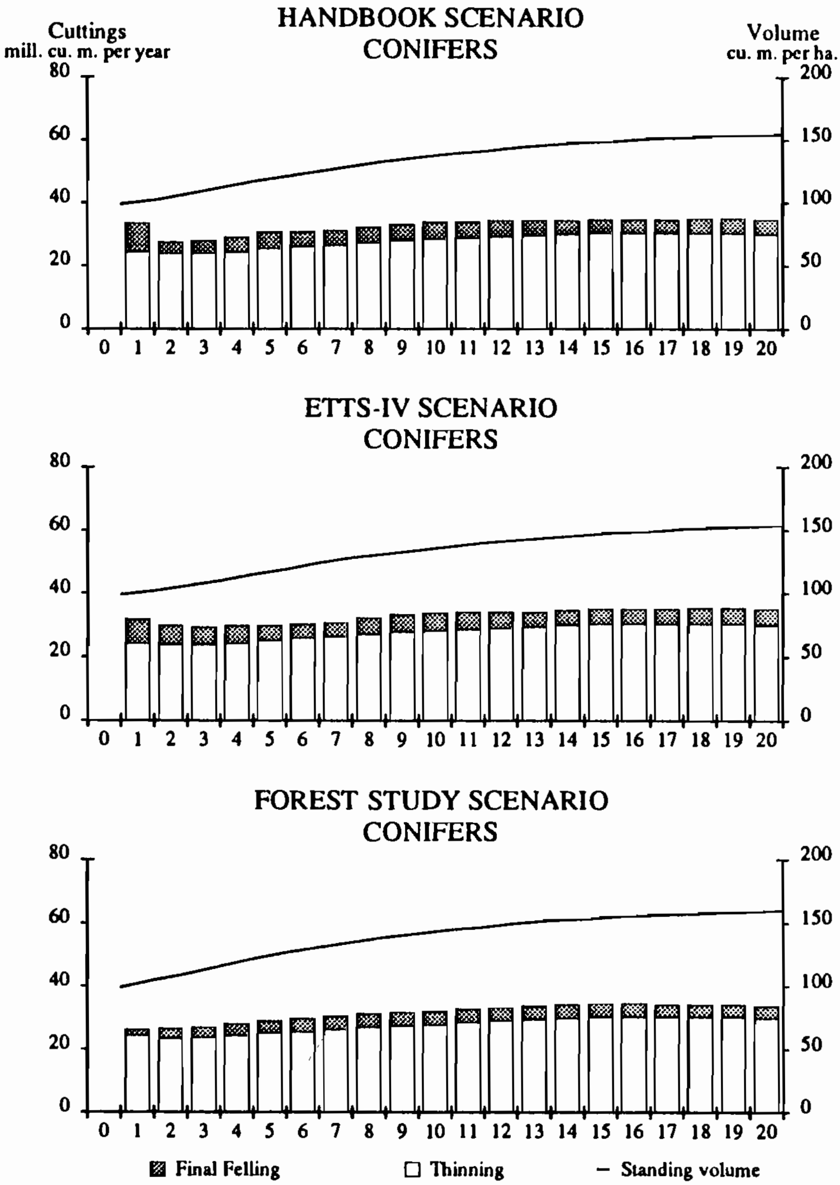

Figure 5.16. Projections for potential harvest and growing stock of coniferous forests in the Southern region under the decline scenarios.

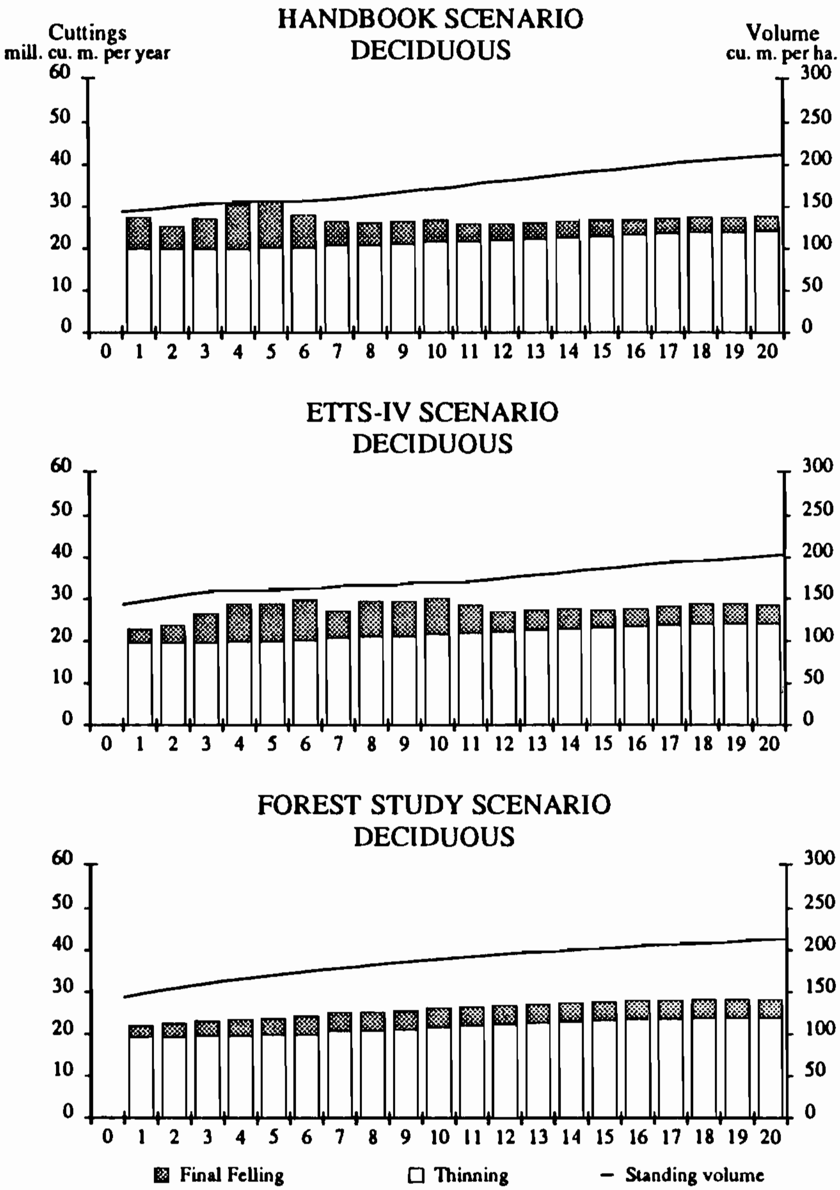

Figure 5.17. Projections for potential harvest and growing stock of deciduous forests in the Southern region under the decline scenarios.

Table 5.23. Selected data on potential harvest and growing stock in the Eastern region under the decline scenarios.

Variable	Handbook Decline	ETTS-IV Decline	Forest Study Decline
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	169–148	169–147	169–200
Fellings (mill. m^3 o.b./yr)			
Year 1	279.1	92.1	83.2
Year 40	105.9	111.3	94.8
Year 80	95.8	104.8	94.9
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	186–171	186–171	185–241
Fellings (mill. m^3 o.b./yr)			
Year 1	147.6	56.4	50.2
Year 40	70.2	67.6	56.3
Year 80	60.0	67.3	56.5
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	156–126	156–122	156–155
Fellings (mill. m^3 o.b./yr)			
Year 1	122.4	33.6	30.8
Year 40	32.2	40.7	35.8
Year 80	31.5	34.7	35.8
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	97–81	97–107	97–125
Fellings (mill. m^3 o.b./yr)			
Year 1	9.1	2.1	2.2
Year 40	3.5	3.0	2.7
Year 80	4.3	2.8	2.6

over the whole simulation period. The decreased total harvest is about 30 million cubic meters (averaged over the whole simulation period) lower per year in the decline situation. It is mainly final fellings that are affected by a decreasing harvest potential in the decline scenario.

In the Forest Study Decline Scenario, it is not possible to reach the same growing-stock level for conifers as in the Basic Forest Study Scenario. Besides the lower growing-stock level, the potential harvest level of conifers is reduced by nearly 30 million cubic meters per year in the decline scenario.

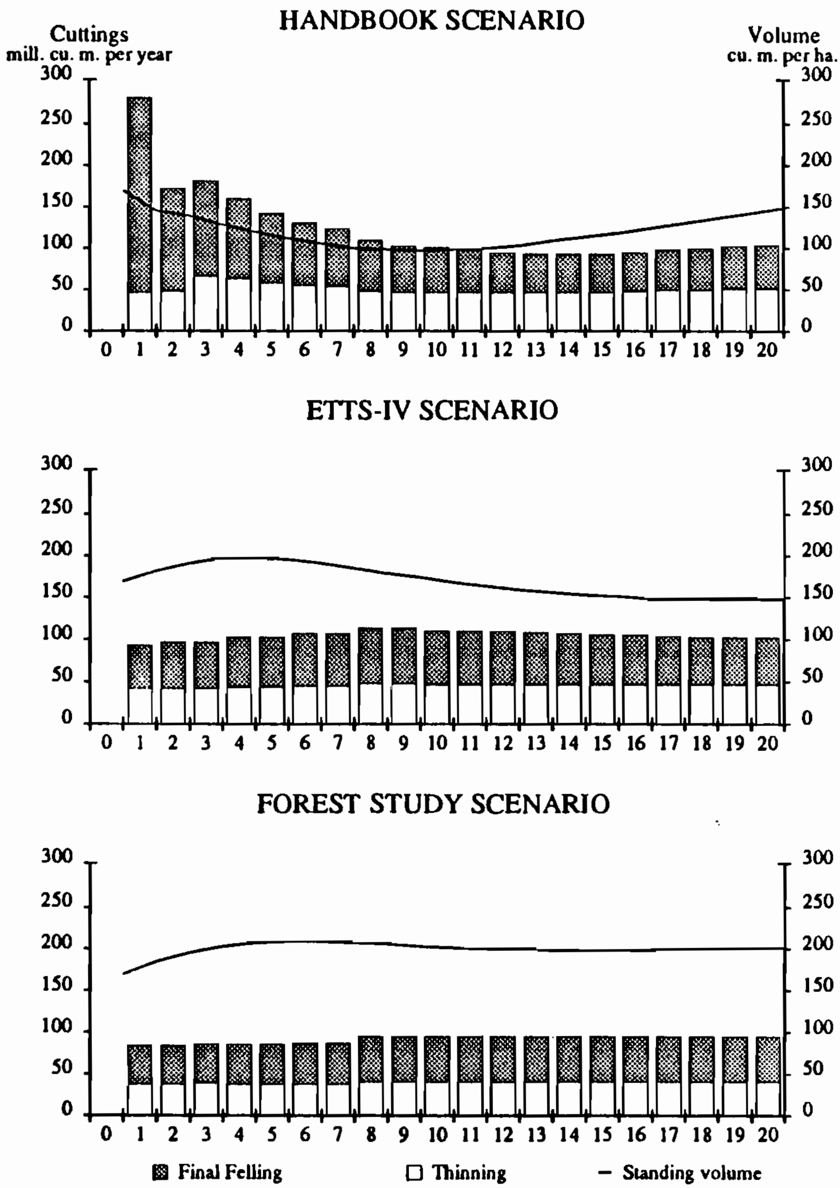

Figure 5.18. Projections for total potential harvest and growing stock in the Eastern region under the decline scenarios.

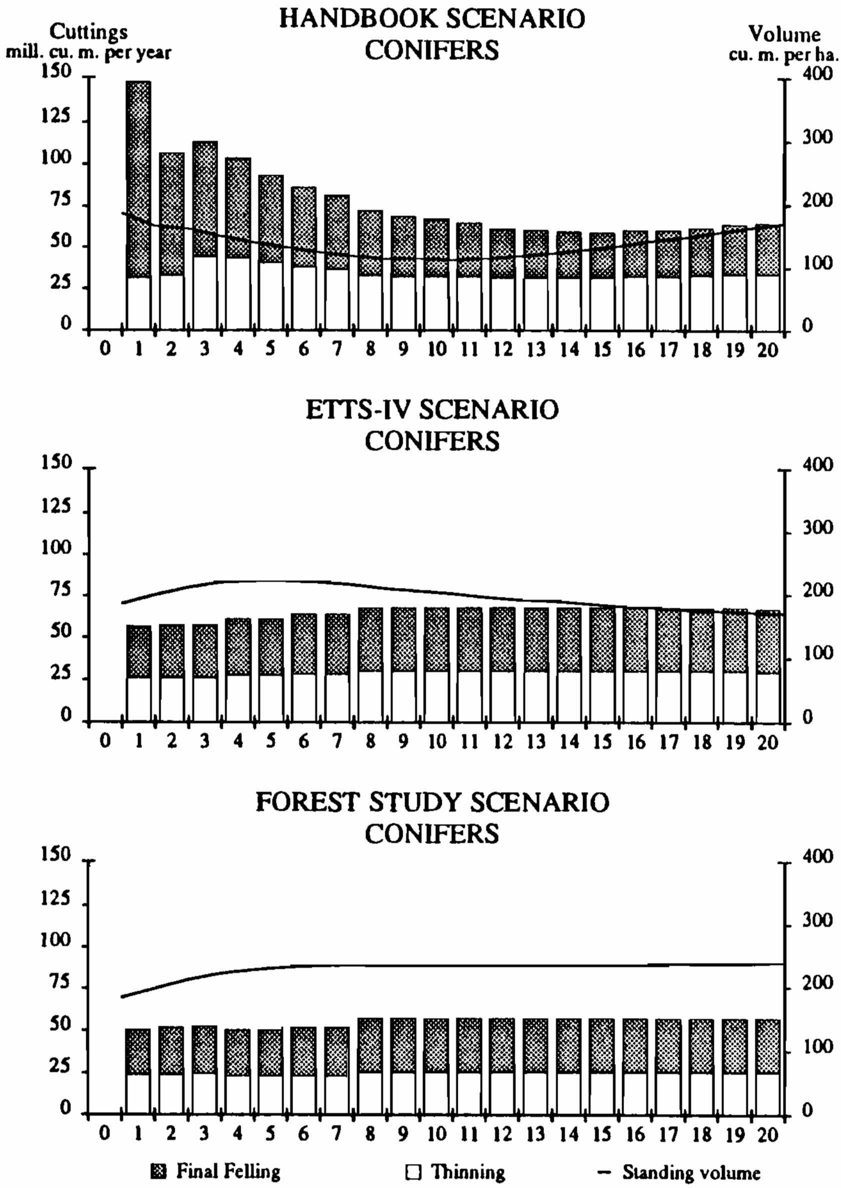

Figure 5.19. Projections for potential harvest and growing stock of coniferous forests in the Eastern region under the decline scenarios.

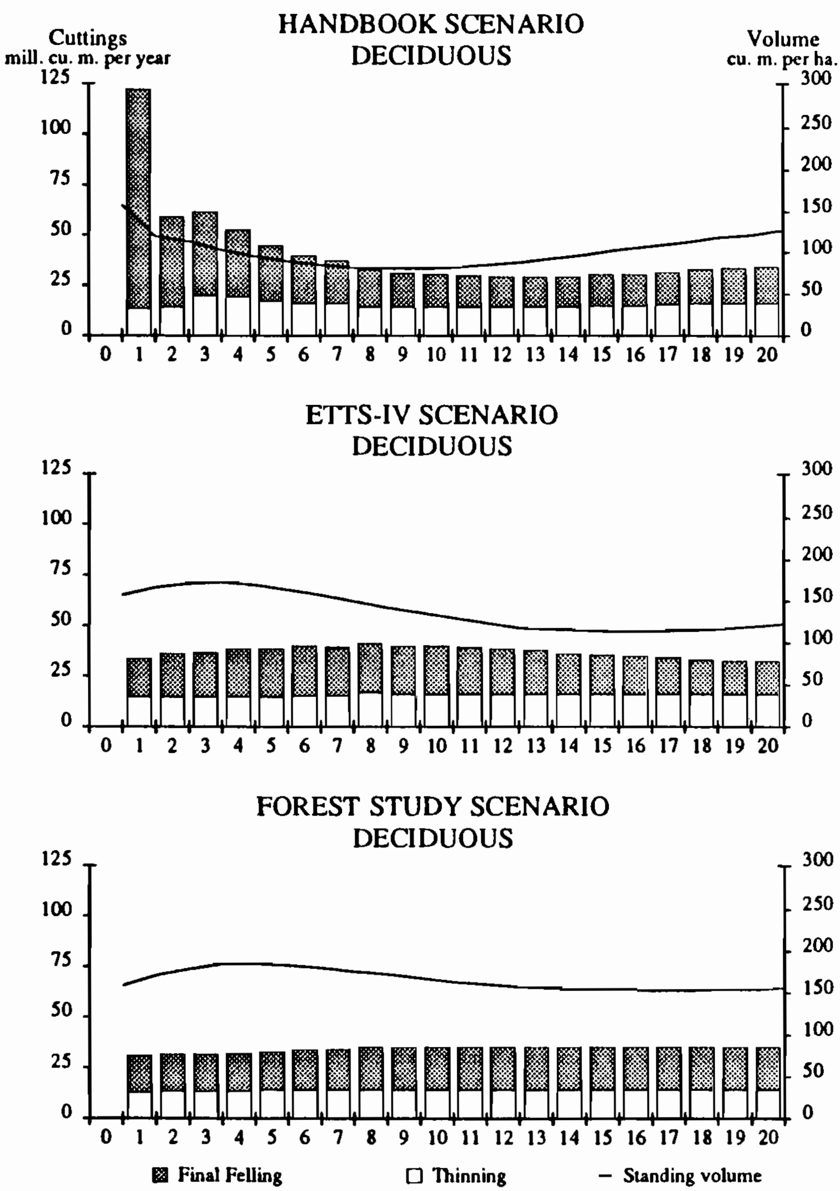

Figure 5.20. Projections for potential harvest and growing stock of deciduous forests in the Eastern region under the decline scenarios.

Table 5.24. Selected data on potential harvest and growing stock in Europe under the decline scenarios.

Variable	Handbook Decline	ETTS-IV Decline	Forest Study Decline
Total			
Growing stock (m^3 o.b./ha; yr0–yr100)	122–138	122–137	122–164
Fellings (mill. m^3 o.b./yr)			
Year 1	1092.3	407.6	396.6
Year 40	452.1	510.2	467.8
Year 80	492.4	476.7	475.0
Coniferous			
Growing stock (m^3 o.b./ha; yr0–yr100)	131–156	131–154	131–185
Fellings (mill. m^3 o.b./yr)			
Year 1	720.1	271.1	255.7
Year 40	310.1	353.4	327.1
Year 80	343.7	336.8	332.8
Deciduous			
Growing stock (m^3 o.b./ha; yr0–yr100)	150–145	150–140	150–172
Fellings (mill. m^3 o.b./yr)			
Year 1	281.5	108.1	84.7
Year 40	98.9	119.3	105.4
Year 80	99.1	104.6	106.9
Coppice			
Growing stock (m^3 o.b./ha; yr0–yr100)	59–59	59–73	59–75
Fellings (mill. m^3 o.b./yr)			
Year 1	90.7	28.4	29.2
Year 40	43.1	37.5	35.3
Year 80	49.6	35.3	35.3

5.5.6 Europe (Table 5.24 and Figures 5.21 to 5.23)

Because some results on forest decline in Southern Europe are missing, it is only meaningful to compare the Basic Forest Study Scenario and the Forest Study Decline Scenario for all Europe. It should be emphasized that the decline effects described for total Europe are underestimates owing to missing quantifications of the decline in Spain. For all Europe, it is nearly possible to reach the same development and level of the growing stock in the decline situation as under the basic conditions. However, the total harvest potential will be much lower in the decline situation, by about 80 million cubic meters per year, than under basic conditions. All species groups are affected in a similar way by the decline attributed to air pollutants.

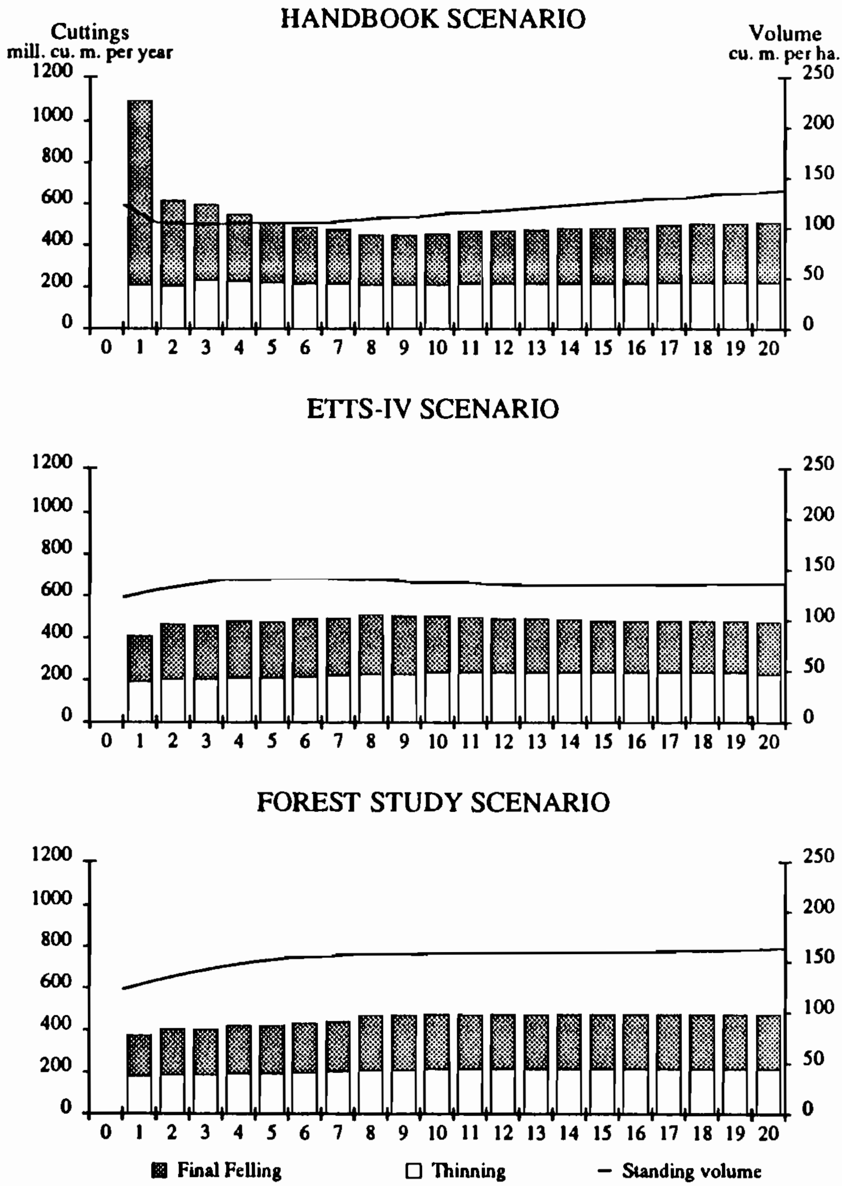

Figure 5.21. Projections for total potential harvest and growing stock in Europe under the decline scenarios.

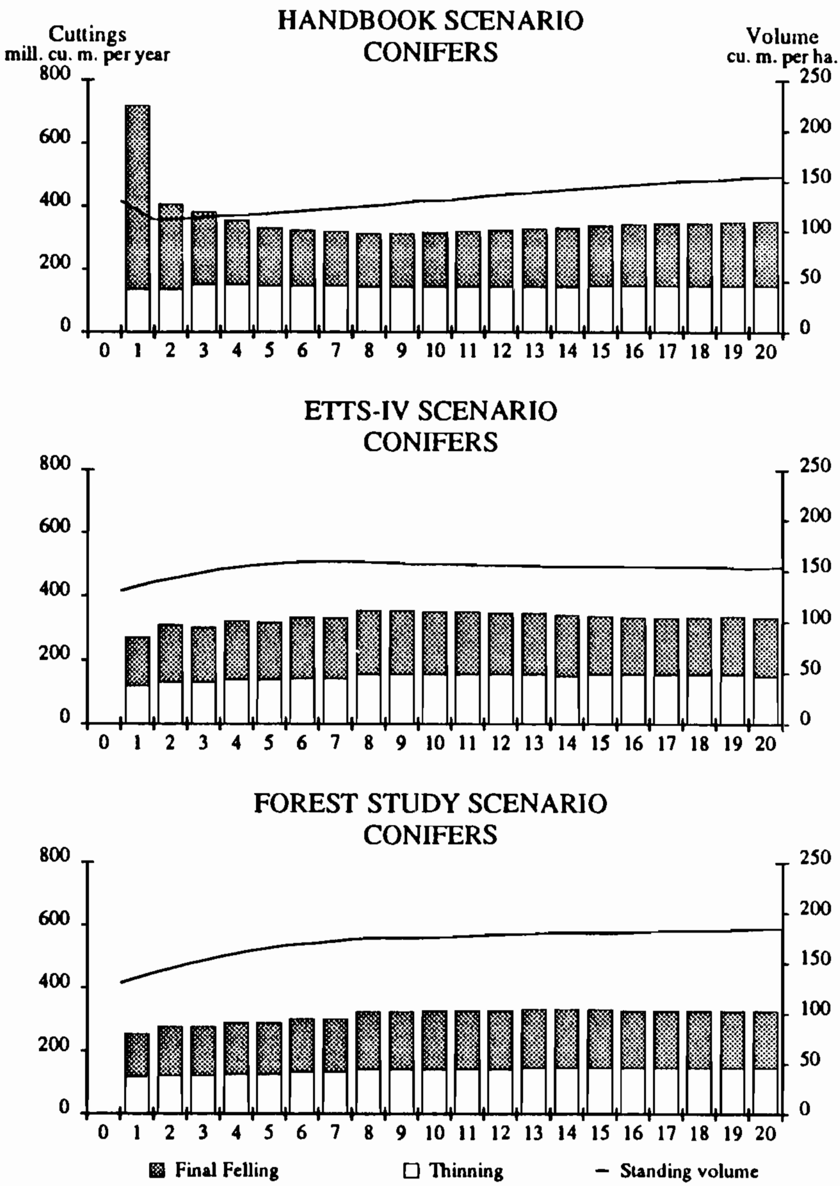

Figure 5.22. Projections for potential harvest and growing stock of coniferous forests in Europe under the decline scenarios.

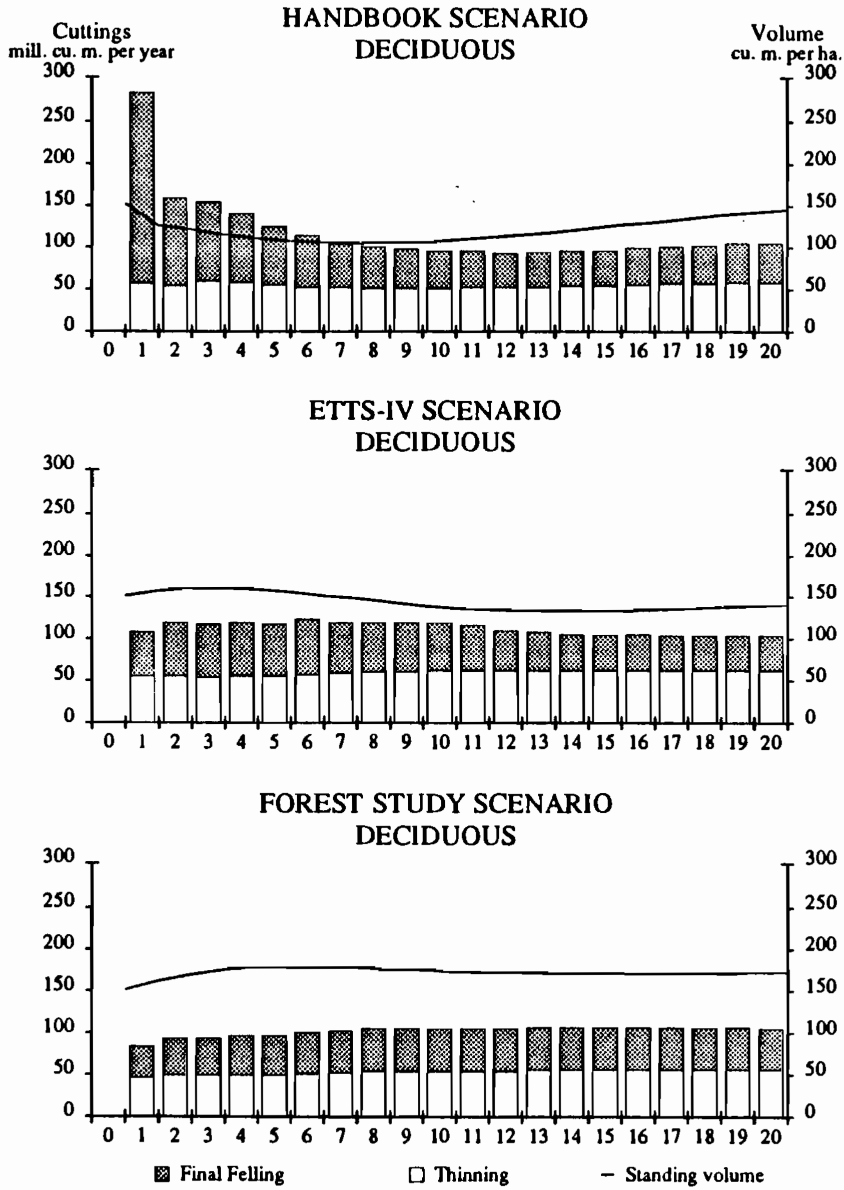

Figure 5.23. Projections for potential harvest and growing stock of deciduous forests in Europe under the decline scenarios.

5.6 Conclusions

We have summarized the main trends from the simulation results under the forest-decline scenarios in *Table 5.25*. Regarding the Handbook Decline Scenario, it seems that forest decline attributed to air pollutants results in greater imbalances, in comparison with the Basic Handbook Scenario, in the structure of existing forest resources and the actual silvicultural programs. This results partly from changed silvicultural strategies for declining forests. Under decline conditions, thinning intensity is increased, rotation periods shortened, and other changes are initiated. The overall conclusion based on the Handbook Decline Scenario is that European countries must formulate new forest policies to meet the new conditions caused by the decline and to keep forest resources vital. Even if optimal silviculture is employed in the decline situation according to the Basic Handbook Scenario, the total potential harvest level and the growing stock are both reduced in comparison with the Basic Forest Study Scenario. This conclusion is valid for all countries and regions, as we have found no significant differences in the results for the handbook silviculture scenarios.

Concerning the ETTS-IV harvest levels, it can be seen that under decline conditions the total harvest potentials identified in the basic alternative cannot be reached in many countries. However, in some regions (e.g., Nordic and Central) there are possibilities to reach the basic ETTS-IV levels. However, implementing these harvest levels forces growing-stock levels down in the decline situation. The growing stocks will be forced down in all countries in the ETTS-IV Decline Scenario compared with the Basic ETTS-IV Scenario.

Results from the ETTS-IV Decline Scenario confirm our earlier conclusion that the decline conditions will force countries to implement new forest policies to combat the effects of forest decline. The harvest levels identified by ETTS-IV are based on implementation of current forest policies (not taking forest decline into account) in individual countries. Based on the Forest Study Decline Scenario, it is evident that the total potential harvest level has to be forced down in comparison with the basic conditions. This is a result of the goal in the scenarios to keep growing stocks at a high, nondeclining level. As discussed earlier (Section 1.3 and *Table 1.1*), most European countries have an objective to keep the forest resources at a sustainable level. In this scenario, we have interpreted sustainability as nondeclining development of the growing stock.

In the decline situation, the total potential harvest level is reduced in comparison with the basic conditions. The most affected regions (in relative terms) are the Eastern, Central, and EEC-9 regions. However, the absolute volume effects are also rather large in the Nordic region. These results seem logical in relation to the deposition patterns, pattern of sensitivities, and extent of existing forest resources.

In *Table 5.26*, we compare the projected effects of air pollutants in the Forest Study with 1988 data analyzed according to the procedures in UN-ECE (1986) and summarized by Nilsson (1989c). The ranking in *Table 5.26* for the Forest Study scenarios is based on the difference in average harvest potential over 100 years compared with the Basic Forest Study Scenario. The UN-ECE ranking is based on the percentage of the growing stock with different degrees of losses of foliage.

Some discrepancies can be identified in *Table 5.26*. We reiterate that we were unable to calculate any decline effects for Spain in the Forest Study; therefore, there is an obvious explanation for the ranking of this country. For Romania and Turkey, there are no 1988 vitality monitoring results.

There is a big discrepancy between the rankings for Greece: a very low ranking according to the Forest Study and high rankings according to the UN-ECE monitoring (Nilsson, 1989c). The loss of foliage monitored following the UN-ECE manual for Greece has been attributed to such causes as fires, forest grazing, lack of proper management, and prolonged periods of drought, and not to air pollutants (Nilsson, 1989c).

Another outlier in the ranking is Denmark; Denmark has a medium ranking according to the Forest Study and a high ranking according to UN-ECE monitoring. In the official reports to UN-ECE from Denmark concerning the monitoring results, it is argued that most of the declining vitality (loss of foliage) is caused by factors other than air pollutants.

The former GDR has a high ranking according to the Forest Study but a medium ranking according to the monitoring by the UN-ECE system. Nilsson (1988) expresses strong doubts about the reported vitality figures for the GDR. According to other sources, the declining vitality monitored should be much higher.

Hungary has a high ranking according to the Forest Study but a low ranking according to the UN-ECE monitoring. One explanation for this discrepancy is that the Forest Study takes into account emissions up to 2000 to 2005 and the UN-ECE monitoring does not. If this is correct, higher loss of foliage can be expected in Hungary. To some extent this explanation applies also to Portugal and Austria.

Table 5.25. Summary of trends in decline scenarios and comparisons with corresponding basic scenarios.

	Handbook Decline Scenario			ETTS-IV Decline Scenario		Forest Study Decline Scenario	
Country Region	Balance of structure with handbook silviculture	Harvest level	Development of growing stock	Harvest level	Development of growing stock	Harvest level	Development of growing stock
Finland	Worse	Decreased	Lower	Same	Lower	Lower ~4.5 mill m^3/yr	Same
Norway	Dramatically worse	Decreased	Lower	Same	Lower	Lower ~0.8 mill m^3/yr	Lower
Sweden	Worse	Decreased	Lower	Nearly same	Lower	Lower ~5.8 mill m^3/yr	Same
Nordic	Worse	Decreased	Lower	Lower	Lower	Lower ~11.1 mill m^3/yr	Nearly same
Belgium	Worse	First increased later decreased	Lower	Nearly same	Much lower	Lower ~0.7 mill m^3/yr	Same
Denmark	Worse	Decreased	Lower	Nearly same	Much lower	Lower ~0.4 mill m^3/yr	Lower
France	Worse	First increased later decreased	Lower	Lower	Lower	Much lower ~3.5 mill m^3/yr	Same
FRG	Much worse	First increased later decreased	Much lower	Nearly same	Much lower	Much lower ~11.9 mill m^3/yr	Same
Ireland	Same	Slightly lower	Lower	Same	Same	Lower ~0.2 mill m^3/yr	Same
Italy	Worse	Decreased	Nearly same	Lower	Lower	Lower ~5.8 mill m^3/yr	Lower
Luxembourg	Worse	Decreased	Much lower	Lower	Much lower	Lower ~0.06 mill m^3/yr	Same
Netherlands	Worse	Decreased	Lower	Lower	Lower	Lower ~0.2 mill m^3/yr	Nearly same
UK	Worse	Decreased	Lower	Lower	Lower	Lower ~3.7 mill m^3/yr	Same
EEC-9	Worse	First increased later decreased	Lower	Lower	Lower	Lower ~25.9 mill m^3/yr	Lower
Austria	Worse	First increased later decreased	Much lower	Same	Much lower	Lower ~3.4 mill m^3/yr	Same
Switzerland	Worse	Lower	Much lower	Same	Much lower	Much lower ~2.4 mill m^3/yr	Nearly same
Central	Worse	First increased later decreased	Much lower	Same	Much lower	Much lower ~5.8 mill m^3/yr	Same

Table 5.25. Continued.

Country Region	Handbook Decline Scenario: Balance of structure with handbook silviculture	Handbook Decline Scenario: Harvest level	Handbook Decline Scenario: Development of growing stock	ETTS-IV Decline Scenario: Harvest level	ETTS-IV Decline Scenario: Development of growing stock	Forest Study Decline Scenario: Harvest level	Forest Study Decline Scenario: Development of growing stock
Greece	–	–	–	–	–	Lower ~0.1 mill m^3/yr	Same
Portugal	Same	Same	Same	Lower	Same	Lower ~1.5 mill m^3/yr	Nearly same
Spain	–	–	–	–	–	–	–
Turkey	–	–	–	–	–	Lower ~2.8 mill m^3/yr	Same
Yugoslavia	Worse	Lower	Lower	Lower	Lower	Lower ~2.8 mill m^3/yr	Nearly same
Southern	–	–	–	–	–	Lower ~7.2 mill m^3/yr	Same
Bulgaria	Worse	First increased later decreased	Lower	Same	Lower	Lower ~2.2 mill m^3/yr	Same
CSFR	Dramatically worse	First increased later decreased	Much lower	Lower	Much lower	Much lower 9.5 mill m^3/yr	Nearly same
GDR	Dramatically worse	First increased later decreased	Much lower	Lower	Much lower	Much lower ~4.9 mill m^3/yr	Same
Hungary	Much worse	First increased later decreased	Lower	Lower	Lower	Much lower ~3.0 mill m^3/yr	Nearly same
Poland	Much worse	First increased later decreased	Lower	Lower	Much lower	Much lower ~11.1 mill m^3/yr	Same
Romania	Worse	First increased later decreased	Lower	Same	Much lower	Lower ~3.8 mill m^3/yr	Lower
Eastern	Worse	First increased later decreased	Lower	Lower	Much lower	Much lower ~25.0 mill m^3/yr	Same
Europe	–	–	–	–	–	Lower 84.0 mill m^3/yr	Nearly same

Table 5.26. Ranking of decline effects according to the Forest Study projections and to UN-ECE monitoring in 1988.

Country	Potential harvest during 100 years difference between Basic Forest Study Scenario and adjusted Forest Study Scenario (in %)	Percentage of the growing stock with a loss of >10% of foliage in 1988	Percentage of the growing stock with a loss of foliage > 20 to 25% of foliage in 1988	Forest Study ranking of decline effects	UN-ECE ranking according to a loss of > 10% of foliage	UN-ECE ranking according to a loss of > 20 to 25% of foliage
CSFR	40	70	38	1	1	5
Poland	36	50	23	2	7	12
Hungary	35	21	19	3	22	17
GDR	34	45	20	4	10	15
Switzerland	32	51	23	5	6	13
United Kingdom	28	63	41	6	2	3
Luxembourg	26	47	43	7	8	2
Bulgaria	26	41	28	8	13	7
FRG	24	51	27	9	4	10
Netherlands	22	47	29	10	9	6
Portugal	20	6	3	11	23	23
Austria	20	31	10	12	18	21
Belgium	18	43	27	13	11	8
Italy	15	32	25	14	17	11
Denmark	12	51	43	15	5	1
Yugoslavia	12	34	27	16	16	9
Ireland	11	24	4	17	21	22
Turkey	10	–	–	18	24	24
Romania	9	–	–	19	25	25
Sweden	8	41	14	20	12	20
Finland	8	39	20	21	15	16
France	6	27	20	22	20	14
Norway	4	40	17	23	14	17
Greece	4	63	38	24	3	4
Spain	0	31	17	25	19	19

Chapter 6

The Forest Land Expansion Scenario

6.1 Major Assumptions

Presently, agricultural policies are under review in many European countries. Current policy subsidizes overproduction of foodstuffs. Governments do not want this pattern to continue, so alternative uses of excess agricultural land are being investigated. These investigations suggest, in general, that about half of the surplus land should be put under forest cover. In addition, large areas in Europe with bush vegetation and degenerated forests are available for afforestation. This land has also been taken into consideration as a potential for expansion of the forest landbase.

Through our policy-exercise work and other activities, the Forest Study has worked closely with collaborators throughout Europe, especially the EEC/CEC head office in Brussels, on this subject. The results were sent to our collaborators throughout Europe for review in 1989. The collaborators then reacted to our suggestions on agricultural land conversion, rehabilitation of degraded forest, and afforestation of brush cover.

For the Forest Land Expansion Scenario we have implemented changes in the forest landbase for 19 of the 25 countries in the study for the period 1985 to 2020 (*Table 6.1*). The increased landbase takes into account only land which can be fully available for industrial roundwood production and exploitation. Thus, areas for fast-growing plantations for energy production are not considered in these land expansions. We have also made explicit assumptions about which species become established over time on these new

Table 6.1. Estimates of future expansions of forest land and species composition on the expansions.

Country Region	Forest area in 1985 (1,000 ha)	Annual increase 1985 to 2020 (1,000 ha)	Forest area in 2020 (1,000 ha)	Species composition: Coniferous (% of total)	Species composition: Deciduous (% of total)
Finland	19,335	0	19,355		
Norway	5,184	0	5,184		
Sweden	23,365	14	23,859	80	20
Nordic	47,884	14	48,398		
Belgium	584	3	689	30	70
Denmark	434	6	644	80	20
France	13,231	44	14,771	70	30
FRG	7,477	28	8,457	80	20
Ireland	271	20	971	100	0
Italy	4,787	15	5,312	30	70
Luxembourg	34	0.5	51.5	60	40
Netherlands	221	1.5	273.5	55	45
UK	1,924	33	3,079	80	20
EEC-9	28,963	151	34,248		
Austria	2,831	7	3,076	100	0
Switzerland	1,092	12	1,512	58	42
Central	3,923	19	4,588		
Greece	1,947	2[a]	2,017	40	60
Portugal	1,475	25	2,350	75	25
Spain	5,605	60	7,705	25	75
Turkey	15,877	0	15,877		
Yugoslavia	8,028	16	8,588	30	70
Southern	32,932	103	36,537		
Bulgaria	3,196	2	3,248	80	20
CSFR	4,159	0	4,159		
GDR	2,461	0	2,461		
Hungary	1,503	7	1,748	25	75
Poland	7,938	28	8,918	80	20
Romania	6,207	0	6,207		
Eastern	25,464	37	26,741		
Europe	139,166	324	150,512		

[a]Not implemented in the simulations.

forest lands (*Table 6.1*). For these estimates of forest-land expansion, we are using silviculture and harvest patterns of the Basic Forest Study Scenario, we consider this to be the only realistic silvicultural scenario for practical implementation among the three scenarios we have constructed (see Chapter 4 for discussion on the practical problems of the handbook and ETTS-IV scenarios). We also try to follow the growing-stock development of the Basic Forest Study Scenario.

The land-expansion scenario depicted in *Table 6.1* is just that – a scenario, among many potential and different scenarios, of plausible changes in the forest landbase of European countries. The estimates are not forecasts of what will happen, but simply projections of what could happen, developed with the help of numerous collaborators in such a way as to provide useful input into our modeling framework for analysis. Alternative data and assumptions about rates of forest-land expansion could easily be explored using our modeling framework. In this chapter we present the results of one scenario of plausible changes. We re-emphasize that the Forest Land Expansion Scenario incorporates no effects of forest decline. Therefore, the results of the scenario are properly compared with results of the Basic Forest Study Scenario.

6.2 Guide to the Results

For each region, and for Europe as a whole, we present data on cuttings and growing stock under the Forest Land Expansion Scenario (*Table 6.2*). Then, we present one figure for each region and one for Europe showing total, coniferous, and deciduous cuttings and growing stocks under this scenario. The results are discussed region by region. Country-specific results are presented in Appendix B – where, in addition to development of cuttings and growing stocks, we present coniferous and deciduous age-class structures as influenced by the increases specified in the forest landbase.

6.3 Discussion

6.3.1 Nordic region (Table 6.2 and Figure 6.1)

The expansion of the forest landbase is expected to be rather limited in the Nordic region, since only Sweden indicates an increase of the forest landbase up to year 2020. Therefore the effects on potential harvest are limited. We

Table 6.2. Selected data on potential harvest and growing stock in Europe under the Forest Land Expansion Scenario.

Variable	Nordic	EEC-9	Central	Southern	Eastern	Europe
Total						
Growing stock (m^3/ha; yr0–yr100)	93–141	152–182	298–345	82–120	170–206	122–164
Fellings (mill. m^3/yr)						
Year 1	130.3	133.3	23.2	69.8	116.3	473.1
Year 40	162.7	174.1	25.5	82.6	131.9	576.7
Year 80	165.4	187.4	26.2	91.4	129.5	600.0
Coniferous						
Growing stock (m^3/ha; yr0–yr100)	94–145	181–213	301–348	99–154	185–236	131–182
Fellings (mill. m^3/yr)						
Year 1	117.3	81.3	21.8	28.4	68.6	317.7
Year 40	149.5	110.9	24.0	35.1	77.3	396.7
Year 80	151.0	121.7	24.4	40.2	77.3	414.6
Deciduous						
Growing stock (m^3/ha; yr0–yr100)	82–102	179–181	260–319	143–184	160–176	151–173
Fellings (mill. m^3/yr)						
Year 1	13.0	35.3	1.4	25.4	45.4	120.4
Year 40	13.2	41.4	1.5	31.0	51.8	138.9
Year 80	14.4	45.5	1.8	34.7	49.4	145.8
Coppice						
Growing stock (m^3/ha; yr0–yr100)	–	95–121	–	27–31	97–130	58–72
Fellings (mill. m^3/yr)						
Year 1	–	16.7	–	16.0	2.3	35.0
Year 40	–	21.8	–	16.5	2.8	41.1
Year 80	–	20.2	–	16.5	2.8	39.6

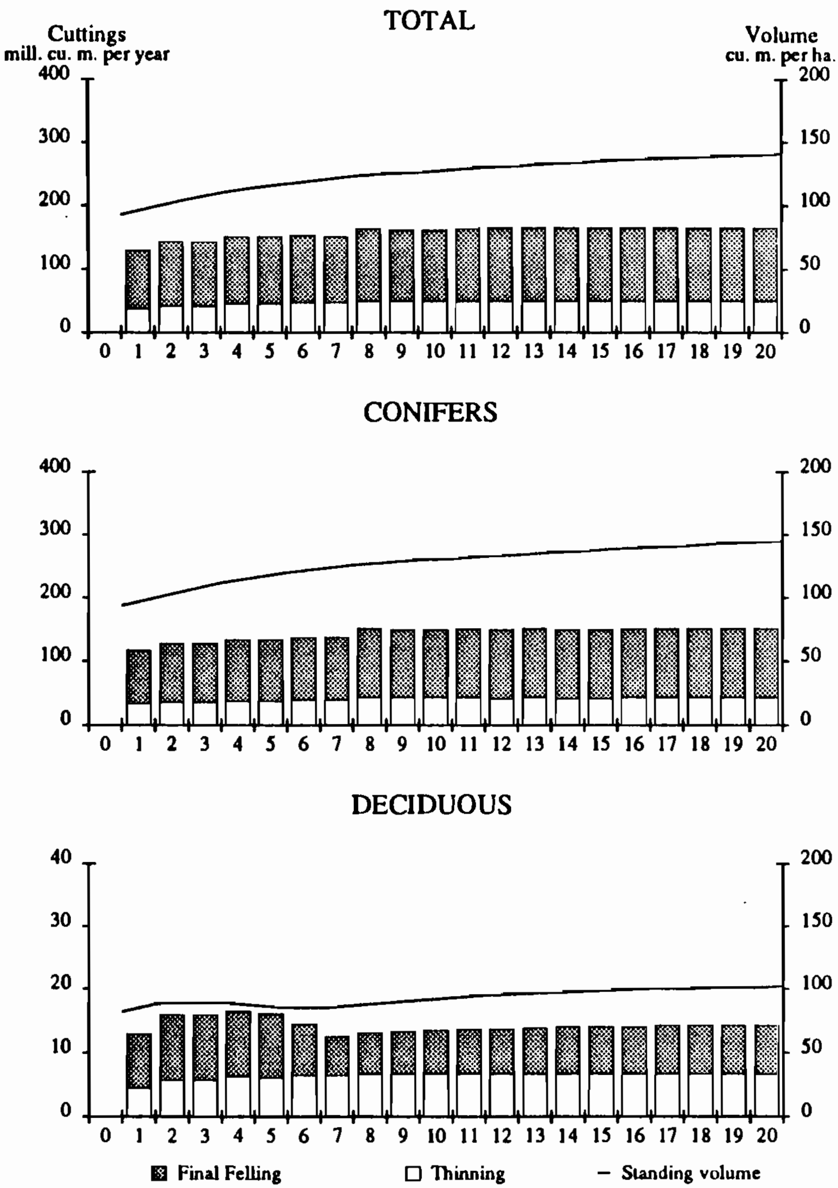

Figure 6.1. Projections for potential harvest and growing stock for total, coniferous, and deciduous forests in the Nordic region under the Forest Land Expansion Scenario.

project a slight increase in the total harvest potential after about 25 years. The expanded landbase occurs mostly in the coniferous forest, because 80 percent of the new land is to be planted with coniferous species.

6.3.2 EEC-9 region (Table 6.2 and Figure 6.2)

The anticipated expansion of the forest landbase to the year 2020 is relatively large. The expansion generates a strong increase in the potential harvest level throughout the whole period. At the end of the period, the potential harvest level is about 40 million cubic meters higher per year than that of the Basic Forest Study Scenario. Growing-stock development follows that of the basic scenario. In the Forest Land Expansion Scenario, the harvest consists of increasing proportions of final fellings over time.

The development of coniferous species will have a similar development over time as the development of the aggregated species in the EEC-9 region. Thus, the potential harvest level of conifers will increase from the beginning of the simulation period. The potential coniferous harvest level in the Forest Land Expansion Scenario will be about 55 million cubic meters higher per year than in the Basic Forest Study Scenario. The development of the coniferous growing stock will not reach as high a level as in the Basic Forest Study Scenario. The extent of coniferous thinnings will increase by about 20 percent in the Forest Land Expansion Scenario.

In comparison with the Basic Forest Study Scenario, the potential harvest of deciduous species in the Forest Land Expansion Scenario will increase rather dramatically from the beginning of the simulation period. The potential harvest will continue to grow throughout the simulation period, with about 10 million cubic meters more per year in the Forest Land Expansion Scenario than in the Basic Forest Study Scenario. The development of the growing stock of the deciduous species is about the same in the two scenarios. The extent of final felling is much higher in the Forest Land Expansion Scenario.

6.3.3 Central region (Table 6.2 and Figure 6.3)

The estimated increase of the forest landbase up to the year 2020 in the Central region is rather modest. This is reflected in the scenario results with a marginal increase in the total potential harvest level starting after about 40 years. The growing-stock development and level will be nearly the same as in the Basic Forest Study Scenario. However, the increased landbase will

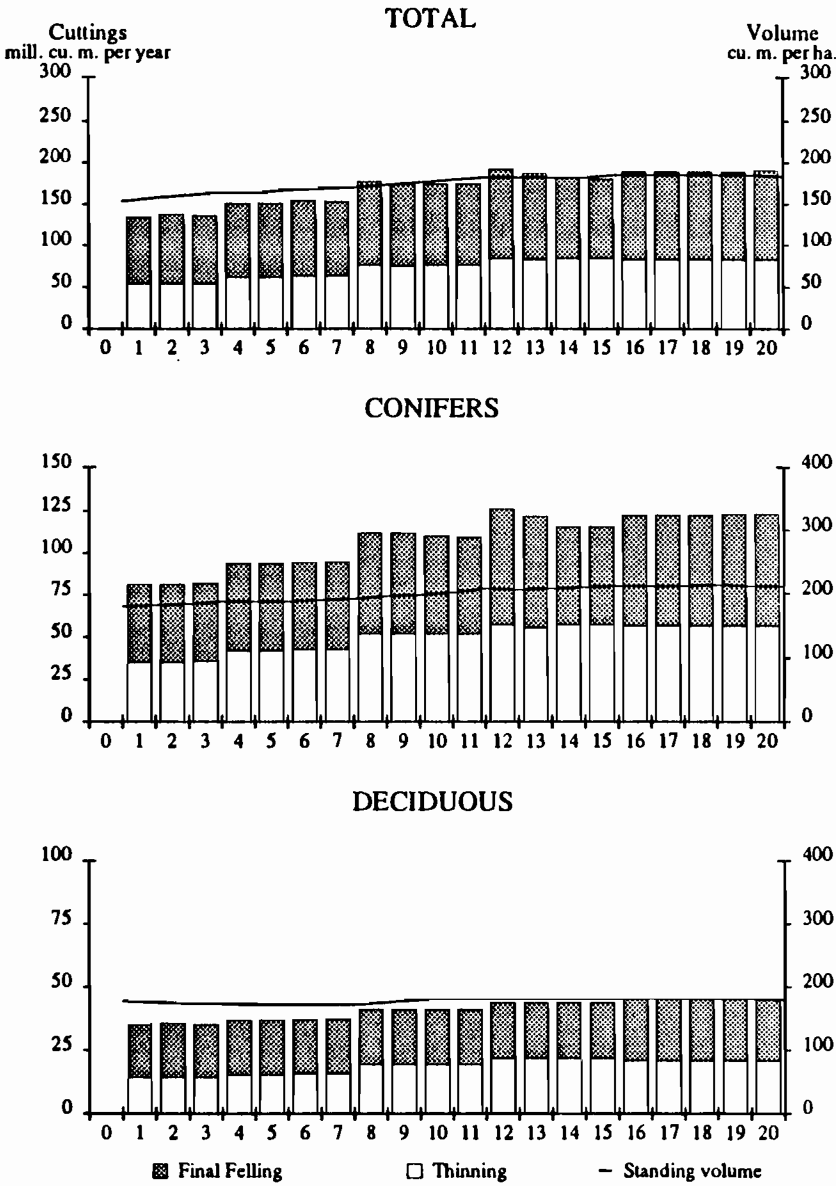

Figure 6.2. Projections for potential harvest and growing stock for total, coniferous, and deciduous forests in the EEC-9 region under the Forest Land Expansion Scenario.

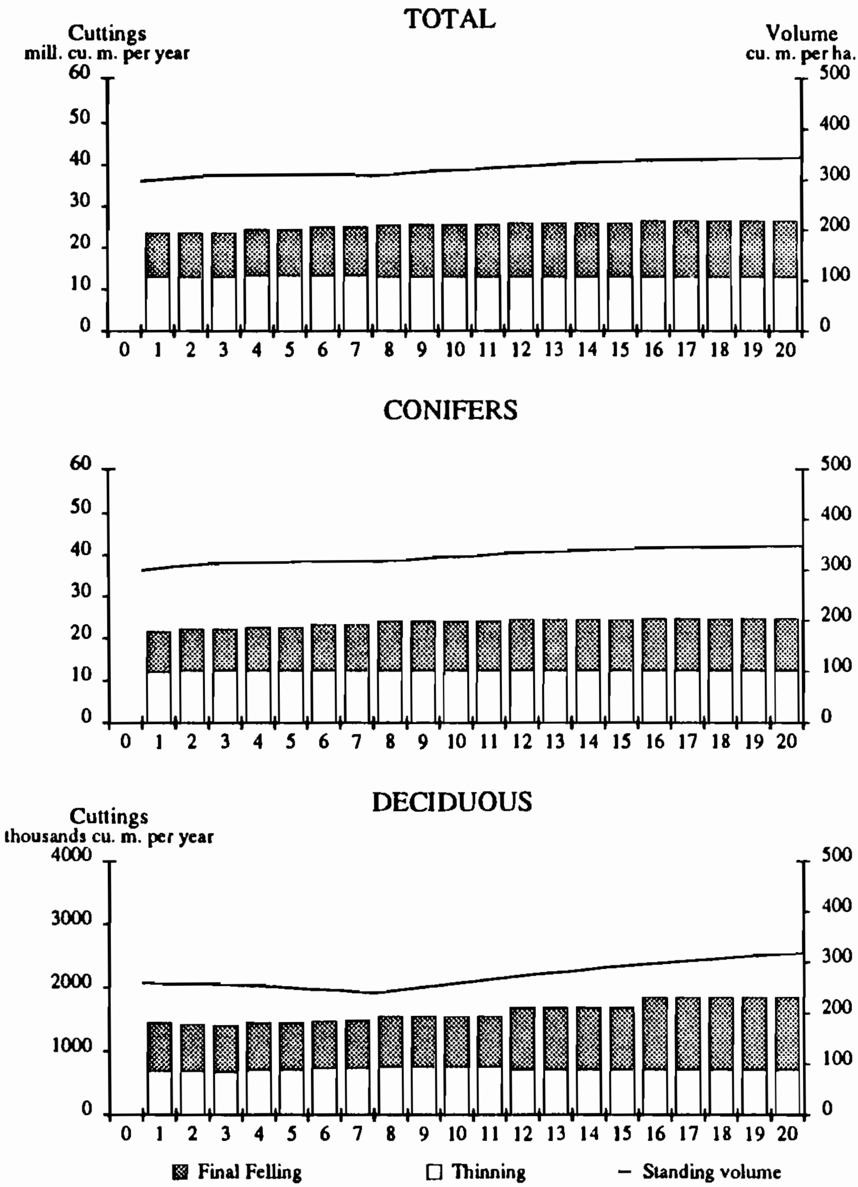

Figure 6.3. Projections for potential harvest and growing stock for total, coniferous, and deciduous forests in the Central region under the Forest Land Expansion Scenario.

generate a smoother development of the growing stock in comparison with the basic scenario.

The potential deciduous harvest will increase over time in the Forest Land Expansion Scenario in comparison with the Basic Forest Study Scenario. Most of the increased potential will become available at the end of the simulation period. The development illustrated for deciduous types is only valid for Switzerland and not the total region; the basic data for Austria do not allow disaggregation by species groups. The development of conifers is similar to the development for all species combined.

6.3.4 Southern region (Table 6.2 and Figure 6.4)

The Southern region has the second largest anticipated expansion of the forest landbase among the regions of Europe. The effect on forest-resource development is not as strong for each unit area as in the EEC-9 region. At the end of the simulation period, the total potential harvest is about 7 million cubic meters higher per year in the Forest Land Expansion Scenario than in the Basic Forest Study Scenario. This means an increase of the potential harvest of only about 150 cubic meters for each new hectare cultivated, calculated at the end of the simulation period. This is quite low compared with the EEC-9, where the corresponding figure is about 470 cubic meters per new hectare implemented. The contribution to the potential increased harvest comes mainly from Portugal and Spain.

The development of the growing stock is nearly the same in the two scenarios. In the Forest Land Expansion Scenario, the increase of potential harvest starts after about 40 years and increases over time. Coniferous growing stock is slightly lower in the Forest Land Expansion Scenario. The potential harvest of deciduous species has a similar increasing development visible first after about 50 years. In the Forest Land Expansion Scenario, the growing stock of deciduous types is definitely lower in comparison with the growing-stock level in the Basic Forest Study Scenario.

6.3.5 Eastern region (Table 6.2 and Figure 6.5)

Within the Eastern region, expansion of the forest landbase is expected only in Bulgaria, Hungary, and Poland. In Bulgaria, only a marginal increase of the existing forest landbase is projected. The modest increase expected in the forest landbase in the region is reflected in the forest-resource development with a marginal increase in comparison with the Basic Forest Study

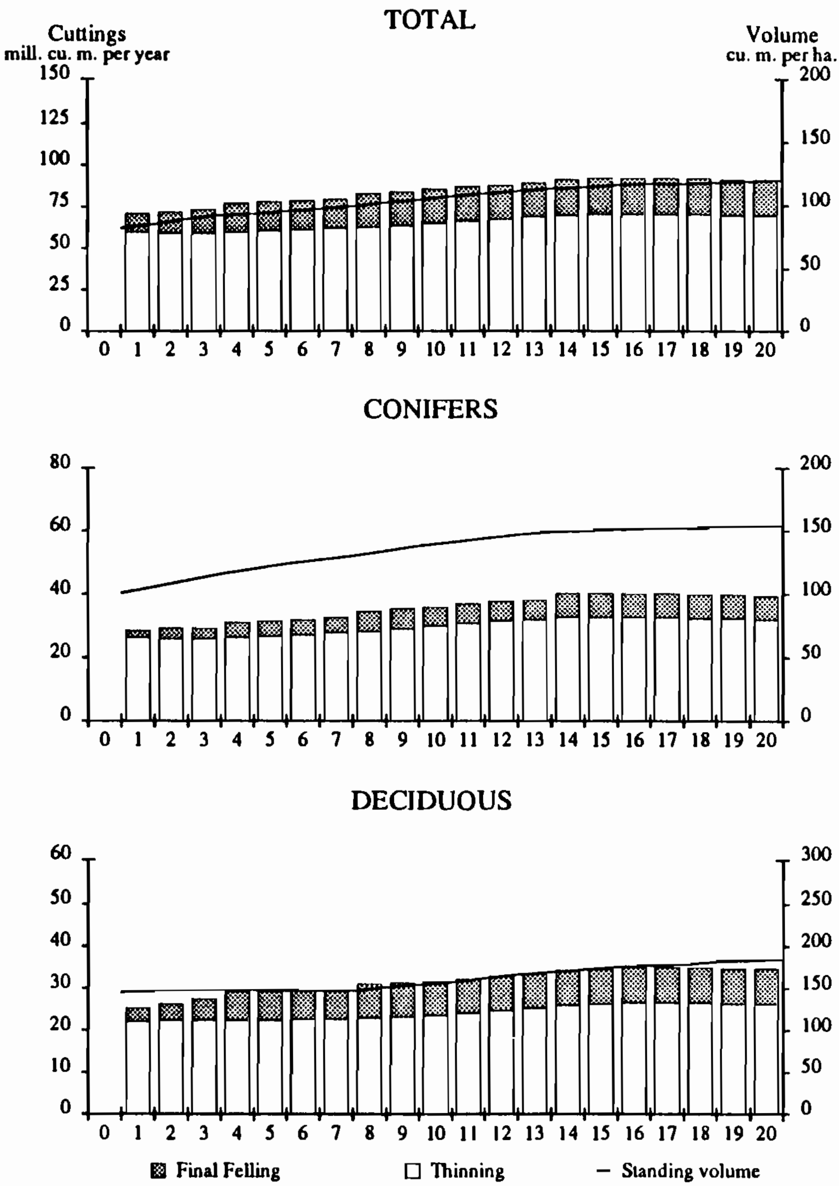

Figure 6.4. Projections for potential harvest and growing stock for total, coniferous, and deciduous forests in the Southern region under the Forest Land Expansion Scenario.

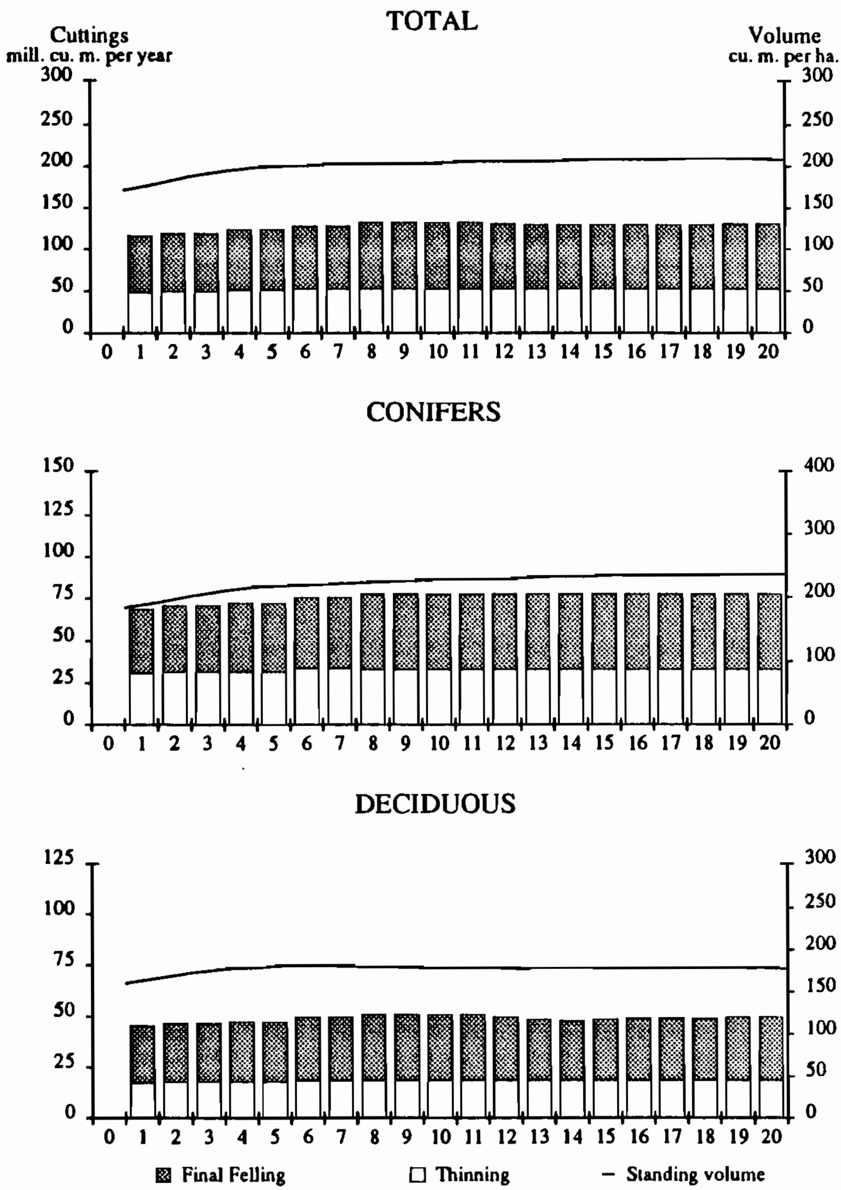

Figure 6.5. Projections for potential harvest and growing stock for total, coniferous, and deciduous forests in the Eastern region under the Forest Land Expansion Scenario.

Scenario of the total potential harvest at the end of the simulation period. Growing-stock development will be the same in the two scenarios. In the Forest Land Expansion Scenario, the development of conifers follows the same pattern as for all species together. Concerning deciduous and coppice types, the increased landbase will not affect the potential harvest and the growing stock.

6.3.6 Europe (Table 6.2 and Figure 6.6)

The increased forest landbase across Europe will result in an increased total harvest potential in comparison with the Basic Forest Study Scenario, starting at the beginning of the simulation period and continuing smoothly throughout the period. At the end of the simulation period, the total potential harvest level in the Forest Land Expansion Scenario is approximately 50 million cubic meters higher per year than that of the Basic Forest Study Scenario. The level and development of the growing stock are nearly the same in the two scenarios. The increased harvest potential is accompanied by an increased proportion of final fellings within the harvest.

In the Forest Land Expansion Scenario, the development of coniferous species follows closely that of the total aggregated species. This means a smooth increase of the potential coniferous harvest throughout the whole simulation period and a growing stock which is more or less identical with the development in the Basic Forest Study Scenario. At the end of the simulation period, the potential harvest of conifers is higher in the Forest Land Expansion Scenario by about 40 million cubic meters per year. The proportion of the harvest in final fellings also increases. The increase in harvest potential for deciduous species will start in the beginning of the simulation period and continue gradually. At the end of the simulation period, the potential harvest level of deciduous types will be nearly 35 million cubic meters higher for each year. The development of the growing stock is similar in the two scenarios, but the proportion of the harvest in final fellings also increases. The coppice group is not strongly influenced by the increased landbase. There is a marginal increase over time of the potential harvest in total Europe. The growing stock of coppice will be the same in the two scenarios.

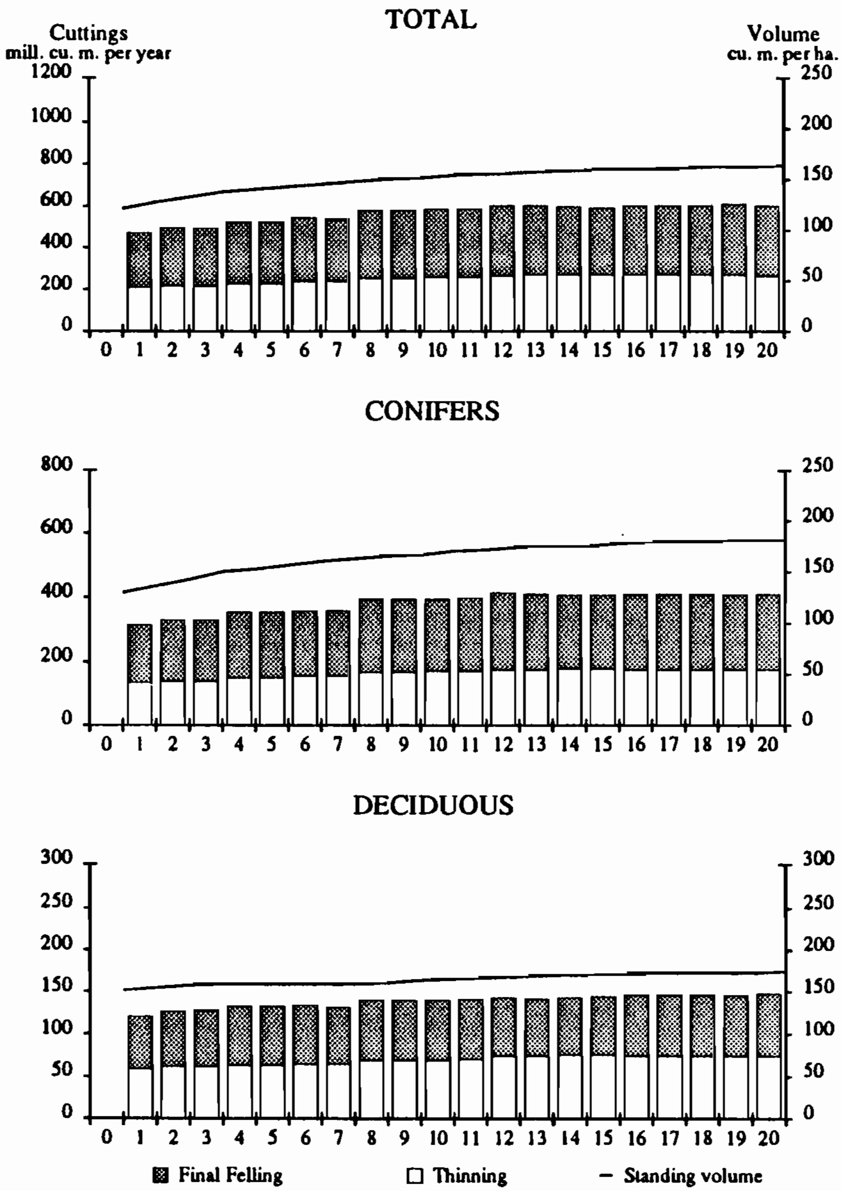

Figure 6.6. Projections for potential harvest and growing stock for total, coniferous, and deciduous forests in Europe under the Forest Land Expansion Scenario.

Table 6.3. Summary of trends in the Forest Land Expansion Scenario. Comparisons are made with the Basic Forest Study Scenario.

Country Region	Harvest pattern	Potential harvest level	Growing-stock development
Finland	No expansion of the landbase		
Norway	No expansion of the landbase		
Sweden	No change	Marginal increase	No change
Nordic	No change	Marginal increase	No change
Belgium	No change	Increase	Lower
Denmark	No change	Strong increase	Lower
France	Final felling increase	Increase	No change
FRG	No change	Increase	No change
Ireland	Thinning increase	Dramatic increase	Much lower
Italy	Final felling increase	Increase	No change
Luxembourg	Final felling increase	Strong increase	No change
Netherlands	No change	Increase	Lower
UK	Thinning increase	Strong increase	No change
EEC-9	Final felling increase	Strong increase	No change
Austria	No change	Marginal increase	No change
Switzerland	No change	Marginal increase	Slight increase
Central	No change	Marginal increase	No change
Greece	Cannot quantify		
Portugal	No change	Increase	Increase
Spain	No change	Increase	Slight increase
Turkey	No expansion of the landbase		
Yugoslavia	No change	Marginal increase	No change
Southern	No change	Increase	No change
Bulgaria	No change	Increase	Lower
CSFR	No expansion of the landbase		
GDR	No expansion of the landbase		
Hungary	No change	Increase	Lower
Poland	No change	Increase	Nearly same
Romania	No expansion of the landbase		
Eastern	No change	Marginal increase	No change
Europe	Marginal final felling increase	Strong increase	No change

6.4 Conclusions

We have summarized the main trends from the simulation results under our Forest Land Expansion Scenario in *Table 6.3*. We re-emphasize that the extent of the anticipated expansion of the forest landbase in the future is very unevenly distributed across the individual regions in Europe. The dominating part of the land expansion will occur in the EEC-9 and Southern regions. We also reiterate that there have been difficulties to quantify the effects of the land expansion in an effective way for the Southern region. It is difficult to handle the effects of land expansion in a controlled manner using diameter-distribution models. The diameter approach has been fully employed for Spain and partly employed for Yugoslavia. For Greece there have been no possibilities to quantify the effects of the land expansion expected; this is mainly due to problems of data availability. Therefore, effects of the expansion of the forest landbase are probably underestimated for the Southern region.

With regard to wood supply, the dominating effects of an expanded forest landbase are expected to be generated in the EEC-9 region. The second region of any importance in this respect is the Southern region. The effects on wood supply in the other regions are only marginal.

With a strong increase of the forest landbase, the average growing stock for each unit area will, in principle, be lower in comparison with the Basic Forest Study Scenario. The harvest pattern will also be influenced by a strong increase of the landbase, with the proportion of final fellings in most cases higher than those of the Basic Forest Study Scenario.

Chapter 7

Summary of the Seven Scenarios

We now present a summary of results for the seven scenarios for each region (*Tables 7.1* to *7.6*). The summary data are expressed as averages for the whole simulation period of 100 years. The growth figures relating to the Forest Land Expansion Scenario are calculated as total production during 100 years divided by 100 and by the forest area at the end of the simulation. The growth figures would have been as much as 15 percent higher if they had been calculated as period-weighted averages.

7.1 Nordic Region

The three basic no-decline scenarios for the Nordic region (*Table 7.1*) give similar results concerning potential harvest and growth. The decline attributed to air pollutants causes a decrease in the total potential harvest of 11 million cubic meters for each year during the 100-year period in comparison with the basic analysis. The increased landbase adds 3 million cubic meters per year to the total potential harvest in comparison with basic conditions.

7.2 EEC-9 Region

There are large differences in the results concerning both growth rates and potential harvest between the different basic scenarios for the EEC-9 region

Table 7.1. Summary of different scenarios for the Nordic region.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study	Handbook Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Potential harvest (mill. m^3 o.b./yr)[a]							
Total	153.4	150.8	155.3	155.2	149.9	144.3	158.3
Coniferous	139.5	136.0	141.3	142.1	136.1	131.7	143.9
Deciduous	13.9	14.8	14.0	13.1	13.8	12.6	14.4
Growth (m^3 o.b./ha/yr)[a]							
Total	3.8	3.7	3.8	3.6	3.4	3.5	3.7
Coniferous	3.8	3.7	3.8	3.6	3.5	3.5	3.7
Deciduous	4.0	3.6	3.9	3.2	3.0	3.2	3.6
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	93–154	93–147	93–147	93–125	93–124	93–139	93–141
Coniferous	94–156	94–154	94–150	94–129	94–132	94–144	94–145
Deciduous	82–127	82–66	82–115	82–71	82–42	82–85	82–102

[a]Average for the simulations over 100 years.

Table 7.2. Summary of different scenarios for the EEC-9 region.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study	Handbook Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Potential harvest (mill. m^3 o.b./yr)[a]							
Total	159.3	129.5	150.1	146.5	122.7	126.2	169.1
Coniferous	91.5	82.3	92.0	84.7	77.4	79.6	107.2
Deciduous	37.3	30.8	37.4	32.8	29.9	28.3	41.2
Coppice	30.5	16.4	20.7	29.0	15.4	18.3	20.7
Growth (m^3 o.b./ha/yr)[a]							
Total	5.2	4.7	5.0	4.6	4.0	4.3	5.1
Coniferous	7.4	6.9	7.3	6.6	6.0	6.4	6.6
Deciduous	4.0	4.1	4.1	3.1	2.9	3.2	4.7
Coppice	3.3	2.2	2.4	3.1	2.0	2.2	2.4
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	152–184	152–222	152–185	152–161	152–170	152–190	152–182
Coniferous	181–244	181–264	181–229	181–216	181–206	181–234	181–213
Deciduous	179–187	179–262	179–189	179–143	179–156	179–195	179–181
Coppice	95–100	95–137	95–121	95–99	95–131	95–126	95–121

[a]Average for the simulations over 100 years.

(*Table 7.2*). The Basic Handbook Scenario gives much higher harvest potential and growth rate than the other two basic scenarios. This is a strong indication of a need to reorganize the structure of the forests, especially in terms of more intensified silviculture in this region. Also, the harvest level suggested by ETTS-IV can easily be exceeded if the appropriate policies are implemented.

The decline attributed to air pollutants forces the total harvest potential strongly downward. The decrease is 26 million cubic meters per year over 100 years in comparison with unaffected conditions. The increase expected in the forest landbase will generate a significant increase in the harvest potential. The total increase is estimated to be 20 million cubic meters for each year over 100 years. The dominating part of the increase will be in coniferous species (15 million cubic meters per year).

7.3 Central Region

The three basic scenarios for the Central region (*Table 7.3*) give similar results. However, there is an indication that a reorganization of the forest structure is required. New policies must aim at more intensified silviculture, as indicated by results from the Basic Handbook Scenario. Forest decline attributed to air pollutants will reduce the total potential harvest by 5.8 million cubic meters per year during 100 years. The increase of the total harvest potential in the Forest Land Expansion Scenario is only marginal, estimated to be about 0.5 million cubic meters per year throughout the simulation period.

7.4 Southern Region

For the Southern region (*Table 7.4*) we were able to compare only three scenarios: the Basic Forest Study Scenario, the Forest Study Decline Scenario, and the Forest Land Expansion Scenario. Based on the information available, we find that the decline attributed to air pollutants will reduce the total potential harvest by 7.2 million cubic meters per year throughout the simulation period. The increased landbase will add 5.3 million cubic meters per year throughout the 100 years to the total potential harvest. This effect is rather small in comparison with the new area estimated to be added to the forest landbase.

Table 7.3. Summary of different scenarios for the Central region.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Potential harvest (mill. m^3 o.b./yr)[a]							
Total	26.7	25.8	24.7	25.4	25.8	18.9	25.2
Coniferous	25.0	24.1	23.2	23.8	24.1	17.8	23.6
Deciduous	1.7	1.7	1.5	1.6	1.7	1.1	1.6
Growth (m^3 o.b./ha/yr)[a]							
Total	7.3	6.8	6.9	5.8	5.5	5.6	6.5
Coniferous	7.5	6.9	7.0	5.9	5.6	5.7	6.7
Deciduous	6.2	6.2	6.2	4.1	4.1	4.3	4.8
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	298–342	298–315	298–350	298–215	298–179	298–369	298–345
Coniferous	301–343	301–312	301–345	301–221	301–184	301–372	301–348
Deciduous	260–334	260–348	260–408	260–144	260–125	260–343	260–319

[a]Average for the simulations over 100 years.

Table 7.4. Summary of different scenarios for the Southern region.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest[b] Study Decline	Forest Land Expansion
Potential harvest (mill. m^3 o.b./yr)[a]							
Total			78.3			71.1	83.6
Coniferous			32.8			31.8	35.7
Deciduous			29.1			25.8	31.5
Coppice			16.4			13.5	16.4
Growth (m^3 o.b./ha/yr)[a]							
Total			2.8			2.6	2.8
Coniferous			3.2			3.1	3.1
Deciduous			4.6			4.1	4.0
Coppice			1.3			1.1	1.3
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total			82–127	82–119	82–117	82–124	82–119
Coniferous			99–164	99–155	99–154	99–160	99–154
Deciduous			143–222	143–210	143–202	143–212	143–184
Coppice			27–29	27–27	27–26	27–32	27–27

[a]Average for the simulations over 100 years.
[b]Decline effects for Spain not included.

7.5 Eastern Region

Among the basic scenarios for the Eastern region (*Table 7.5*), the Basic Handbook Scenario gives the highest total harvest potential and the highest growth rate. This is an indication that the basic structure of forest resources should be changed by new policies including more intensive silviculture. The harvest levels suggested by ETTS-IV can easily be exceeded. The effects of decline attributed to air pollutants are strong in this region. The decline will reduce the total harvest potential by 34 million cubic meters per year throughout the simulation period of 100 years. The effects of the increased landbase are estimated to be rather marginal, amounting to an additional harvest potential of only 1.4 million cubic meters per year throughout the simulation period.

Table 7.5. Summary of different scenarios for the Eastern region.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study	Handbook Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Potential harvest (mill. m^3 o.b./yr)[a]							
Total	130.7	108.5	126.0	123.2	104.6	91.7	127.4
Coniferous	78.1	64.6	74.5	77.4	64.7	54.5	75.4
Deciduous	48.6	41.0	48.8	41.4	37.1	34.6	49.3
Coppice	4.0	2.9	2.7	4.4	2.8	2.6	2.7
Growth (m^3 o.b./ha/yr)[a]							
Total	5.4	5.0	5.3	4.6	3.9	3.9	5.2
Coniferous	6.0	5.5	5.8	5.3	4.4	4.4	5.6
Deciduous	4.8	4.6	4.8	3.6	3.2	3.3	4.8
Coppice	3.7	2.9	2.9	3.9	2.7	2.7	2.9
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	169–202	169–239	169–206	169–148	169–147	169–200	169–206
Coniferous	185–234	185–260	185–235	185–171	185–171	185–241	185–236
Deciduous	158–174	158–224	158–174	158–126	158–122	158–155	158–176
Coppice	97–93	97–119	97–130	97–81	97–107	97–125	97–130

[a]Average for the simulations over 100 years.

7.6 Europe

For all Europe (*Table 7.6*), we were able to compare only the Basic Forest Study Scenario, the Forest Study Decline Scenario, and the Forest Land Expansion Scenario. The decline scenario is incomplete owing to lack of quantification of the decline effects in Spain. However, the available information illustrates that forest decline attributed to air pollutants will decrease the total potential harvest in Europe by some 83 million cubic meters per year calculated as an average for the whole simulation period of 100 years. The expansion of the forest landbase will increase the total harvest potential in Europe by 29 million cubic meters per year throughout the simulation period. The increased harvest potential by land expansion does not account for any effects of air pollutants on this new forest land.

Table 7.6. Summary of different scenarios for Europe.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Potential harvest (mill. m^3 o.b./yr)[a]							
Total			534.6[b]			452.0[b]	563.7
Coniferous			363.9			315.4	385.9
Deciduous			130.7			102.4	138.0
Coppice			39.8			34.4	39.8
Growth (m^3 o.b./ha/yr)[a]							
Total			4.2			3.6	4.2
Coniferous			4.7			4.1	4.6
Deciduous			4.5			3.4	4.4
Coppice			1.9			1.7	1.9
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total			122–166	122–138	122–137	122–164	122–164
Coniferous			131–185	131–156	131–154	131–185	131–182
Deciduous			150–185	150–145	150–140	150–172	150–173
Coppice			58–72	58–59	58–73	58–75	58–72

[a]Average for the simulations over 100 years.
[b]Errors in totals are due to rounding.

Chapter 8

Validation of the Forest Study Results

8.1 Comparisons

The timber-assessment results can be validated by comparing them with the results from two other studies, namely, those of Kuusela (1985) and ETTS-IV (UN, 1986). Comparisons with the Kuusela study can be carried out only up to year 2000. Comparisons with the ETTS-IV study can be carried out for year 2000 and year 2020. Unfortunately, there are no possibilities to validate our long-term projections against results of other studies.

The forecasts given by ETTS-IV take into account the following external factors affecting wood supply: physical accessibility; provision of non-wood goods and services; ownership structure; fiscal factors; labor conditions; economic factors; and increased forest landbase. These factors are taken into account, to different extents, in the analysis of each country. For some countries, the ETTS-IV forecasts also consider the impact of air pollution and other forms of damage. The ETTS-IV scenarios include both low and high forecasts. The two sets of ETTS-IV projections are defined roughly as follows:

- The low estimate is based on modest but realistic assumptions of biological developments and low growth of economic development.
- The high estimate is based on more expansive, but realistic, assumptions of biological developments and strong economic development.

The following conclusions are drawn from the ETTS-IV analyses:

- There is a backlog of thinnings which, under favorable market conditions, could be added to future removals.
- The differences between the countries' low and high forecasts vary considerably, reflecting difficulties in predicting the impact of external factors on wood supply.

The variation (range) of the Kuusela estimates stems from two assumptions concerning the basic conditions for the projections. In one case, the projection is based on conditions in 1970; in the other case, on basic conditions in 1980.

We have undertaken a series of validation tests on a regional basis (*Tables 8.1* to *8.6*). We have chosen the Forest Land Expansion Scenario for the comparison with the other two studies, which are assumed to have taken land expansion into account in their projections.

It should be emphasized that the Kuusela and ETTS-IV studies use the unit cubic meters u.b. (under bark), whereas the Forest Study uses the unit cubic meters o.b. (over bark). The conversion factor from cubic meters u.b. to cubic meters o.b. is roughly 1.10 to 1.15, but there is a strong variation among countries and species.

8.1.1 Nordic region

The growth figures from the Forest Study match the figures from Kuusela and ETTS-IV quite well for Finland and Sweden (*Table 8.1*). For Norway the Forest Study has a growth rate that is more than double that of the other two studies. This condition is reflected in the potential harvest figures. The Forest Study has a much higher potential harvest (removals) in Norway in comparison with the other two studies. For Finland there is a good correspondence between the three studies concerning removals. For Sweden the Forest Study gives a slightly higher harvest than the other two studies. The forest landbase is highest in the Forest Study for Sweden in comparison with the other studies.

8.1.2 EEC-9 region

The Forest Study has significantly higher growth rates in the FRG, Italy, Luxembourg, and the United Kingdom than do the other two studies (*Table 8.2*). This is because the Forest Study has used more recent growth information. For Ireland the growth rate is much lower in the Forest Study. One explanation can be that the basic data for Ireland focus on area; no

Table 8.1. Validation test of Forest Study results, all species in the Nordic region.

	Net annual increment (NAI) in million m^3		Growth in m^3/ha			Removals in million m^3		
Country	Kuusela	ETTS-IV	Kuusela	ETTS-IV	Forest Study	Kuusela	ETTS-IV	Forest Study
Year 2000								
Finland	68.6–71.0	67.9–68.0	3.56–3.59	3.3–3.4	4.0	46.0–49.0	47.7–52.1	52.3
Norway	18.3–19.0	18.0–18.8	2.60–2.90	2.7–2.9	6.7	9.4–12.0	9.2–11.0	19.2
Sweden	61.0–81.7	74.6–76.5	2.75–3.90	3.3–3.4	3.5	55.9–65.0	49.7–61.7	75.9
Nordic						111.3–126.0	106.6–124.8	147.4
Year 2020								
Finland		71.7–73.9		3.5–3.6	3.3		51.7–57.0	54.5
Norway		18.2–20.4		2.8–3.1	5.6		10.0–13.5	19.9
Sweden		77.2–83.1		3.5–3.7	3.7		54.5–64.7	77.4
Nordic							116.2–135.2	151.8

Table 8.2. Validation test of Forest Study results, all species in the EEC-9 region.

	Net annual increment (NAI) in million m^3		Growth in m^3/ha			Removals in million m^3		
Country	Kuusela	ETTS-IV	Kuusela	ETTS-IV	Forest Study	Kuusela	ETTS-IV	Forest Study
Year 2000								
Belgium	3.8–4.2[a]	4.4–4.9	5.57–6.14[a]	7.3–7.7	7.3	2.9–3.3[a]	2.9–3.3	4.2
Denmark	2.5–3.1	2.8–3.1	6.50–8.50	7.5–8.1	8.5	2.3–2.5	2.3–2.4	2.9
France	46.8–65.8	59.7–63.4	3.90–5.15	4.4–4.7	4.5	42.4–46.8	39.4–46.4	53.1
FRG	34.4–41.2	38.3–40.1	5.38–6.00	5.5–5.7	6.7	30.0–34.2	30.0–33.5	48.1
Ireland	4.1–5.8	4.4–4.5	9.47–12.00	9.6–10.4	4.9	2.2–3.0	3.0–3.0	2.2
Italy	12.5–24.6	11.8–13.0	3.26–4.15	3.0–3.3	6.8	8.8–9.0	8.2–9.0	20.2
Luxembourg	[a]	0.3–0.4	[a]	3.9–4.3	6.6	[a]	0.3–0.3	0.2
Netherlands	1.3–1.4	1.4–1.5	4.20–4.33	4.3–4.3	4.9	1.0–1.0	0.9–1.0	0.9
UK	15.3–16.0	15.3–15.9	6.50–6.78	5.7–6.4	7.1	7.3–9.0	6.7–8.5	11.3
EEC-9						96.9–108.8	93.7–107.4	143.1
Year 2020								
Belgium		4.3–5.1		7.1–7.9	6.6		3.3–4.0	4.3
Denmark		3.3–3.9		8.5–9.2	8.5		2.5–3.1	3.6
France		66.1–71.3		4.8–5.2	4.3		50.6–60.0	57.9
FRG		36.9–40.6		5.3–5.7	6.9		30.0–35.0	48.5
Ireland		4.3–5.5		9.1–10.0	4.7		4.3–4.5	2.9
Italy		11.1–14.0		2.8–3.3	5.0		8.6–10.7	21.4
Luxembourg		0.3–0.4		3.7–4.5	6.6		0.2–0.3	0.3
Netherlands		1.6		4.6–4.7	5.0		1.2	1.0
UK		17.9–22.5		6.3–6.4	7.5		11.8–13.2	12.9
EEC-9							112.5–132.0	152.8

[a]Luxembourg is included in Belgium.

figures for standing volume are available, so the figures had to be estimated from yield tables. The differences in growth rates are also reflected in the estimates of removals. Countries with a higher growth rate in the Forest Study also have higher removals in comparison with the other two studies. France, the FRG, and Italy have a much stronger expansion of the forest landbase in the Forest Study in comparison with the two reference studies.

The estimate of removals in Ireland is much lower in the Forest Study than in the reference studies. One explanation is the lower growth rate; another is a smaller forest landbase in the Forest Study at the beginning of the simulation period. For Belgium and Denmark, we project slightly higher removals than do the other two studies. The remaining countries have about the same level of removals in the three studies.

8.1.3 Central region

The growth figures and the estimates of removals for Austria from the Forest Study correspond quite well with the two reference studies (*Table 8.3*). However, the Forest Study gives both higher growth rates and higher removals for Switzerland. This is probably a result of more recent basic forest data in the Forest Study for this country. The increase in the forest landbase is also higher in the case of the Forest Study.

8.1.4 Southern region

The growth rates of the countries in the Southern region are lower in the Forest Study in comparison with the other studies, with the exception of Portugal (*Table 8.4*). The estimate of the increased landbase is lower for all countries in the Forest Study. The landbase at the beginning of the simulation period is also lower in four out of five countries in the Forest Study in comparison with the reference studies. Our explanation for the difference is that in the Forest Study, more realistic estimates about future expansions of the forest landbase were employed. The lower starting value of the forest landbase in the Forest Study may indicate that in the reference studies areas not classified as closed forests, in reality, have been included in the forest landbase. Also, increases in the forest landbase in Greece have not been considered in our study owing to methodological problems. These factors result in a lower removal figure for the total Southern region in the Forest Study in comparison with the other two studies.

Table 8.3. Validation test of Forest Study results, all species in the Central region.

	Net annual increment (NAI) in million m^3		Growth in m^3/ha			Removals in million m^3		
Country	Kuusela	ETTS-IV	Kuusela	ETTS-IV	Forest Study	Kuusela	ETTS-IV	Forest Study
Year 2000								
Austria	20.6–22.4	22.6–23.4	6.44–6.55	7.1–7.3	7.5	16.3–16.5	15.4–16.4	16.6
Switzerland	5.2–5.7	3.8–4.7	5.40–6.10	4.0–4.9	7.0	4.9–5.0	4.2–5.1	7.2
Central						21.2–21.5	19.6–21.5	23.8
Year 2020								
Austria		22.6–23.4		7.1–7.3	7.0		15.4–16.4	17.4
Switzerland		3.7–3.9		3.9–5.2	5.7		4.3–4.6	7.3
Central							19.7–21.0	24.7

Table 8.4. Validation test of Forest Study results, all species in the Southern region.

	Net annual increment (NAI) in million m^3		Growth in m^3/ha			Removals in million m^3		
Country	Kuusela	ETTS-IV	Kuusela	ETTS-IV	Forest Study	Kuusela	ETTS-IV	Forest Study
Year 2000								
Greece	4.3–4.4	4.6–5.0	2.20–2.22	1.9–2.0	1.9	2.6–3.7	3.1–3.4	2.8
Portugal	9.3–12.1	15.0–15.7	2.66–4.60	4.3–4.2	6.4	6.7–9.7	9.9–10.7	7.5
Spain	30.5–35.9	29.4–29.8	2.88–4.60	3.6–3.8	3.5	14.2–18.9	18.4–20.3	14.4
Turkey	19.3–28.9	21.6–23.9	3.0	2.9	2.0	22.5–23.0	18.9–20.9	27.0
Yugoslavia	25.1–27.9	30.6	3.4	3.5	3.6	15.9–18.0	19.0	23.2
Southern						61.9–73.3	69.3–74.3	74.9
Year 2020								
Greece		5.0–5.8		2.0–2.2	1.9		3.7–4.3	2.8
Portugal		16.6–18.9		4.3–5.2	5.4		11.0–13.3	8.9
Spain		32.3–32.9		4.6–5.0	3.2		26.0–26.6	16.1
Turkey		23.9–28.5		2.9	1.9		20.7–24.6	27.0
Yugoslavia		32.5		3.6	3.5		22.5	23.6
Southern							83.9–91.3	78.4

8.1.5 Eastern region

The Forest Study has similar or higher growth rates in comparison with the reference studies, with the exception of the former GDR (*Table 8.5*). The Forest Study has a lower estimate of forest landbase for both year 2000 and year 2020 compared with the reference studies in all countries except Romania. Removals in the Forest Study are at or above the level of those in the reference studies. In the case of Romania, the Forest Study generates a much higher level of removals than the other studies. In this case, it is known that the ETTS-IV researchers had difficulties collecting good basic information.

8.1.6 Europe

At the European level (*Table 8.6*) both growth rates and harvest levels are higher in the Forest Study than in the reference studies. One explanation for higher growth rates in the Forest Study is that yield investigations carried out in Europe during recent years indicate that actual growth rates strongly exceed existing yield tables, perhaps by 20 to 30 percent (for example, see Kenk, 1987; Eriksson, 1988). The increase of the growth rate is probably an effect of nitrogen fertilization from air pollution; it cannot be fully explained by changed silviculture or other factors. The data collected by the Forest Study have to some extent accounted for this new development, while those upon which the two reference studies were based have not.

From these tests of the basic scenarios, the following conclusions can be made:

(1) In countries with good forest-inventory data and developed systems for timber-assessment studies, there is a strong correspondence among the three studies.

(2) In countries with weak data and where no simulation tools for timber assessments are used, there are significant differences between results of the Forest Study and the two reference studies. For these countries the Forest Study has been able to collect the basic data with best available quality to use in the timber-assessment model.

(3) There is a difference between results of the Forest Study and the reference studies for countries with rapid expansion of forest land (like Ireland and Portugal). Even in this case, we conclude that the Forest Study has estimated a more relevant and realistic set of land-expansion rates in comparison with the reference studies.

Table 8.5. Validation test of Forest Study results, all species in the Eastern region.

	Net annual increment (NAI) in million m^3		Growth in m^3/ha			Removals in million m^3		
Country	Kuusela	ETTS-IV	Kuusela	ETTS-IV	Forest Study	Kuusela	ETTS-IV	Forest Study
Year 2000								
Bulgaria	7.0–8.0	6.7–7.5	2.09–2.60	2.0–2.2	3.2	5.4–5.9	4.5–5.1	8.5
CSFR	19.0–25.0	19.5–21.0	4.94–5.50	4.7–5.0	7.1	16.0–19.5	17.6–18.9	22.9
GDR	14.5–16.1	14.5–15.4	5.50–6.40	5.6–5.8	6.1	10.0–12.7	11.0–11.1	14.4
Hungary	9.2–11.2	9.9	5.57–6.74	5.8–6.0	5.7	7.2–7.5	6.1–7.5	8.3
Poland	40.2–41.0	30.0–37.2	4.55–4.78	3.4–4.2	4.7	26.2–26.6	22.7–22.8	27.6
Romania	29.0–29.7	31.5–33.2	4.84–5.00	5.5–5.7	8.4	23.2–23.5	20.5–21.6	39.8
Eastern						88.0–95.7	82.4–87.0	121.5
Year 2020								
Bulgaria		6.9–8.4		2.0–2.4	2.8		4.7–6.0	9.1
CSFR		19.0–21.5		4.5–5.1	6.0		17.6–19.4	23.6
GDR		14.0–15.7		5.4–5.8	5.5		11.1–12.3	14.5
Hungary		10.4–10.8		5.6–5.7	5.4		6.2–7.6	9.1
Poland		29.8–37.0		3.4–4.1	4.2		26.0	30.4
Romania		31.5–34.9		5.5–5.9	6.8		22.5–25.0	41.1
Eastern							88.1–96.3	127.8

Table 8.6. Validation test of Forest Study results, all species in total Europe.

	Net annual increment (NAI) in million m^3		Growth in m^3/ha			Removals in million m^3		
	Kuusela	ETTS-IV	Kuusela	ETTS-IV	Forest Study	Kuusela	ETTS-IV	Forest Study
Year 2000								
Europe			4.2–4.3	3.9–4.0	4.8	379.3–425.3	371.6–415.0	510.7
Year 2020								
Europe			n.a.	n.a.	4.5	n.a.	420.4–475.8	535.5

Our overall conclusion based on these validation tests is that the simulation models and databases used in the Forest Study generate relevant and consistent results.

ETTS-IV did not include quantitative analyses of the effects on wood supply of forest decline caused by air pollutants, mainly because sufficient infrastructure of experience and knowledge had not yet been developed at the time of finalizing the work. However, three different theoretical scenarios of the effects of forest decline attributed to air pollutants are discussed in the ETTS-IV report (UN, 1986). The report stresses that there are no possibilities to assign any degree of probability to the scenarios. The general approach used in building these qualitative scenarios was to carry out sanitation fellings as soon as an area was classified as "dying" or "dead" and to reduce other types of felling as much as possible to minimize fluctuations in volumes of removals.

After the theoretical discussion about the effects of air pollutants, the ETTS-IV report (UN, 1986) concluded that "satisfactory decision-taking requires adequate information on extent and type of forest decline.... It is a prerequisite for the establishment of new forest policies." Kuusela (1985) did not take the effects of air pollutants into consideration in his estimates of future wood supply in Europe. Thus, there are no possibilities to carry out validation tests of the decline scenarios generated by the Forest Study.

8.2 General Discussion

To summarize the spatial aspects of the timber-assessment results, the information presented in earlier chapters has been strongly aggregated in *Table 8.7.*

The table lists the results for the three scenarios: the Basic Forest Study Scenario; the Forest Study Decline Scenario; and the Forest Land Expansion Scenario. In the basic scenario the Nordic and EEC-9 regions have the potential to increase their role as wood suppliers in Europe. These two regions are closely followed by the Eastern region with regard to wood supply. Under basic conditions, the highest growth rates are expected in the EEC-9, Central, and Eastern regions. ETTS-IV has achieved the same basic results for potential harvests under conditions with no effects of air pollutants; this study provides evidence of the difficulties to utilize fully the harvest potential and to transform it into real removals or fellings. ETTS-IV concludes that the gap between net annual increment and fellings on exploitable closed

Table 8.7. Aggregated information for all species about potential harvest and growth rate, expressed as average per year for the 100-year simulation period.

Region	Basic Forest Study	Forest Study Decline		Forest Land Expansion	
Potential harvest (mill. m^3/yr)					
Nordic	155.3	144.2	(93%)	158.3	(102%)
EEC-9	150.1	126.2	(84%)	169.1	(113%)
Central	24.8	18.9	(77%)	25.2	(102%)
Southern	78.4	71.0	(87%)	83.6	(103%)
Eastern	126.0	91.7	(91%)	127.4	(107%)
Europe	534.6	452.0	(85%)	563.6	(105%)
Growth (m^3/ha/yr)					
Nordic	3.8	3.5	(92%)	3.7	(97%)
EEC-9	5.0	4.3	(86%)	5.1	(102%)
Central	6.9	5.6	(81%)	6.5	(94%)
Southern	2.8	2.6	(93%)	2.8	(100%)
Eastern	5.3	3.9	(74%)	5.2	(98%)
Europe	4.2	3.6	(85%)	4.2	(100%)

forest will close somewhat in the future, but increment will still exceed the fellings with the result that growing stock will continue to expand in Europe. Thus, the fellings are estimated to increase up to the year 2020 by about 20 percent (UN, 1986). The gap between growth and fellings will also result in an increased growing stock in Europe up to the year 2020. ETTS-IV concludes that:

> wood supply in Europe still has a certain degree of flexibility, if demand should grow sufficiently strongly. The reverse of the coin is that, under conditions of persistently weak demand for wood, fellings will not take place, growing stock will expand to the point where policy would have, sooner or later, to be directed towards stimulating consumption or taking measures to discourage further growth in supply. Alternatively, in the absence of such measures, natural losses would increase and net annual increment would decline, as would the vitality of the forest resource. (UN, 1986)

The anticipated expansion of the forest landbase in Europe will generate an increase in the total harvest potential in Europe. The increase is estimated to be some 29 million cubic meters per year during 100 years in comparison with a constant forest landbase and no decline. Since about 65 percent of the increase will take place in the EEC-9 region, this region has the possibility to challenge the Nordic region as the leading wood supplier in Europe. Thus, should this scenario begin to unfold, major structural changes in the European forest-products industry would occur.

ETTS-IV (UN, 1986) acknowledges the difficulties of estimating expansions of the forest landbase in a quantitative way. Identification of general directions of changes in the forest landbase is rather easy; however, there are serious difficulties in assessing rates of the land change over time, given that forest policy is only one part of overall land-use policy. Moreover, land-use policy can be strongly affected by other policies such as those for agriculture, rural development, and industrial infrastructure. The Forest Study has also encountered these problems. Nevertheless, we feel that, since the ETTS-IV study was carried out, the possibilities to quantify increases in the future forest landbase have improved. The major driving force for increase in the forest landbase is the change expected in agricultural policies in many European countries. In their report based on information from de Wit *et al.* (1987) and Wong (1986) concerning major trends for cereal crops, Stigliani *et al.* (1989) estimate that some 40 million hectares of agricultural land in Europe are expected to be taken out of production up to year 2030, corresponding to about 30 percent of the present land used for growing cereal crops. Many analysts (e.g., Kreysa and Last, 1986) believe that forestry is the only realistic alternative use for most of the agricultural land that may not be required for food production.

A special comparison between prognoses in the ETTS-IV (UN, 1986) and the Forest Land Expansion Scenario has been carried out (*Table 8.8*). We use the Forest Land Expansion Scenario in this comparison because the ETTS-IV Scenario includes expansion of the forest landbase. We point out that the total forest-land expansions in our scenario amount to only about 75 percent of the expansions in the ETTS-IV Scenario. Also, for the comparison we have used the upper estimates (high scenario) of harvests from ETTS-IV. The comparison shows that fellings during the base period (1985) in the Forest Study are well above the level suggested by ETTS-IV, and above actual 1987 fellings. However, by the year 2020 the Forest Land Expansion Scenario shows harvest levels very close to those of ETTS-IV.

The initially unexpected concordance between potential harvests projected in the Forest Land Expansion Scenario and the projections of actual harvests in the ETTS-IV Scenario can be explained by growing-stock developments. From the early 1980s to the year 2020, growing stock for all Europe increases slightly by 7 cubic meters per hectare in the ETTS-IV Scenario, while the corresponding figure in the Forest Land Expansion Scenario

Table 8.8. A comparison between the results from the Forest Study and the ETTS-IV, expressed in million cubic meters.

	Nordic	EEC-9	Central	Southern	Eastern	Europe
Removals 1987 (FAO, 1989)	120.7	109.3	22.3	72.0	99.5	423.8
Fellings Base Period, ETTS-IV	123.8	98.2	20.0	66.7	93.1	401.8
Fellings 1985, Forest Study	130.3	133.2	23.2	70.2	116.2	473.1
Fellings 2020, ETTS-IV	167.6	149.0	26.1	113.4	113.1	569.2
Fellings 2020, Forest Study	162.7	174.1	25.5	82.6	131.6	576.5
Average annual fellings for the period 1980–2020, ETTS-IV	151.7	125.4	24.8	92.0	103.0	496.9
Average annual fellings for the period 1985–2020, Forest Study	147.7	148.3	24.2	75.9	124.1	520.2
Increase of growing stock between 1985–2020, m^3/ha, ETTS-IV	8	11	13	8	23	7
Increase of growing stock between 1985–2020, m^3/ha, Forest Study	31	18	13	18	32	27
Additional potential harvests, mill. m^3/yr, by harvesting the increased growing stock achieved in the Basic Forest Study Scenario	32	8	1	27	7	73

is 27 cubic meters per hectare. Thus, while the harvest levels of the two studies are similar at the year 2020, the dynamics of the forests are quite different. If the difference in growing-stock consolidation between the two studies had been taken out in the form of harvests in the Forest Land Expansion Scenario, the average harvest level during the 40 years could have been increased by 73 million cubic meters per year (see the bottom row in *Table 8.8*). Also, the total average harvest per year for the period studied would have been 593 million cubic meters in comparison with 497 million cubic meters for the ETTS-IV Scenario.

Another factor contributing to our conclusion that the Forest Study harvest levels are conservative is the growing-stock development that would ensue if we had accounted properly for the difference between our harvest levels and the actual harvest levels today and those projected by ETTS-IV up to 2020. The difference between the 1987 harvest level and the average annual harvest level (over 100 years) from the Basic Forest Study Scenario is about 110 cubic meters. The foregone harvest contributes strongly to growing-stock development but has not been taken into account in the Forest Study scenarios.

The results presented in *Table 8.8* imply that, although the Forest Study objective is to assess potential harvest levels, our simulations are rather cautious. The inventory and growing stock of the forests are consolidated, and the harvest patterns are not extreme. This is in line with behavior in the European forest sector during the past several decades. These results also suggest that harvest levels in the Forest Study scenarios could be pursued even with restrictions and increased demands on non-wood benefits from European forests.

Another indication that the Basic Forest Study Scenario and the Forest Land Expansion Scenario are rather cautious is that earlier estimates of future fellings have been revised upward on several occasions recently (see *Figure 8.1*; UN, 1986). We note that the Basic Forest Study Scenario yields results close to the high harvest levels of ETTS-IV (*Figure 8.1*). We also note that the whole scope or potential for increased wood supplies up to 2020 as identified in ETTS-IV may be all but negated if effects of air pollutants, as we have represented them in our analyses, continue.

We have used the ETTS-IV regionalization of Europe so that our results could be directly compared with those of ETTS-IV. This regionalization includes the EEC-9 grouping, which was expanded recently to 12 countries, with the addition of Spain, Portugal, and Greece. Results from country aggregations for the EEC-12 show that biological potential wood supplies

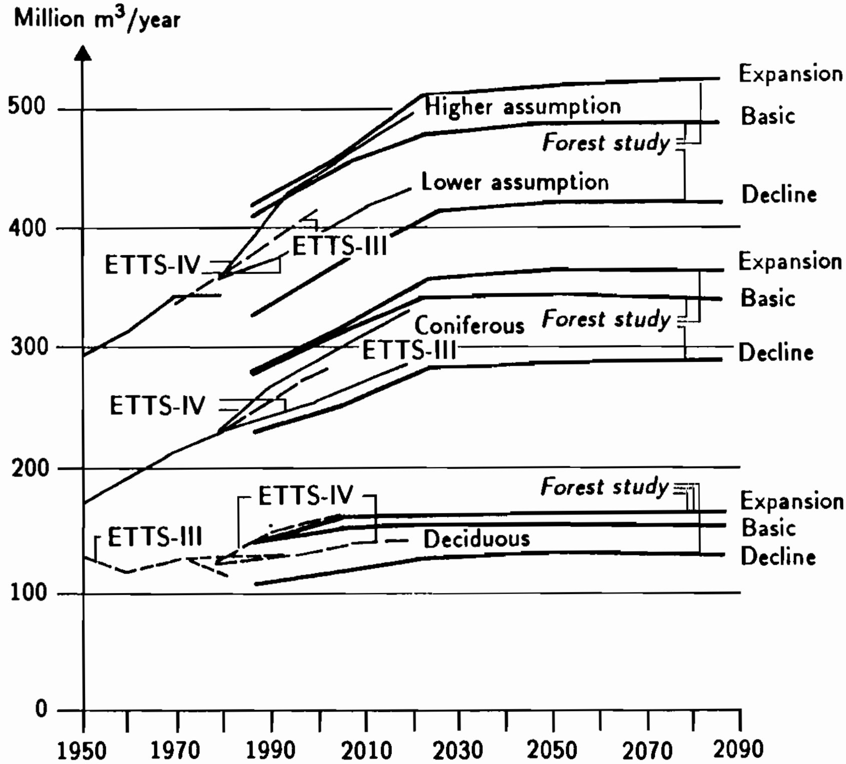

Figure 8.1. Comparison between results from ETTS-III, ETTS-IV, and the Forest Study, expressed in million cubic meters per year.

projected by the Basic Forest Study Scenario are about 20 million cubic meters higher per year up to year 2020 than the high ETTS-IV estimates (*Table 8.9*).

The regions most affected by forest decline attributed to air pollutants are the Eastern and Central regions, followed by the EEC-9 (*Table 8.7*). The total loss of potential harvest caused by air pollutants expected to be emitted in Europe up to 2000 to 2005 is estimated to be 16 percent of the total potential timber harvest in Europe. This represents a loss of about 83 million cubic meters per year averaged over 100 years.

One way to verify the results of our decline scenarios (*Table 8.7*) is to compare the distribution of sensitivity classes, the areas exceeding target loads for sulfur, and the existing loss of foliage. Chadwick and Kuylenstierna

Table 8.9. Summary of different scenarios for the EEC-12 region.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Potential harvest (mill. m^3 o.b./yr)[a]							
Total	188.5	158.7	179.4	174.1	151.7	152.6	202.2
Coniferous	108.7	99.5	109.3	101.6	94.9	95.9	126.6
Deciduous	48.9	42.4	49.0	43.2	41.0	38.0	54.5
Coppice	30.9	16.8	21.1	29.3	15.8	18.7	21.1
Growth (m^3 o.b./ha/yr)[a]							
Total	5.3	4.8	5.1	4.8	4.2	4.4	4.7
Coniferous	6.4	6.0	6.3	5.8	5.3	5.6	5.6
Deciduous	5.4	5.3	5.5	4.5	4.4	4.4	4.4
Coppice	3.3	2.2	2.5	3.1	2.0	2.3	2.5
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	134–172	134–201	134–173	134–154	134–159	134–177	134–167
Coniferous	146–206	146–219	146–196	147–186	147–177	147–199	147–188
Deciduous	148–177	148–231	148–179	148–147	148–152	148–186	149–157
Coppice	94–100	94–136	94–120	94–99	94–131	94–126	94–120

[a]Average for the simulations over 100 years.

(1990) have produced such a comparison for the IIASA Forest Study on Switzerland. The comparison is illustrated in *Figure 8.2*. The information about the existing losses of foliage in 1985 is collected from Anon (1985). The good correspondence shown in the three illustrations of *Figure 8.2* validates the methodology used to generate the decline scenarios.

It should be clearly stated that the links between pollutant concentrations and depositions and forest decline are still not understood completely. The roles of specific pollutants relative to each other, and the role of all pollutants relative to other decline-causing stress factors such as insects and diseases, climate, and inappropriate silviculture, are notoriously difficult to ascertain. Such profound ignorance renders forecasts of specific air-pollution effects on forests across broad regions and over long periods of time rather speculative. However, such speculations are useful, if for no other reason than to bound the dimensions and seriousness of the problem and to identify critical research needs.

No quantitative approach has heretofore been used in scenario building about the effects of forest decline in large regions. Modeling attempts have been made in several countries to quantify the effects at regional or national

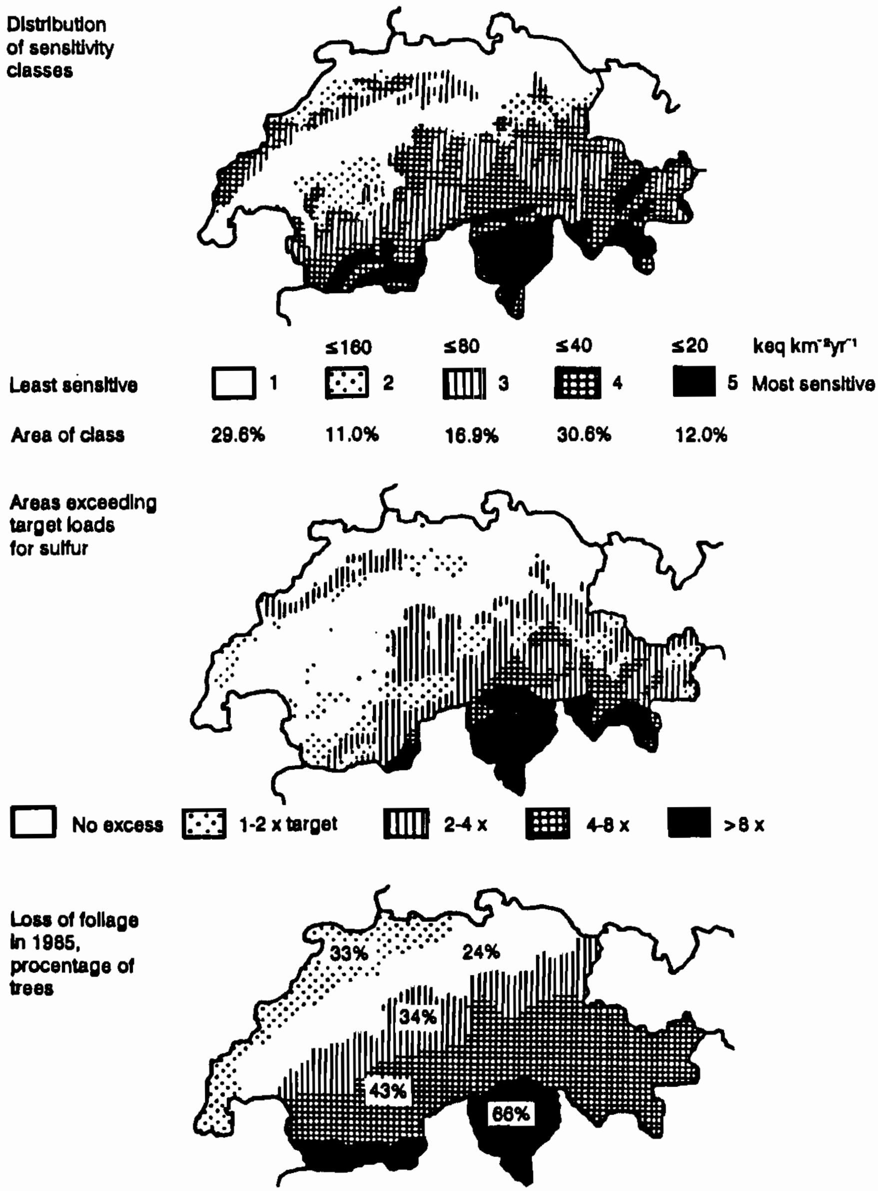

Figure 8.2. Comparison between distribution of sensitivity classes, areas exceeding target loads for sulfur, and loss of foliage in 1985 in Switzerland. Source: Chadwick and Kuylenstierna (1990).

levels. For example, Möhring (1986) developed a detailed model based on a theory of normal forest conditions in the FRG. However, the model deals only with single-stand developments and not with total forests. Ewers *et al.* (1986) used a simulation model based on Markov chains for estimating the development of the decline in the FRG. The analyses had a time horizon up to 2060. The species taken into account was spruce. Three scenarios were implemented:

(1) A trend scenario, in which 1983 air pollutant emissions were continuously reduced by 25 to 35 percent to the year 2060.
(2) A status quo scenario, where the level of emissions in 1983 was maintained during the simulation period.
(3) A reference scenario, where emission rates during the 1930s and 1940s were used.

The major output from this model is a distribution of the damage classes (loss of foliage) over time in different age classes. Unfortunately, it is not possible to compare the results achieved by Möhring (1986) and Ewers *et al.* (1986) and the Forest Study results presented in this book.

8.3 Economic Effects of Forest Decline

This book does not try to produce an economic evaluation of the future effects of forest decline. However, the basic information embodied in our simulation results is one of the cornerstones for calculating the economic effects of forest decline in Europe in an efficient way. Metz (1988) carried out a detailed literature review on the economic consequences of the forest decline attributed to air pollutants in Central Europe. Calculations based on Metz's review do not consider effects on the forest-products industry (*Table 8.10*). It can be concluded from Metz's work that it is very difficult to consider all aspects of forest decline in economic evaluations.

In Poland the economic losses resulting from declining forests have been estimated to be some 60 billion zlotys per year (*Ambio*, 1989; Gorka and Poskrobko, 1987). Netsch (1985) studied the economic effects of forest decline on farm enterprises in Bavaria. By studying model enterprises in this region, Netsch calculated a gross loss ranging between DM 66,000 and 124,000 per year for the model farm enterprise, depending on the future development of the decline. Kornai (1988) attempted to evaluate the economic effects of forest decline, taking forest resources, industry, and markets into account,

Table 8.10. Total monetary damage in Austria (A), Switzerland (CH), and the Federal Republic of Germany (FRG), evaluated monetary damage in percent of the GNP, damage per total forest area (ha), and damage per inhabitant.

Country	Study	Monetary damage in billion DM	Damage in % of GNP	Damage per total forest area, DM/ha	Damage per inhabitant in DM
A[a]	Annual 1985	0.64	0.3	170	85
	Annual 1987	3.09	max 1.5	815	410
CH[b]	Total	53.24	17.0	48,500	8,205
	I Phase	2.18/yr	0.7	1,985	335
	II Phase	1.45/yr	0.5	1,310	220
FRG[c]	Total T	211.4	11.0	28,960	3,460
	Total S	344.2	18.0	47,150	5,635
	Annual 2%T	5.5	0.3	755	90
	Annual 2%S	8.8	0.5	1,205	145
	Annual 0%T	11.5	0.6	1,575	190
	Annual 0%S	18.3	0.9	2,510	300

[a]Two annual studies carried out: 1985 and 1987.
[b]Discount rate 0%, residual damage not taken into account.
[c]Discount rate 2%, residual damage taken into account. T = Trend scenario, S = Status quo scenario.
Source: Metz (1988).

using the IIASA Global Trade model (Kallio *et al.*, 1987). In Kornai's analyses, very tentative results from the Forest Study were used concerning the changes in wood supply caused by air pollutants. Kornai concluded that forest decline will have significant economic impacts in both the short and the long term. However, the impacts would unlikely be sudden or dramatic. A natural step to further analyses is to use the results we present in this book as input to the IIASA Global Trade model for more detailed analyses.

Chapter 9

Policy Implications of Continued Forest Decline

9.1 Atmospheric Pollutant Emissions

9.1.1 Background

Air pollution is without question a key contributor to much of the forest decline witnessed in the 1980s in Europe. Thus, if forest stress due to air pollutants is to be reduced, policymakers must focus on air-pollution control. The major pollutants implicated as causal agents in forest declines are sulfur dioxide, nitrogen oxides, and ozone, but other pollutants such as ammonium and organic compounds are also suspected of contributing to some forest declines.

Sulfur dioxide is emitted into the European atmosphere mainly by coal- and oil-burning power plants and smelters. Nitrogen oxides enter the European air principally from power plants and petroleum-powered vehicles. Ozone in the lower atmosphere is mainly a product of photochemical reactions involving nitrogen oxides.

Air-pollution emissions in Europe have risen steadily during the twentieth century. Even optimistic scenarios of future patterns of air-pollutant emissions in Europe (*Table 9.1*) are little cause to take lightly the air-pollutant-induced stress on forests (*Table 9.2*). So-called lag effects of air pollutants on forest ecosystems may last several decades; therefore, even if pollutant emissions are adequately controlled soon, forests will not respond fully to

Table 9.1. Emissions of sulfur and nitrogen in Europe.

	Sulfur dioxide				Nitrogen dioxide[a]			
		2000				2000		
Region	1980 kt	kt	% of Europe	% change	1980 kt	kt	% of Europe	% change
Nordic	1,205	675	1.9	−44.0	751	526	3.4	−30.0
EEC−9	17,048	10,020	28.8	−41.2	10,139	7,916	51.2	−21.9
Central	481	170	0.5	−64.7	356	250	1.6	−30.0
Southern	6,172	9,873	28.3	+60.0	2,018	2,936	19.0	+45.5
Eastern	16,332	14,092	40.5	−13.7	3,631	3,841	24.8	+5.8
Europe	41,238	34,830	100.0	−15.5	16,895	15,469	100.0	−8.4

[a]Quantitative estimates are available only for NO_2 emissions. If NH_3 emissions are taken into account, the total N emissions will be about double the figures presented for NO_2. Data were provided by the IIASA Transboundary Air Pollution Project.

Table 9.2. Exposure of European forests to significant amounts of air pollutants. Data for sulfur and nitrogen are percentages of the total forest area exceeding critical loads. Data for ozone are based on mean diurnal concentration distributions, April–September, 1986.

Forest type Period	Nordic	EEC-9	Central	Southern	Eastern
Sulfur					
Coniferous					
1985	59	88	98	62	98
2000	48	76	93	84	98
Nonconiferous					
1985	19	34	50	18	84
2000	7	24	46	40	76
Nitrogen					
Coniferous					
1985–2000	75	83	100	34	76
Nonconiferous					
1985–2000	52	55	86	21	47
Ozone[a]					
1985–2000	1–2×CL	1.5–2×CL	2–2.5×CL	n.a.	1.5–2.5×CL

n.a. = Not available due to insufficient data.
CL = Critical load.
[a]Source: Grennfelt *et al.* (1988).

the clean atmosphere immediately. Results of our timber-assessment scenarios that incorporate pollutant effects on potential wood supplies are rather conservative in the sense that we have assumed a clean atmosphere from 2005.

If air pollutants are having the effects on forests that we suspect, the whole of European society loses significantly. The forest-products industry loses wood quality and, over the long term, wood quantity as well. Declining stands lose their ability to provide wildlife habitat, recreation, and water and soil protection. Clearly, all European residents and visitors lose important benefits from air-pollution effects on forests.

Based on our simulation work, we estimate, in response to the sulfur and nitrogen emission scenarios in *Table 9.1*, the lost potential wood supply in the regions of Europe, in million cubic meters per year averaged over a 100-year period to be: Nordic, 11; EEC-9, 24; Central, 6; Southern, 7; and Eastern, 34. Thus, for all Europe (excluding the Soviet Union), lost potential wood supply owing to air-pollution effects could average some 83 million cubic meters per year.

9.1.2 Policy opportunities

There are two major pathways to mitigate the potential effects caused by air-pollutant emissions: pollution control and raising the stress resistance of forests. The latter is discussed in Section 9.2. With respect to air-pollution control, our results show that current policies for emission reductions of sulfur and nitrogen oxides will make relatively small reductions in the areas of forest at risk (*Table 9.2*). Indeed, the current policy will allow more pollution in some areas like the Southern and Eastern regions and will likely increase the forest areas at risk.

Blanket application of fixed-proportion reductions of air-pollutant emissions across Europe clearly ignores several facts: some forest ecosystems are more sensitive than others; countries are emitting very different absolute amounts and amounts standardized to per caput, per unit land area, or per unit GDP; and pollutants are usually not deposited in the locale of their emission. Under the auspices of the UN-ECE Convention on Long-Range Transboundary Air Pollution, policies should be devised for pollution controls that are targeted to specific pollutants and specific polluters with the objective of reducing pollutant depositions to below critical loads for all forests of Europe.

National governments are clearly responsible for developing and implementing new targeted policies for air-pollution control. However, because of the international nature of the problem, international organizations such as the European Community and the UN-ECE have a responsibility to bring representatives from various nations together to undertake international impact assessments and to develop strong pollution-control policies acceptable to all parties. Despite potential problems in implementing new pollution controls in old industrial plants, the technology for advanced pollution control, especially for sulfur, is available. The key resource required to install and operate pollution controls is money.

Of course, a key constraint in implementing policies targeted for air-pollution control in Europe is the availability of funds in the countries where most controls ought to be installed. One can expect significant difficulties in international negotiations: first, in determining which countries ought to take blame for pollutant depositions exceeding critical loads and, second, in determining who should shoulder the financial burden of controlling the pollution.

Unless pollution-control programs are increased substantially, in a manner that targets specific polluters considered to be "worst offenders," forest decline caused by air pollution in Europe will not likely decrease. We cannot overemphasize the need for strong action against air pollution to secure healthy and vibrant forest resources in Europe.

9.2 Forest Policies

9.2.1 Harvest levels and silviculture practices

Background

Actual silvicultural practices in European forests have, in large measure, deviated from the declared policies of most countries. Three basic silvicultural elements are critical in determining the level of vitality of forest stands: the timing and intensity of thinnings that control density of trees in forest stands; the age at final felling that controls the degree to which stands become overmature; and the vigor with which certain species can grow on specific sites. In the Forest Study, we have concentrated our analysis on the effects of thinnings and final fellings as tools to reduce risk of forest stands to air-pollution stress. Because these tools together account for all timber extraction, changes in their implementation automatically imply changes in the harvest levels of European forests.

Like all biota, trees can exhibit signs of stress or decline when they are in strong competition with other trees for light, nutrients, and water and when they are old. Thinning forest stands can control tree density so that intertree competition does not induce tree decline, and final stand felling (or final tree felling in the case of uneven-aged management) can remove trees before they become physiologically old and unable to grow and maintain vigor. We believe that proper thinning regimes to eliminate stressful competition and proper rotation to prevent old-age decline are not being implemented in many European forests.

We have used the indicator of forest harvest volume to discover to what degree "handbook" silviculture (i.e., the silvicultural practices that are recommended by research institutions in each country as those required to keep stands vigorous, and thus form the basis for most policies) has been applied in each country. Harvest volume can make this discrimination because it is governed by the application of thinning and final-felling regimes.

Appropriate silvicultural practices have been researched and developed intensively in Europe for more than a century. However, for a variety of reasons handbook silviculture has not been implemented in all countries. Our analyses show that all European regions except the Southern region displayed very large immediate harvest pulses when we implemented handbook silviculture in our simulations. The Southern region results do not display a strong reaction of this type because the forests have a more balanced age-class structure; coppices are an important component of the forest resources; and basic forest-inventory data for use in our simulations were of poor quality. We conclude that the problem of silviculturally induced stress in European forests is a widespread and serious problem.

Our findings are well supported in the literature. Kuusela (1987) argues that in many European countries the silviculture regimes currently used are less than adequate even under no-decline conditions. Many forests, according to Kuusela, are overly dense, have standing volumes that are too high, and are too old. These factors, together with the fact that fellings have been for some time about 20 percent lower than the increment, will cause an increasing decline (Kuusela, 1987). Kuusela's recommendation is to decrease gradually the density and rotation age of the stands to keep vitality up and avoid decline. These measures will, of course, generate increased removals in Europe. In a later analysis Kuusela (1988) predicts little change in implementation of actual silvicultural practices throughout Europe, suggesting that silviculturally induced stress will not be reduced in the next several decades.

Ulrich (1988) finds that to decrease the total acid load in an ecosystem, the internal net proton production must be minimized. He recommends the following silvicultural measures (among others) in this respect:

(1) Aim at low densities and strong thinnings to avoid the accumulation of nutrients and bases in the tree biomass which cannot be utilized by the ecosystem.
(2) Apply early thinnings to allow ground vegetation to persist and to minimize the accumulation of an organic top layer from the litter of the stand.
(3) Allow deciduous species to remain within the stand throughout the rotation to facilitate litter decomposition.

Scholz (1984) arrives at conclusions similar to those of Kuusela (1987, 1988) and Ulrich (1988), and emphasizes in addition the importance of tree species selection. Tree species and provenances should be selected to be as well adapted as possible to natural site conditions to buffer against effects of air pollutants. In general analysts agree that there are serious mismatches throughout Europe between site types and species regenerated. Because this is a very local phenomenon, and basic data permitting analysis of this situation are not available, the possibilities to improve future forest conditions through better species-site matching could not be explored in our study.

Ovaskainen (1987) and Lohmander (1989) have studied optimal harvesting patterns under conditions of air-pollutant stress based on theoretical approaches (traditional stand-level economic calculations). The general conclusion from these studies is that the optimal harvest year occurs earlier if stand growth is reduced by air pollutants. Moreover, short-term harvest activities increase in the decline situation, but in the long run the harvest level is reduced in comparison with undisturbed conditions.

A specific silvicultural measure for stand revitalization is fertilization. Effects of fertilization have been studied in several countries. The results indicate that application of lime and/or other fertilizers containing Mg, K, and P would improve conditions in declining stands (e.g., Huettl, 1988). The risk with fertilization is that it may cause displacement of nutrient cations because of relative increases of hydrogen ions. However, countries such as the FRG and Sweden have started nationwide programs to fertilize declining stands and stands at risk. The long-term effects are not quantifiable at the moment, so fertilization has not been taken into account in our analyses.

Policy Opportunities

Based on our results and other studies, we conclude that it is important to carry out intensive forest management in situations with forests under stress from air pollutants. This contradicts many policies employed in several countries in Europe today. These policies are often based on the assumption that intensive forest management will worsen the effects of air pollutants. The results from the Forest Study and the literature review do not support these assumptions and the resultant policies.

Good silvicultural practice with respect to stand density and age to keep up vitality is known throughout Europe. Forest-stand resistance to stresses such as air pollution can be raised significantly by implementing known silvicultural practices.

Many European forests now have age-class structures and growing stocks that have evolved under decades of nonideal silviculture. Therefore, it would be logistically impossible to implement proper silviculture immediately. What is required in each country, and indeed in each forest-management area, is a careful analysis of the harvest-level implications of various schedules of implementation of handbook silviculture programs. The objective should be as rapid a full implementation as possible with acceptable increases in wood harvest.

All members of the forest sector have a role to play in bringing about higher resilience of European forests to stress through application of appropriate silviculture. Research institutions must determine what the good practices are, and adjust them to the relatively new stress of air pollution on so many European forest stands. Landowners, including private interests and governments, must become aware of the consequences of not implementing resilience-building silvicultural practices, and must find means to implement these practices. The forest-products industry has the responsibility to be receptive to an increased wood supply that would result from implementation of proper silviculture practices. Governments have the responsibility to assist industry in its efforts to absorb the increased wood supplies, which our analyses show do not need to be temporary if countries wish to increase long-term production of forest products.

Full implementation of handbook silviculture in European countries would require increases in labor and machinery resources, as well as new markets – either domestic or international – for the increased wood supply. Several constraints need to be overcome if silviculture is to be used to its full potential to raise the vitality of European forests. First, governments that have policies calling for good silvicultural practices must begin to implement those policies; this may even mean legislation governing silvicultural practices. Second, public and private landowners need to be aware that old and dense forest stands, while attractive for a time, have low resistance to air-pollution stress, and that judicious cutting is the most powerful tool to improve stress resistance. Third, the shortage of skilled forestry workers already found in Europe needs to be overcome with training, image improvement, and higher wages. Finally, markets for roundwood need to be enhanced, partly through increases in industrial processing capacity, to make it profitable for landowners to implement harvest-oriented silviculture.

Many European forests have a low resistance to stress because they are too dense (thus in competitive environments), too old (thus physiologically overmature), and inappropriately matched to site conditions (thus growing on inhospitable sites). Harvest-oriented silviculture is a powerful approach to increase stand resistance to stress factors such as air pollution. Many obstacles must be overcome before stress-reducing silvicultural practices can be implemented in most European countries. If these obstacles are not overcome soon, we may expect that continuation of current silvicultural practices will further contribute to forest decline.

9.2.2 Forest-land expansions

Background

During the last few decades, huge surpluses of food have been produced in Europe by heavily subsidized farmers. There is serious discussion in most countries and in international organizations such as the European Community to redirect agricultural subsidization from food production to tree production. European planners are discussing vigorous programs that will convert land from farms to forest stands. Recent attention has focused on the reforestation of degraded and unused land. As a result there is a strong potential for overall increases in the amount of forest land in Europe.

It is by no means clear to what degree any new stands established under such land-conversion programs would be available for timber production. Landowners may be led to establish such stands primarily for amenity purposes, such as water and soil protection and recreation and wildlife habitat, and only secondarily for wood supply. Indeed, in view of impending climate change, even carbon sequestration may be seen as a meaningful objective for new forests. However, to get an idea of the biological potential that forest-land expansion programs may contribute to wood supply in Europe, we have simulated a series of forest-land expansions as part of our European timber assessment. We discuss the results below, along with the policy implications of not being able to capture the biological potential wood supplies.

Input data to our simulations are average annual forest-land expansions in each country in hectares per year. Potential effects of such expansions on wood supply in each country are described as annual harvest volumes at specific times in the future.

Results of our simulations suggest that, if the biological potential wood supply is actually harvested, total potentials increase marginally for the Nordic, Central, and Eastern regions, modestly for the Southern region, and strongly in the EEC-9 (*Table 6.2*). The increases occur even in the short term (i.e., by 2020) because, although the newly established stands will not be available for harvest until some time later, their availability allows harvest levels to increase sooner on stands already available.

Two uncertainties have a bearing on the results of our analyses of forest-land expansions. The first is simply whether the land-expansion scenarios we have simulated will occur. A controversy exists within the European forest sector as to whether the proposed programs can be implemented. Many argue that the programs are too optimistic. In the context of ETTS-IV, our estimates of forest-land expansions seem reasonable.

The second major uncertainty concerns the degree to which wood will be harvested for profit at the rate we have assumed to be the biological potential under proper silvicultural practices. As noted above, landowners may want to retain growing stocks on the land expansions for amenity values. We specifically asked our collaborators in each country to tailor their estimates to expansions for timber-supply purposes.

Nevertheless, given these uncertainties, our simulation results may be interpreted as absolute high limits of the potential contribution of forest-land expansions to wood supply in Europe.

Policy Opportunities

If European nations are concerned about long-term availability of forest products to meet rising domestic demand, it may be necessary not only to expand the forest landbase but also to ensure that owners have sufficient incentives to apply proper silvicultural practices and to harvest and market their wood. Each country needs to examine the potential future course of domestic forest-products demand and the capacities of the forest-products industry. At the same time, each country must analyze the potential abilities of domestic forests to meet these needs. Our results show that forest-land expansions can play a significant role in increasing long-term sustainable timber-harvest levels. Such analyses should reveal to what degree governments ought to encourage forest-land expansions and wood harvests from the newly forested lands. If such harvests are deemed desirable, governments could provide tax incentives or subsidies in the form of funds or supplies and services such as management planning, site preparation, stock planting, and stand tending.

When forests are large enough to allow for annual harvest activity, management expenses can be considered as costs to be charged against revenues from timber sales. However, farm and other small woodlots receive rather infrequent harvests, so stand establishment may have to be seen as an investment. When rotations are long, such investments are seldom economically justifiable. Private owners of small parcels of land, e.g., farmers, may need considerable subsidies before considering changing land use from food crops to tree crops. A huge amount of money may be required to implement the land-conversion scenarios we used in our simulations.

Several constraints may impede future expansions of the forest landbase in Europe. With world population continuing to grow, Europe may be called upon to produce food for export to hungry nations. This may reverse the current vision that there is surplus agricultural land in Europe. Second, amenity values of tree stands will become more and more important, and landowners (as well as the general public) might become less and less inclined to treat new woodlots as sources of timber but rather as venues for recreation and ways of implementing land stewardship, not to mention slowing the buildup of carbon in the atmosphere. Finally, even if landowners want to establish new timber-oriented woodlots, and governments encourage this, the funds required may be difficult to secure.

Summary and Outlook

Forest-land expansions are expected to be large only in the EEC-9 region. If the biological potential wood supply from such expansions can actually be taken, over the long-term there will be significant increases in total wood supply in EEC-9. Because there is doubt with respect to whether the expansions will occur, and whether wood supply will be their main function, we cannot say with certainty that the expansions can be counted on to increase the overall wood supply. If countries wish this to be so, strong policies, backed up with financial support, will be needed.

9.3 Demand/Supply Balances for Industrial Roundwood in Europe

Actual 1987 harvest data and 1985 demand data (both derived from FAO sources) show that Europe in the late 1980s had a surplus wood supply (*Table 9.3*). The surplus of overall wood supply over wood demand amounted to some 55 million cubic meters per year. When we look at the years 2000 and 2010, the picture changes significantly. For example, even in the case of no future decline in European forests, the Continent may face an annual roundwood deficit of some 40 million cubic meters by 2010. If we account for decline as we have in our Forest Study Decline Scenario, that deficit amounts to about 130 million cubic meters for each year. Increased wood-harvest of forest land can only mitigate these annual deficits in 2010 by about 8 million cubic meters.

The region that will experience the most serious potential deficits is the EEC-9, largely because roundwood demand is expected to grow so strongly in this region. The strongest effects of pollution-induced forest decline in making potential deficits worse are projected to be in the EEC-9, Eastern, and Southern regions.

9.4 Potential Wood Supplies and Industrial Capacities

Every nation concerned about the future of its forest sector will want to find a reasonable balance between actual/potential wood supply and industrial wood-processing capacities. Overcapacity in industry should be avoided because it indicates inefficient industrial investments. When roundwood imports are not available significant overcapacities cannot be kept active for very long, and mill closures would be disruptive to local economies. Undercapacity in industry signifies either that roundwood is being exported, thus contributing little to high value-added domestic manufacturing and the attendant economic benefits, or that biological potential harvests are not being realized because of inadequate domestic roundwood markets.

Table 9.3. Outlook for regional wood demand/supply balances in Europe. Data are expressed in million cubic meters of roundwood equivalents.

Region	Variable	Balances at mid-1980s	2000	2010
Nordic	Domestic demand[a]	31.2	41.2	43.4
	Surpluses/Deficits with:			
	1987 actual harvest	+89.5		
	No decline[b]		+109.0	+104.6
	Decline[c]		+88.9	+91.5
	Land expansion [d]		+109.7	+109.5
EEC-9	Domestic demand	202.5	279.0	326.5
	Surpluses/Deficits with:			
	1987 actual harvest	−93.2		
	No decline		−132.6	−173.4
	Decline		−160.1	−200.0
	Land expansion		−128.4	−175.9
Central	Domestic demand	13.8	18.3	22.8
	Surpluses/Deficits with:			
	1987 actual harvest	+8.5		
	No decline		+5.7	+1.8
	Decline		−0.2	−3.9
	Land expansion		+5.8	+1.9
Southern	Domestic demand	49.3	67.2	77.2
	Surpluses/Deficits with:			
	1987 actual harvest	+22.8		
	No decline		+7.0	−1.4
	Decline[e]		−1.9	−9.3
	Land expansion		+9.3	+0.9
Eastern	Domestic demand	69.4	91.3	105.6
	Surpluses/Deficits with:			
	1987 actual harvest	+30.1		
	No decline		+31.5	+20.9
	Decline		−5.4	−17.6
	Land expansion		+31.8	+21.6
Europe	Domestic demand	366.2	497.0	575.5
	Surpluses/Deficits with:			
	1987 actual harvest	+57.6		
	No decline		+20.6	−47.5
	Decline		−75.4	−139.3
	Land expansion		+31.3	−40.0

[a] Roundwood demand to meet domestic consumption of final industrial products.
[b] Potential wood supply according to the Basic Forest Study Scenario.
[c] Potential wood supply according to the Forest Study Decline Scenario.
[d] Potential wood supply according to the Forest Land Expansion Scenario. No effects of air pollution are accounted for in this scenario.
[e] No decline effects have been calculated for Spain.

Most countries welcome the economic benefits that come from vigorous industrial, manufacturing, and commercial activity, and would probably encourage expansion of the forest-products industry if markets for consumer products are expected to be buoyant and if depressed roundwood markets are the major constraints against realizing wood-harvest potentials. Major factors to consider in planning for change in industrial wood-processing capacity include: current capacity structure, including technological efficiencies and ages of physical plant; outlook for reasonable-cost wood supply; outlook for product markets; availability of capital, labor, and energy at reasonable costs; and environmental restrictions on establishment and operation of new processing facilities. Obviously, such planning is plagued by many uncertainties, but these must be overcome if industrial futures are to progress in an orderly fashion and are not to suffer from serious imbalances between actual wood supply and processing capacity.

We have examined the current and potential balances between wood supply and industrial capacity in the regions of Europe (*Table 9.4*). In the late 1980s all regions had apparent excess industrial capacity compared to actual wood harvests, with the most serious overcapacities in the Central region (we say apparent because there is significant interregional trade of roundwood and chips in Europe). This implies that the physical lack of processing facilities may not be a strong constraint (or in some places no constraint at all) on increasing wood harvests from actual levels to the higher potential levels indicated in our simulations. Thus, other factors, such as unfavorable profit margins owing to low roundwood prices (e.g., from the EEC "inner market"), high harvest, and silviculture costs and forest-owner attitudes favoring the non-wood forest benefits from dense mature and overmature forest stands, may be more prevalent in keeping actual roundwood harvests below biological potentials.

However, industrial undercapacity does become a constraint to full achievement of the biological wood-supply potentials we have calculated in our simulation analyses. If it becomes possible to remove other constraints, our simulation assuming no forest decline suggests that all regions except the Central region will face industrial undercapacities (*Table 9.4*). These undercapacities would be largest in the EEC-9 and Eastern regions. In the event that forest-land expansions are implemented to the extent we have assumed in the Forest Land Expansion Scenario, and the resultant wood is available for industrial processing, the undercapacities are even more significant, particularly in EEC-9. Again, the Central region escapes this constraint.

In the late 1980s, most countries had industrial overcapacities compared with actual levels of timber harvest (*Table 9.4*). Exceptions include Denmark, Ireland, and the UK. Under the Basic Forest Study Scenario, this general situation would change such that most countries would be short of industrial capacity compared with the potential wood supply. This situation would be most severe in Norway, Denmark, the FRG, Ireland, Italy, the UK, Bulgaria, Romania, Switzerland, Turkey, and Yugoslavia. With the Basic Forest Study Scenario, there are few wood-supply constraints to expansion of industrial capacities. Taking potential forest-land expansion into account, this opportunity would be even stronger in Denmark, the FRG, Ireland, Italy, and the UK. However, a comparison of current capacities with potential wood supplies under forest-decline conditions, as exemplified by the Forest Study Decline Scenario (*Table 9.4*) suggests that many European countries would experience overcapacity if decline continues as we expect it might.

Of most interest here are comparisons of current industrial capacities with the Forest Study Decline Scenario. Again, the comparison assumes that all other constraints on biological harvest potentials can be lifted. If they can, forest decline has different effects on the adjustments required to reach industrial capacity in each region and to process the wood supply (*Table 9.4*). In the Nordic region, the current industrial capacity would be matched by the long-term sustainable wood supply, suggesting that the capacity would need to be expanded slightly (assuming that capacities cannot be 100 percent utilized). Significant undercapacity would exist in EEC-9 under forest-decline conditions, but overcapacities would exist in the other regions. Our calculations for the Southern region do not show much of a difference between current overcapacity with actual wood supply and the overcapacity with a potentially available supply under decline conditions. This is due to our inability to account for effects of forest decline in Spain.

In summary, there are three classes of overall outlooks with respect to industrial capacities and potential wood supplies. If biological wood-supply potentials can be achieved, capacities would need to be expanded in the Nordic and EEC-9 regions regardless of whether forest decline occurs as we have simulated it. Of course, the degree of capacity expansion is significantly less in the decline case than in the other scenarios. In the case of the Central region, all scenarios show that significant overcapacity exists. Policies relating to softening the impact of capacity closures and to restructuring the industry will be needed. Finally, in the Southern and Eastern regions, if forest decline persists as we assume it will in the Forest Study Decline Scenario,

Table 9.4. Industrial capacities (IC) in 1987–1988 and 1987 actual harvests and potential harvests under the Forest Study Scenarios. Data for the scenarios are 100-year averages. Percent of IC in parentheses.

			Forest Study Scenarios		
Country Region	1987–1988 IC mill. m^3	1987 removals mill. m^3	Basic mill. m^3	Decline mill. m^3	Forest Land Expansion mill. m^3
Finland	55.5	47.5 (86)	59.1 (106)	54.6 (98)	59.1 (106)
Norway	15.3	11.8 (77)	20.6 (135)	19.8 (129)	20.6 (135)
Sweden	77.0	61.4 (79)	75.6 (98)	69.8 (91)	78.6 (102)
Nordic	147.8	120.7 (82)	155.3 (105)	144.2 (98)	158.3 (107)
Belg. & Lux.	6.8	3.9 (7)	4.0 (59)	3.3 (49)	4.7 (69)
Denmark	1.8	2.4 (133)	3.3 (183)	2.9 (161)	4.7 (261)
France	49.0	47.4 (97)	56.7 (116)	53.2 (109)	61.8 (126)
FRG	38.2	37.1 (97)	49.4 (129)	37.5 (98)	52.3 (137)
Ireland	1.3	1.5 (115)	1.9 (146)	1.7 (131)	4.7 (362)
Italy	16.3	9.6 (59)	20.3 (125)	17.2 (106)	22.2 (136)
Netherlands	1.6	1.4 (88)	0.9 (56)	0.7 (44)	1.1 (69)
UK	5.8	5.9 (102)	13.4 (231)	9.7 (167)	17.6 (303)
EEC-9	120.8	109.2 (90)	149.9 (124)	126.2 (104)	169.1 (140)
Austria	24.7	16.9 (68)	17.1 (69)	13.7 (55)	17.6 (71)
Switzerland	5.7	5.4 (95)	7.5 (132)	5.1 (89)	7.7 (135)
Central	30.4	22.3 (73)	24.7 (81)	18.8 (62)	25.3 (83)
Greece	4.6	3.4 (74)	2.8 (61)	2.7 (59)	2.8 (61)
Portugal	12.6	11.5 (91)	7.4 (59)	5.9 (47)	10.3 (82)
Spain	25.4	21.9 (86)	17.8 (70)	17.8 (70)	20.0 (79)
Turkey	20.1	17.8 (89)	27.0 (134)	24.2 (120)	27.0 (134)
Yugoslavia	19.2	17.4 (91)	23.2 (121)	20.4 (106)	23.6 (123)
Southern	81.9	72.0 (88)	78.2 (95)	71.0 (87)	83.7 (102)
Bulgaria	6.0	5.1 (85)	8.6 (143)	6.4 (107)	9.2 (153)
CSFR	21.1	20.7 (98)	23.7 (112)	14.2 (67)	23.7 (112)
GDR	13.9	12.5 (90)	14.6 (105)	9.7 (70)	14.6 (105)
Hungary	7.7	7.1 (92)	8.5 (110)	5.5 (71)	9.5 (123)
Poland	30.7	27.3 (89)	30.5 (99)	19.4 (63)	30.9 (102)
Romania	29.8	26.9 (90)	40.2 (135)	36.4 (122)	40.2 (135)
Eastern	109.2	99.6 (91)	126.1 (116)	91.6 (83)	128.1 (117)
Europe	490.1	423.7 (87)	534.1 (109)	451.8 (92)	564.5 (115)

current overcapacity will be exacerbated. If forest decline does not persist and biological potential harvests can take place, processing capacities will need to be expanded significantly. In these regions, it becomes crucial to undertake applied policy analyses linking potential forest-resource futures and industrial futures. It would be relatively easy under such uncertain circumstances to make the wrong decisions.

9.5 Non-Timber Forest Values

Because of serious paucities of appropriate data and functional relationships for building forecasting models, we have been unable to prepare Europewide scenarios of future non-timber forest benefits and their responses to changing forest structure and to pollution-induced forest decline. This is unfortunate because forest owners and the general public are ascribing increased importance to non-wood forest benefits such as recreation, wildlife habitat, soil and water protection, microclimate amelioration, and carbon sequestration. In this section we wish to consider two distinct characteristics of non-wood forest values: the role of these values in restricting actual wood harvests from attaining biological potentials and the potential role of air pollutants in reducing these values.

9.5.1 Role in restricting potential wood harvests

Typical European forest-management practices focus on timber production and usually involve mono-specific, even-aged stands, which are mainly coniferous. These stands are normally not allowed to persist long into the mature phase before they are clear-cut. Rigorous application of such silvicultural practices on a large forest would result in a fairly young forest with a balanced age-class structure that is void of overmature stands. Many European landowners seem to feel that timber-production silviculture is not entirely appropriate for land that should produce a balanced mix of benefits or, indeed, mainly non-timber benefits. They see more appropriate silviculture for forest stands, primarily for recreation and protection purposes, as including mixed species (uneven-aged management often with significant proportions of overmature trees). This is not to say that timber-production forests provide no significant recreational and protection benefits, nor that recreation and protection forests can provide no timber flows. However, traditional timber production probably does not concomitantly produce the highest recreation and protection benefit flows, and recreation and protection forests do not yield the volumes of reasonable-cost timber that can be achieved from the same landbase under timber-oriented management.

Presently, we sense a strong wave in Europe, and in North America, toward multiple-use forests with less emphasis on timber production and more emphasis on non-timber values. Given the momentum of this broadly based environmentalism in a relatively affluent Europe, we expect this revaluation of forest benefits to continue. For the forest-products industry, this likely means the following: wood supplies may become more scarce, which would drive competition and prices up, or even if wood supplies were to remain stable or to increase, prices may go up owing to implementation of more environmentally sensitive silviculture.

With respect to implications of these trends, clearly governments will try to achieve: plentiful, healthy, attractive forests; a thriving forest-products sector that contributes to national economic development; and a forest industry that produces competitively priced, wood-derived consumer products. Policies aimed at providing plentiful, healthy, and attractive forests may need to foster forest-land expansion programs and changes in silviculture not only to maintain stand vitality through judicious implementation of timber harvests but to improve both stand vitality and attractiveness through changes in stand age-class structure and species composition. Policies to enhance the viability of the forest-products sector may need to focus not only on forest-land expansions, but also on public-education programs outlining the importance of timber harvests both to keep stands in a resilient condition and to provide raw materials for strategically important industries. Finally, policies for achieving competitively priced consumer products may need to encourage development of much more efficient harvest and silvicultural technologies to counterbalance increased costs of operations in recreation and protection forests. Achieving the balance will be difficult indeed, and we may therefore anticipate increased controversies over forest-land use and forest-management practices in Europe in the future.

9.5.2 Potential effects of air pollutants

We have already demonstrated the likely serious effects of continued pollution-induced forest decline on biological potential wood supplies and thus on the forest-products industry. Forest decline shows no discrimination for forest values and will negatively affect all non-timber benefits as well. The scant literature on effects of air pollution on non-timber forest values (e.g., Metz, 1988; Duinker and Stoklasa, 1988) suggests that the losses associated with impacts on non-timber benefits may significantly overshadow losses associated with timber.

Potential impacts of continued air pollution in Europe on non-timber forest values strongly indicate two lines of policy development. First, these impacts lend additional weight to the call for more vigorous schedules and programs for air-pollution control. Second, they underline the importance of implementing changes in silviculture practices that will maximize forest-stand vitality and resistance to air-pollution stress.

9.6 Research and Monitoring

Through our intensive analytical work and our discussions with forest-policy experts throughout Europe, we find that new or strengthened policies are required in the following areas of research and monitoring.

9.6.1 Basic forest inventory

A fundamental prerequisite of quantitative forest-policy analysis is a sound forest inventory. Such an inventory should serve not merely as a snapshot of current forest composition and structure, but also as an indicator of "current conditions" in simulation models that project inventory change through time as influenced by such factors as stand aging and succession, harvest and silviculture, and air-pollution stress. Some countries in Europe are already taking excellent inventories as a basis for policy analyses (e.g., Sweden, Poland, France), whereas others have yet to design and implement strong inventory programs (e.g., Spain, Greece, Turkey).

9.6.2 Monitoring forest conditions

Fortunately, most countries in Europe are already conforming to the basic requirements of the UN-ECE protocol for monitoring forest decline by assessing the density and discoloration of tree canopies. This monitoring activity is well established throughout most of Europe, although it requires strengthening in the Southern region.

The main decline indicators, i.e., defoliation and foliage discoloration, suffer from two key problems: they are both subjective estimates, and thus susceptible to observer biases; and they are not useful as early warning indicators of pollution-induced decline because they cannot identify the factors which affect them. There is a need to develop and implement more objective and discriminating variables for Continentwide monitoring of forest decline.

9.6.3 Effects of pollutants on stand growth and yield

Probably the weakest link in knowledge of the cause-effect chain between air pollutant emissions and forest decline is basic understanding of how atmospheric concentrations and ground depositions of various pollutants actually affect a wide range of forest stands that differ by age, species composition, site quality, silvicultural/sanitary condition, etc. We are convinced that the strongest evidence for building such relationships for use in forest-level impact simulators will come from insightfully designed research programs combining stand-level simulation with field-data measurements. Already several laboratories in Europe are building and testing stand-level simulators for analyzing air-pollution impacts. Every country ought to sponsor research of this type so that the stock of new data is rich and represents a wide range of pollutants, stand types, and conditions. Perhaps a coordinated network or consortium of research institutions working on this theme ought to be established.

9.6.4 Region-scale scenario analysis of potential wood supplies

While it is a basic forest-management principle that long-term future forest performance is predicated basically on near-term actions, our study emphasizes the need to make quantitative, internally consistent, long-term projections of forest response to management and air pollution to discover what policies are reasonable to pursue now. It is not enough, especially during this period of attention to resource stewardship and sustainable development, simply to react to changing resource conditions as they occur and focus only on maintaining current levels and types of economic activity.

The kind of quantitative scenario building in which we have engaged, and which we strongly propose should be undertaken in every country, does not have the purpose of sketching most likely forest-sector futures; rather, the purpose is to discover what policies make sense under a wide range of possible futures and what specific information should be generated to improve our abilities to manage forest resources properly. Policy choice can be greatly enlightened with the increased understanding of resource-system dynamics that comes from quantitative scenario analysis. Thus, our conclusion is that each country should be studying forest-sector futures with the aid of quantitative simulation tools for building possible alternative scenarios. With respect to the influence of air pollutants on forest condition, there is a need to complement our work on sulfur and nitrogen pollutants with analyses of ozone, and perhaps other pollutants.

9.6.5 Determination of economic wood supply

A vital caveat on the results of our analyses is that we have calculated biological potential wood supplies for all forests where industrial timber harvest is permitted. Thus, we have calculated what the forests *can* produce under conditions in which all that is produced is actually harvested. Such analyses assume that future potential harvests may be higher when one increases current harvest, depending on current forest structure and current harvest rates. In other cases, of course, one may face a situation of current overharvesting such that future potentials can be raised only if current harvest levels are reduced.

Several factors interact with each other to prevent actual harvest levels in each country or region from reaching potential harvest levels, including inaccessibility of harvestable stands, excessive costs for forest operations, shortage of labor, depressed roundwood markets, inclination of forest owners not to harvest for a variety of reasons, and laws and regulations curtailing harvests. For at least two reasons, analyses of biological potential harvests should be supplemented with analyses incorporating realistic assumptions about harvest restrictions. First, more accurate projections of actual wood supply would be generated. These projections would certainly be of interest throughout the forest sector under an assumption that restrictions on reaching the biological harvest potential cannot, should not, or will not be lifted. On the other hand, countries may be quite interested in discovering the relative importance of each restriction, with an eye to developing policies to lift specific restrictions and trying to capture a greater share of the biological harvest potential.

9.6.6 Quantification of non-wood forest values

Despite serious shortages of data and understanding, we have been able to develop quantitative scenarios of forest growing stocks and harvest levels to analyze basic forest-policy goals relating to maintenance or increases of these indicators. Owing to an overwhelming lack of data and information, we have been unable to build quantitative scenarios of the potential responses of non-wood forest benefits to continued pollution-induced forest decline. Moreover, we have also been unable to compare relative forest benefits of wood and non-wood in our scenarios of biological harvest potentials, and to use non-wood benefits in developing reasonable restrictions on wood supply.

Interestingly, most European countries have included many issues in their forest policies that cannot currently be analyzed quantitatively and comprehensively for incisive national policy formulation (Nilsson, 1989b). These issues include increasing forest productivity, improving the social and environmental values of forestry, avoiding forest decline, improving forest-sector profitability, and improving rural development based on forestry. We believe that sound policies for addressing these issues must be based on appropriately scaled quantitative analyses including simulation and scenario building. Therefore, we urge countries that consider such forest-policy objectives as significant to begin the important work of gathering the data and undertaking the cause-effect research required to analyze future possibilities to reach these objectives.

9.6.7 Climate change

Our work has dealt with just some major air pollutants, i.e., sulfur and nitrogen, and their potential effects on European forests and the forest sector. Current debates on global environmental change point strongly to what could be an even more important threat to forests worldwide, namely, atmospheric carbon dioxide. Preliminary indications are that forests around the world, particularly in temperate areas such as Europe, may suffer increased declines as the global climate warms and precipitation patterns change. We strongly believe that analyses of the potential responses of European forests to a changing future climate, similar in structure to the work reported in this book, need to be undertaken soon. After the first stage of such analyses, it will be important to look at simultaneous threats to European forests from both air pollutants and climatic change in combination. Analytical systems of the kind we have implemented should be expanded to explore the potential effects of climate change on European forests.

Epilogue

Forests are strategic resources for human well-being, and their importance will without doubt increase in the future. The forest landbase in Europe is fairly stable, but will likely increase since many governments are making policies with this goal in mind. With careful and insightful forest-resource management and policy formulation across Europe, forest resources can surely provide more wood and non-wood benefits, but only if the threat of air pollution can be avoided.

We conclude that immediate targeted reductions of air pollutants in Europe are required. However, even complete success in controlling the major damaging air pollutants will not be enough to remove all signs of stress in European forests. We believe that inadequate implementation of good silvicultural practices is also responsible for much of the decline visible today, so improvements in implementing basic forest management are also required. Emissions of noxious air pollutants will continue in the near future. Therefore, the European forest sector needs to implement silvicultural practices that help mitigate the damaging effects of air pollutants. European policymakers have a responsibility to humanity to conserve Europe's forests and keep them in a vital condition.

With respect to forest resources, Europeans are facing several complex problems:

(1) Pollutant emissions are unlikely to be controlled as rapidly and comprehensively as desirable.
(2) Several major polluting countries in Europe face uncertain political and economic futures, at least over the near to medium term.
(3) A host of constraints will act to prevent easy improvement of the vitality of forest resources.
(4) Many policymakers have a pessimistic outlook on the possibilities to expand the forest landbase.

(5) Strong demands for both non-wood benefits and forest products can be expected in the coming decades.
(6) Lower prices may be foreseen for roundwood on international markets. This development, which is due mainly to fewer trade barriers, may result in lower incentives for European landowners to harvest roundwood, intensify management, and afforest land.

Design and implementation of policies to cope with or even alleviate these problems will require strong partnerships among industrial, governmental, and environmental interests. Building the trust required, raising the critical awareness, generating the needed understanding, and finding resources for tackling the forest-decline problem expeditiously and effectively call for a cooperation of economic and environmental interests paralleled only by the need to address global problems such as climatic change and tropical deforestation.

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Appendix A

The PEMU Forest Decline Model

Cumulated Dose Response Approach to Evaluate Needle Loss in Pine Stands under Sulfur and Nitrogen Depositions in the Northeast German Lowlands

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A.1 Introduction

The prognosis and decision support model for environmental conservation (PEMU/AIR) has two major components: the pollutant emission and transport model and the pine stand decline model. The PEMU system has been described in detail by Bellmann and Lasch (1988a and 1988b) and Bellmann *et al.* (1988 and 1990).

The PEMU pollutant emission and transport model works with emission and deposition matrices (concentrations and dry and wet depositions) for specifically classified sources. The transfer matrices are based on a three-dimensional partial differential equation with the inputs of meteorological data and SO_2 and NO_x emission data from point sources which yield SO_2, NO_x, and NO_3 concentrations and S and N depositions. These output variables are calculated for different weather classes, which are based on average wind velocity, precipitation, and specific wind data for seasons, time of day, and different regions. Based on this information, grid calculations or receptor point calculations are carried out. The depositions are calculated for total, dry, and wet depositions. Thus, with this model component the deposition pattern can, for example, be calculated for different abatement strategies of and effects on the regions studied.

Linked to this model is the pine stand decline model (PSD) which describes the decline effects at different deposition rates. The PSD model is based on field observations at a set of test sites along a deposition gradient, gas chamber experiments, chemical analyses of needles, soil, and bark, and established pine yield table equations for forest production. The driving forces of the model are time series on SO_2 and NO_x concentrations. The PSD model calculates various time series – e.g., loss of foliage (foliage index), stem wood and needle growth rates, mortality rate, stand density, and the probability of a stand being fully productive and alive. These calculations are carried out for different age classes of the stand, for different site classes, for different classes of alkalinity, and for different trophic levels of the sites.

The model accounts for both direct and indirect ways that sulfur and nitrogen components are accumulated. The main PSD modules controlling the dynamics of the state variables, or algorithmic component (ALG), are:

ALG 1: Air and soil pathways response.
ALG 2: Maximal dose compensation rate for test sites.
ALG 3: Foliage index at test sites.
ALG 4: Compensation rate function.

ALG 5: Maximal dose compensation rate.
ALG 6: Foliage index at non-test sites.
ALG 7: Reduction in stem volume growth rate.
ALG 8: Increase in stem volume growth rate.
ALG 9: Stem volume growth rate – long-term adaptation of parameters.
ALG 10: Stem volume mortality rate.
ALG 11: Recommended harvesting rate.
ALG 12: Stand density.

The PSD model also calculates other effect parameters. Examples of these parameters are:

- Needle growth rate.
- Breast height diameter of harvested and standing volume.
- Height of harvested and standing volume.
- Point in time when productivity losses occur (abnormal growth rate in comparison with yield tables).
- Point in time when collapse of the stand occurs.
- Probability of a stand being fully productive.
- Probability of a stand being alive.

As indicated above, the entire PSD model is described by Bellmann and Lasch (1988a). The objective of this Appendix is to give an overview of the foliage decline module of the PSD model. The description deals with the structure of the module and numerical data for parameter estimation of the foliage decline module, i.e., it deals with the algorithmic components ALG 1 to ALG 6. For discussions on the modifications of functions for the growth rate of stem wood and the mortality rate depending on the foliage index, i.e., algorithmic components ALG 7 to ALG 10, see Bellmann and Lasch (1988a).

The basic approach to modeling the loss of foliage caused by air pollutants is an expansion of a well-known dose response concept described and applied by Mäkelä (1985) and Mäkelä *et al.* (1987) for spruce decline. They report on different stand responses under specific site and emission characteristics. In comparison with this approach the PSD module also considers different dose compensation capabilities at different sites.

The cumulative dose response concept for SO_2 spruce-decline risk calculations according to Mäkelä (1985) and Mäkelä *et al.* (1987) is a static approach for forecasting the stand collapse points mainly dependent on cumulated dose, altitude, and temperature. Our objective was to generate a more dynamic response concept concerning air pollutants and loss of foliage.

A.2 Characteristics of Experimental Field Sites

The parameter estimations for the foliage decline algorithm are based on data from a set of test sites along an SO_2 concentration gradient. The foliage index has been measured at each test site together with deposition mixtures (relations between cations and other ions determined by bark analysis) and with sulfur and nitrogen depositions.

The location of the experimental fields are presented in *Figure A.1*. The test sites DH, PIE, and URW represent high SO_2 concentration areas and also represent a more extreme gradient. The sites TH, ST, and NA represent medium SO_2 concentration areas. The PL and NE sites represent low SO_2 concentration areas and are one gradient more extreme in the opposite direction (see parameter SI in *Table A.1a*).

For each site five plots, each with 25 trees, have been analyzed. These trees were also used for bark analysis. The experimental field sites were established in 1962 and have been consistently observed over time. *Tables A.1a* through *A.1c* describe the aggregated values for each site (average of five plots).

Tables A.1a and *A.1b* describe the conditions in 1984, as an average for the years 1983–1985 if no other information is added to the tables. *Table A.1c* describes the concentrations accumulated for the period from 1965 to 1984.

In *Table A.1* values for a site called *worst case* are also given. This worst site requires further explanation. For a given region under investigation a worst case test site (WTS) must be identified. The WTS represents the most damaged site within the region studied and is a reference site for which the following characteristics should be valid:

- Maximum air pollution concentration and depositions (SI^{WTS}).
- Lowest foliage index (LD^{WTS}).
- Poorest soil with lowest nutrient levels (TL^{WTS}).
- No compensation through depositions of basic cations (ALK^{WTS}).

The data for the worst case test site (WTS) for this region are from one area on the Dübener Heide (DH) site and are presented in *Tables A.1a*

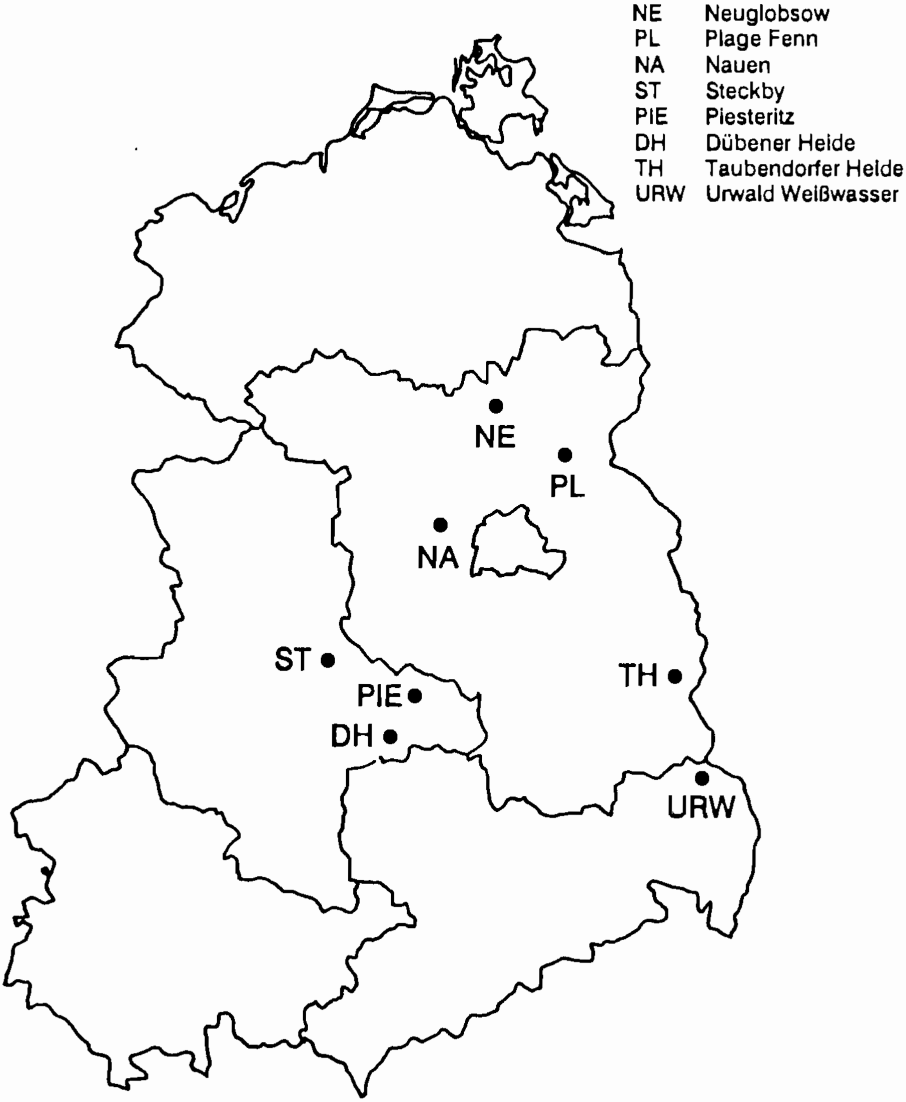


Figure A.1. Geographical location of the experimental fields. The map illustrates the eastern part of Germany.

Table A.1a. Aggregated site characteristics.

Test site	SO_2 conc. $\mu g\ m^{-3}$ SI_{84}	S dep. $g\ m^{-2}$ SD_{84}	Bark analysis$_{84}$ Ca^{2+} $mg\ g^{-1}$	Bark analysis$_{84}$ H^+ $mg\ g^{-1}$	Ca^{2+}/H^+ alkalinity ALK_{84}	Ca dep. $kg\ ha^{-1}\ yr^{-1}$ CAD_{84}
Piesteritz (PIE)	230	41	1.92	21.4	0.090	90
Dübener Heide with fertilization (DH^+)	143	26	8.00	16.0	0.500	122
Dübener Heide without fertilization (DH^-)	143	26	8.00	16.0	0.500	122
Urwald Weißwasser (URW)	116	27	2.52	20.0	0.126	70
Taubendorfer Heide (TH)	72	18	2.50	15.0	0.170	76
Steckby (ST)	69	14	5.00	15.0	0.330	100
Nauen (NA)	41	9	0.90	14.0	0.060	35
Plage Fenn (PL)	24	8	0.30	16.0	0.019	35
Neuglobsow (NE)	18	6	0.24	14.0	0.017	21
Worst case (DH) 1947–1962	72 (1962)	14 (1962)	~0.10[a]	15.0[a]	~0[a]	~5[a]
Worst case (DH) 1965–1982	107 (1982)	21 (1982)	~1.00[a]	20.0[a]	~0[a]	~5[a]

[a] No observations; estimated worst case test site valuation.

Table A.1b. Aggregated site characteristics.

Test site	N dep. free area kg ha^{-1} yr^{-1} NDF_{84}	N dep. under canopy kg ha^{-1} yr^{-1} ND_{84}	N fixation rate kg ha^{-1} yr^{-1} NFR_{69-84}	N/Ca index NCI_{84}	Trophic level soil[c] TL_{87}
Piesteritz (PIE)	39	51.0	[b]	96.0	[b]
Dübener Heide					
with fertilization (DH^+)	71	77.9	53.3	138.9	8.2
Dübener Heide					
without fertilization (DH^-)	24	31.2	33.3	92.2	6.5
Urwald Weißwasser (URW)	22	28.6	30.0	63.6	4.1
Taubendorfer Heide (TH)	22	28.6	20.0	66.6	3.2
Steckby (ST)	22	28.6	43.3	78.6	7.4
Nauen (NA)	18	23.4	8.0	40.9	4.4
Plage Fenn (PL)	22	28.6	20.0	46.1	6.0
Neuglobsow (NE)	18	23.4	13.0	33.9	3.2
Worst case (DH) 1947–1962	~1 (1962)[a]	~1.3[a]	[b]	2.5[a]	1.0[a]
Worst case (DH) 1965–1982	~2 (1982)[a]	~3.0[a]	[b]	2.6[a]	1.5[a]

[a]Estimated values.
[b]No observations.
[c]$0 \leq TL \leq 10$ (0 = poor; 10 = rich).

Table A.1c. Aggregated site characteristics: foliage index and dose compensation rate.

Test site	Foliage index LD_{84}	Cumulated dose $\mu g\ SO_2\ m^{-3}$ KI_{65-84}	Compensated cumulated dose $\mu g\ SO_2\ m^{-3}$ KKI_{65-84}	Active cumulated dose $\mu g\ SO_2\ m^{-3}$ AKI_{65-84}	Maximal compensation rate: $KRMAX_{84}$ (abs.)	Maximal compensation rate: RKR_{84} (rel.)
Piesteritz (PIE)	3.2	3910	2945	969	155	0.67
Dübener Heide with fertilization (DH^+)	4.9	1949	1539	410	81	0.57
Dübener Heide without fertilization (DH^-)	3.0	1949	1045	907	55	0.38
Urwald Weißwasser (URW)	6.8	969	969	0	51	0.44
Taubendorfer Heide (TH)	6.2	880	741	139	39	0.54
Steckby (ST)	6.1	909	741	168	39	0.56
Nauen (NA)	5.9	533	285	248	15	0.37
Plage Fenn (PL)	5.9	353	89	264	5	0.20
Neuglobsow (NE)	6.3	249	84	165	4	0.24
Worst case (DH) 1947–1962	2.5 (1962)	976	0	976	0	0
Worst case (DH) 1965–1982	0.4 (1982)	1672	0	1672	0	0

through *A.1c* (the last two rows). The objective of studying the worst case test site is to obtain data for calibration of the data from the test sites. The WTS data must cover a longer time period. In this case, the WTS data cover a first series for the period 1947 to 1962 and a second series for the period from 1965 to 1982.

A special characteristic of the sites is the alkalinity content of the pollutant mixture of the depositions. The alkalinity (expressed by the coefficient ALK = Ca^{2+}/H^{+}) varies from 0.5 at high SO_2 concentrations (site DII) to 0.017 at the low concentration sites (NE). The variation of the Ca depositions follows the same pattern as for alkalinity. The Ca^{2+} and H^{+} values are concentrations measured by bark analysis.

In general, the concentration of Ca^{2+} increases with increasing SO_2 concentrations. The explanation for this relation is that the SO_2 emitters have not been equipped with efficient dust filters. The concentration of H^{+} in the bark follows this pattern to a limited extent. Thus, there is no strong correlation between the concentrations of H^{+} and Ca^{2+} in the bark. These conclusions are based on information presented in *Figures A.2* and *A.3*. Based on this information, it can be concluded that alkalinity mainly depends on the Ca^{2+} (see *Figures A.4*, *A.5*, and *A.6*).

In spite of high SO_2 concentrations up to 1984, a rather limited pH decrease has been observed in the soil. This explains the relatively low foliage decline observed, despite the high deposition sulfur and high SO_2 concentrations. Thus, the emission of dust (Ca) has had a buffering impact on the SO_2 concentrations.

In *Table A.1b* an overview is given of N deposition [deposition on the free area (NDF) and deposition under a canopy (ND)]. The cumulative fixation of N in the upper soil layer (NFR) during a 15-year period (1969 to 1984) is also presented in *Table A.1b.* The N fixation rate (NFR) is the result of N and Ca input to the humus horizon. The Ca/N relation and the N depositions were observed in 1969 and 1984 at each test site. The changes during this period in the parameters were used for the NFR calculations. The N deposition under a canopy and the soil N fixation rate for the sites are illustrated in *Figure A.7*. The relation between the N fixation rate and the N/Ca index (NCI) is presented in *Table A.1b* and illustrated in *Figure A.8*. NCI has proved to be an important indicator for the N accumulation in the soils in the test sites. NCI is defined

$$NCI = N + 0.5Ca\ (kg\ ha^{-1}\ yr^{-1})\ .$$

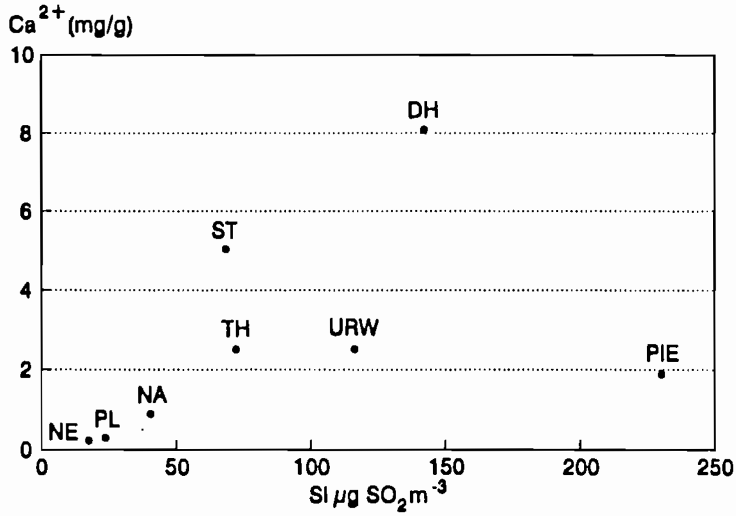


Figure A.2. Bark analysis data: Ca^{2+} (1984).

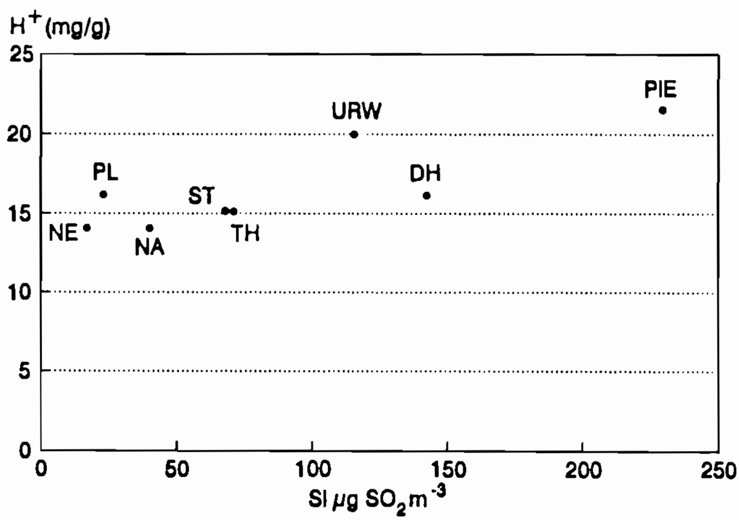


Figure A.3. Bark analysis data: H^+ (1984).

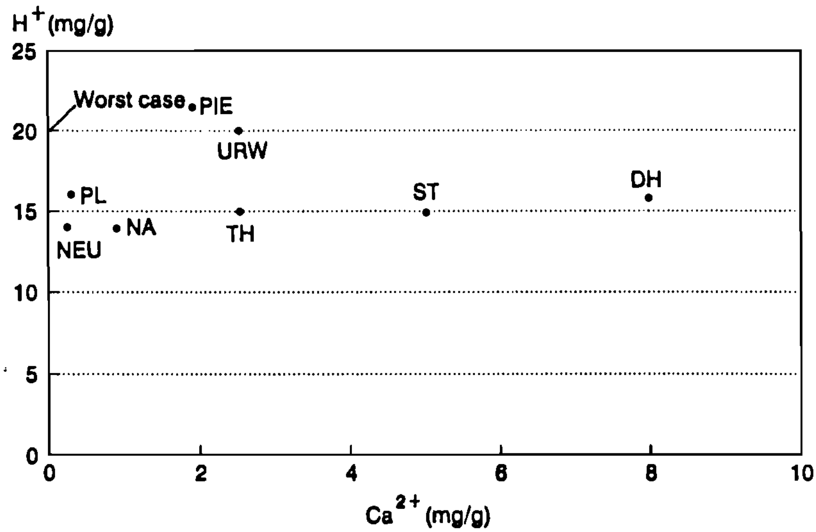


Figure A.4. Bark analysis data: H^+/Ca^{2+} (1984).

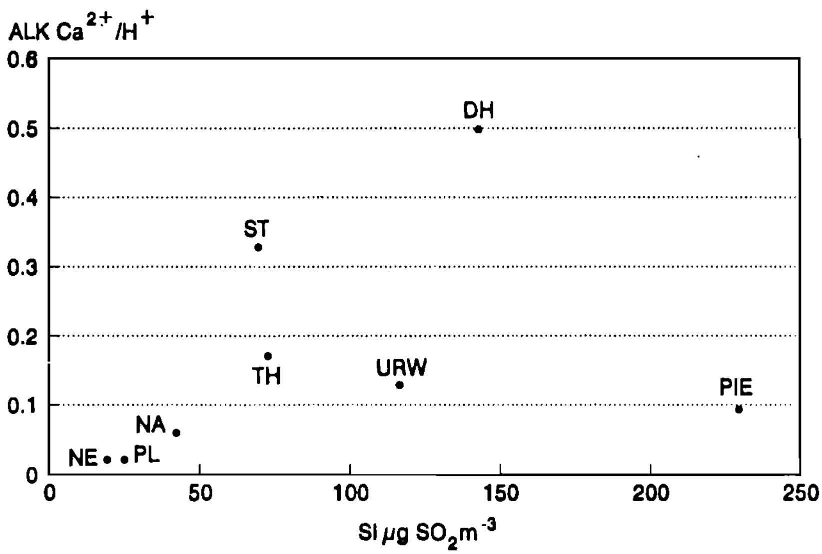


Figure A.5. Bark analysis data: alkalinity of emission (1984).

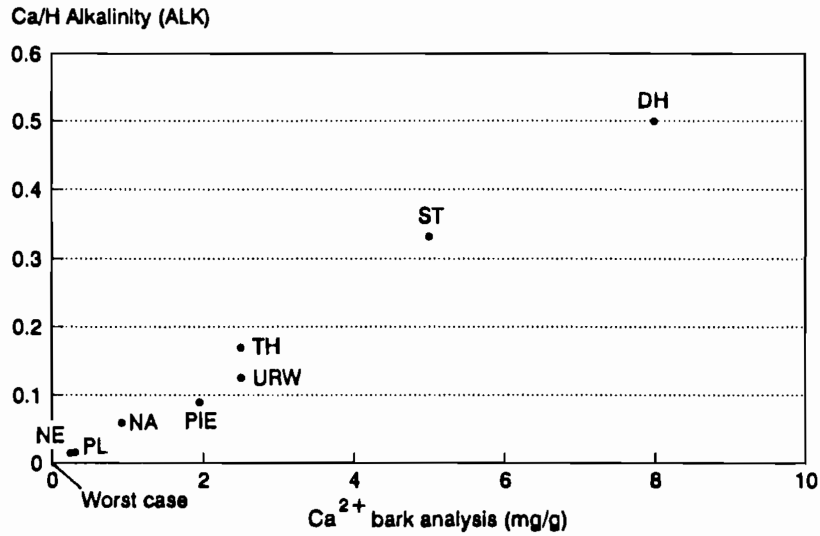


Figure A.6. Bark analysis data: alkalinity (ALK) depending on Ca^{2+} (1984).

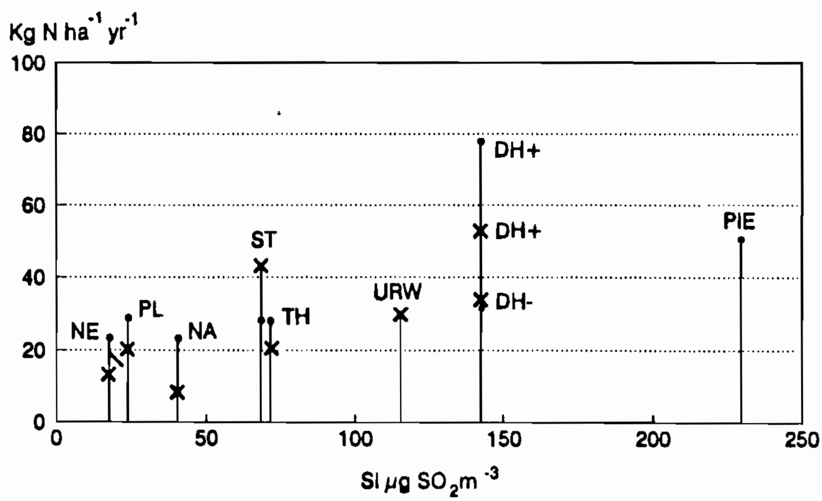


Figure A.7. Test site analysis: N deposition under canopy and soil N fixation rate: –•–, N deposition in 1984 under canopy; –*–, changes in the N fixation rate during the period from 1969 to 1984 in the top soil layer.

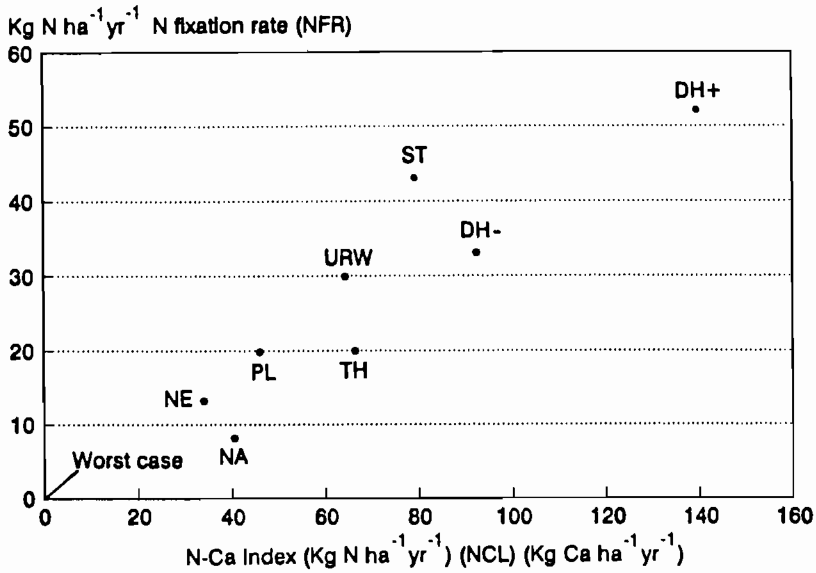


Figure A.8. N fixation rate (NFR) depending on the N/Ca index (NCI) (1969 to 1984).

In *Table A.1b*, the last column indicates the nutrient level of the soils (trophic level, TL). TL is calculated on the base of the soil nutrient ions and cations of the test sites (0<TL <10; 0 = poor, 10 = rich). The TL parameters have a wide range on the actual test sites (3.2–8.2).

In the first column of *Table A.1c* an average for the foliage index (LD) for the years 1983 to 1985 (LD_{84}) is presented. The foliage index is defined from 0 to 7. A foliage index equal to 7 indicates a complete and undisturbed set of 3.5 needle age classes.

The basic data used for calculating the site compensation rate KRMAX (*Table A.1c*) and the observed foliage index (LD) have been collected by various research institutes in Germany – the Forestry Biomonitoring Programme performed by the Forest Management Agency (Potsdam); the Centre of Environmental Management, Division Wittenberg; the Institute of Forest Sciences (Eberswalde); and the Institute for Landscape Research and Nature Conservation, Halle.

A.3 The Dose Response Concept: The Decline Functions

In general, dose response relations are employed to describe the way in which organisms respond to substances applied to them. The response may be a change in metabolism, sickness, a change in psychological behavior, mortality, and so on. For these approaches the responses of the system under study is dependent upon exposure time and the characteristics of the system. In addition, other substances applied simultaneously are of great importance for the responses.

Important lessons concerning a cumulative dose response approach can be learned from cancer epidemiology. Becker (1989a and 1989b) has introduced a "system specific resistance component" (cellular repair mechanisms or immune response) in studying cancer epidemiology. This component describes the filter effect of the applied dose. The system's response only corresponds fully with the applied cumulated dose if there is no resistance. This means that the decline process is not reduced when the system lacks compensatory capabilities. This aggregated approach has proved to be fruitful in cases where detailed knowledge about the causal dependencies concerning dose responses is limited (Becker, 1989a and 1989b).

In 1987, a similar cumulative dose response concept was developed concerning air pollution and foliage loss dynamics. It was implemented in the PSD model and described by Bellmann and Lasch (1988a) and Bellmann *et al.* (1988).

As illustrated in *Figure A.9*, there seems to be no direct relation between foliage decline (LD) and SO_2 concentrations up to a dose of about 100 μg SO_2 m^{-3}. It can therefore be concluded that the ecosystems have a compensation capability for the SO_2 dose.

We have also built into our approach some site characteristics (like deposition mixtures, soil nutrient levels, and observed air concentration and deposition time series) concerning air pollution and foliage decline dynamics; this was necessary to improve the description of the dynamic process. This approach is compulsory to characterize site dependent dose compensation capabilities.

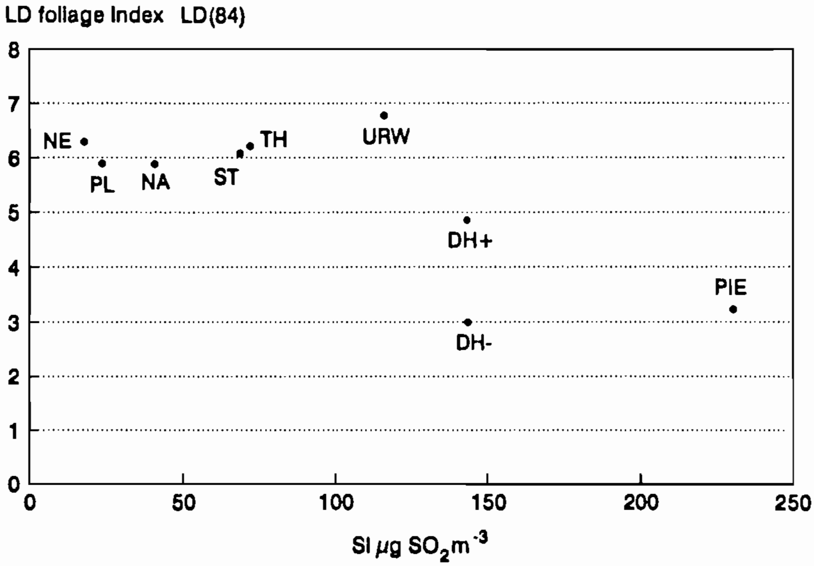


Figure A.9. Test analysis: foliage index (LD) depending on the current SO_2 concentrations (SI).

A.3.1 Basic assumptions on the dose response model concept concerning air pollution and foliage decline

The following assumptions were considered for the development of the dose response model concept concerning foliage decline and air pollutants in the PSD model:

- The observed needle loss (LD, foliage index) is caused by a direct impact process (air pathway) as a steady state/noncumulative process or an indirect impact process (soil pathway) as a cumulative process.
- The foliage decline caused via the soil pathway is a result of a cumulative and filtered dose of air-pollution concentrations. The filtered size of the dose depends on the stand's capability to resist the actual doses. The degree of this dose compensation capability depends on factors like site characteristics, mixture of pollutants, soil nutrient level, and water supply.
- In the region studied (the test sites presented in *Figure A.1* and *Tables A.1a* through *A.1c*), the foliage decline is mainly caused by sulfur (the so-called classic decline) in combination with overfertilization of nitrogen. The ozone concentrations are moderate and homogeneous in the region.

- The dose response is further increased by water stress and extreme temperatures.

The overall scheme of the dose response calculation concerning the foliage decline in the PSD model is illustrated in *Figure A.10*.

Before discussing the dose response calculations presented in *Figure A.10*, we would like to introduce the definitions of some key parameters and variables:

LD^{max}	=	The unreduced foliage index for the region, site, or stand – $LD^{max} = 7$, i.e., $0<LD<7$.
LD(t)	=	The total foliage index at year t.
DLDL(t)	=	The foliage index loss attributable to the air pathway at year t.
DLDB(t)	=	The cumulated foliage index loss owing to the soil pathway up to year t.
LDB(t)	=	The resulting foliage index after deduction of the cumulated foliage loss caused by soil pathway up to year t.
AKI(t)	=	Cumulated part of total dose which leads to needle loss at year t. This can also be termed the active cumulated dose.
KKI(t)	=	Cumulated nonactive (compensated) part of the dose which does not lead to any needle loss up to year t.
KRMAX	=	Annual maximal dose compensation capability calculated according to retrospective analyses, based on KKI.
FKR	=	A shifter (constant) for decreasing annual dose compensation capability due to a decreased foliage index [LD(t – 1)].

The dynamics of the foliage index, LD(t), is assumed to follow the following formulas:

LD(t)	=	LD^{max} – DLDB(t) – DLDL(t), which means
LD(t)	=	LDB(t) – DLDL(t), where
LDB(t)	=	7 – DLDB(t), where
DLDB(t)	=	$b_B \times$ AKI(t), where
AKI(t)	=	AKI(t-1) + DAI(t), where
DAI(t)	=	active dose at year t, so
DAI(t)	=	SI(t) – DKI(t), where
SI(t)	=	total dose at year t, and
DKI(t)	=	nonactive (compensated) dose at year t.

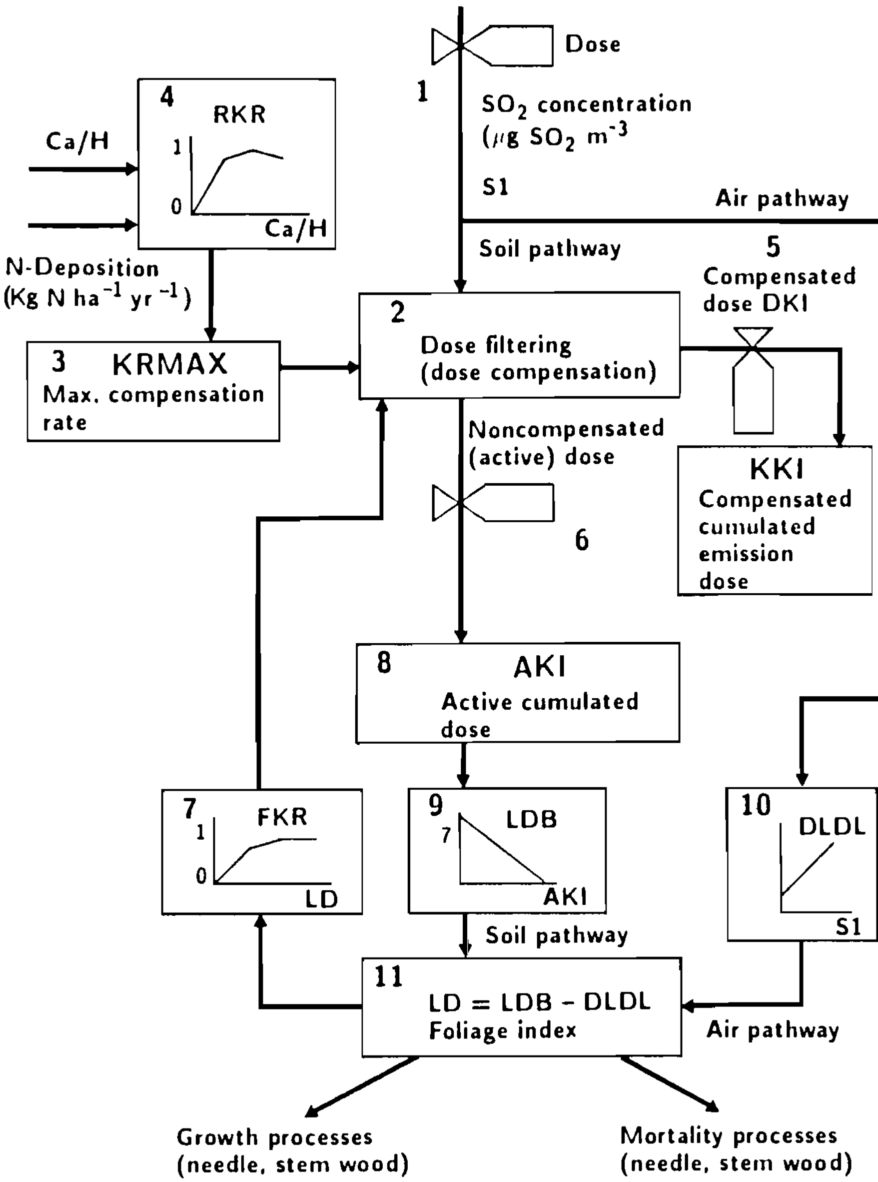


Figure A.10. The dose response calculation scheme for foliage decline in the PSD model.

A.3.2 Foliage decline caused by direct impacts: The air pathway

A linear relationship between air pathway decline and the SO_2 dose (SO_2 concentration) is calculated according to the following formula (see box 10 in *Figure A.10*):

$$\mathrm{DLDL} = \mathrm{b_L} \times \mathrm{SI} ,$$

where DLDL is the foliage index decline caused through the air pathway, SI is the total SO_2 concentration in μg per cubic meter, and b_L is the regression coefficient for the air pathway decline.

The estimation of the coefficient b_L is based on three years of gas chamber investigations by Schulz (1986). The investigations were carried out with depositions of 800 μg SO_2 m^{-3} on three age classes of needles. The mean needle percentage was analyzed by age class: age class 1, 90 percent; age class 2, 55 percent; and age class 3, 0 percent. The total needle content for all three age classes of needles amounted to a total of 145 percent, which corresponds to a foliage index (LD) of 4. Thus, the estimated foliage index loss through air pathway (DLDL) is equal to 3. Therefore, the regression coefficient b_L of 0.0037 has been used in most analyses with the PSD model concerning foliage decline as a result of the air pathway. We have, in some cases, worked with nonlinear relations, although these are not presented here.

A.3.3 Foliage decline caused by indirect impacts: The soil pathway

Following the dose compensation concept, the indirect impact dose is considered to be divided into two parts – one active and one nonactive (compensated) – according to the following formula:

$$\mathrm{SI}(t) = \mathrm{DAI}(t) + \mathrm{DKI}(t) ,$$

where SI(t) is total SO_2 concentration dose at year t, DAI(t) is the active dose portion causing foliage decline at year t, and DKI(t) is the compensated dose portion causing no foliage decline at year t.

Both DAI(t) and DKI(t) are cumulating variables, leading to the variables AKI(t) and KKI(t), respectively (see 5, 6, 8, and 9 in *Figure A.10*). KI(t) is calculated according to the following equation:

$$\mathrm{KI}(t) = \mathrm{AKI}(t) + \mathrm{KKI}(t) ,$$

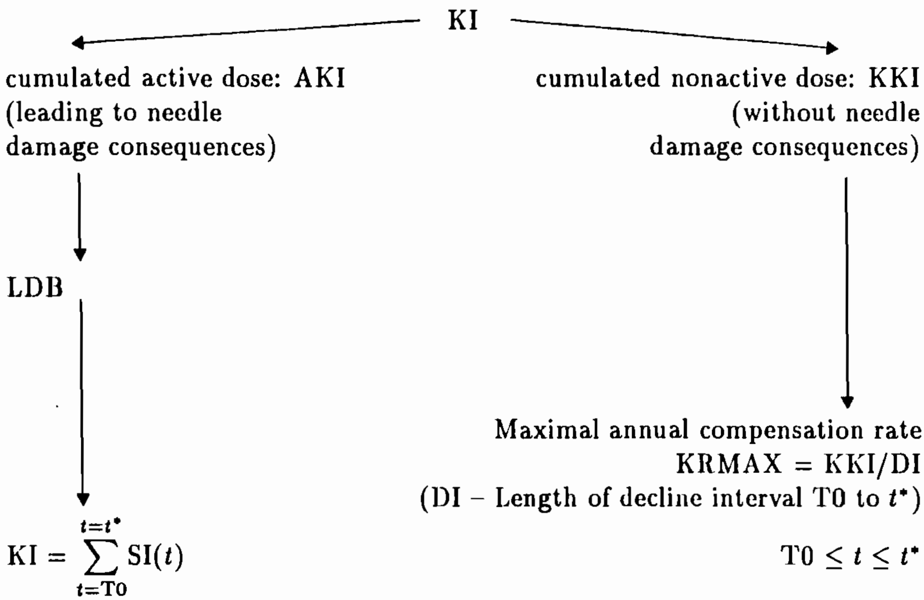


Figure A.11. Breakdown of the total cumulated dose, KI.

where KI(t) is total cumulated dose of SO_2 at year t, AKI(t) is cumulated part of the total dose leading to needle loss up to year t (active dose), and KKI(t) is cumulated part of the total dose up to year t which does *not* lead to any needle loss (nonactive dose).

Analyses of actual SO_2 concentrations (dose) time series at a given test site during an observed decline interval (DI) and analyses of the foliage loss during this period constitute the basis for the calculation of the maximal dose compensation rate (KRMAX) on the actual site.

The breakdown of the cumulated total dose, KI(t^*), during the decline interval, DI = [T0,t^*], into one active part, AKI, and one nonactive part, KKI, is illustrated in *Figure A.11*.

T0 is the point in time when the first irreversible needle losses (decline of foliage index) are observed, and t^* is the end point of the time period studied. For the analyses T0 is the year 1965 and t^* is the year 1984. For the worst test site (WTS) analyses for the first time period, T0 is the year 1947 and t^* is the year 1962.

The time series on concentrations (SI) and accumulations are based on observations from the test sites backed up and calibrated by historical statistical data on industrial development and energy production in the region studied.

As discussed earlier, KKI(t^*) is a measure for the cumulated compensation capability of a specific site during the decline period T0 to t^*, which does not cause any foliage decline.

The mean annual compensated dose rate (MKR) is defined according to:

$$\text{MKR} = \text{KKI}(t^*)/\text{DI} \ ,$$

where DI is T0 − t^*.

The compensation rate, estimated with the help of the time series, is a maximal rate. A reduction of the compensation capability takes place with decreasing stand vitality (declining foliage index, loss of needles). This is in line with findings by Ulrich (1989) and Ulrich and Pankrath (1983). These findings emphasize that the buffer quota of protons vary with the vitality of the tree. For this reason the mean annual compensated dose (MKR) is not always equal to the maximal compensation capability (KRMAX). To obtain a correct estimate on absolute KRMAX, a correction of MKR is needed according to the following:

$$\text{KRMAX} = \text{MKR}/\text{FKR} \ ,$$

where FKR is an empirical function derived from field observations from the sites (discussed later in Section A.4 and illustrated in *Figure A.17*). The relative compensation rate RKR(t^*) is defined as the following:

$$\text{RKR}(t^*) = \text{KRMAX}(t^*)/\text{SI}(t^*) \ ,$$

where KRMAX(t^*) is calculated from the interval (T0, t^*) and SI(t^*) is the SO_2 concentration in the year t^*. RKR depends on the alkalinity of the pollutant mixture and the nutrient level of the site. These conditions change over time. Therefore, taking into account possible differences between observed decline data and parallel model calculations, RKR must be corrected approximately every five years. This correction can be carried out by using the relation given later in *Figure A.14* or by repeating the KRMAX calculations according to the steps presented in *Table A.2*.

In *Figure A.12* the needle losses (foliage index) from the soil pathway in 1984 [LDB(84)] for the nine sites are plotted against the total cumulated dose [KI(84)]. In *Figure A.12*, it can be seen that some sites (e.g., PIE, DH^+,

Table A.2. Steps for calculating absolute KRMAX for each test site.

Step (1)	Cumulated dose: $KI = \sum_{t=T0}^{t=t^*} SI(t)$; T0 = 1965, t^* = 1984 T0 = time point of first irreversible foliage losses. t^* = time point of present foliage index observation, $LD(t^*)$.
Step (2)	Active cumulated dose: $AKI = [7 - LDB(t^*)]/b_B^{TS}$ following $LDB(t^*) = 7 - b_B^{TS} \times AKI$ (see *Figure A.12*) $b_B^{TS} = 0.003827$.
Step (3)	Following the additive concept introduced for direct and indirect damage pathways, then $LD(t^*) = LDB(t^*) - DLDL(t^*)$ and $LDB(t^*) = LD(t^*) + DLDL(t^*)$ $DLDL(t^*) = b_L^{TS} \times SI(t^*)$; $b_L^{TS} = 0.0037$.
Step (4)	Compensated cumulated dose – nonactive part. $KKI(t^*) = KI(t^*) - AKI(t^*)$
Step (5)	Maximal compensation rate: KRMAX = MKR/FKR FKR (LD) – see 7 in *Figure A.10* and *Figure A.17* $FKR = \begin{cases} 1, LD \geq 4 \\ 0 \leq FKR < 1 \end{cases}$ see *Figure A.17* $0 \leq \quad KR \leq 7$, otherwise $(LD) = (7 + LD)/2$ MKR = KKI/DI $DI = T0 - t^*$ (decline interval).
Step (6)	Relative compensation rate: RKR = KRMAX/SI.

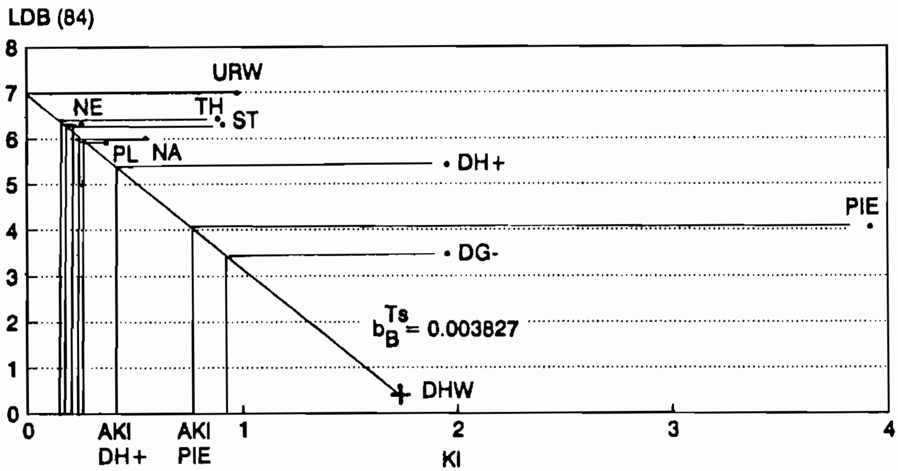


Figure A.12. Test site dose response analysis: observed LDB (84) for the test sites and calculation.

DH⁻), in spite of a high cumulated dose (KI), have had only moderate foliage decline. The lengths of the horizontal lines between the plotted LDB(84) and plotted KI(84) and the resulting value of the linearly decreasing function with the coefficient b_B^{TS} illustrate the nonactive part [KKI(84)] of the cumulated dose KI(84) for the period from 1965 to 1984 (TS is used as an index for test site).

Thus, the length of the horizontal lines gives an estimate for the compensation capability during the decline period studied. The vertical lines in *Figure A.12* illustrate the corresponding cumulated active part of the dose for the specific sites that cause foliage decline [AKI(84)]. The numerical values for the sites are given in *Table A.1c*.

The Worst Case Analysis

As discussed earlier, for each region studied a worst case test site (WTS) must be defined. The WTS represents the most damaged site within the region and is a reference site with the following characteristics:

- Having a maximum load of SO_2 concentrations and S depositions (SI^{WTS}).
- Having the lowest foliage index, heaviest loss of needles (LD^{WTS}).

- Having the poorest soil conditions with the lowest nutrient level (TL^{WTS}).
- Having no or a low compensating capability of basic cations (ALK^{WTS}).

Under such conditions, the total cumulated dose (KI^{WTS}) is equal to the active part of the cumulated dose (AKI^{WTS}). This implies that the nonactive accumulated dose (KKI^{WTS}) and the maximal compensation rate (KRMAX) are zero.

In this case, the worst case site data are from Dübener Heide (DH) (*Tables A.1a* through *A.1c*). The decline interval covers the period 1947 (T0) to 1962 (t^*) with the following foliage indices: LD(T0) = 7 and LD(t^*) = 2.50. The foliage index was calculated on measurements from 2,272 trees from 20 plots (Lux, 1965). The cumulated total dose [KI(62)] for the period studied was 976 $\mu g\ SO_2\ m^{-3}$.

The decline in the foliage index is estimated to follow a linear function between increasing cumulated AKI (active dose) and a decrease in the foliage index (LDB) according to the regression

$$\mathrm{LDB} = 7 - b_B^{WTS} \times \mathrm{AKI}\ ,$$

where LDB is the foliage index caused by the soil pathway.

The estimate of the coefficient b_B^{WTS} is given by the expression:

$$b_B^{WTS} = [\mathrm{LD}^{max} - \mathrm{LDB}(t^*)]/\mathrm{KI}(t^*)\ ,$$

which gives

$$0.004314 = (7 - 2.79)/976\ ,$$

where

$$\mathrm{LDB}(t^*) = \mathrm{LD}(t^*) + \mathrm{DLDL}(t^*) : t^* = 1962\ ,$$

with

$$2.79 = 2.50 + 0.29\ ,$$

0.29 refers to losses through air pathway. The calculation is illustrated in *Figure A.13*.

In cases with high compensation rates (high nonactive parts of the dose), the accumulated active part of the dose will grow slowly and the foliage index will decrease slowly. Thus, the annual decline steps are small.

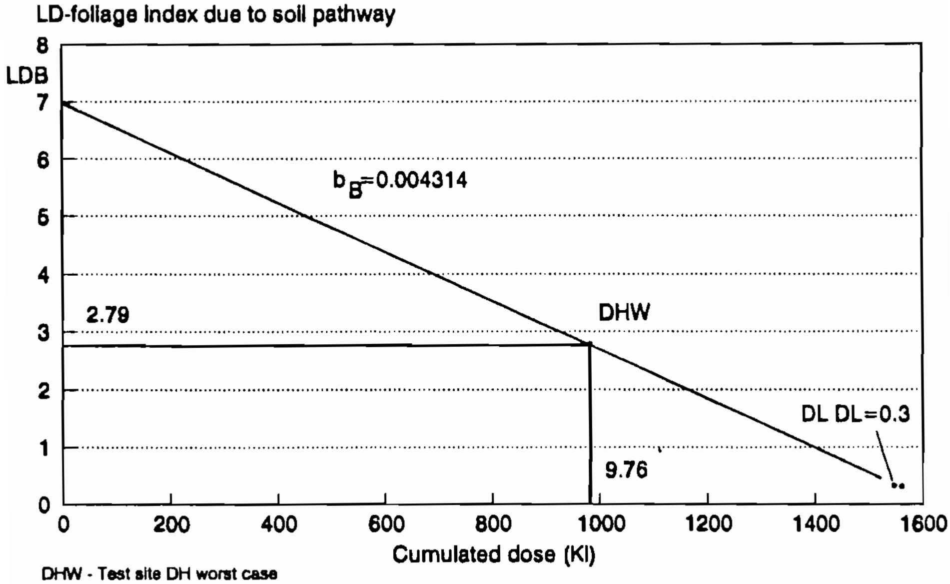


Figure A.13. Worst case analysis: LD foliage index due to soil pathway (LDB), depending on the cumulated dose.

The worst case analyses were also carried out for the period 1965 to 1982. In this case the following regression was achieved:

$$b_B^{WTS} = (7 - 0.6)/1672 = 0.003827 .$$

This worst case value for 1982 [$LD^{WTS}(1982)$] is regarded to reflect the trends observed in data concerning missing compensation effect of Ca and N depositions in an efficient way.

In *Figure A.12*, the foliage indices caused by the active part of the cumulated dose (LDB) are plotted over the total cumulated dose (KI) for the 12 test sites during the period 1965 to 1984. As discussed earlier the foliage indices have been calculated according the following formula:

$$LDB(t^*) = 7 - b_B^{WTS} \times AKI(t^*) .$$

The cumulated part of the dose which causes foliage decline [$AKI(t^*)$] is calculated for each specific site according to the formula:

$$AKI(t^*) = [7 - LDB(t^*)]/b_B^{TS} .$$

By following the steps listed in *Table A.2*, the absolute KRMAX and the relative KRMAX were calculated for each test site. The results are presented in *Table A.1c*.

Correction of the Compensation Rate

In *Figures A.14, A.15*, and *A.16* the relative compensation rates (RKR) are plotted over the alkalinity coefficient (ALK), the N/Ca index (NCI), and the N fixation rate (NFR), respectively. From *Figure A.14*, it can be seen that the relative compensation rate depends on the concentration of alkalinity and N deposition (see sites PIE and DII^+ in *Figure A.14*; site DII^+ has been fertilized with extra N). In the case of low NCIs (0 to 60 in *Figure A.15*), intermediate relative compensation rates (RKR) were found. High RKRs were found in situations with high NCIs (60 to 160 in *Figure A.15*). A similar dependence on the relative compensation rate can be identified for the N fixation rate (see *Figure A.16*).

From other field observations and experiments on the nitrogen cycle (see Heinsdorf, 1978 and 1988; Hofmann *et al.*, 1990) it can be concluded that an increase in increment can be expected as long as the nitrogen depositions do not exceed the optimal N content of the needles (1.8 to 2.0 percent N of dry weight). Based on these observations it can be concluded that the compensation effects of Ca and N depositions shown in *Figures A.14, A.15*, and *A.16* only hold in the case with nonoptimal N levels in the soil and the needles.

A.4 Summing up the Foliage Decline Calculations (LD Foliage Index)

The annual increment of stem wood, the needle growth, and mortality rates in the pine stand decline (PSD) model depend on the development of the foliage index and whether or not the stand is fertilized with nitrogen. These functions are based on comprehensive field experiments with sample plots of different age, site index, and stand density. These functions are described by Bellmann and Lasch (1988a). The objective of this section is to explain the foliage index calculations. *Figure A.10* is used as a starting point to describe these calculations beginning at $t_0 = t^*$.

The driving force for forest decline is the total cumulated dose of SO_2 concentrations (1 in *Figure A.10*). This total dose influences the stand in

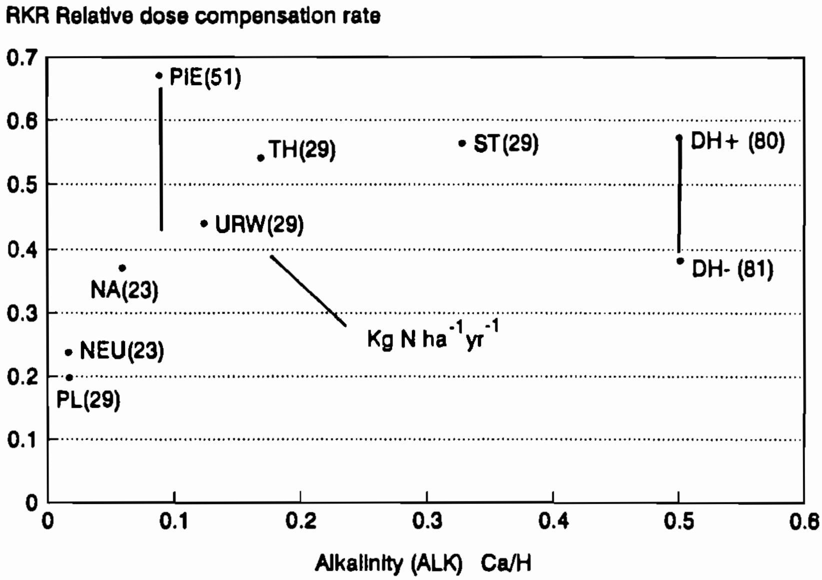


Figure A.14. Relative dose compensation rate (RKR) depending on alkalinity (ALK).

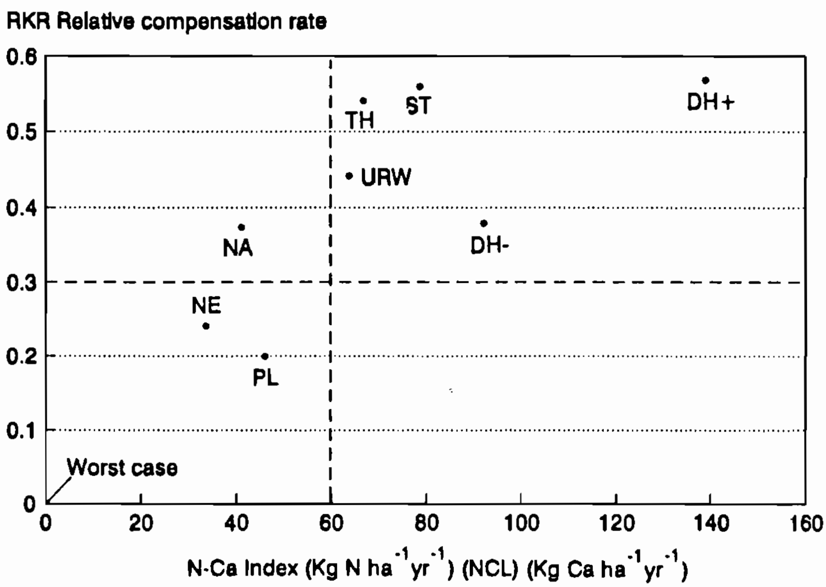


Figure A.15. Relative dose compensation rate (RKR) depending on the N/Ca index (NCI).

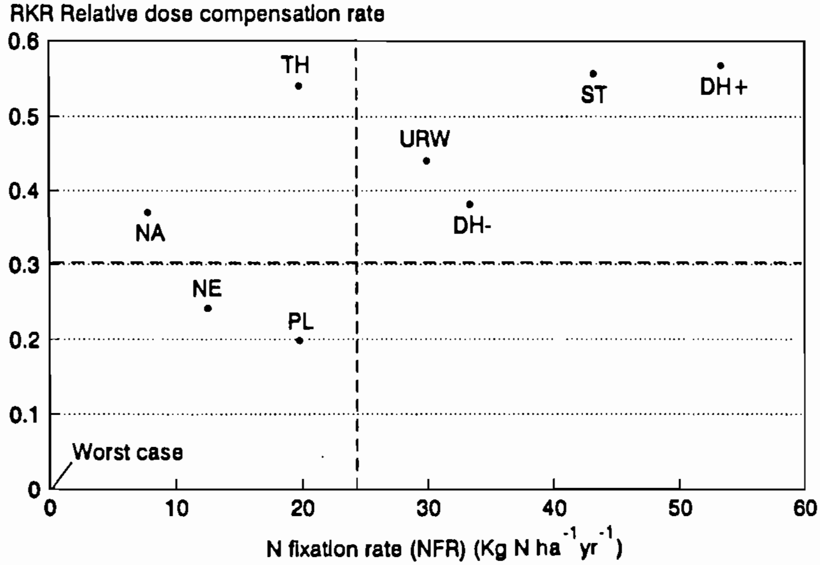


Figure A.16. Relative dose compensation rate (RKR) depending on N fixation rate (NFR).

two ways. The first is through an air pathway which has a direct impact on the trees in the stand (10 in *Figure A.10*). The foliage loss attributed to the direct impact at time t (DLDL) is calculated according to the formula:

$$\mathrm{DLDL}(t) = \mathrm{b}_{\mathrm{L}}^{\mathrm{TS}} \times \mathrm{SI}(t), \mathrm{b}_{\mathrm{L}}^{\mathrm{TS}} = 0.0037 .$$

The second way the stand is influenced by SO_2 is indirectly, through the soil pathway. The total dose SI(t) via the soil pathway is reduced by the compensated dose, i.e., that part of the dose that does not generate any decline effects. This filtering process of the soil pathway dose (2 in *Figure A.10*) is calculated according to the following:

$$\mathrm{DKI}(t) = \mathrm{KRMAX} \times \mathrm{FKR}(t) ,$$

where KRMAX = RKR × SI(t).

In this function DKI (5 in *Figure A.10*) stands for the compensated dose, which means the nonactive part of the soil pathway dose. The calculation of KRMAX (3 in *Figure A.10*) is illustrated in *Table A.2*. This is also valid for the relative compensation rate (RKR, 4 in *Figure A.10*).

Figure A.17. Nonlinear feedback function FKR for control of the dose filtering process.

The feedback function for calibration of the compensation capability due to decreased vitality (decreased foliage index, FKR, 7 in *Figure A.10*) is derived from field observations on the different sites and is presented in *Figure A.17*. The compensating capacity is decreased as vitality decreases. FN stands for a modifying function, which alters the compensation capability owing to trophic status of the soils and the number of years with N fertilization. The function FN has to be adapted for certain intervals.

The annual active dose (DAI, 6 in *Figure A.10*) is cumulated over time to AKI (8 in *Figure A.10*) according to the following calculations:

$$\begin{aligned} \mathrm{AKI}(t) &= \mathrm{AKI}(t-1) + \mathrm{DAI}(t) \\ \mathrm{DAI}(t) &= \mathrm{SI}(t) - \mathrm{DKI}(t) \ . \end{aligned}$$

The cumulated active dose controls the foliage index (influenced by the soil pathway; 9 in *Figure A.10*) according to the following:

$$\mathrm{LDB}(t) = 7 - \mathrm{b}_{\mathrm{B}}^{\mathrm{TS}} \times \mathrm{AKI}(t); \mathrm{b}_{\mathrm{B}}^{\mathrm{TS}} = 0.003827 \ .$$

The total foliage index LD (11 in *Figure A.10*) is the result of the influence of both the air pathway and the soil pathway according to:

$$\mathrm{LD}(t) = \mathrm{LDB}(t) - \mathrm{DLDL}(t) \ .$$

Table A.3. Relative foliage (FOL) in percent.

Decline class	Needle content
0	90 < FOL < 100
1	75 < FOL < 90
2	40 < FOL < 75
3	5 < FOL < 40
4	0 < FOL < 5

A.5 Uncertainty Analysis

Test studies were performed at a test site with a high concentration of SO_2 (109 μg SO_2 m^{-3}) and a high compensation rate (61 μg SO_2 m^{-3}). This dose leads to a certain decline response by the stand which was disturbed by various stochastic processes. The Monte Carlo ability of the simulation system SONCHES was used for studying the effects. The stochastic processes were applied to the input process of SO_2 (step-by-step input noise) and to the mapped internal key processes that control the decline dynamics, mainly owing to biological variability in realizing the compensating ability described by the process parameter KRMAX step by step. Three stochastic processes were considered:

- SO_2 concentration: equal distribution (E) with deviation (D) = ± 30 percent.
- SO_2 concentration: normal distribution (N) with s = ± 30 percent.
  KRMAX: normal distribution (N) with s = ± 30 percent.
- SO_2 concentration: equal distribution (E) with deviation (D) = ± 30 percent.
  KRMAX: normal distribution (N) with s = ± 30 percent.

In *Figure A.18* other results concerning the decline class (DC) are presented. The decline class dynamics were calculated with the statistical α equal to 0.1 percent confidence interval and the maxima and minima are shown in *Figure A.18*. The decline classes are defined in *Table A.3*.

It can be seen that the input noise alone (SO_2 concentration) leads to an extreme deviation from the mean of 0.5 decline class units in all decline classes. Internal process noise (biological variability), both with and without input stochastics, leads to an extreme increase of the deviation up to ± 1.5 ... ± 2.0. Thus it can be concluded that internal system noises dominate the uncertainty of the decline process. This statement can be further substantiated with the statistics presented in *Table A.4*.

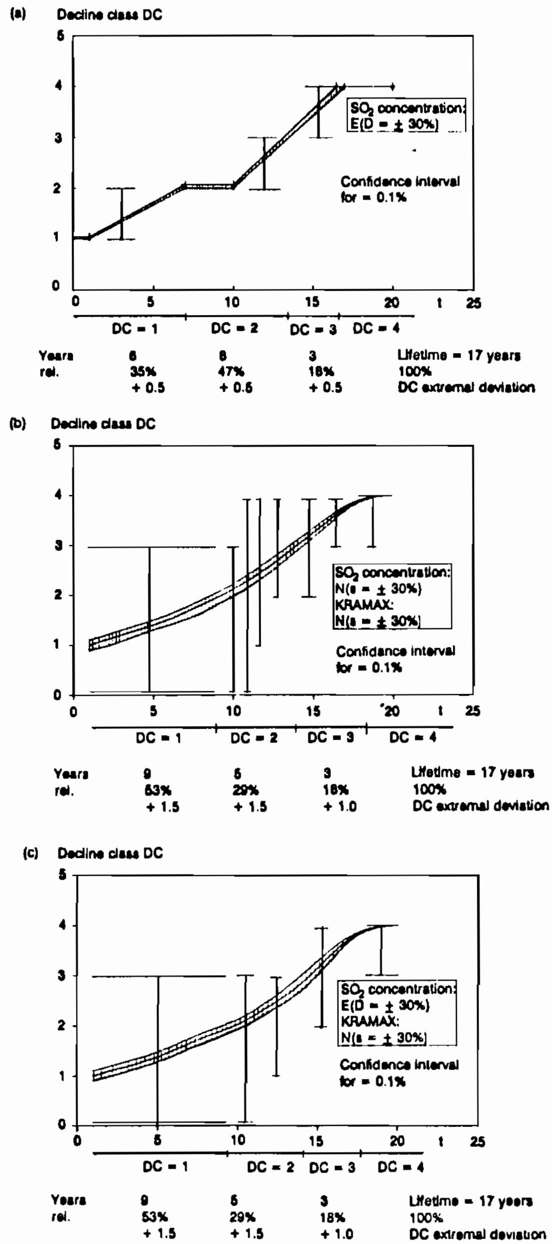


Figure A.18. Uncertainty analysis of decline classes (loss of foliage).

Table A.4. Statistical estimates for decline class (DC) for full stochastics. SO_2 concentration: equal distribution (E) with deviation (D) equal to ± 30 percent and KRMAX normal distribution (N) with s equal to ± 30 percent.

Age	Mean	$\alpha = 0.1\%$ conf. interval	s	s%	s(X)
51	0.95	0.81, 1.09	0.930	97.0	0.04150
55	1.36	1.23, 1.49	0.910	67.0	0.04060
60	2.14	2.05, 2.23	0.610	28.0	0.02720
65	3.19	3.12, 3.26	0.510	16.0	0.02270
68	3.96	3.93, 3.99	0.200	5.1	0.00892
70	4.00	3.99, 4.00	0.043	1.2	0.00192

To analyze the sensitivity of the precision of the input parameters to the precision of output, specific sensitivity analyses were carried out by the SONCHES software on the pine stand decline model. The results concerning the precision of KRMAX (compensation capability) and the full productivity age limit (AEP) are presented in *Figure A.19*. Full productivity is achieved in the 0 and 1 decline classes. The analyses show that an inaccurate estimation of the compensation rate does not seem to be too serious. The allowed interval for KRMAX is 22 percent to −30 percent. It also means that the decline estimates (foliage decline) are not extremely sensitive to the site conditions.

These sensitivity analyses have been further discussed by Bellmann and Lasch (1990).

A.6 Nitrogen Effects

A.6.1 Introduction

The basic data from the test sites used by the PSD model (see *Table A.1a* to *A.1c*) illustrate that there has been a strong accumulation effect of both sulfur and nitrogen over time on the test sites. The critical/target loads for both sulfur and nitrogen employed by the Forest Study have been reached or exceeded. This means that the decline effects calculated by the PSD model, and employed by the Forest Study, take into account the individual as well as the combined effects of sulfur and nitrogen depositions even if only the sulfur deposition has been used as the entry parameter in the calculations.

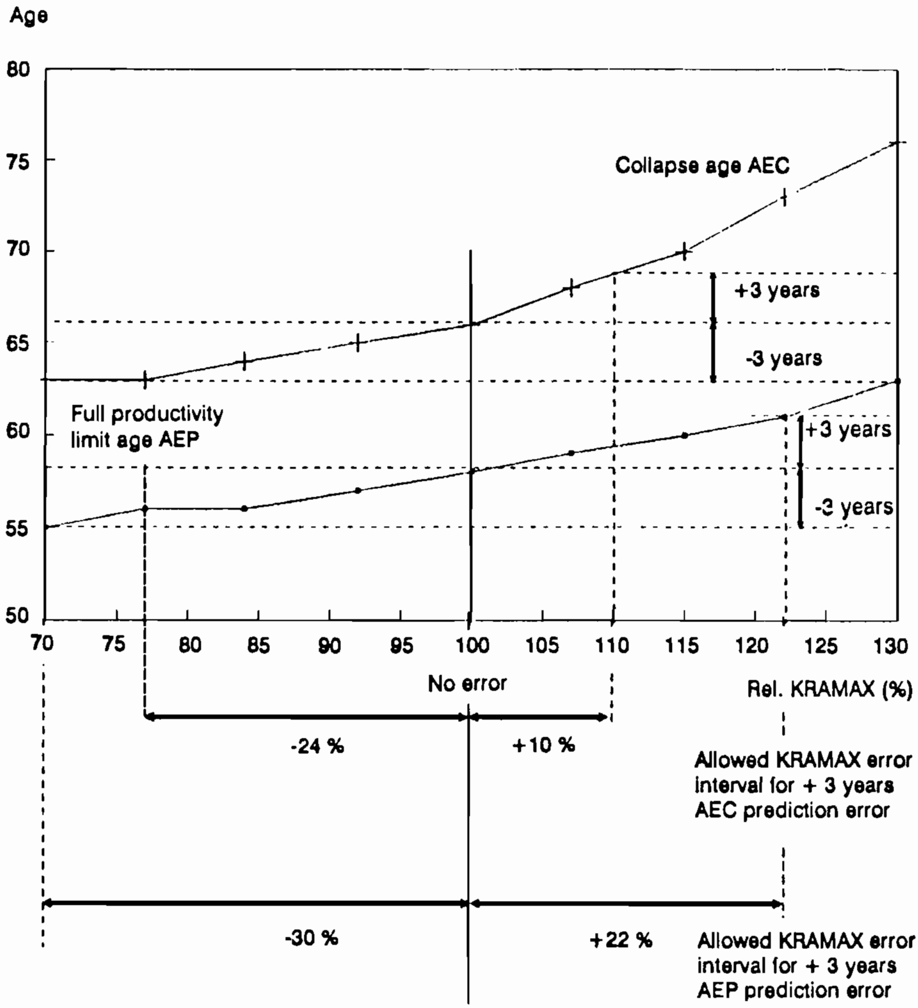


Figure A.19. Sensitivity analysis of the precision required for the compensation rate (KRMAX).

It is known that sulfur is only partially responsible for decline. Nitrogen can increase the decline process. Therefore, the PSD model has been extended to include a separate nitrogen component with the objective of illustrating how the sulfur and nitrogen pollutants act together in the decline process. The discussions in Sections A.1 through A.5 deal with what happens when the critical/target loads for both sulfur and nitrogen are exceeded without attempting to separate the effects of the individual pollutants.

The nitrogen component in the extended PSD model is based on experimental data from research carried out by the Institute of Forest Sciences, Eberswalde. Essential contributions to the model consist of results presented by Heinsdorf (1988) and Hofmann *et al.* (1990). The following description is based on research conducted by the Forest Study and the Institute for Ecosystems Research, Berlin/Halle, and the Institute of Forest Sciences, Eberswalde (Bellmann *et al.*, 1990).

It should be emphasized that the existing model approach does not distinguish between depositions of nitric oxide or ammonia, but only considers total nitrogen deposition. The results achieved should also be seen as illustrations of how sulfur and nitrogen act together in the decline process and not as general quantifications of the interactions.

A.6.2 Features of nitrogen effects

The nitrogen impact approach is based on investigations from 150 test areas in seven different regions of northeast Germany with different deposition characteristics. Additional knowledge about the effects of increased nitrogen deposition is derived from field experiments described by Heinsdorf (1988).

Since the nitrogen content of the needles reacts rapidly to changing input conditions (see Simon and Westendorff, 1988), this reaction has been used for establishing a relationship between nitrogen depositions and growth rates. The nitrogen content of the needles has been used in other studies as an indicator of changing environmental impacts on growth rate (see Tamm, 1963; Nihlgård, 1972; Melin, 1986; Schulze, 1989). The nitrogen content of the needles has also been used for identifying the different developmental stages of the stand with different depositions of nitrogen. The developmental stages identified are enrichment, saturation, and damage and dissolution. These stages are illustrated in *Figure A.20*. The mortality caused by nitrogen deposition is evident after the decline stage, and the rate of mortality depends on the load of nitrogen deposition (unpublished material by Hofmann, 1990).

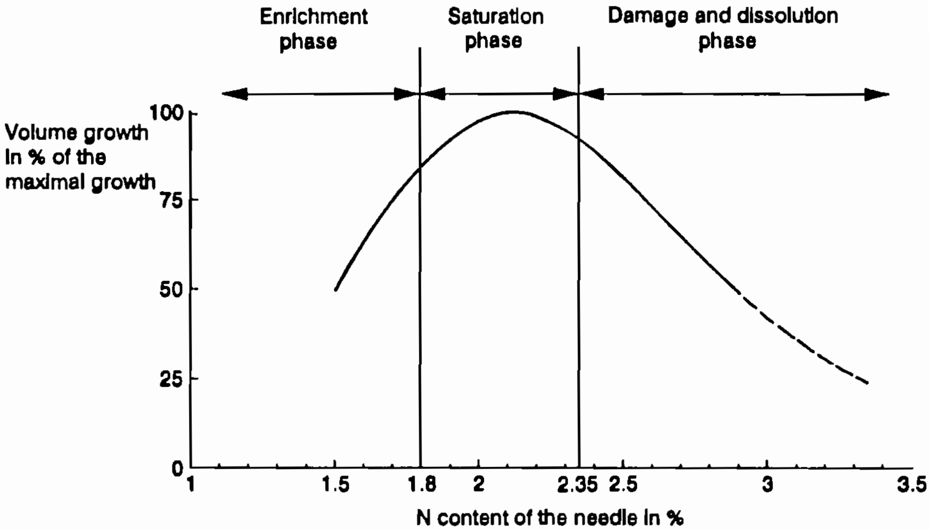


Figure A.20. Volume growth in relation to the N content of the needles. Source: Hofmann *et al.* (1990).

Two major effects of combined sulfur and nitrogen depositions (exceeding critical/target loads) can be distinguished:

(a) The nitrogen depositions compensate the individual decline effect of sulfur depositions during the enrichment and, to some extent, during the saturation stages of a stand. The fertilization by nitrogen decreases the mortality rate caused by the sulfur deposition. The reduction in the growth rate (increment) caused by the sulfur impact is compensated, to some extent, by nitrogen deposition.

The development of the growth rate (increment) for a 50-year-old stand with a medium load of SO_2 is illustrated in *Figure A.21*. Without an SO_2 load, the fertilizing effect caused by the nitrogen deposition increases the growth rate and decreases the mortality rate. This is illustrated in *Figure A.22*. The results in *Figures A.21* and *A.22* are valid for medium site classes (24 meters high and 100 years old). Corresponding results for low site classes are presented in *Figures A.23* and *A.24* (18 meters). It is obvious that the growth effects caused by fertilization from nitrogen are dependent on the site quality, in addition to the SO_2 load. The relative growth effect of the fertilization impact is larger for

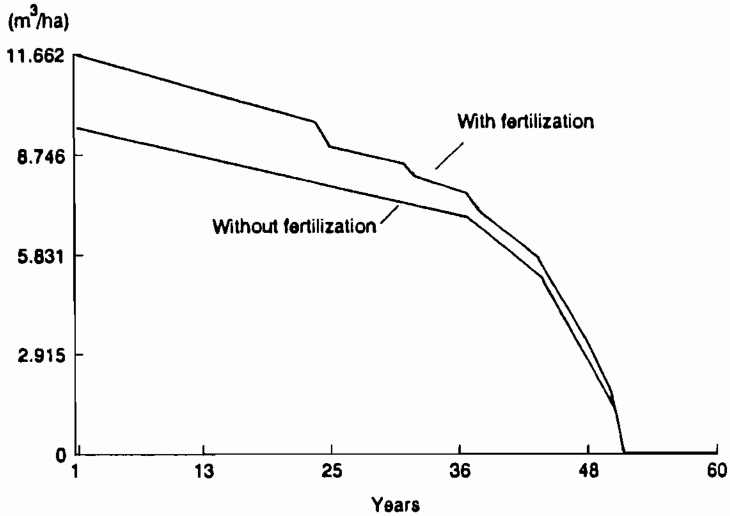


Figure A.21. The mean annual stem volume growth rate during 60 years for a stand with S depositions and with medium site quality (24 meters).

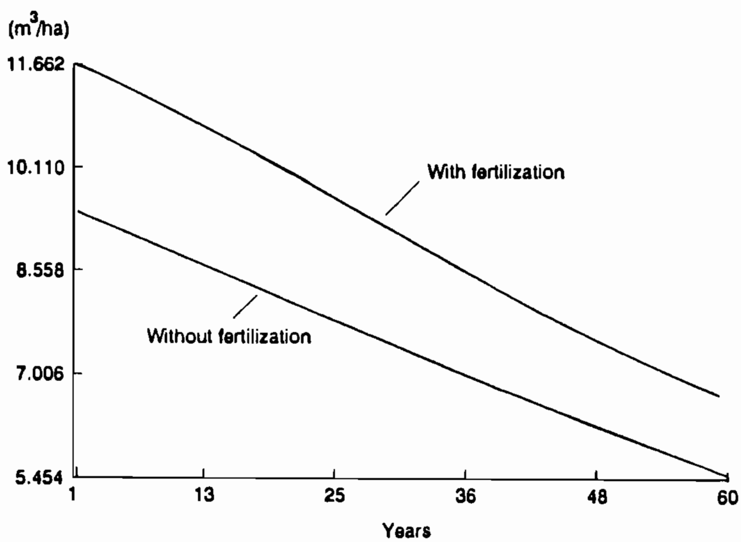


Figure A.22. The mean annual stem volume growth rate during 60 years for a stand without S depositions and with medium site quality (24 meters).

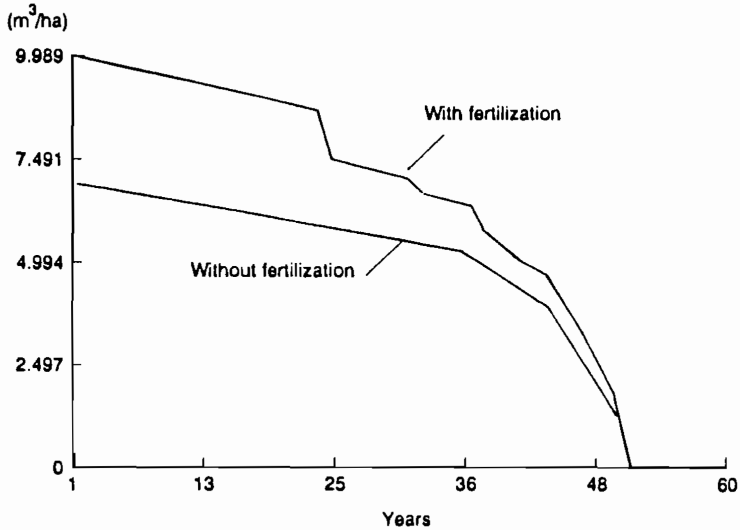


Figure A.23. The mean annual stem growth rate during 60 years for a stand with S depositions and with low site quality (18 meters).

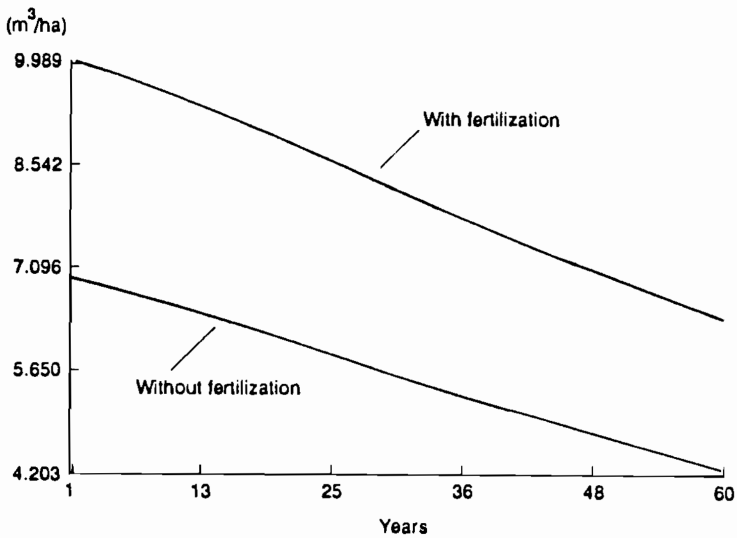


Figure A.24. The mean annual stem volume growth rate during 60 years for a stand without S depositions and with low site quality (18 meters).

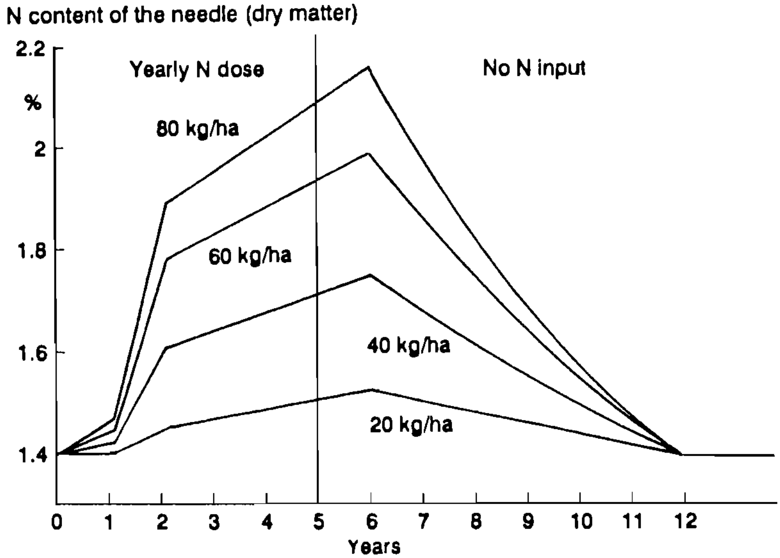


Figure A.25. N content of the needle, depending on the annual N dose over a five-year period. Source: Heinsdorf (1988).

low site classes in comparison with medium and high site classes because of a difference in the nutrient content of the soils.

(b) During the decline and disintegration stages the combined effects of sulfur and nitrogen depositions leads to an increase in decline as compared with the individual effects of sulfur and nitrogen. This is in line with results presented by Schulze (1989).

Section A.6.3 will briefly discuss the modules of the nitrogen component of the PSD model.

A.6.3 The nitrogen modules

Estimation of the N Content of the Needles

The estimated nitrogen content of the needles is based on times series of the annual level of nitrogen depositions. The accumulation of nitrogen in the needles has been calculated by means of regression analyses based on time series on nitrogen depositions and nitrogen content of needles (Heinsdorf, 1988; Hofmann *et al.*, 1990). *Figure A.25* shows that in the beginning, with increased nitrogen depositions (first and second year after increased

Table A.5. Estimated life span of a stand as a function of nitrogen depositions.

N input per year in kg N/ha	Number of years after which first decline was identified	Expected life span
20	–	110 (full life span)
40	28	90
60	21	65
100	9	45

deposition), the N content of the needles increases drastically although later on the effect changes to a slightly linear increase. A reduction in the nitrogen load leads (after a one-year delay) to a decrease in the N content of the needles where the decrease corresponds to the reduced amount of nitrogen.

Volume Growth Effects of Excess Nitrogen Depositions

Heinsdorf (1988) and Hofmann *et al.* (1990) generated a growth curve for the nitrogen content of needles for middle-aged pine stands on medium site classes. This curve shows an increased volume growth during the enrichment stage (phase) caused by an increase in the nitrogen content of the needles. The N content (dry matter) of the needles in the test area under normal conditions was 1.8 percent. Values over 1.8 percent indicate an oversupply of nitrogen. In this case the growth effects culminate with an N content of 2.1 percent. Further increases in nitrogen lead to a reduction in growth (see *Figure A.20*).

Nitrogen-caused Mortality

The oversupply of nitrogen that causes growth reductions also leads to an increased mortality rate and, with continuing oversupply, to a collapse of the stand.

Hofmann *et al.* (1990) have estimated the expected lifetime of stands with the current nitrogen load. These estimates are presented in *Table A.5* for the test area in question.

The reduction in the volume of the stand is expected to follow a linear function from the time when decline is first identified to the estimated point of collapse of the stand.

Interaction Between S and N Deposition Impacts

In earlier sections it was noted that stands with low nutritional status are able to offset the decline effects of sulfur up to a certain level by excess nitrogen depositions. This conclusion is based on the field experiments presented in *Tables A.1a* through *A.1c*. This effect was dealt with by the KRMAX parameter (see Section A.3.3). The N compensation effect equations based on these field experiments cover the range of N content from 1.4 percent to 2.35 percent. According to the results of Heinsdorf (1988) and Hofmann *et al.* (1990), the compensation ability decreases gradually at an N content above 2.35 percent. Beyond an N content of 2.5 percent, the compensating effect of nitrogen becomes zero. This means that in such situations, the advantage of nitrogen depositions disappears and that at high depositions of sulfur the decline aspect of sulfur dominates the total decline effect.

A.6.4 Simulation results

The extended PSD model has been employed for six test sites in *Tables A.1a* through *A.1c* to illustrate the combined effects of sulfur and nitrogen depositions. The simulations are only valid under the following conditions:

- Pine stands.
- 40- to 60-year-old stands.
- Medium nutrient conditions.
- Medium site classes, i.e., average height of stand is 24 meters.
- Initial N contents of needles 1.2 percent to 1.8 percent.
- A stand density of 1.

The objective of these simulations has been to obtain insights into the behavior of the stands under different nutrient conditions and different depositions of sulfur and nitrogen. In *Table A.6*, the mean annual SO_2 concentrations in 1988 and the initial N content are presented for the test sites. The nitrogen load varied between 20 to 65 kilograms per hectare at the test sites.

Two of the test sites have high concentrations of SO_2 (Dübener Heide and Urwald Weißwasser). Three sites represent medium SO_2 concentrations (Taubendorfer Heide, Steckby, and Nauen). The test site Neuglobsow represents low SO_2 concentrations.

The development of the stands were simulated over a period of 60 years. Simulations are carried out for different N loads and with:

Table A.6. Description of the test sites.

Site	SO_2 concentration in 1988 ($\mu g/m^3$)	Initial N content of needles (%)
Dübener Heide (DH)	143 (high)	1.6
Urwald Weißwasser (UW)	116 (high)	1.5
Taubendorfer Heide (TH)	72 (medium)	1.2
Steckby (ST)	69 (medium)	1.8
Nauen (NAU)	41 (medium)	1.8
Neuglobsow (NE)	18 (low)	1.6

Table A.7. Possibilities of achieving normal life span according to yield tables.

Initial nitrogen content	SO_2 concentration ($\mu g/m^3$)	Decline dominated by	Requirements for achieving full life span: Required SO_2 reduction	Maximum N load
Low (1.2%)	72 (medium)	SO_2, N	50–70%	40kg/ha
Medium (1.5%)	116 (high)	SO_2	50–70%	20–30kg/ha
Medium (1.6%)	143 (high)	SO_2	70%	20kg/ha
Medium (1.6%)	18 (low)	N	–	20–40kg/ha
Optimal (1.8%)	69 (medium)	N, SO_2	50%	10–20kg/ha
Optimal (1.8%)	41 (medium)	N, SO_2	50%	10–20kg/ha

- Full SO_2 concentration according to 1988 measurements.
- SO_2 concentration reduced by 30 percent.
- SO_2 concentration reduced by 50 percent.
- SO_2 concentration reduced by 70 percent.

Mortality Rate

The objective of these analyses was to illustrate under what conditions it was possible to achieve a normal, expected life span (according to yield tables) for the tested stands. The results are summarized in *Table A.7*.

From *Table A.7* it can be seen that in cases with medium SO_2 concentrations and an optimal initial nitrogen content the decline process is dominated by nitrogen and the stands can carry less excess nitrogen deposition in comparison with the other test areas. However, a reduction in the SO_2 concentration is required to achieve a full life span. Where there is a low concentration of SO_2 and a medium-level initial nitrogen content, decline is dominated by nitrogen but the stand can carry a larger load of nitrogen and still achieve a full life span. In the other cases, decline is dominated by SO_2 and, to achieve a full life span, heavy reductions are required in SO_2 concentrations (70 percent) and a maximum load of nitrogen is in the range of 20 to 30 kilograms per hectare.

Unfortunately, the basic material (test sites) does not cover the case which deals with an overoptimal initial nitrogen content (>1.8 percent N content of the needles). Nilsson (1991) has illustrated that in about 80 percent of the European coniferous forests, the critical loads for nitrogen are exceeded. The corresponding figure for deciduous forests is about 45 percent. This means that most of the European forests probably have an initial nitrogen content ranging from 1.9 percent to 2.1 percent. In these cases the nitrogen depositions must have had a larger influence on the mortality rate than illustrated in *Table A.7*.

Incremental Growth Rate Effects

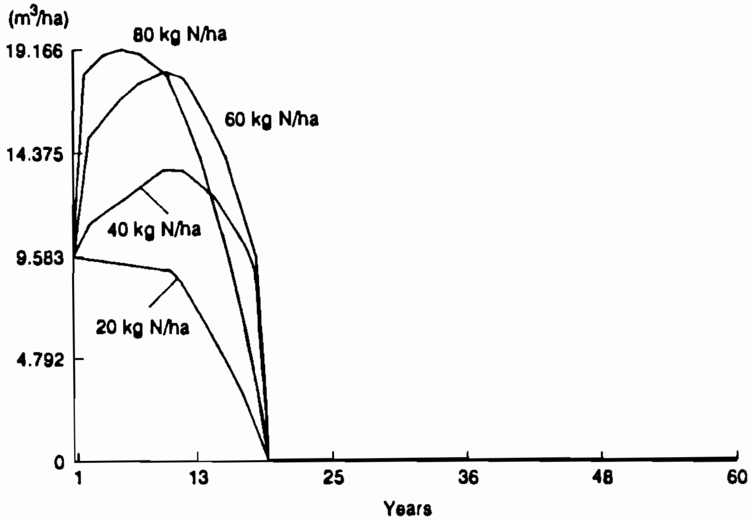
The growth rate effects are illustrated for two different stands in *Figures A.26* and *A.27*. The first stand (Urwald Weißwasser, *Figure A.26*) has a high SO_2 concentration (116) and a medium initial nitrogen content (1.5). The second stand (Nauen, *Figure A.27*) has a medium SO_2 concentration (41) and an optimal initial nitrogen content (1.8).

In the first stand (Urwald Weißwasser) we obtain a quick and strong growth response to the nitrogen deposition but as a consequence of the high SO_2 concentrations the stand dies off within the next 15 years [*Figure A.26(a)*]. By reducing the SO_2 concentration in this stand by 50 percent a maximal growth effect is achieved at a nitrogen load of 40 kilograms per hectare.

In the case with a medium level of SO_2 concentration and optimal initial nitrogen concentration (Nauen stand), we obtain a limited increase in growth during the beginning of the deposition of excess nitrogen. The figures show that the stand will die in 25 to 30 years as a result of the combined effect of both sulfur and nitrogen depositions [*Figure A.27(a)* for the Nauen stand]. In this case it is not enough to reduce the SO_2 emissions by 50 percent to avoid growth losses. Growth losses will appear even at N loads of 20 kilograms per hectare.

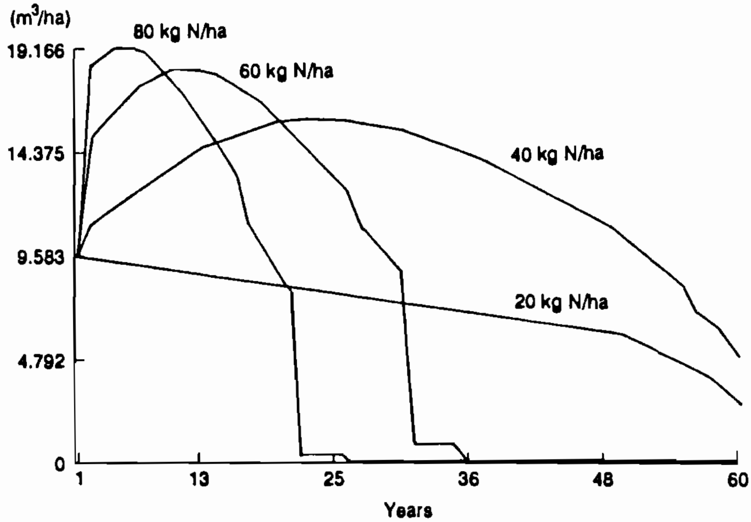
The results for all six test sites are listed in *Table A.8*. In the table it can be seen that the higher the initial nitrogen content, the weaker are the initial growth responses and the stronger are the influences by nitrogen on the decline process. Again it should be emphasized that Nilsson (1991) has

(a)



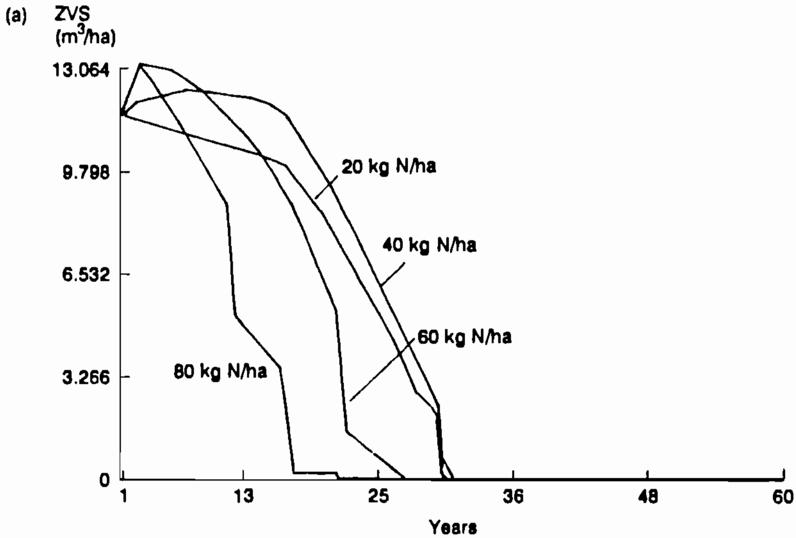
The mean yearly stem volume growth rate for the stand Urwald Weisswasser under full SO_2 emission and different N loads

(b)

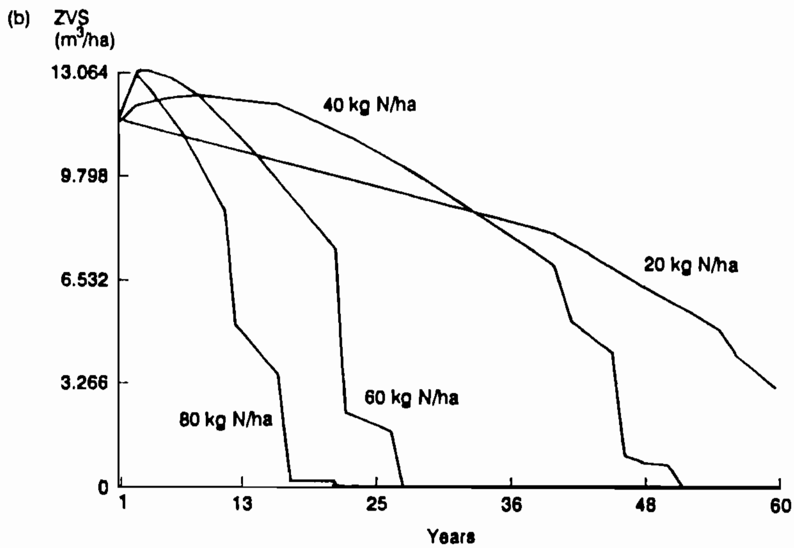


The mean yearly stem volume growth rate for the stand Urwald Weisswasser and 50% reduction of SO_2 emission and different N loads

Figure A.26. Growth effects in the Urwald Weißwasser stand.



The mean yearly stem volume growth rate for the stand Nauen under full SO_2 emission and different N loads



The mean yearly stem volume growth rate for the stand Nauen and 50% reduction of SO_2 emission and different N loads

Figure A.27. Growth effects in the Nauen stand.

Table A.8. Growth responses for different test sites.

Initial nitrogen content	SO_2 concentrations ($\mu g/m^3$)	Growth response during enrichment stage	Growth effects dominated by	Decline stage starts after no. of years
Low (1.2%)	72 (medium)	Extremely strong effects	SO_2	15–25
Medium (1.5%)	116 (high)	Strong positive effects	SO_2	8–10
Medium (1.6%)	143 (high)	Strong effects for high N dep.	SO_2	5–10
Medium (1.6%)	18 (low)	Strong effects for high N dep.	N	10–20
Optimal (1.8%)	69 (medium)	Limited or no effects	Combined N, SO_2	10–15
Optimal (1.8%)	41 (medium)	Limited or no effects	Combined N, SO_2	10–15

demonstrated that most of the European forests have nitrogen depositions close to or above the critical loads for nitrogen. This means that today we have passed the enrichment stage for nitrogen and have a combined decline (growth) effect of sulfur and nitrogen.

A.6.5 Discussion

This approach offers one of the first attempts to illustrate the combined effects of sulfur and nitrogen depositions. To obtain a complete picture of the effects of nitrogen depositions more research has to be carried out on stands with an N content above the optimal level estimated and on stands with poor nutrient conditions. The correlation between N depositions and the growth rate has to be investigated in more detail. The same is valid for the combined effects of sulfur and nitrogen depositions.

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Appendix B

Scenario Results

In this Appendix results are given for each of the 25 countries included in our study of Western and Eastern Europe. Each section begins with an explanation of the tables and charts of the simulation results of the respective country. Data on current conditions of the forest resources of each country are given for forest area and national average growing stock and volume increment (see *Table 3.1*). Species group and age-class are presented for even-aged forest area. The diagrams show proportions of the total area residing in each age class for deciduous and coniferous species at three different times within the simulation period. They refer only to areas modeled as even-aged forests. In a few cases, multiaged forests have been included in the even-aged data set. During the simulations these forests are gradually converted to even-aged forests. In these cases the sum of areas of the initial age classes does not equal the given total area for the species group in the diagrams. The countries are grouped into one of the following categories:

- *Standard structure.* Cuttings and growing stock given for total, coniferous, and deciduous; age-class structures given for coniferous and deciduous; three no-decline scenarios, three decline scenarios, and one land-expansion scenario (if applicable).
- *Only one species group.* As in the standard category, except no breakdown of coniferous and deciduous species.
- *Coppice.* As in the standard structure, with the addition of cuttings and growing stock for the coppice group.
- *Special.* The structure of the basic forest resource data do not permit the generation of age-class diagrams.

Table B. Structure of simulation results for each country in the analyses.

Countries with standard structure	Countries with only one species group	Countries with coppice	Special countries
Belgium	Austria	Bulgaria	Greece
CSFR	Ireland	France	Spain
Denmark	Norway	Italy	Turkey
Finland		Romania	
FRG		Yugoslavia	
GDR			
Hungary			
Luxembourg			
Netherlands			
Poland			
Portugal			
Sweden			
Switzerland			
United Kingdom			

Table B lists each country in its correct category. The scenarios discussed in this Appendix are the same as those discussed in Chapter 4.

Austria (Table B.1 and Figures B.1 to B.6)

The lack of basic information made it impossible to carry out comparisons of the development of the major species groups in Austria.

Basic Scenarios

The forest structure in Austria is not in line with implementation of handbook silviculture, as the initial harvest pulse in the results of the Basic Handbook Scenario shows. This simulation results in an increasing growing stock to about 340 cubic meters per hectare, whereas the Basic ETTS-IV Scenario results in a decreasing stock to about 245 cubic meters per hectare. To match the growing-stock development of the Basic Handbook Scenario, the Basic Forest Study Scenario implements harvests at a level about 20 percent lower than those of the Basic ETTS-IV Scenario, and increases thinnings substantially. The age-class structure develops from one dominated by young and old stands to a more even distribution, across all age classes.

Decline Scenarios

The Handbook Decline Scenario gives a higher initial harvest pulse and a generally increased harvest over a much longer period in comparison with the Basic Handbook Scenario. This is a natural result of shortened rotation periods and intensified thinnings in the decline situation. Thus, during the first 35 years of the simulation, there is a higher potential harvest in the Handbook Decline Scenario. After this period, the potential harvest is much lower than that of the Basic Handbook Scenario. The growing stock decreases over the whole period, finishing the simulation at 117 cubic meters per hectare lower than in the Basic Handbook Scenario.

It is possible to keep the same potential harvest levels in the ETTS-IV Decline Scenario as in the Basic ETTS-IV Scenario. However, this results in a dramatic decrease of the growing stock, a decline which cannot be accepted if sustainability is to be achieved. At the end of the simulation period the growing stock has declined by nearly 130 cubic meters per hectare in comparison with the Basic ETTS-IV Scenario.

In the Forest Study Decline Scenario, it is possible to keep the same growing-stock development as in the Basic Forest Study Scenario, but the long-term sustainable harvest level is about 3.4 million cubic meters per year lower than that of the Basic Forest Study Scenario.

Forest Land Expansion Scenario

In the Forest Land Expansion Scenario, the harvest level increases slightly after about 35 years in comparison with the Basic Forest Study Scenario. Growing-stock development is comparable to that in the Basic Forest Study Scenario.

Summary

Under basic conditions, it is not possible to maintain ETTS-IV harvest levels without significant reductions in growing stock. The Basic Forest Study Scenario results in a mean harvest potential that is about 3 million cubic meters per year lower than that of the ETTS-IV Scenario. The potential harvests are rather strongly affected by forest decline. The decreased potential in the Forest Study Decline Scenario in comparison with the Basic Forest Study Scenario is 3.4 million cubic meters per year over the whole simulation period. An increased forest landbase can generate an increase of the total potential harvest of about 0.5 million cubic meters per year over 100 years.

Table B.1. Austria.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	274–341	274–246	274–357	274–224	274–114	274–358	274–355
Fellings[b]							
Year 1	29.6	15.2	16.0	31.4	15.2	12.8	16.0
Year 40	17.8	20.4	17.4	16.7	20.4	13.9	18.0
Year 80	19.8	20.4	17.4	14.3	20.5	14.0	18.0
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	18.9	20.1	17.1	18.0	20.1	13.7	17.6
Growth (m^3 o.b./ha/yr)[c]							
Total	7.4	6.8	6.9	5.9	5.5	5.7	6.7
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	274–341	274–246	274–357	274–224	274–114	274–358	274–355

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

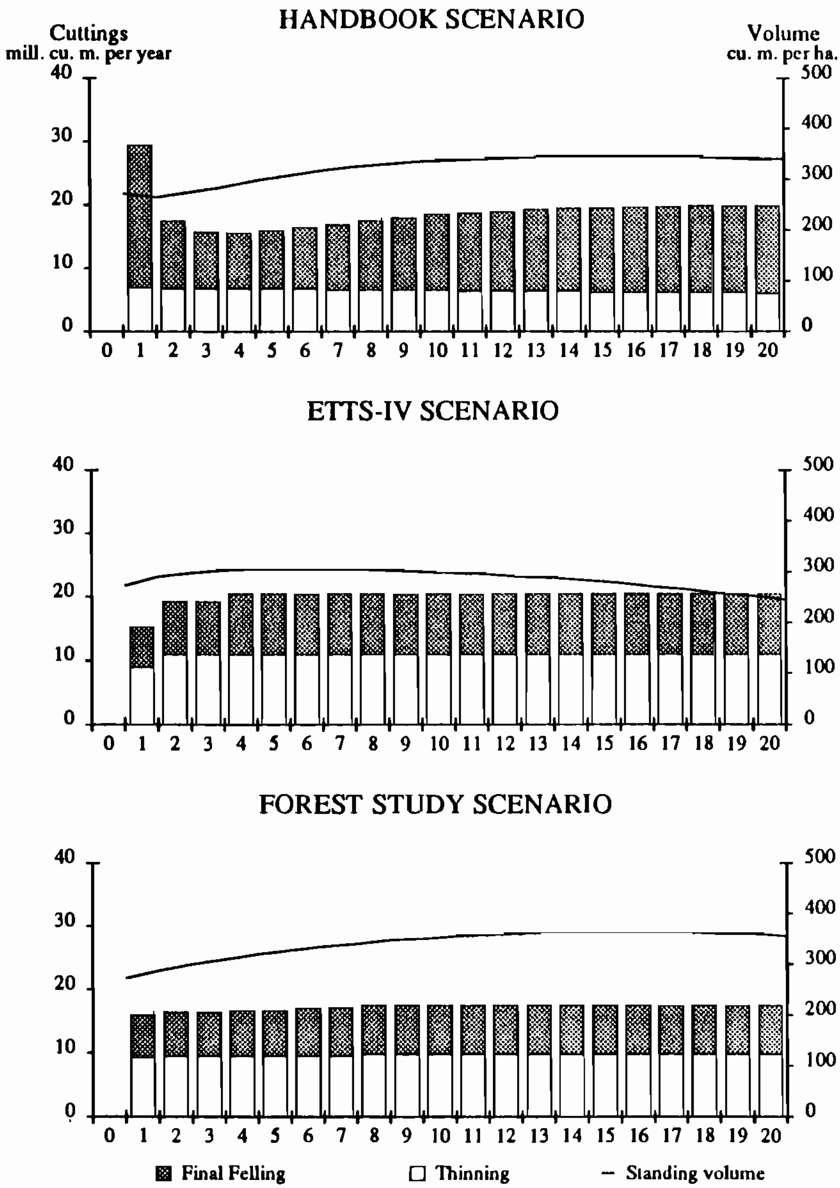


Figure B.1. Projections for total potential harvest and growing stock in Austria under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 15 million cubic meters o.b.

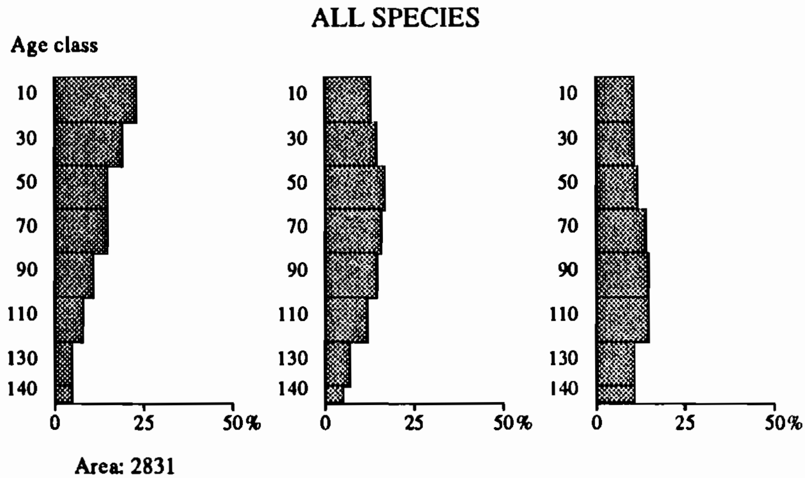


Figure B.2. Age-class distributions in Austria under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

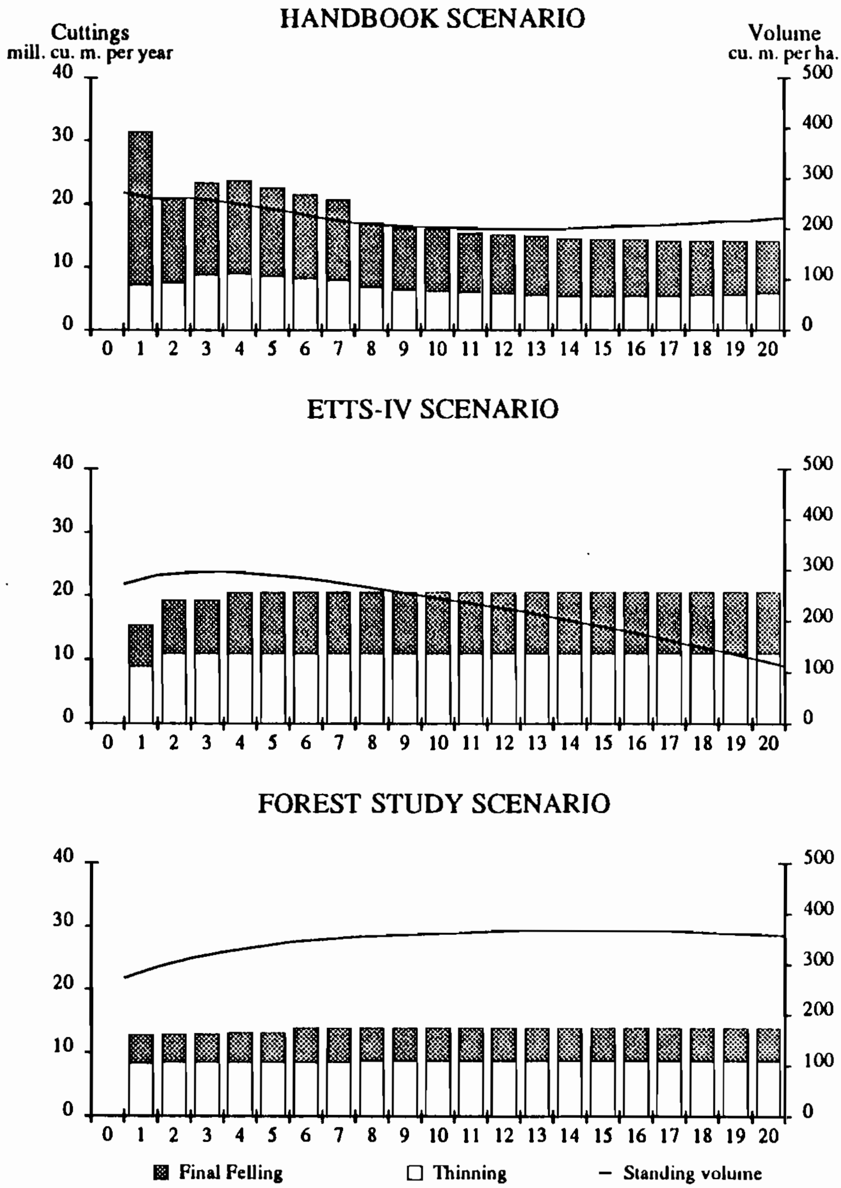


Figure B.3. Projections for total potential harvest and growing stock in Austria under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 15 million cubic meters o.b.

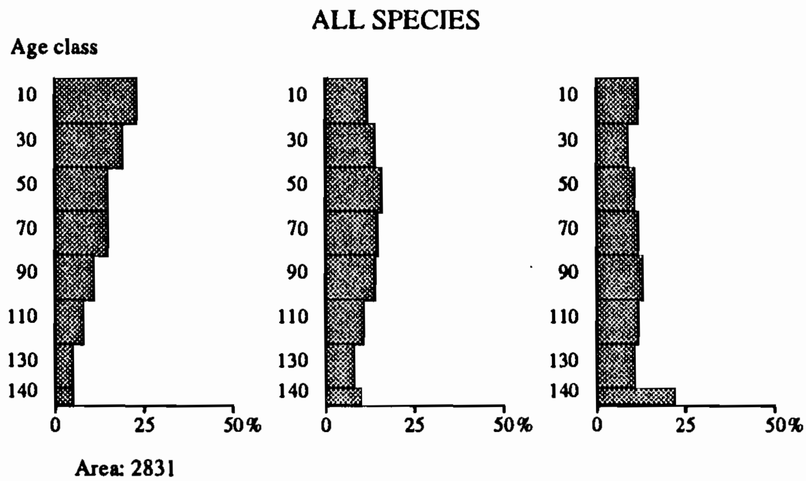


Figure B.4. Age-class distributions in Austria under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

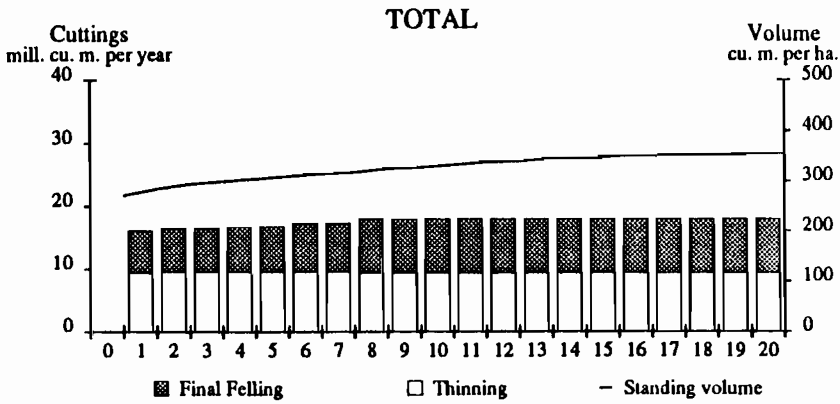


Figure B.5. Projections for total potential harvest and growing stock in Austria under the Forest Land Expansion Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 15 million cubic meters o.b.

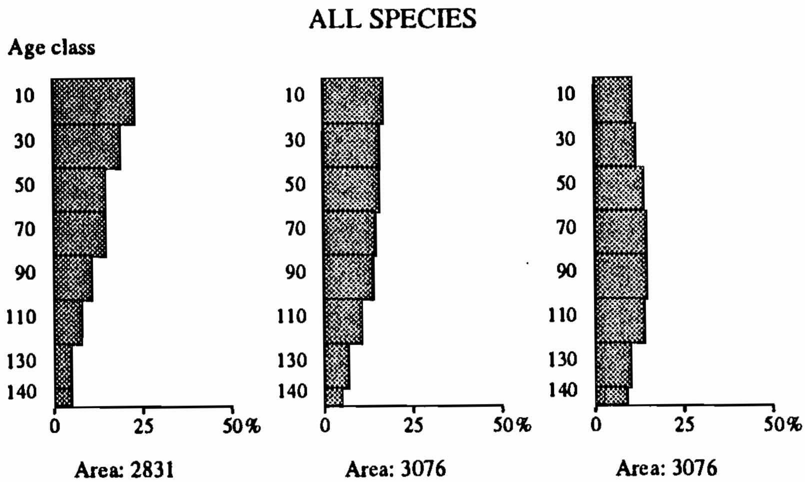


Figure B.6. Age-class distributions in Austria under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Belgium (Table B.2 and Figures B.7 to B.14)

Basic Scenarios

Belgium's forest structure is out of balance with handbook silviculture. Results from the Basic Handbook Scenario show a large harvest pulse in the early years, but growing stock remains stable. ETTS-IV harvest levels are possible during the first decades, but the cutting level suggested from period 7 and onward is not attainable with the silvicultural program defined. In the Basic Forest Study Scenario, harvests are kept at about 4 million cubic meters per year with higher proportions of thinnings, and the growing stock remains slightly lower than in the Basic ETTS-IV Scenario. Some 78 percent of the total harvests is coniferous, with a thinnings proportion of about 60 percent. In the hardwood stands, final cuts dominate the harvests. The age-class structure for conifers remains quite stable over the simulation, but in hardwoods the structure shifts from middle-aged and old stands to young and middle-aged stands.

Decline Scenarios

The Handbook Decline Scenario gives higher harvest pulses in the first phases of the simulation period in comparison with the Basic Handbook Scenario. After about 20 years, the potential harvest level is lower in comparison with the basic scenario, but at the end of the simulation period the potential harvest level is about the same in the two scenarios. The growing stock decreases during the first 40 years, followed by a slight increase. However, the final level is about 20 cubic meters per hectare lower in the decline case than in the basic scenario.

It is almost possible to follow the same potential harvest pattern and level in the ETTS-IV Decline Scenario as in the basic scenario. However, the growing stock at the end of the period is 75 cubic meters per hectare lower than that of the basic scenario. This development is hardly able to maintain sustainability.

According to the Forest Study Decline Scenario, it is possible to keep the growing stock at nearly the same level as in the basic scenario. Also, harvests can be kept at a fairly even level throughout the planning period. However, the level is lower in comparison with the Basic Forest Study Scenario. The decrease in potential harvest level is about 0.7 million cubic meters per year. Forest decline will affect conifers most in terms of potential harvest levels. Deciduous species will also be affected but to a lesser extent.

Forest Land Expansion Scenario

With an increasing forest landbase in Belgium and the current forest structure, there is a possibility to increase harvest levels immediately in comparison with the Basic Forest Study Scenario. A second harvest pulse comes after about 55 years, because of increased production from new coniferous forests. While the dominating part of the increased harvests is taken from coniferous stands, there is also a slight increase for harvest of deciduous species over time.

The development of total growing stock in this scenario is rather flat, but at a lower level in comparison with the basic scenario. For conifers, the growing stock increases slightly over time to a level higher than that of the basic scenario. For deciduous species the development of growing stock will be steady but at a lower level in comparison with the basic scenario.

Summary

Among the seven scenarios, the Basic Handbook Scenario and the Forest Land Expansion Scenario give the highest average potential harvest levels. Forest decline attributed to air pollutants generates a loss of potential harvests of 0.7 million cubic meters per year averaged over 100 years. The increased landbase generates additional potential harvest of 0.6 million cubic meters per year averaged over the simulation period. There are no problems in taking out the harvest levels suggested by ETTS-IV under basic conditions over the 100 year simulation. Interestingly, conifer species have a very high rate of annual increment.

Table B.2. Belgium.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	148–125	148–177	148–173	148–105	148–101	148–167	148–149
Fellings[b]							
Year 1	7.8	2.8	3.8	9.6	2.8	3.2	4.2
Year 40	3.8	3.6	3.8	2.9	3.5	3.0	4.3
Year 80	3.6	3.2	3.7	3.4	3.4	3.1	4.6
Coniferous							
Growing stock[a]	178–151	178–289	178–172	178–147	178–158	178–167	178–201
Fellings[b]							
Year 1	6.0	1.8	3.0	6.6	1.8	2.6	3.2
Year 40	3.0	2.9	3.0	2.4	2.8	2.4	3.3
Year 80	3.0	2.5	2.9	2.9	2.8	2.5	3.5
Deciduous							
Growing stock[a]	121–102	121–76	121–173	121–67	121–50	121–167	121–106
Fellings[b]							
Year 1	1.8	1.0	0.8	3.0	1.0	0.6	1.0
Year 40	0.8	0.7	0.8	0.5	0.7	0.6	1.0
Year 80	0.6	0.7	0.8	0.5	0.6	0.6	1.1
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	4.1	3.5	3.8	3.8	3.6	3.1	4.4
Coniferous	3.2	2.5	3.0	3.0	2.6	2.5	3.3
Deciduous	0.9	1.0	0.8	0.8	1.0	0.6	1.1
Growth (m^3 o.b./ha/yr)[c]							
Total	6.7	6.3	6.8	6.0	5.7	5.5	6.6
Coniferous	11.2	10.3	10.8	10.4	9.3	8.9	11.3
Deciduous	2.6	2.7	3.1	2.0	2.4	2.5	2.8
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	148–125	148–177	148–173	148–105	148–101	148–167	148–149
Coniferous	178–151	178–289	178–172	178–147	178–158	178–167	178–201
Deciduous	121–102	121–76	121–173	121–67	121–50	121–167	121–106

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

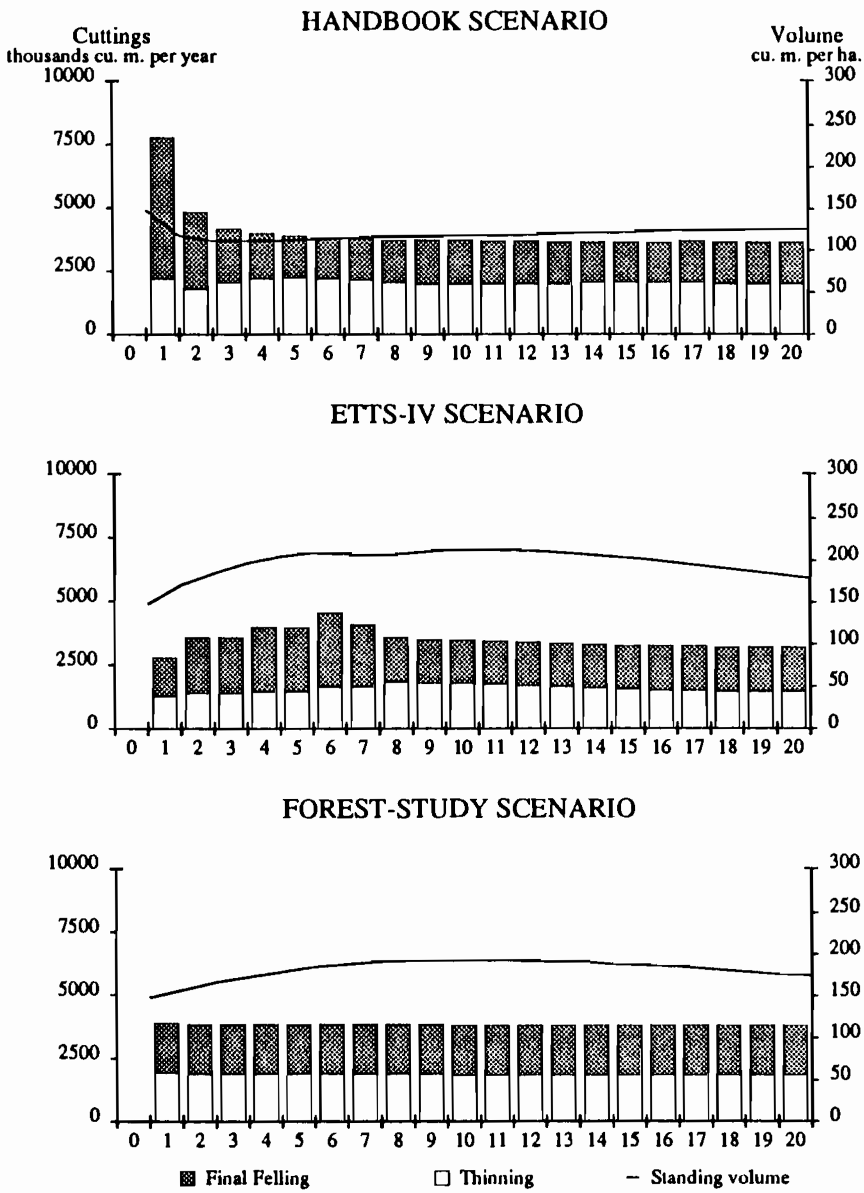


Figure B.7. Projections for total potential harvest and growing stock in Belgium under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 3 million cubic meters o.b.

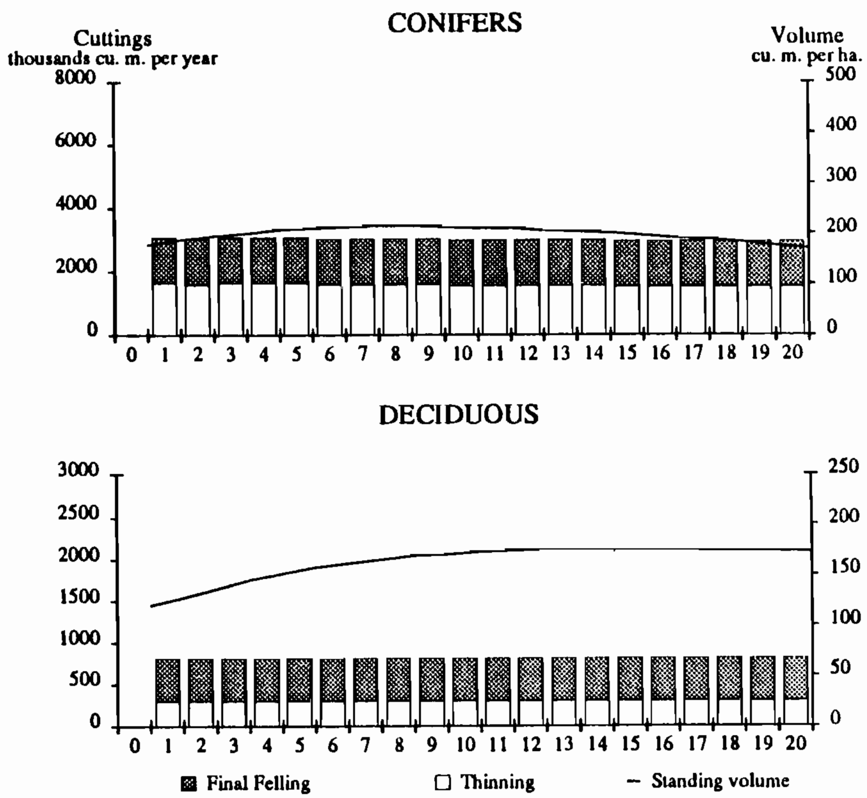


Figure B.8. Projections for total potential harvest and growing stock for coniferous and deciduous species in Belgium under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 2 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.

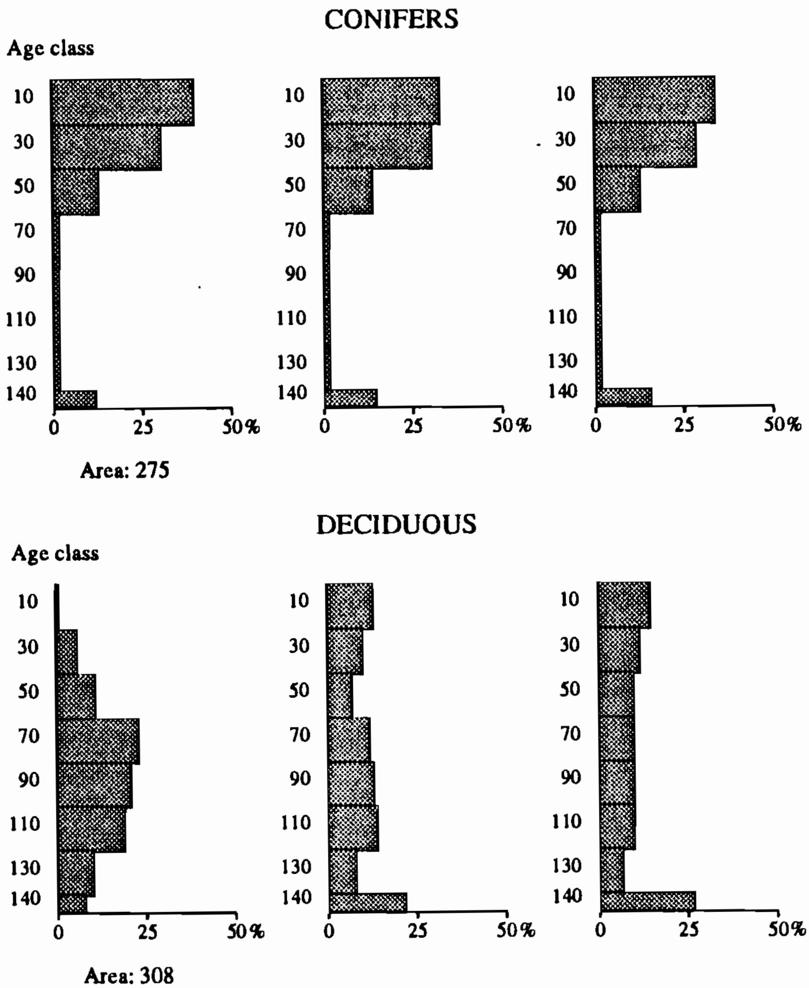


Figure B.9. Age-class distributions in Belgium under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

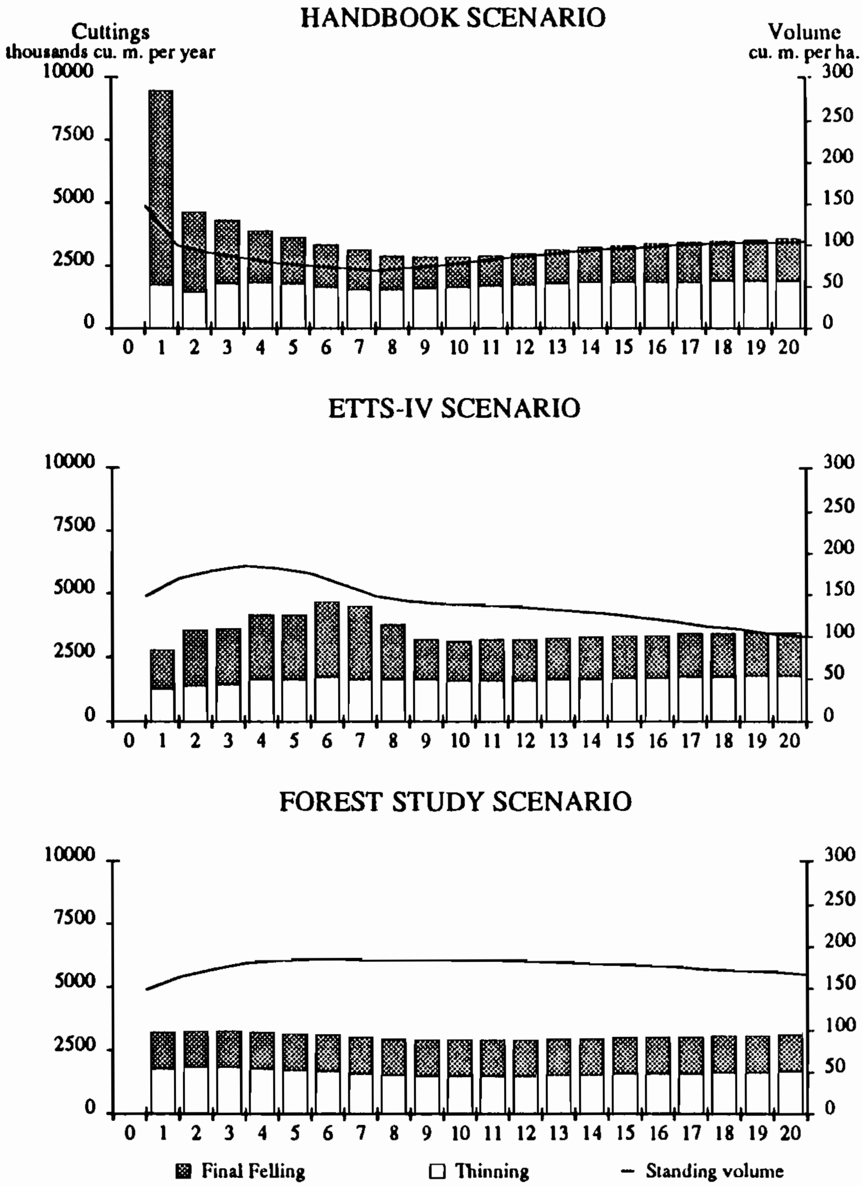


Figure B.10. Projections for total potential harvest and growing stock in Belgium under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 3 million cubic meters o.b.

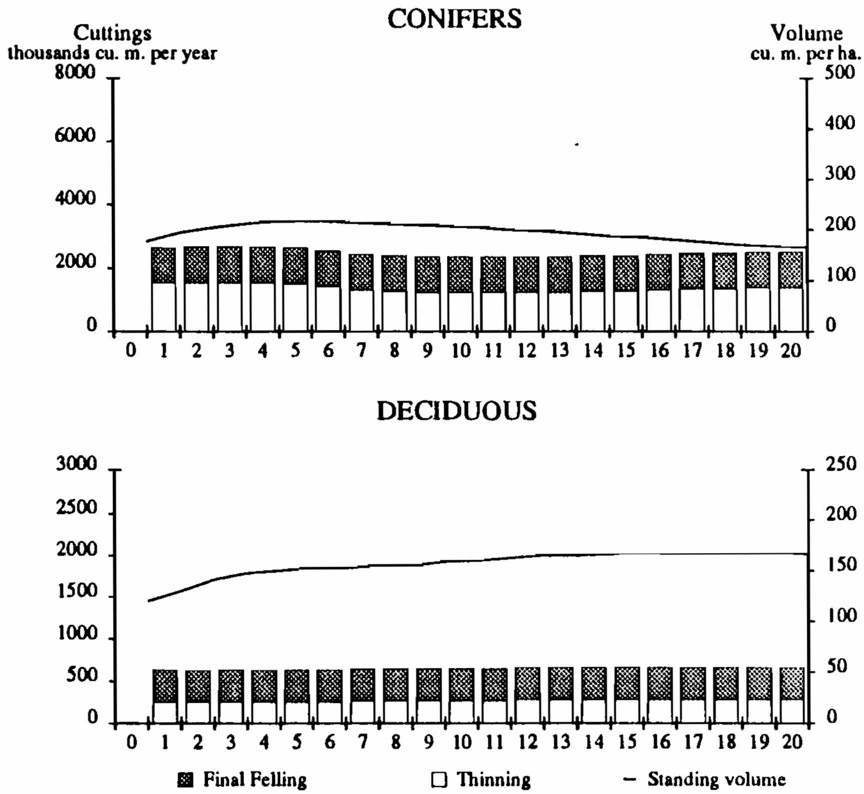


Figure B.11. Projections for total potential harvest and growing stock for coniferous and deciduous species in Belgium under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 2 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.

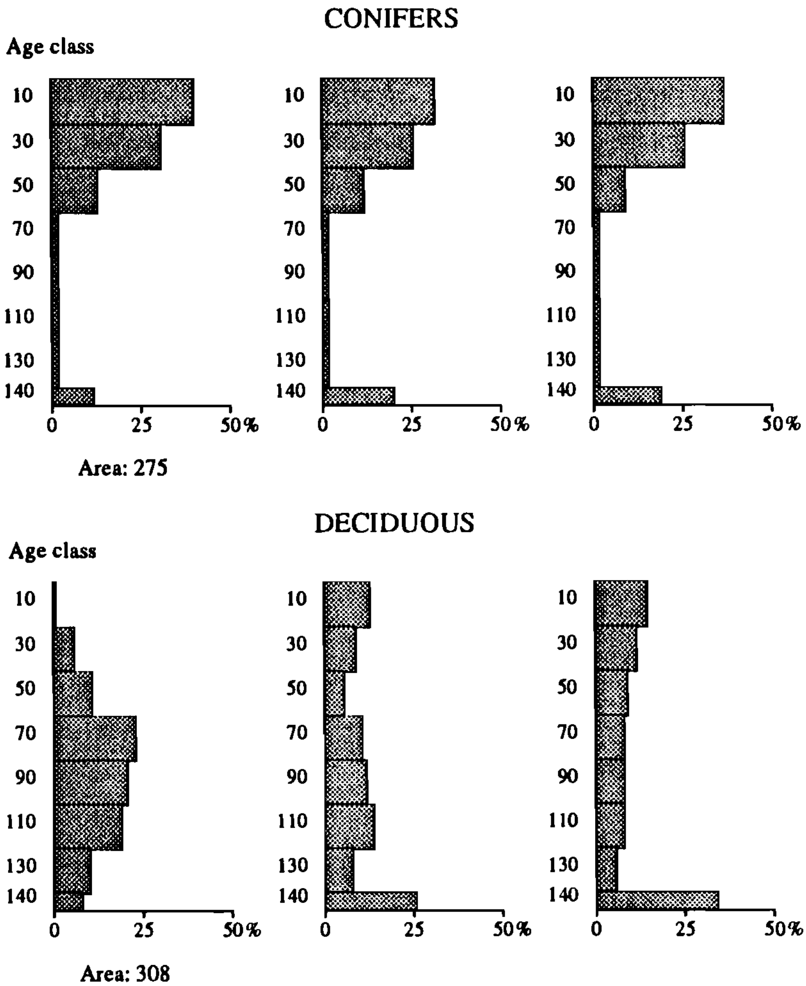


Figure B.12. Age-class distributions in Belgium under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

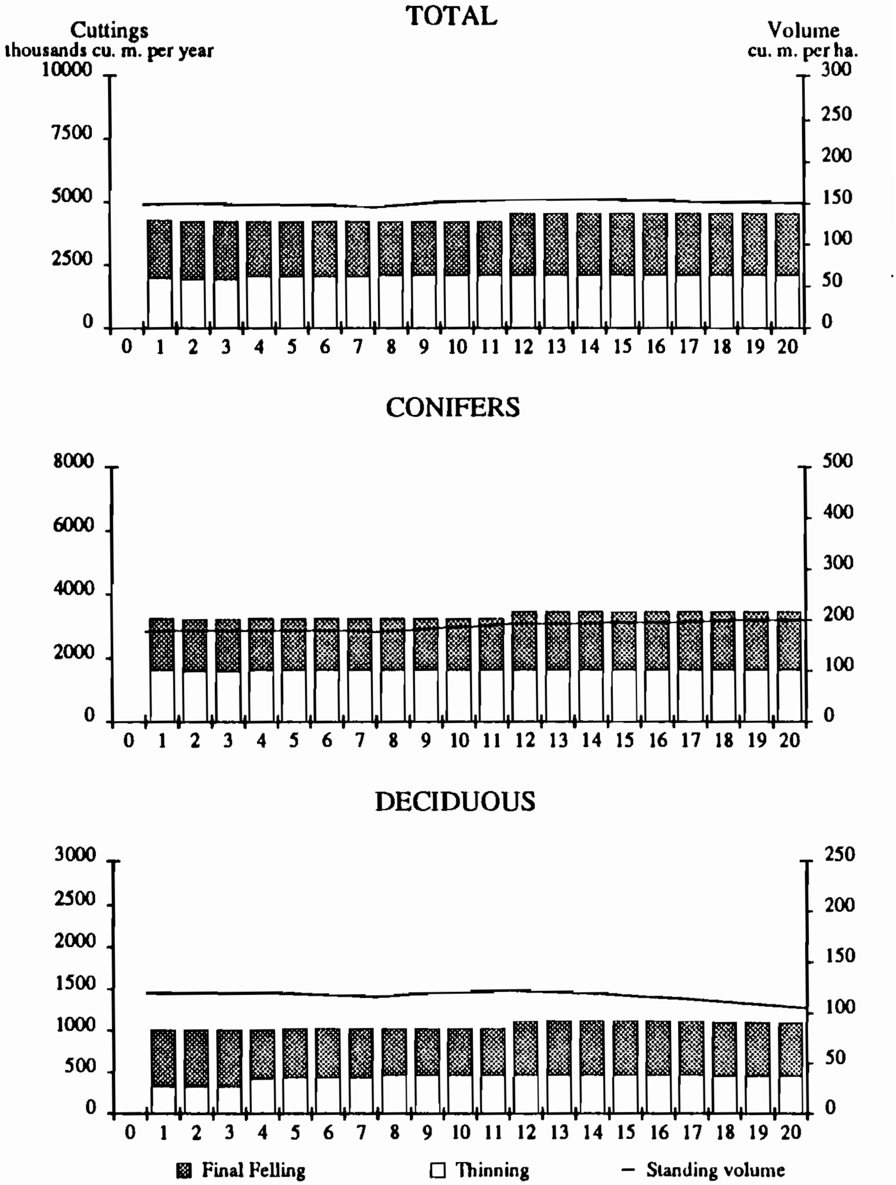


Figure B.13. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Belgium under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 3 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 2 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.

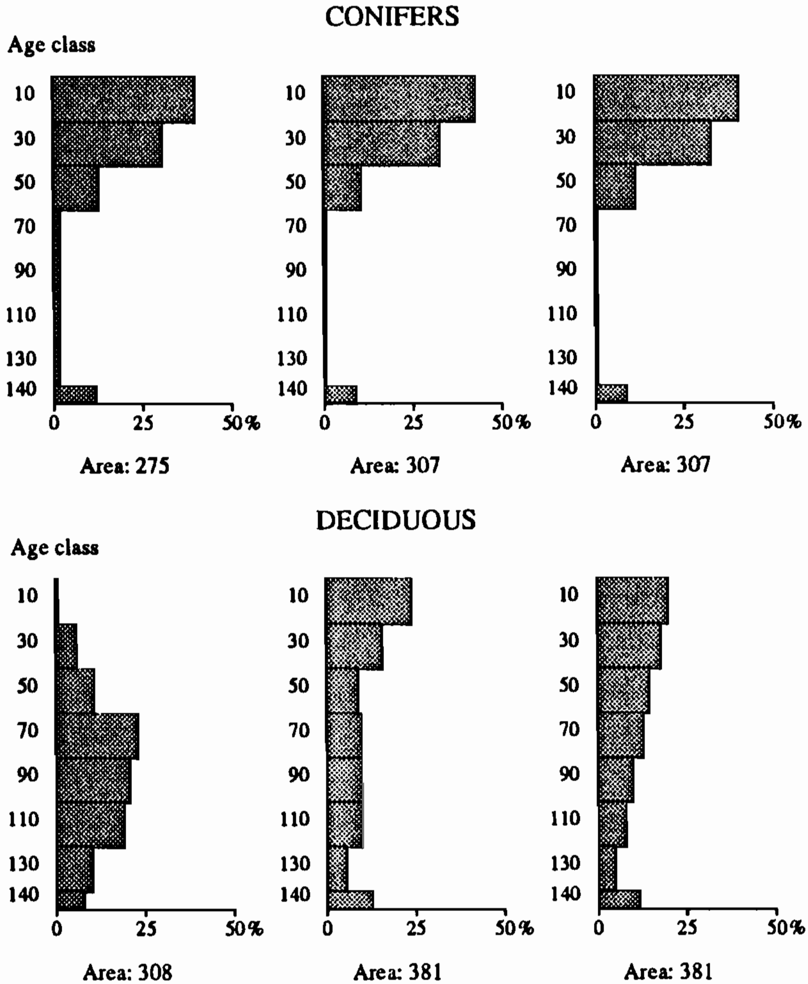


Figure B.14. Age-class distributions in Belgium under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Bulgaria (Table B.3 and Figures B.15 to B.23)

Basic Scenarios

Results of the Basic Handbook Scenario show that the current structure of Bulgarian forest resources did not evolve under application of handbook silviculture. There is a large harvest pulse in the first period of the simulation. The growing stock can be kept at a stable level of about 105 cubic meters per hectare for the entire period. With the ETTS-IV harvest levels, growing stock increases to approximately 150 cubic meters per hectare. The Forest Study Scenario invokes a harvest some 10 percent higher than that of ETTS-IV, with a lower but stable overall growing stock of about 135 cubic meters per hectare. The mean coniferous growing stock reaches about 175 cubic meters per hectare, but the deciduous stock remains stable at approximately 115 cubic meters per hectare. The harvests come mainly from final cuttings, and consist of 60 percent coniferous species. The initial coniferous age-class structure is concentrated in young classes, but over time it becomes a more balanced structure. The evolution of the deciduous age-class structure is similar, but it evolves from a more even initial structure.

Decline Scenarios

In the Handbook Decline Scenario, there will be a much stronger initial harvest pulse and longer increased harvest level in comparison with the basic scenario. After about 35 years, the potential harvest level is much lower than in the basic scenario. Growing stock decreases during the first 40 years but recovers slightly in the latter part of the simulation period. It is possible to keep the same harvest level and pattern in the ETTS-IV Decline Scenario as in the Basic ETTS-IV Scenario. However, the growing stock, is about 40 cubic meters per hectare lower in the decline scenario.

Based on the Forest Study Decline Scenario, it can be assumed that the same growing-stock level can be kept as in the basic scenario. However, the potential harvest level would be rather strongly decreased by about 2.2 million cubic meters per year. Potential harvest levels for both coniferous and deciduous species will decrease by about 1 million cubic meters per year each. The potential harvest level of coppices will be less affected, but there is also a slight decline of the growing stock. Generally, it is mainly the final fellings that are affected by the decline.

Forest Land Expansion Scenario

In the expansion scenario, the increased landbase in Bulgaria immediately generates an increased total harvest in comparison with the basic scenario. Through the whole simulation period, harvest levels can be kept higher than those of the basic scenario. The dominating part of the increased harvest comes from the new coniferous forests. Even for deciduous species there is an immediate increased harvest that can be kept throughout the whole planning period. The total growing stock will be lower in comparison with the basic scenario, but the growing stock of conifers will increase faster. For the deciduous species the growing-stock level will be lower in comparison with the basic scenario.

Summary

There is a strong possibility to exceed the harvest levels identified by ETTS-IV under basic conditions. The highest harvest potential under the basic conditions is identified in the Basic Handbook Scenario. The total harvest potential is negatively affected by pollution-induced decline of about 2.2 million cubic meters per year throughout the simulation period. Expansion of the forest landbase generates an increase of the potential harvest of about 0.6 million cubic meters per year over 100 years. Growth projections indicate that Bulgarian forests have relatively low increments among countries in the Eastern region.

Table B.3. Bulgaria.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	106–106	106–150	106–135	106–85	106–107	106–132	106–116
Fellings[b]							
Year 1	18.0	6.0	7.8	22.2	6.0	5.4	8.2
Year 40	8.7	8.1	8.8	7.8	8.1	6.7	9.5
Year 80	9.6	8.1	8.8	7.8	8.1	6.7	9.5
Coniferous							
Growing stock[a]	111–135	111–261	111–174	111–107	111–193	111–173	111–134
Fellings[b]							
Year 1	5.8	1.4	3.2	6.6	1.4	2.0	3.4
Year 40	3.4	2.4	3.6	3.4	2.4	2.6	4.2
Year 80	4.2	2.4	3.6	3.2	2.4	2.6	4.2
Deciduous							
Growing stock[a]	103–95	103–89	103–116	103–75	103–59	103–115	103–106
Fellings[b]							
Year 1	6.4	2.8	2.8	9.0	2.8	1.8	3.0
Year 40	3.1	3.5	3.0	2.9	3.5	2.1	3.1
Year 80	3.2	3.5	3.0	2.5	3.5	2.1	3.1
Coppice							
Growing stock[a]	103–77	103–108	103–108	103–73	103–76	103–100	103–108
Fellings[b]							
Year 1	5.8	1.8	1.8	6.6	1.8	1.6	1.8
Year 40	2.2	2.2	2.2	1.5	2.2	2.0	2.2
Year 80	2.2	2.2	2.2	2.1	2.2	2.0	2.2
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	9.7	7.7	8.6	9.5	7.7	6.4	9.2
Coniferous	4.0	2.2	3.5	3.9	2.2	2.5	4.0
Deciduous	3.4	3.4	3.0	3.4	3.4	2.0	3.1
Coppice	2.3	2.1	2.1	2.2	2.1	1.9	2.1
Growth (m^3 o.b./ha/yr)[c]							
Total	3.0	2.8	3.0	2.8	2.4	2.3	2.9
Coniferous	3.9	3.5	3.9	3.5	2.9	2.9	3.8
Deciduous	2.0	2.0	2.0	1.9	1.7	1.4	2.0
Coppice	4.3	4.2	4.2	4.0	3.8	3.8	4.2
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	106–106	106–150	106–135	106–85	106–107	106–132	106–116
Coniferous	111–135	111–261	111–174	111–107	111–193	111–173	111–134
Deciduous	103–95	103–89	103–116	103–75	103–59	103–115	103–106
Coppice	103–77	103–108	103–108	103–73	103–76	103–100	103–108

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

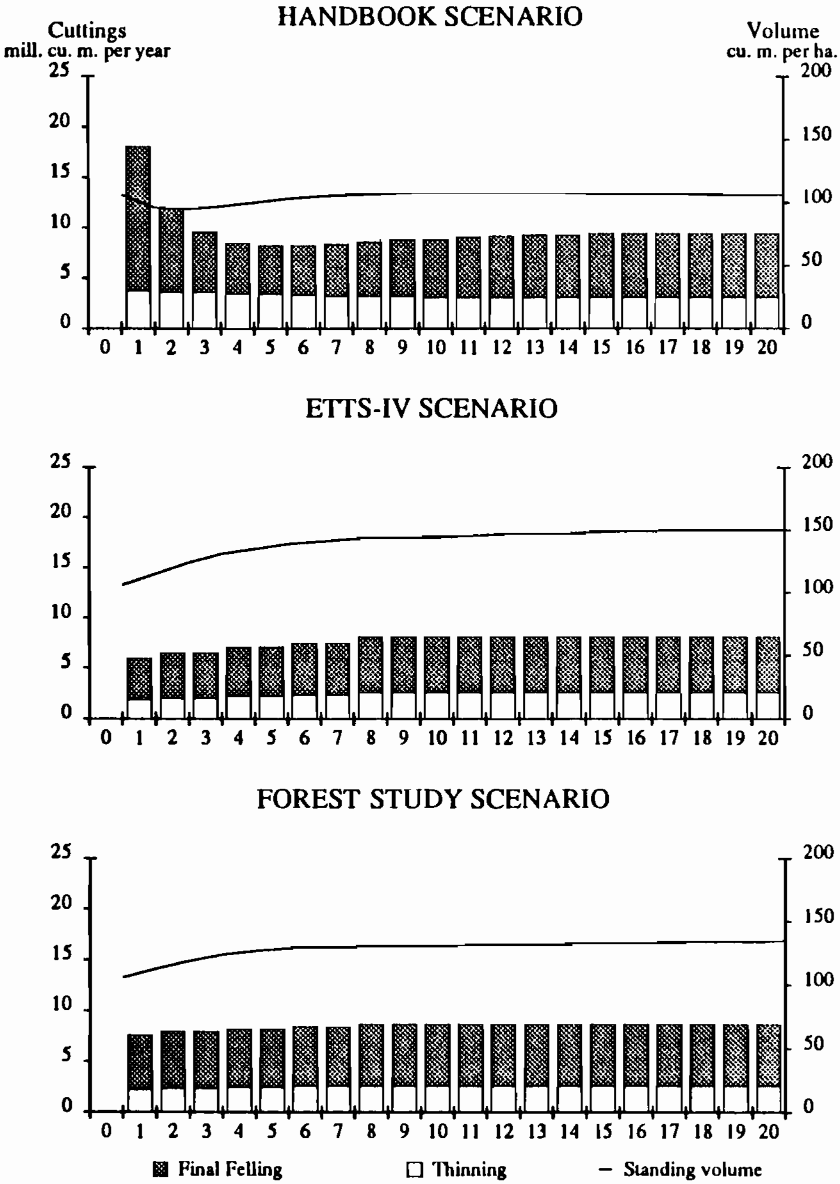


Figure B.15. Projections for total potential harvest and growing stock in Bulgaria under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 6 million cubic meters o.b.

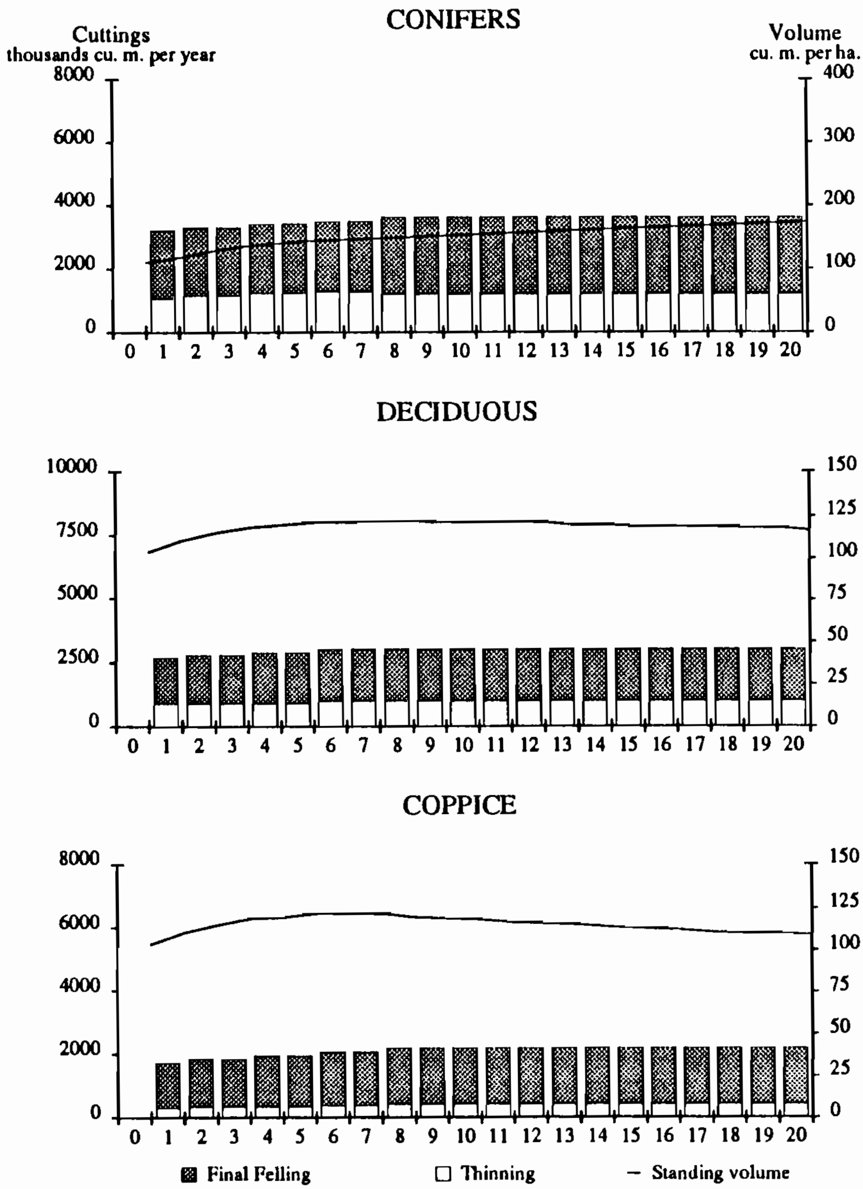


Figure B.16. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Bulgaria under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

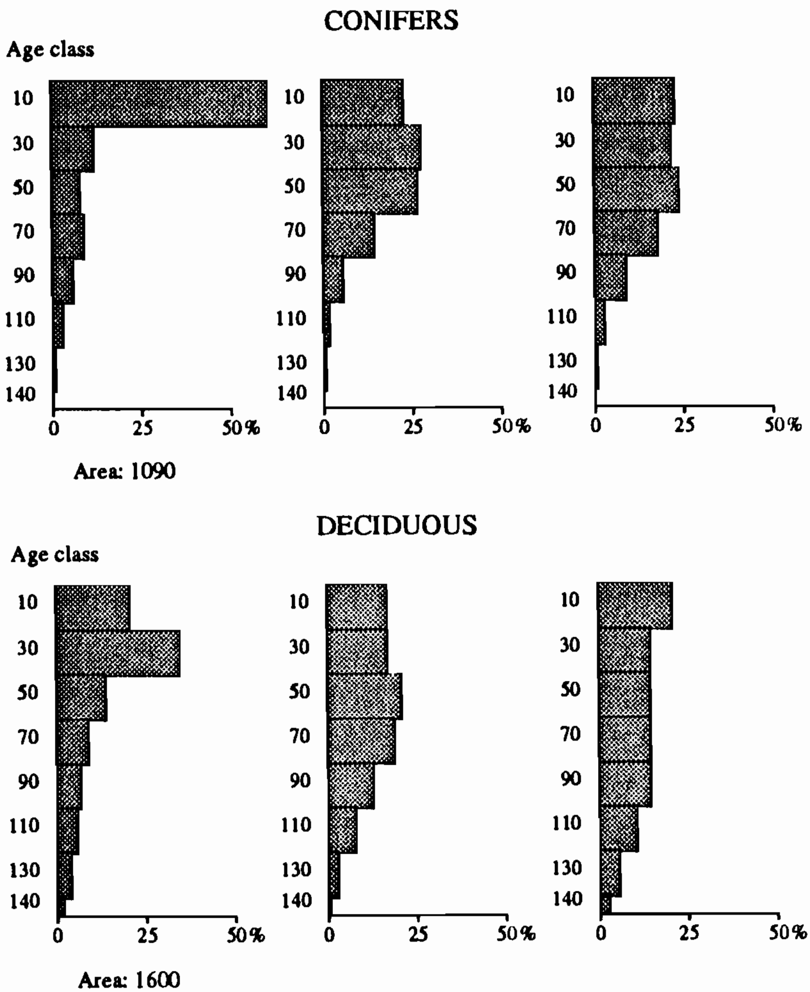


Figure B.17. Age-class distributions in Bulgaria under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

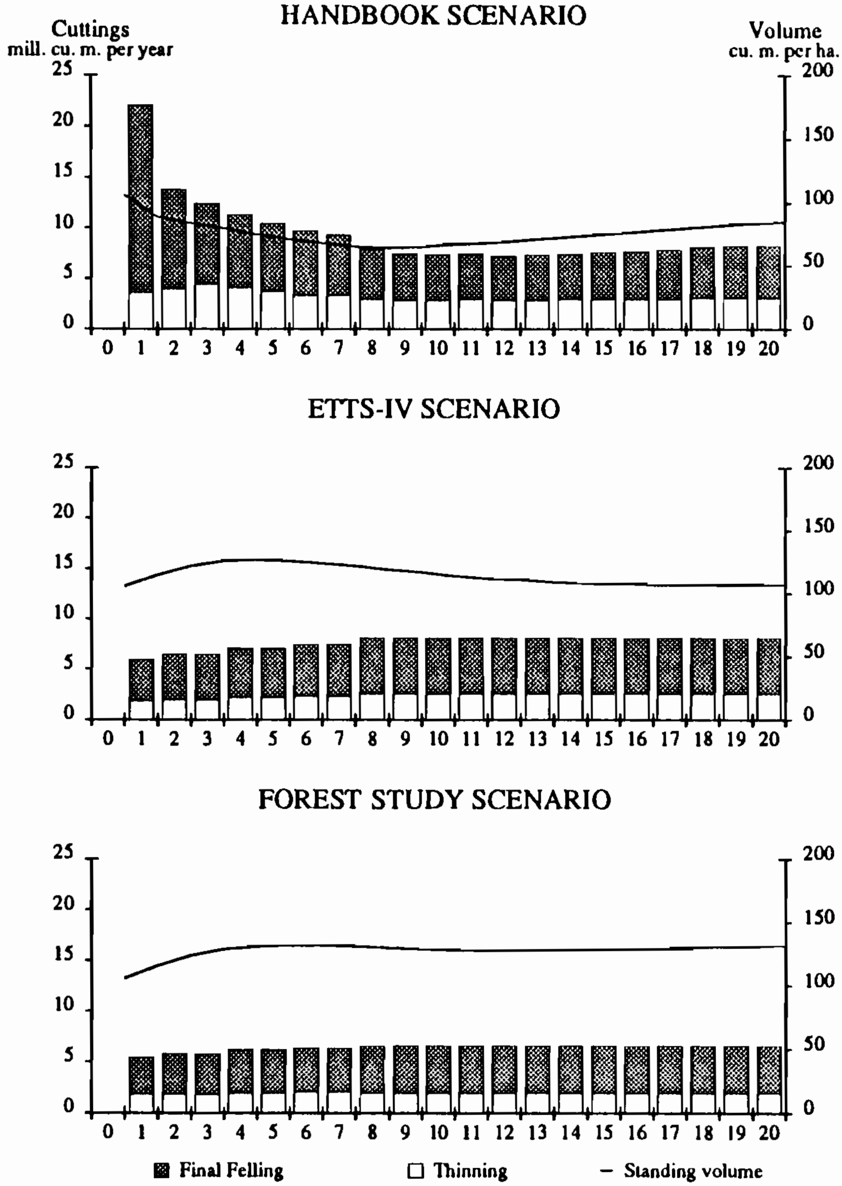


Figure B.18. Projections for total potential harvest and growing stock in Bulgaria under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 6 million cubic meters o.b.

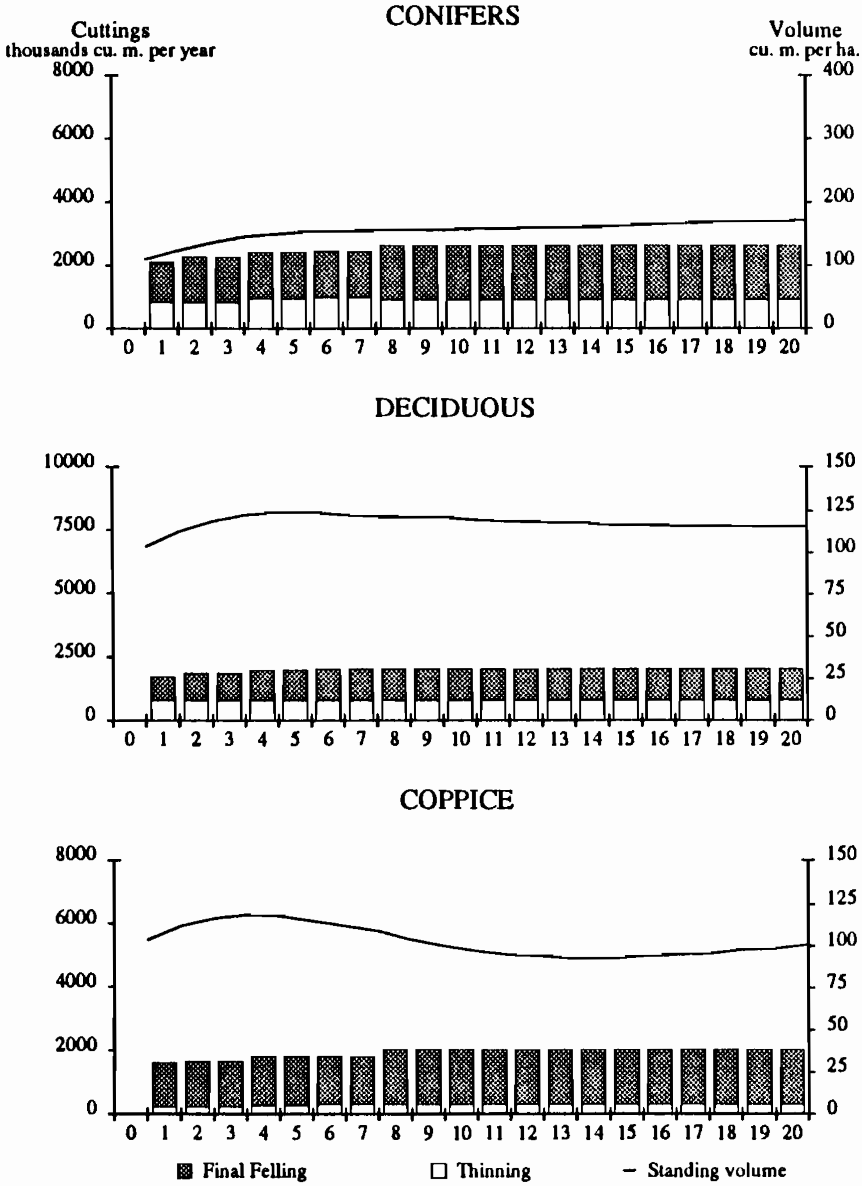


Figure B.19. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Bulgaria under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

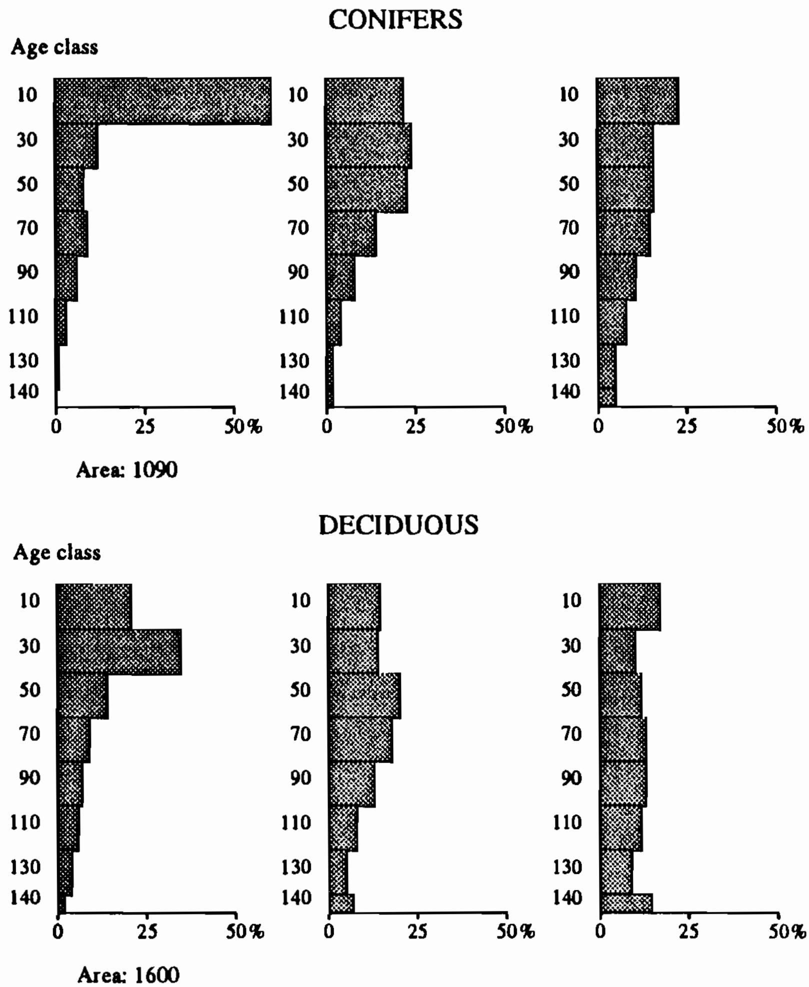


Figure B.20. Age-class distributions in Bulgaria under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

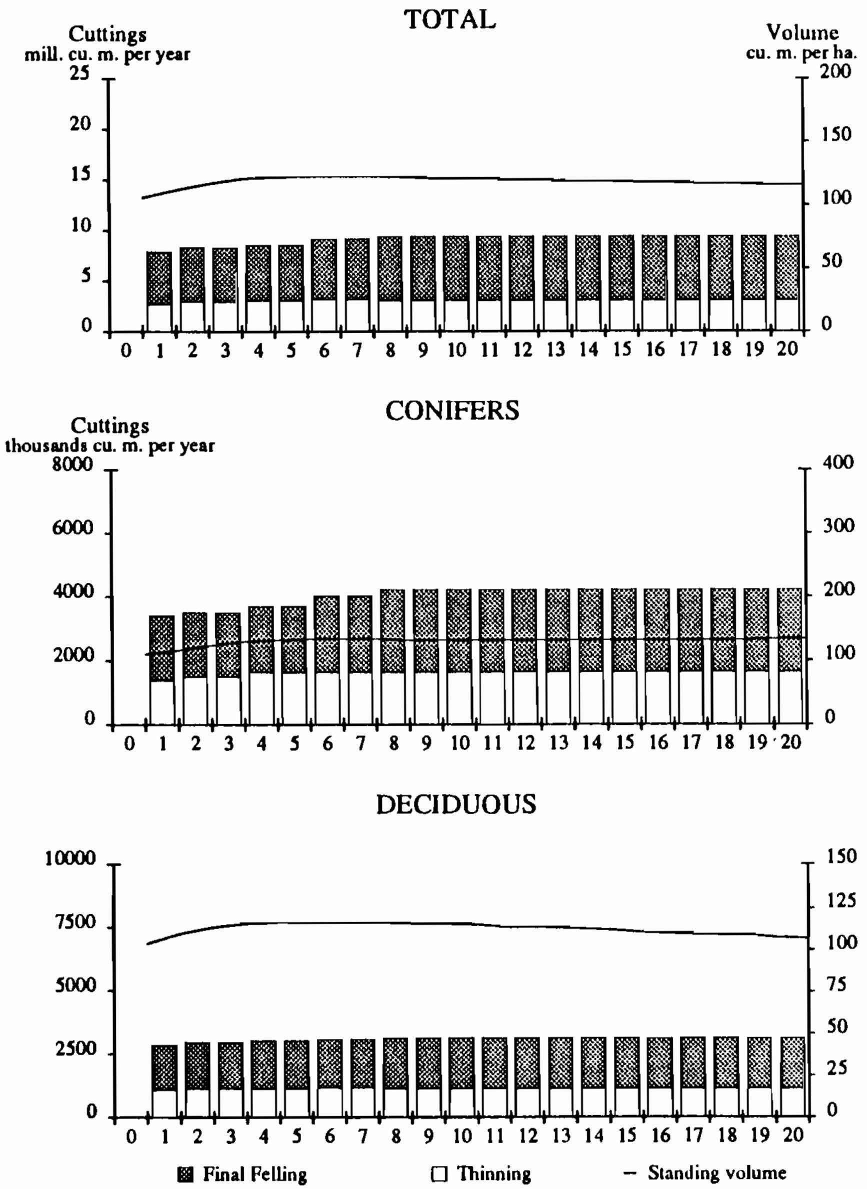


Figure B.21. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Bulgaria under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 6 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

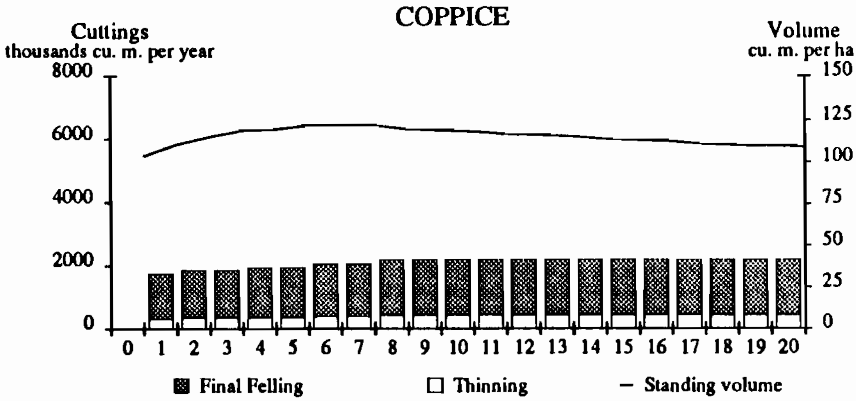


Figure B.22. Projections for total potential harvest and growing stock of coppice in Bulgaria under the Forest Land Expansion Scenario.

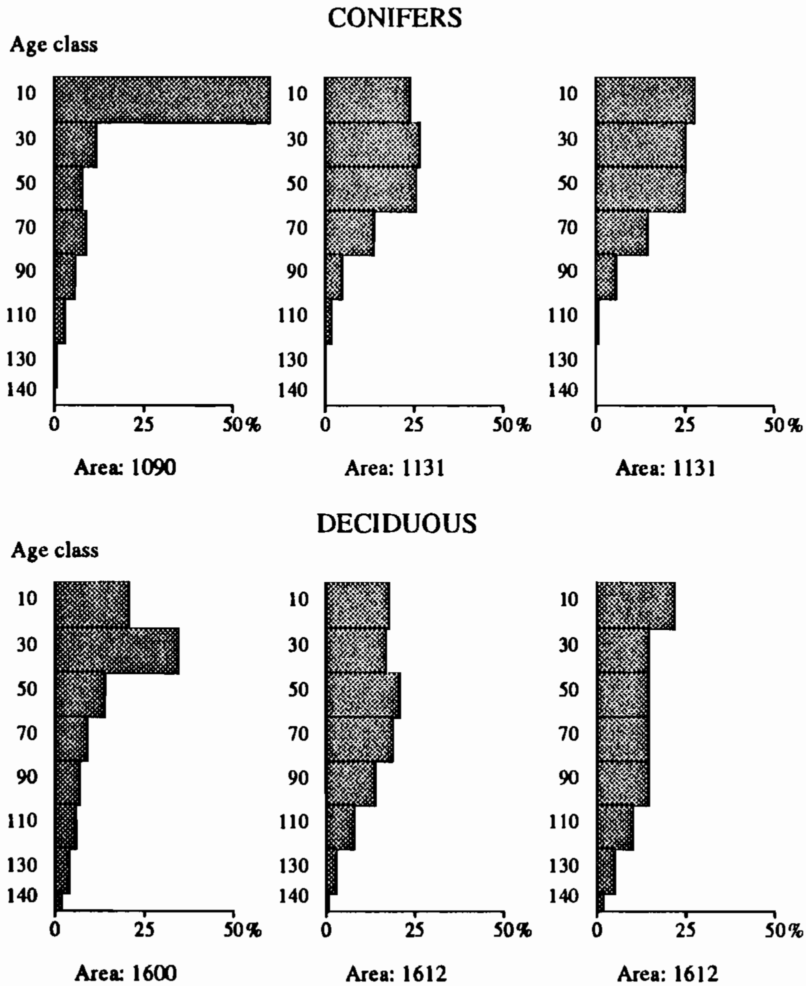


Figure B.23. Age-class distributions in Bulgaria under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

CSFR (Table B.4 and Figures B.24 to B.31)

Basic Scenarios

There is good correspondence between the initial forest structure in the CSFR and the forest structure that would have evolved under application of handbook silviculture. ETTS-IV harvest levels can easily be fulfilled, with mean growing stock increasing from 225 to 275 cubic meters per hectare. Harvest levels in the Basic Forest Study Scenario are about 10 percent higher than those implemented by ETTS-IV, and with a higher proportion of final cuts. In the Basic Forest Study Scenario, the overall growing stock stabilizes at about 250 cubic meters per hectare. The harvests emanate from coniferous stands to 80 percent, whose mean growing stock increases to about 300 cubic meters per hectare. The initial coniferous age-class structure is dominated by middle-aged stands, but evolves to a balanced distribution near the end of the simulation. Similar trends occur in the development of the deciduous structure, with a notably high proportion of regenerating stands late in the simulation. [Because conifers predominate the Czech Republic's forests (the western part of the country) and deciduous species predominate the Slovak Republic's forests (the eastern part), the age-class structures have been disaggregated.]

Decline Scenarios

The Handbook Decline Scenario has a dramatic effect on the development of the forest resources in the CSFR. In the basic scenario there is a good correspondence between the existing structure and handbook silviculture. In the decline case there are extremely high harvest pulses during the first periods. Later the potential harvest levels decrease over time to much lower levels in comparison with the basic scenario. The total growing stock evolves to a much lower level than that of the basic scenario. The decrease of the total growing stock is about 120 cubic meters per hectare.

It is possible to maintain the same harvest levels in the ETTS-IV Decline Scenario as in the basic scenario only during the first 50 years. There is a dramatic decrease of the total growing stock in the decline scenario to about 150 cubic meters per hectare.

In the Forest Study Decline Scenario it is possible to keep nearly the same mean growing stock as that in the basic scenario. However, this demands a dramatic change in potential harvest levels. An even-flow harvest level over the entire simulation period would call for low harvests overall. The decrease of the mean harvest level in comparison with the basic scenario is about 9.5 million cubic meters per year. In relative terms, the coniferous and deciduous species are affected to about the same extent by the decline. It is mainly the extent of potential final fellings that are affected. The dramatic decline effects on development of the forest resources in the CSFR results from the severe pollution situation in this country.

Summary

Under basic conditions, the harvest level suggested by ETTS-IV can be exceeded. As expected, owing to the pollution conditions in the CSFR, continued decline will strongly influence the potential harvest levels by about 9.5 million cubic meters per year over 100 years, compared with basic conditions.

Table B.4. CSFR.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	207–234	207–280	207–254	207–159	207–128	207–232	
Fellings[b]							
Year 1	30.6	21.4	21.8	63.0	21.8	12.2	
Year 40	24.0	21.1	24.1	16.8	21.4	14.5	
Year 80	23.7	21.1	24.1	14.4	19.9	14.8	
Coniferous							
Growing stock[a]	238–282	238–346	238–301	238–207	238–170	238–270	
Fellings[b]							
Year 1	23.6	16.4	17.2	40.4	16.6	10.4	
Year 40	18.4	15.4	18.4	13.4	15.4	11.7	
Year 80	18.2	15.4	18.4	11.6	15.2	11.8	
Deciduous							
Growing stock[a]	154–152	154–166	154–173	154–77	154–57	154–167	
Fellings[b]							
Year 1	7.0	5.0	4.6	22.6	5.2	1.8	
Year 40	5.6	5.7	5.7	3.4	6.0	2.8	
Year 80	5.5	5.7	5.7	2.8	4.7	3.0	
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	24.6	21.1	23.7	21.5	20.3	14.2	
Coniferous	19.0	15.5	18.2	16.8	15.3	11.6	
Deciduous	5.6	5.6	5.5	4.7	5.0	2.5	
Growth (m^3 o.b./ha/yr)[c]							
Total	6.2	5.8	6.2	4.7	4.1	3.7	
Coniferous	7.7	7.0	7.6	6.1	5.2	4.8	
Deciduous	3.7	3.8	3.8	2.3	2.3	1.8	
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	207–234	207–280	207–254	207–159	207–128	207–232	
Coniferous	238–282	238–346	238–301	238–207	238–170	238–270	
Deciduous	154–152	154–166	154–173	154–77	154–57	154–167	

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

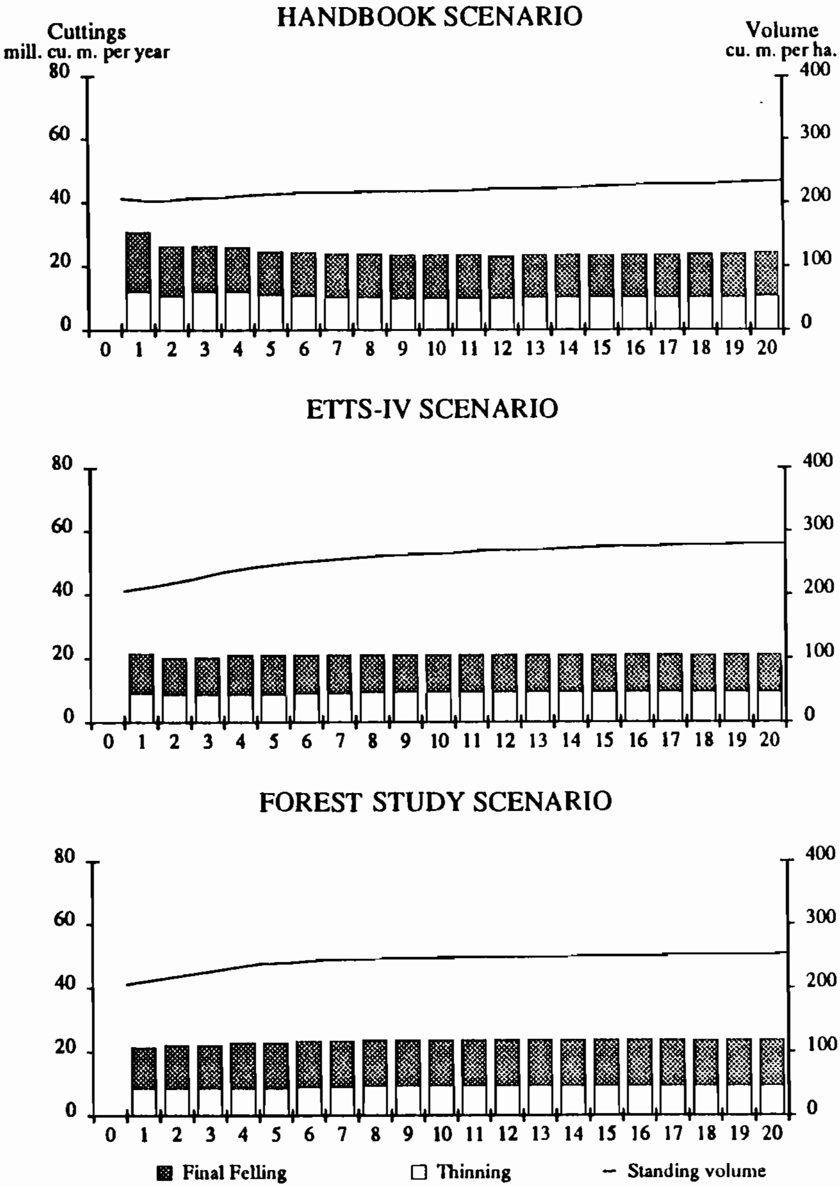


Figure B.24. Projections for total potential harvest and growing stock in the CSFR under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 21 million cubic meters o.b.

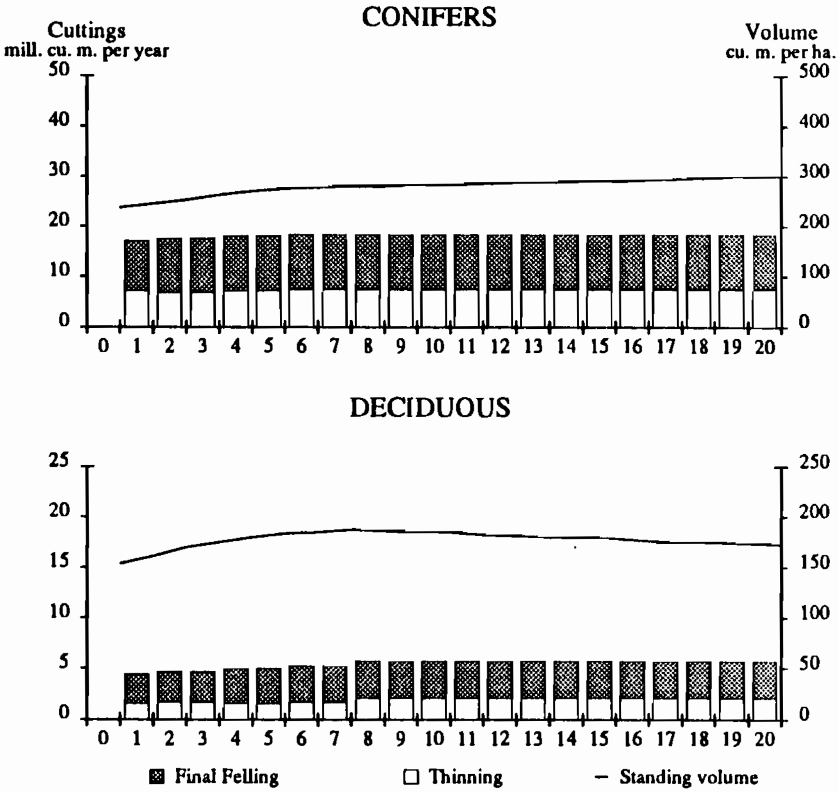


Figure B.25. Projections for total potential harvest and growing stock for coniferous and deciduous species in the CSFR under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 16 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

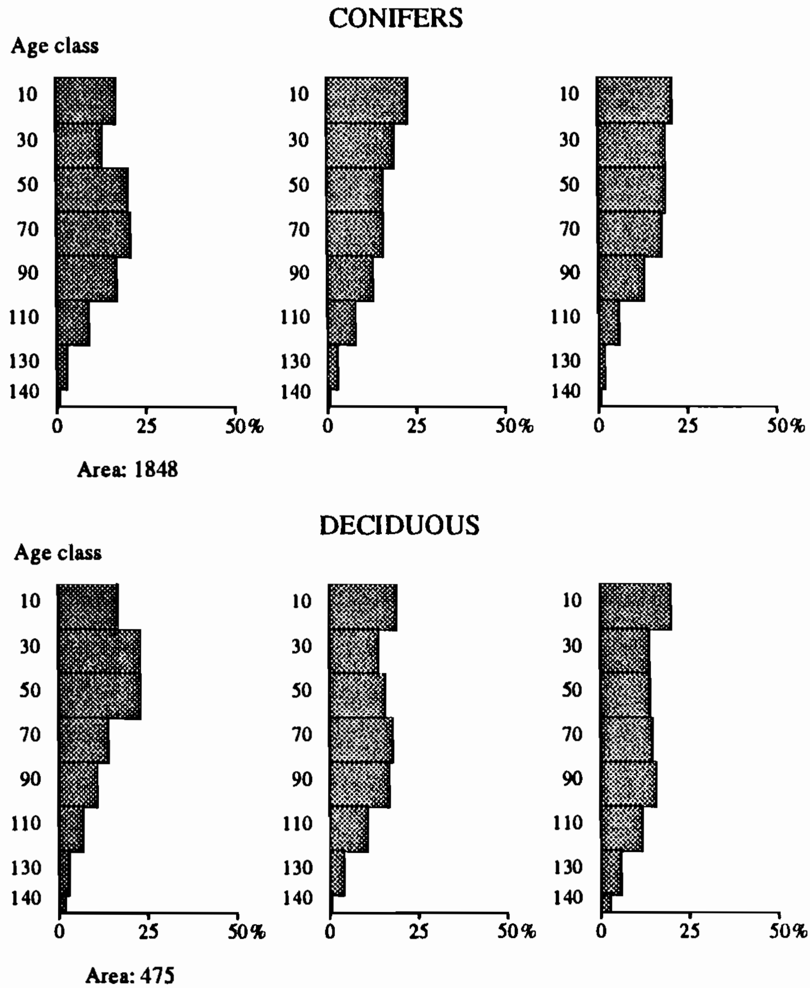


Figure B.26. Age-class distributions in the Czech Republic under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

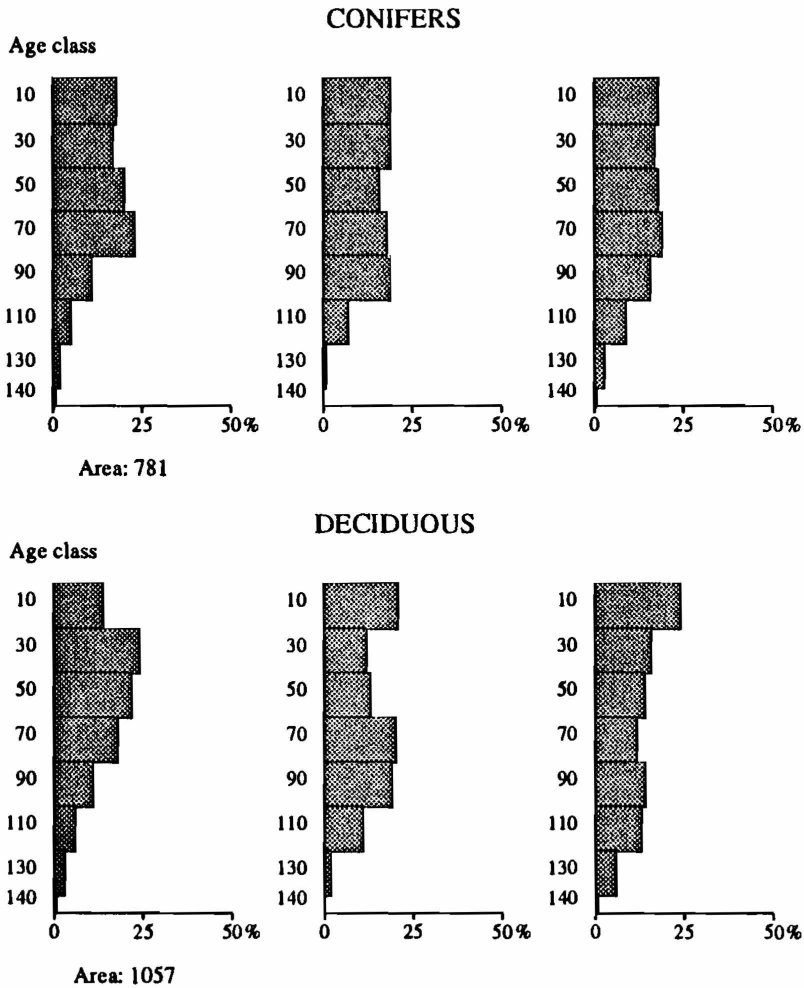


Figure B.27. Age-class distributions in the Slovak Republic under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

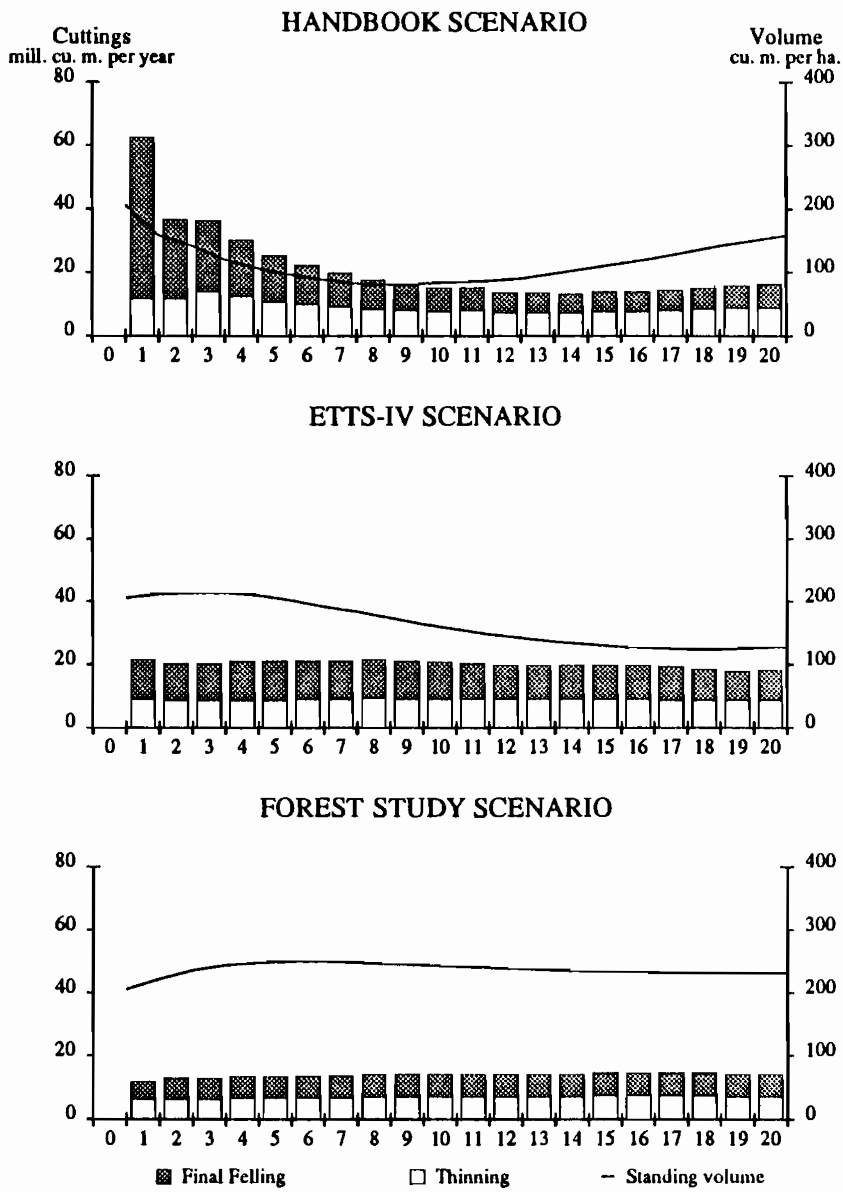


Figure B.28. Projections for total potential harvest and growing stock in the CSFR under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 21 million cubic meters o.b.

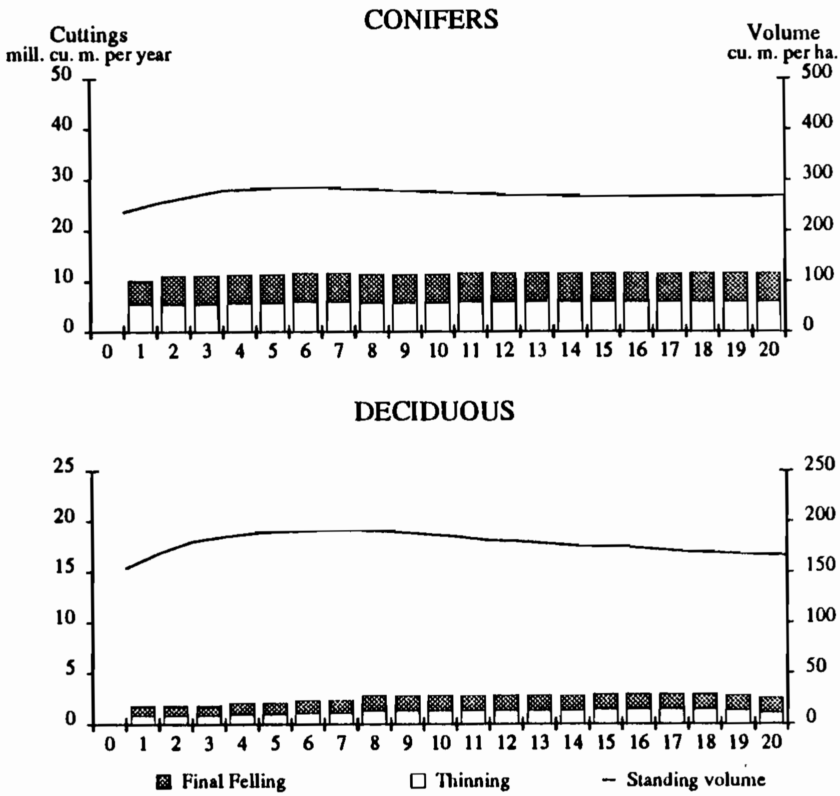


Figure B.29. Projections for total potential harvest and growing stock for coniferous and deciduous species in the CSFR under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 16 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

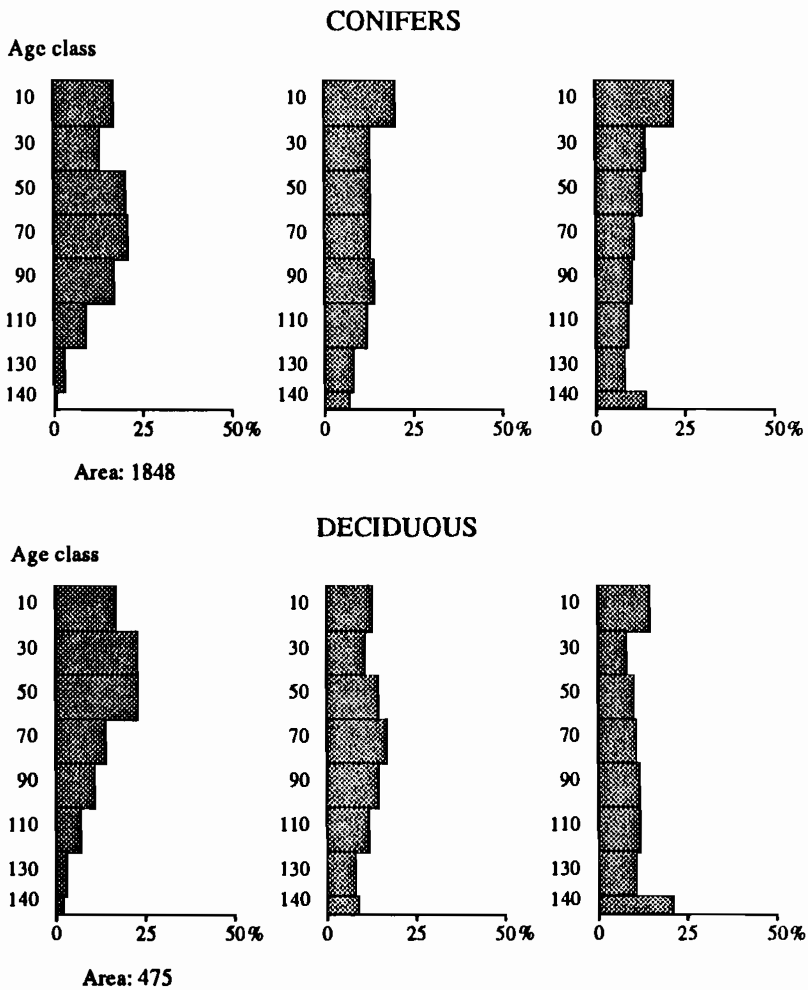


Figure B.30. Age-class distributions in the Czech Republic under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

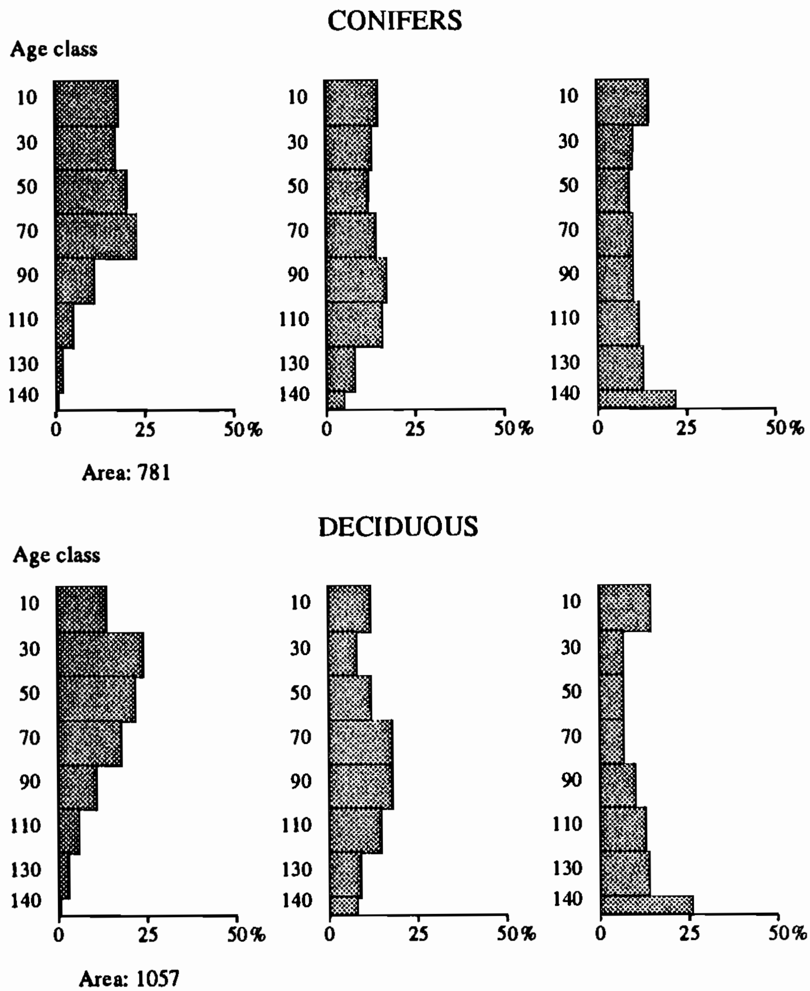


Figure B.31. Age-class distributions in the Slovak Republic under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

Denmark (Table B.5 and Figures B.32 to B.39)

Basic Scenarios

Currently, Danish forests are not structured as they might have been under handbook silviculture, as shown by the early harvest pulse under the Handbook Scenario. However, the pulse is comparatively small. In this scenario the growing stock increases steadily from 141 to 209 cubic meters per hectare. ETTS-IV harvest levels could easily be taken out with the growing stock increasing to about 265 cubic meters per hectare. Harvest levels in the Basic Forest Study Scenario are slightly higher than those of the Basic ETTS-IV Scenario, and overall growing stock reaches similar high levels. Conifers dominate the harvests, and the proportion of final cuts is higher than the proportion in the Basic Handbook Scenario. The coniferous growing stock increases in the Forest Study Scenario to 276 cubic meters per hectare, while the deciduous stock increases (mostly later in the simulation) to 245 cubic meters per hectare. Young stands dominate the initial coniferous age-class structure; the age-class structure then evens out over time. For deciduous species, the initial structure is quite even, but later becomes slightly skewed to younger and middle-age classes.

Decline Scenarios

The Handbook Decline Scenario gives higher harvest pulses in the beginning of the simulation period, after which there are lower potential harvest and growing-stock levels through the whole planning period in comparison with the basic scenario.

It is almost possible to harvest at the levels predicted by ETTS-IV in the case of the ETTS-IV Decline Scenario. However, this generates a strong decrease of the total growing stock – some 60 cubic meters per hectare lower than under basic conditions.

In the Forest Study Decline Scenario, it is not possible to reach the total growing-stock level achieved in the basic scenario. In spite of a lower growing-stock level, the potential harvest level decreases about 0.4 million cubic meters per year.

Coniferous and deciduous species are affected in a similar way by the decline.

Forest Land Expansion Scenario

The scenario for expansion of the forest landbase includes an additional 6,000 hectares per year from 1985 to 2020, bringing the forest landbase from 434,000 to 644,000 hectares. Some 80 percent of the expansion area is planted with conifers, and 20 percent is established as deciduous stands. With the objective to maintain the growing stock in this scenario as close as possible to that described in the Basic Forest Study Scenario, there is no allowable cut effect whereby the new plantations could permit higher harvests in existing mature stands immediately. The expansions generate several harvest pulses, beginning in period 6, leading eventually to an overall harvest twice that of the Basic Forest Study Scenario. Conifers make up a high proportion of the expansions, so the patterns for conifers dominantly influence the overall patterns. Notably, the proportion of thinnings in the harvest of conifers rises in this scenario compared with the Basic Forest Study Scenario. The effects of land expansion on deciduous harvests are not nearly as pronounced as those on coniferous harvests.

Growing stocks overall and especially for conifers continue to rise but to lower levels than in the Basic Forest Study Scenario. The deciduous growing stock decreases for the first half of the simulation, but rises rapidly later on (although to lower levels than in the basic scenario).

Summary

The Basic Handbook Scenario gives the highest harvest levels under basic conditions. There are no problems to remove the harvest levels suggested by ETTS-IV. Forest decline will, in these simulations, affect the future wood supply. In Denmark a strong increase of the forest landbase is expected resulting in an addition to potential harvests of 1.4 million cubic meters per year averaged over the whole simulation period.

Table B.5. Denmark.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	141–209	141–263	141–266	141–186	141–144	141–250	141–250
Fellings[b]							
Year 1	5.0	2.0	2.6	6.8	2.2	2.2	2.8
Year 40	3.5	3.5	3.5	2.6	3.4	3.1	4.8
Year 80	3.8	3.5	3.5	3.3	3.4	3.1	6.2
Coniferous							
Growing stock[a]	113–195	113–246	113–276	113–190	113–186	113–268	113–259
Fellings[b]							
Year 1	2.2	1.2	1.8	3.0	1.4	1.6	1.8
Year 40	2.6	2.6	2.4	2.0	2.6	2.3	3.3
Year 80	2.6	2.6	2.4	2.5	2.6	2.3	4.8
Deciduous							
Growing stock[a]	201–237	201–299	201–245	201–179	201–54	201–211	201–226
Fellings[b]							
Year 1	2.8	0.8	0.8	3.8	0.8	0.6	1.0
Year 40	0.9	0.9	1.1	0.6	0.8	0.8	1.5
Year 80	1.2	0.9	1.1	0.8	0.8	0.8	1.4
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	3.7	3.2	3.2	3.1	3.1	2.9	4.6
Coniferous	2.5	2.3	2.2	2.3	2.3	2.1	3.3
Deciduous	1.2	0.9	1.0	0.8	0.8	0.8	1.3
Growth (m^3 o.b./ha/yr)[c]							
Total	9.0	8.6	8.8	7.6	7.3	7.8	8.8
Coniferous	9.2	9.2	9.2	8.5	8.6	8.6	9.1
Deciduous	8.6	7.4	7.9	5.8	4.5	5.9	8.0
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	141–209	141–263	141–266	141–186	141–144	141–250	141–250
Coniferous	113–195	113–246	113–276	113–190	113–186	113–268	113–259
Deciduous	201–237	201–299	201–245	201–179	201–54	201–211	201–226

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

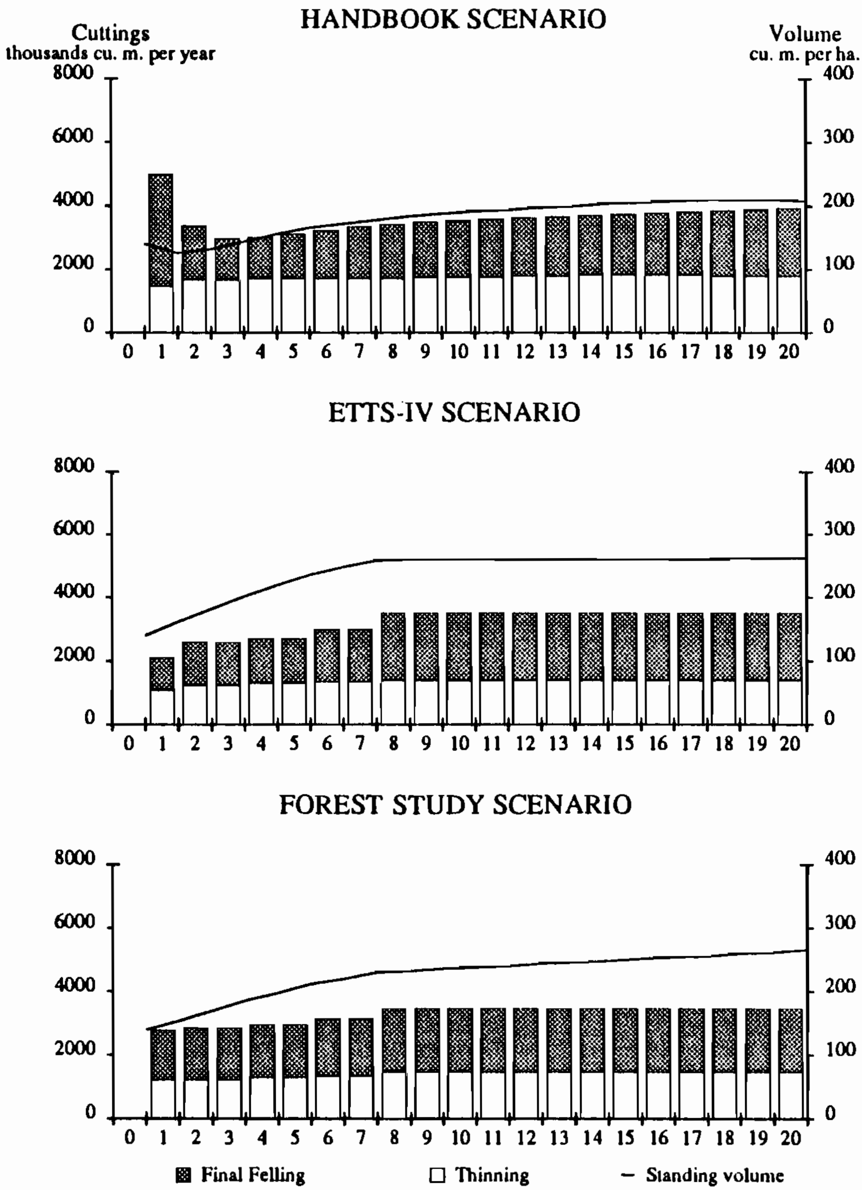


Figure B.32. Projections for total potential harvest and growing stock in Denmark under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 2 million cubic meters o.b.

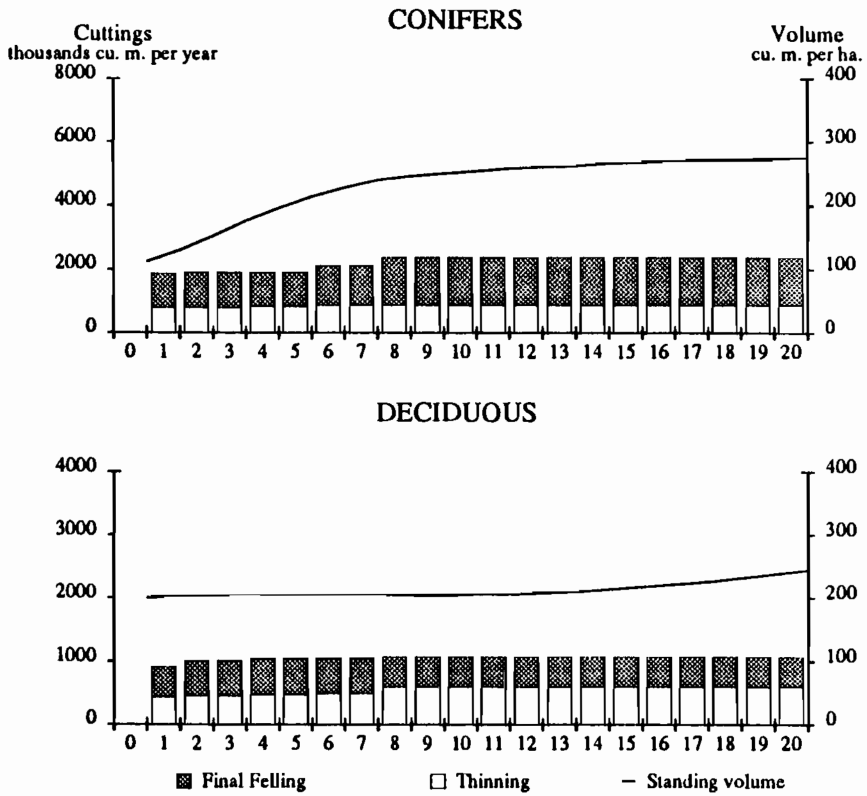


Figure B.33. Projections for total potential harvest and growing stock for coniferous and deciduous species in Denmark under the Basic Forest Study Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters each o.b.

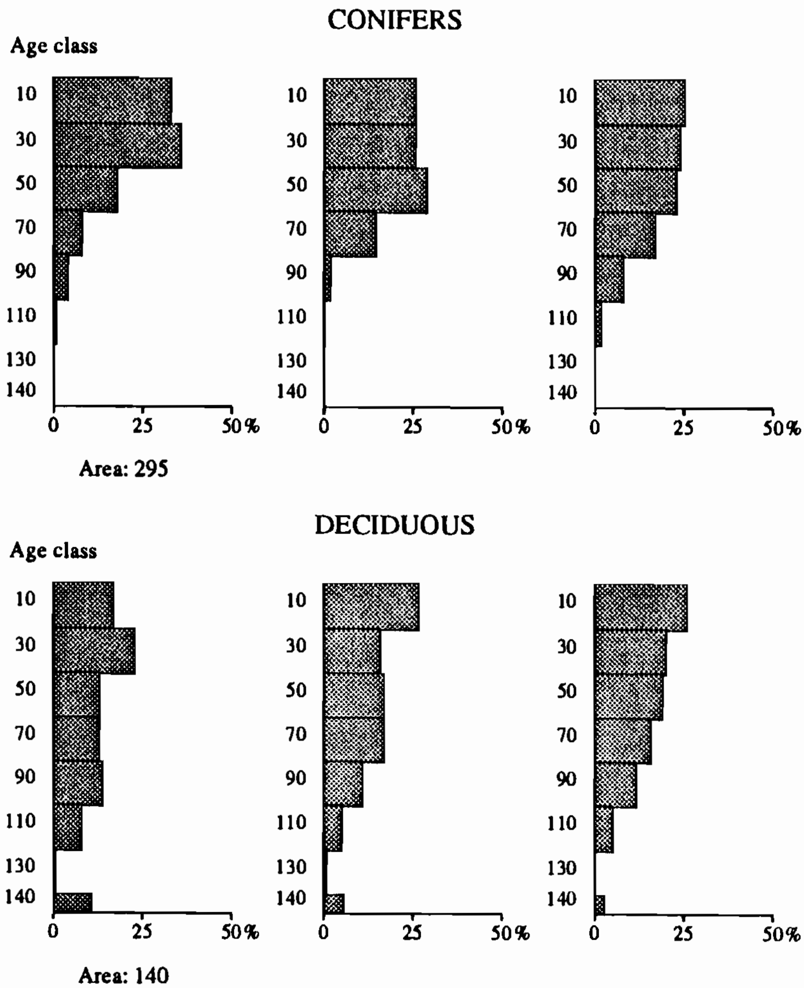


Figure B.34. Age-class distributions in Denmark under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

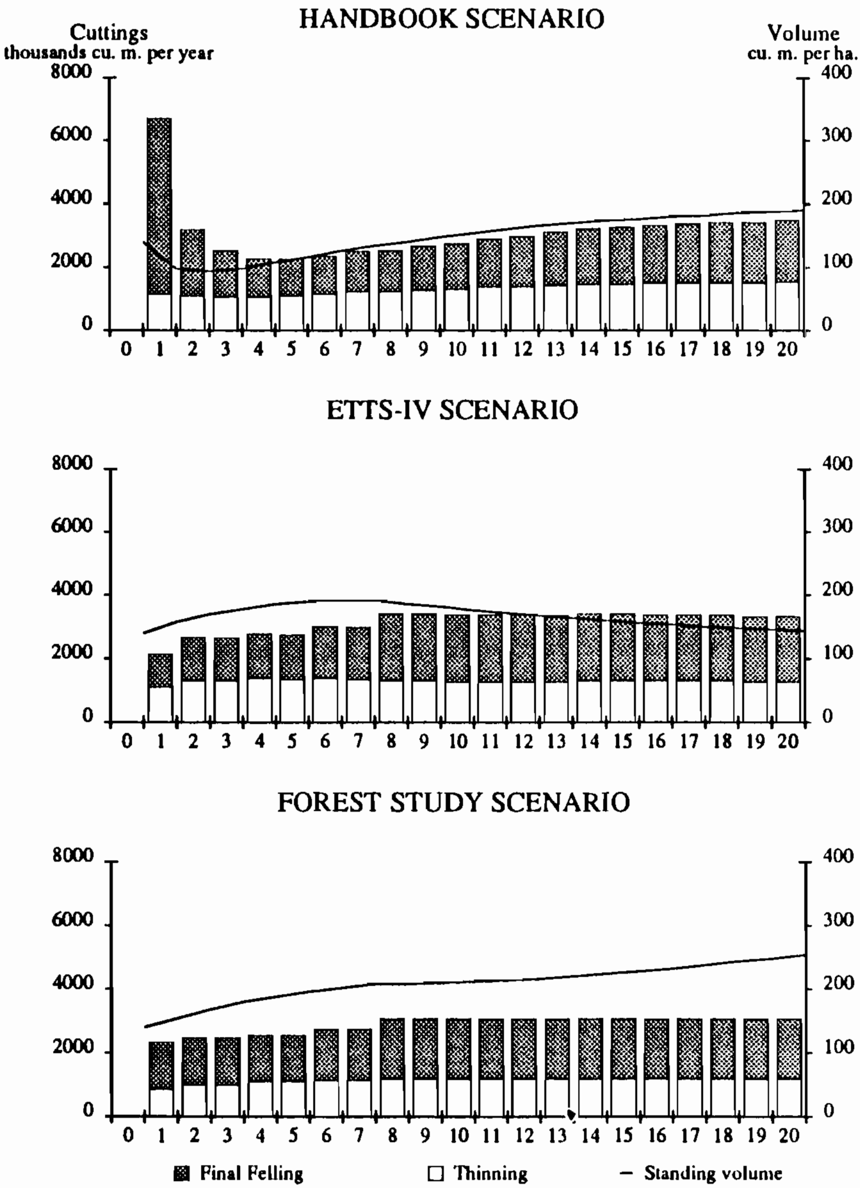


Figure B.35. Projections for total potential harvest and growing stock in Denmark under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 2 million cubic meters each o.b.

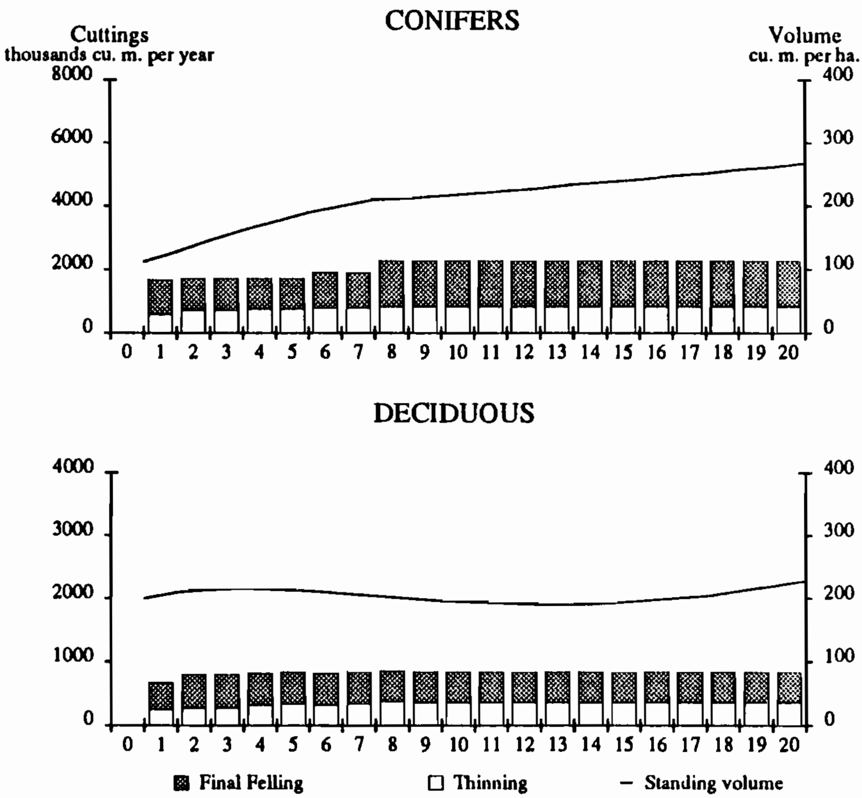


Figure B.36. Projections for total potential harvest and growing stock for coniferous and deciduous species in Denmark under the Forest Study Decline Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters each o.b.

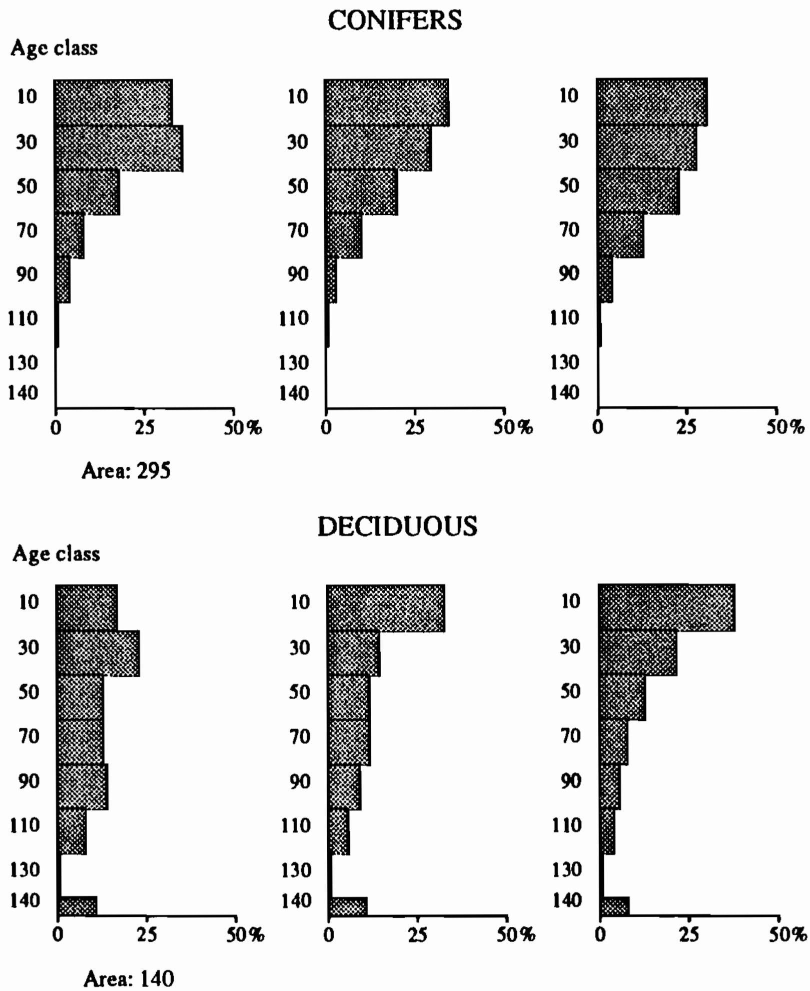


Figure B.37. Age-class distributions in Denmark under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

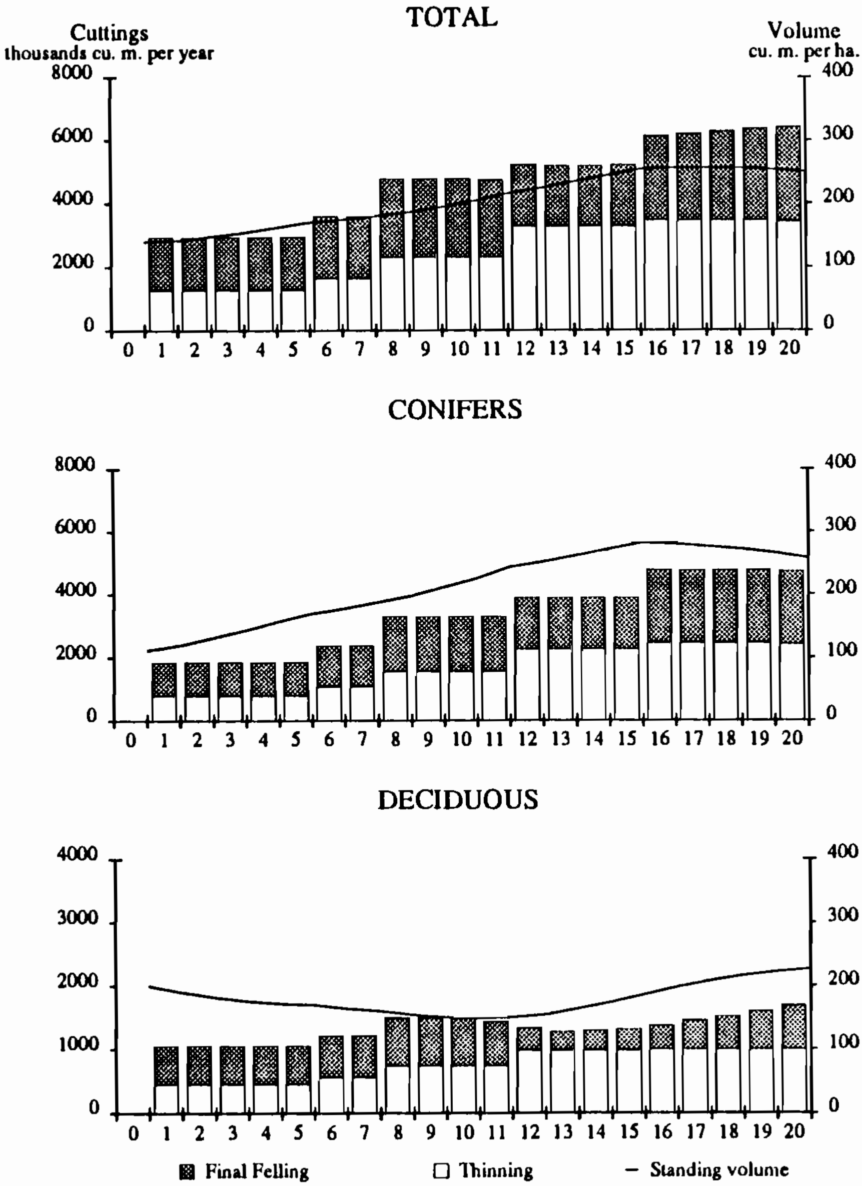


Figure B.38. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Denmark under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 2 million cubic meters o.b.; coniferous and deciduous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters each o.b.

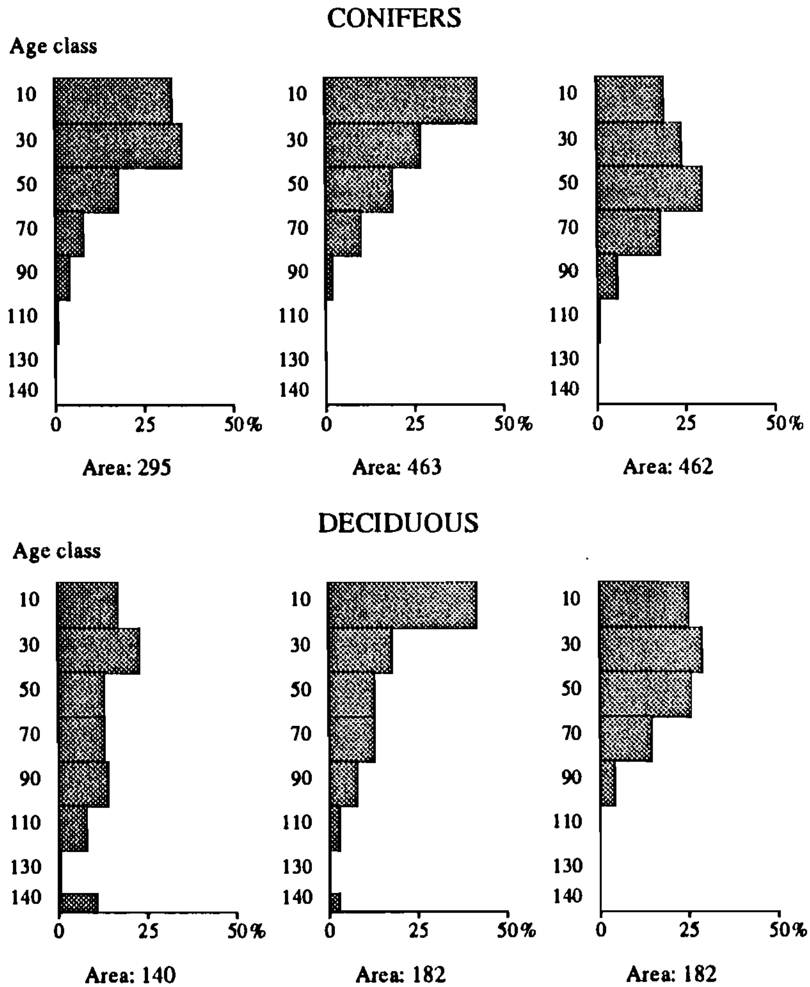


Figure B.39. Age-class distributions in Denmark under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Finland (Table B.6 and Figures B.40 to B.45)

Basic Scenarios

The Basic Handbook Scenario results in strong harvests in the early periods of the simulation, indicating a forest structure that does not match the structure that would have been in place today if ideal silviculture had been implemented. ETTS-IV harvest levels can indeed be sustained for 100 years, but the growing stock is forced lower than in the Basic Handbook Scenario. Thus, the ETTS-IV harvest levels are close to the biological potential. The Basic Forest Study Scenario moves harvests over the first 35 years to slightly lower levels than the ETTS-IV levels, achieving a nondecreasing growing stock over 100 years. There are rapid initial increases in the growing stock for both coniferous (which significantly dominates the overall harvest picture) and deciduous forests. For both coniferous and deciduous age-class structures, the final configurations are concentrated in the younger and middle classes, but the initial structures were not similar; the coniferous forest was fairly evenly distributed across all classes while the deciduous forest was heavily dominated by middle-age classes.

Decline Scenarios

The Handbook Decline Scenario causes a dramatic harvest pulse in the first period. For the rest of the simulation period, the potential total harvest level is lower in the decline case in comparison with the basic scenario. The total growing stock is also lower in comparison with the basic scenario. It is possible to take out the harvest level indicated by ETTS-IV even in the decline situation, but it causes a decline in the total growing stock over time.

According to the Forest Study Decline Scenario there is a possibility to follow the same growing-stock development as in the basic scenario, but the potential total harvest level will be lower by 4.5 million cubic meters per year. The strongest effects take place in coniferous species because they dominate the forests in Finland.

Summary

Concerning potential harvest levels there is a good correspondence among the different basic scenarios. Forest decline will have a rather strong influence on potential harvests, with decreases of about 4.5 million cubic meters per year over 100 years.

Table B.6. Finland.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	86–122	86–113	86–125	86–104	86–94	86–123	
Fellings[b]							
Year 1	117.8	55.6	59.0	147.6	55.6	44.6	
Year 40	46.9	62.6	62.6	45.8	62.4	58.3	
Year 80	62.4	62.1	62.6	58.9	61.7	58.2	
Coniferous							
Growing stock[a]	86–124	86–121	86–123	86–108	86–100	86–121	
Fellings[b]							
Year 1	108.6	45.2	45.2	136.8	45.2	41.4	
Year 40	42.4	57.9	57.9	41.3	58.1	54.3	
Year 80	57.2	57.9	57.9	54.6	57.9	54.2	
Deciduous							
Growing stock[a]	83–96	83–25	83–150	83–64	83–23	83–138	
Fellings[b]							
Year 1	9.2	10.4	3.8	10.8	10.4	3.2	
Year 40	4.5	4.7	4.7	4.5	4.3	4.0	
Year 80	5.2	4.2	4.7	4.3	3.8	4.0	
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	59.3	60.3	59.0	58.5	60.0	54.6	
Coniferous	54.0	55.0	54.5	53.5	55.0	50.8	
Deciduous	5.3	5.3	4.5	5.0	5.0	3.8	
Growth (m^3 o.b./ha/yr)[c]							
Total	3.4	3.4	3.4	3.2	3.2	3.2	
Coniferous	3.4	3.4	3.4	3.2	3.2	3.2	
Deciduous	3.5	2.8	3.6	3.0	2.6	3.0	
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	86–122	86–113	86–125	86–104	86–94	86–123	
Coniferous	86–124	86–121	86–123	86–108	86–100	86–121	
Deciduous	83–96	83–25	83–150	83–64	83–23	83–138	

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

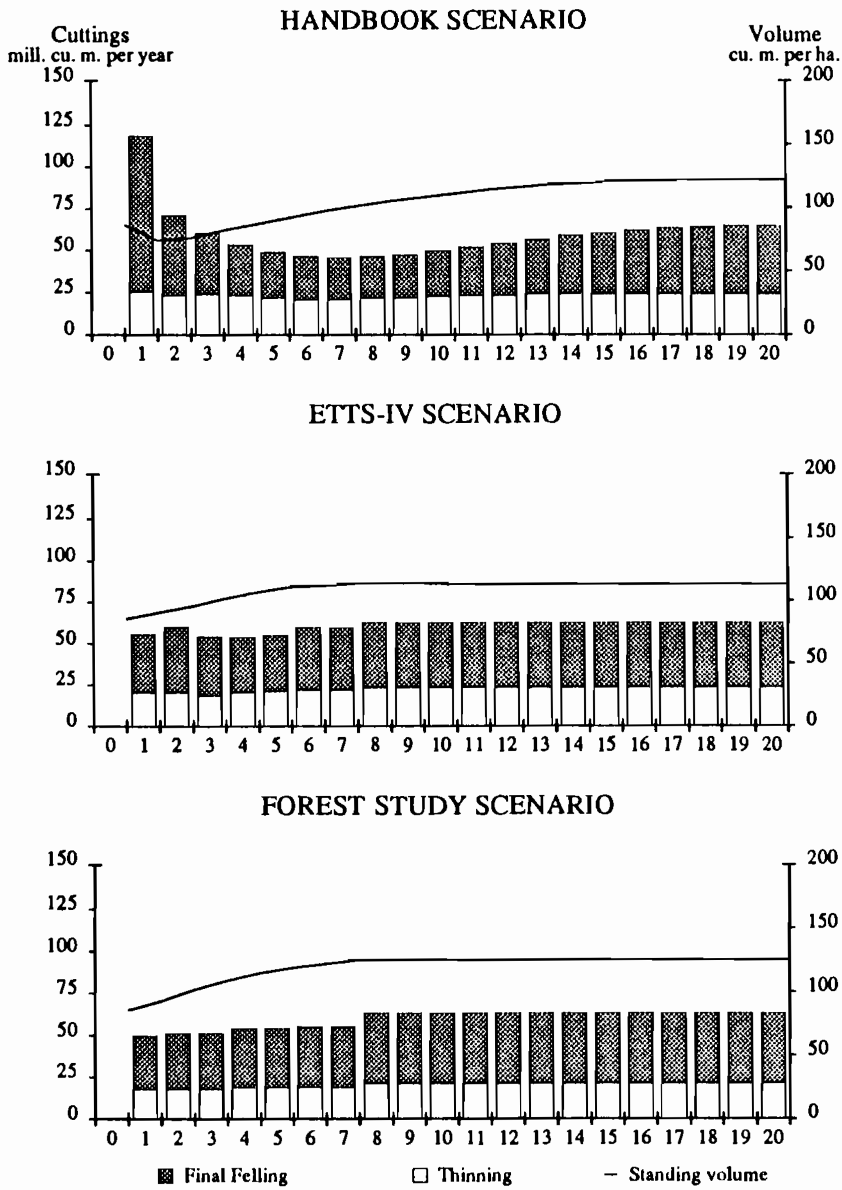


Figure B.40. Projections for total potential harvest and growing stock in Finland under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 56 million cubic meters o.b.

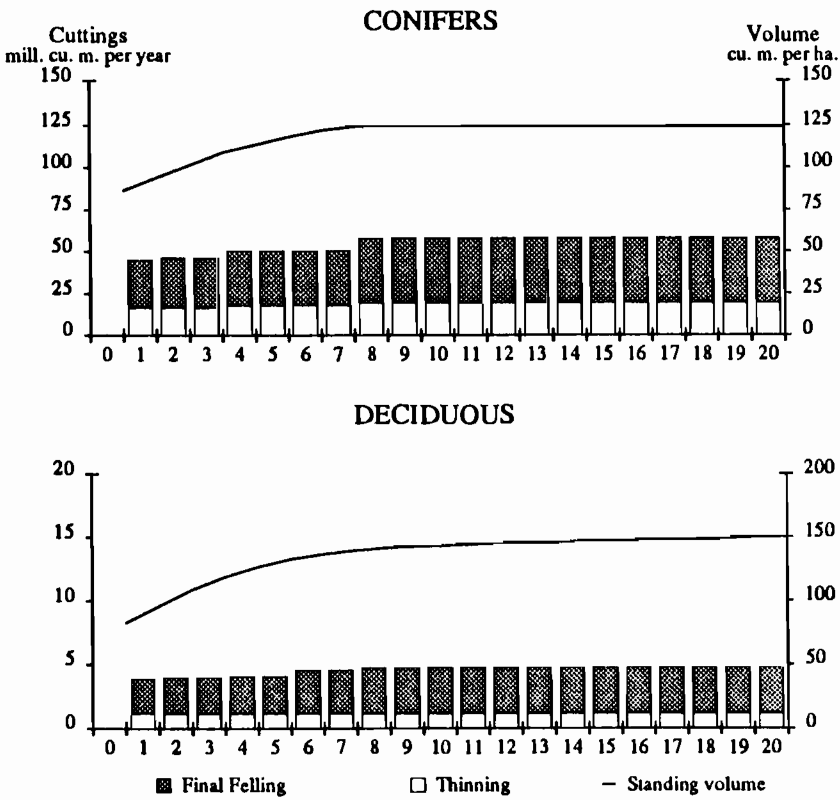


Figure B.41. Projections for total potential harvest and growing stock for coniferous and deciduous species in Finland under the Basic Forest Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 45 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 11 million cubic meters o.b.

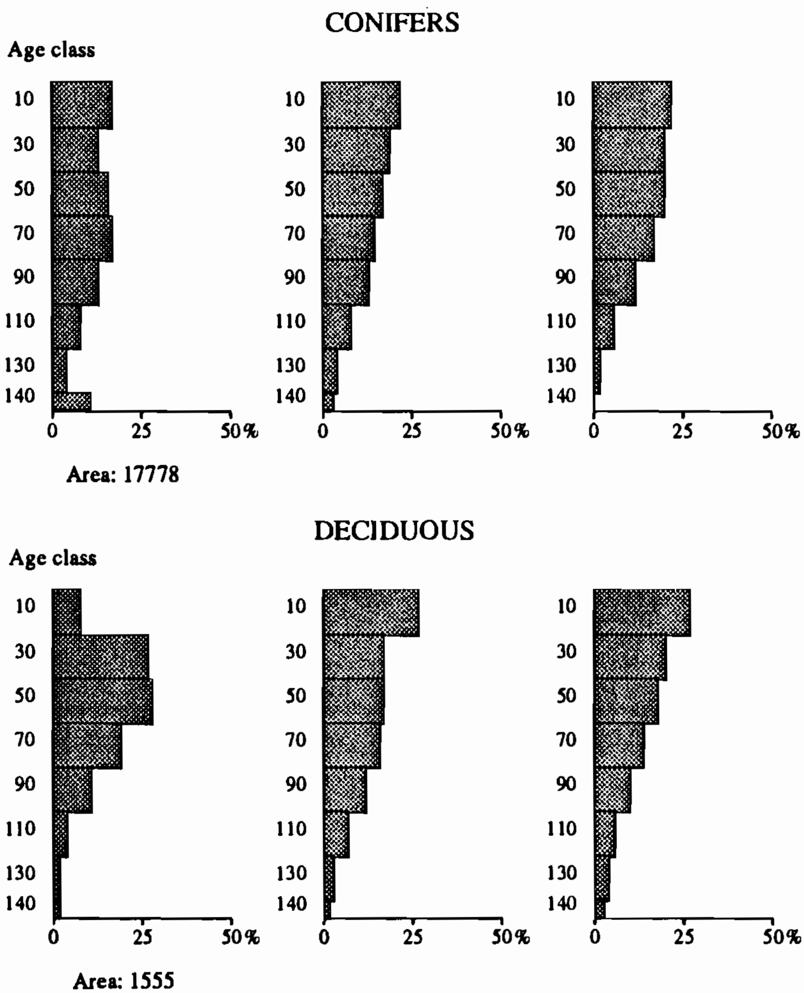


Figure B.42. Age-class distributions in Finland under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

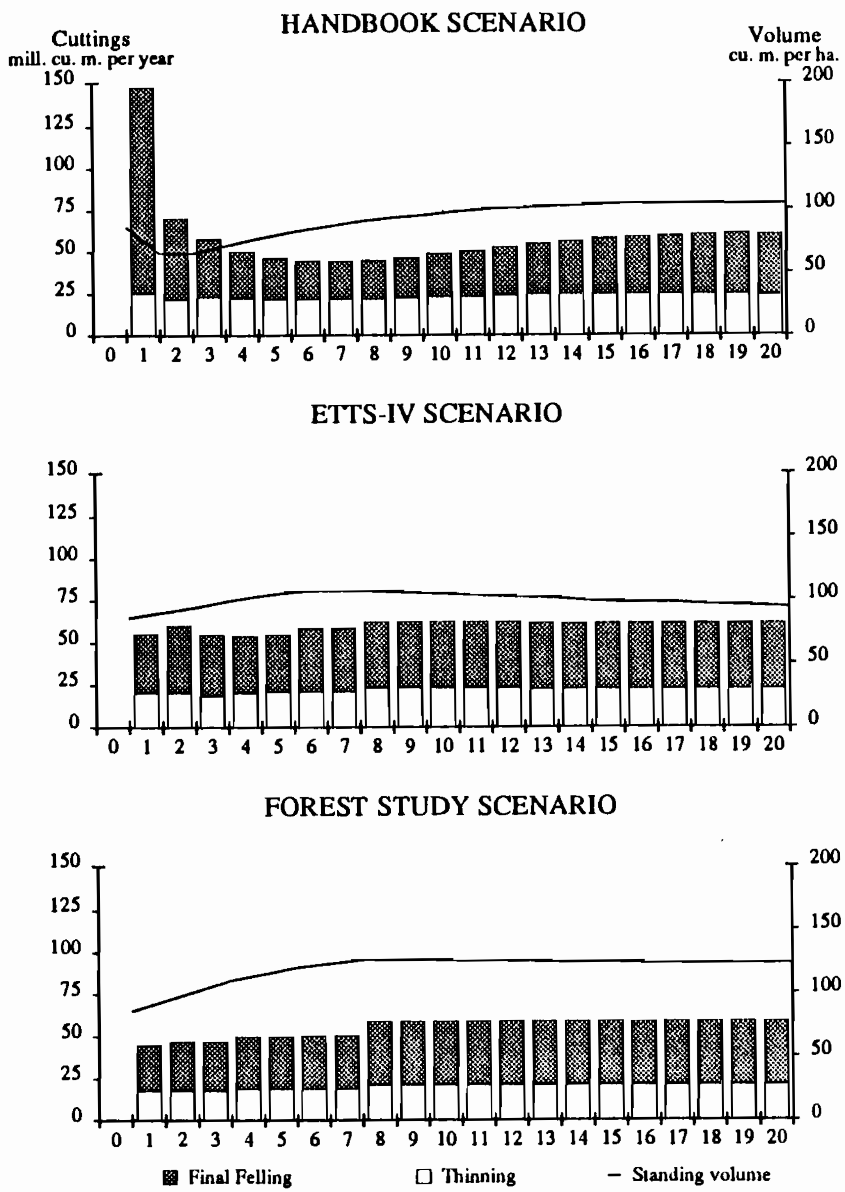


Figure B.43. Projections for total potential harvest and growing stock in Finland under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 56 million cubic meters o.b.

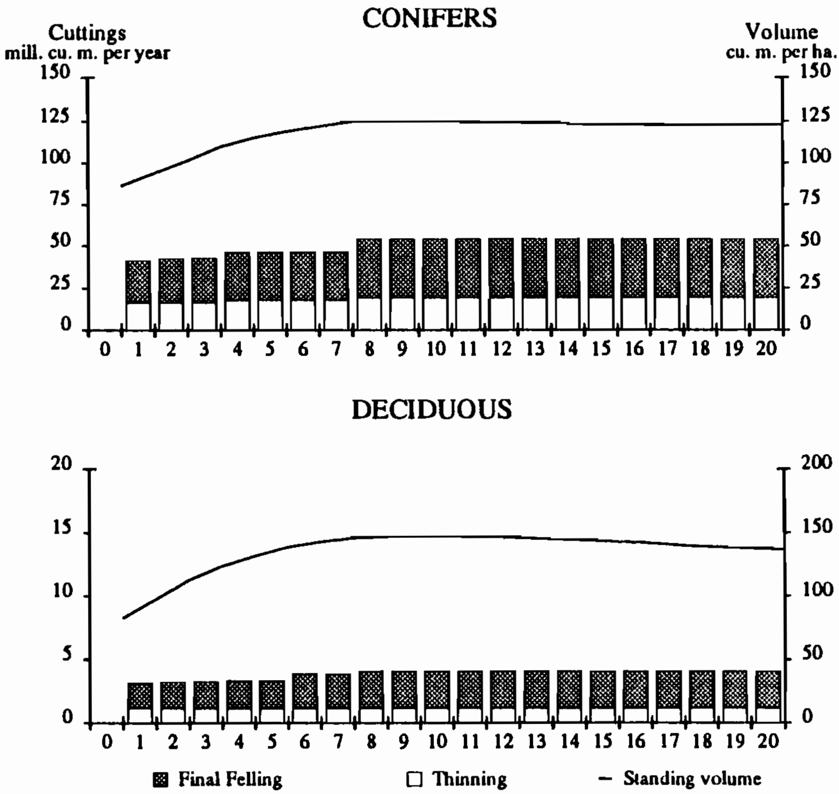


Figure B.44. Projections for total potential harvest and growing stock for coniferous and deciduous species in Finland under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 45 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 11 million cubic meters o.b.

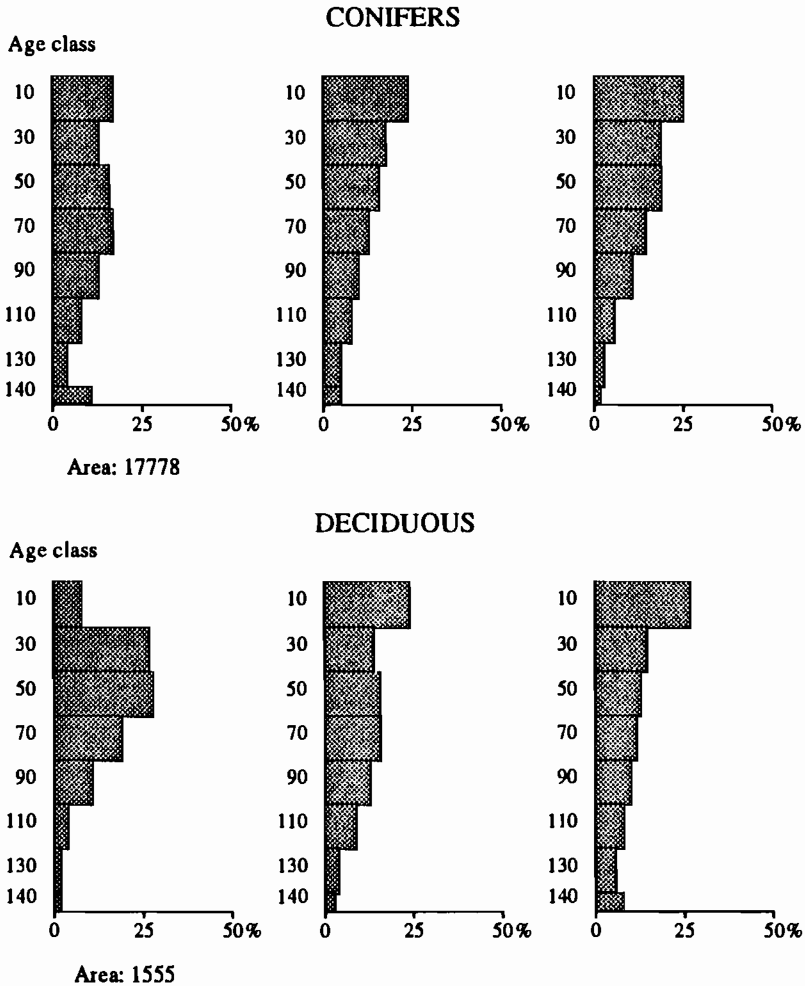


Figure B.45. Age-class distributions in Finland under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

France (Table B.7 and Figures B.46 to B.54)

Basic Scenarios

Presently, the forests in France are not structurally compatible at the present time with handbook silviculture. The Basic Handbook Scenario results in an early harvest pulse, with growing stock increasing during the simulation from 120 to 156 cubic meter per hectare. ETTS-IV harvest levels cannot be maintained throughout the simulation period. Growing stock in this scenario can be maintained at about 120 cubic meter per hectare. The Basic Forest Study Scenario imposes a harvest level less than that of ETTS-IV for the first 50 years. Overall growing stock under this scenario increases to 133 cubic meter per hectare. This is achieved with higher thinning levels than in handbook silviculture. Notable patterns in growing-stock development for the different forest types include steady increases for conifers (to about 180 cubic meter per hectare), where the bulk of the harvest is concentrated; an unstable pattern for deciduous types; and stability for coppice types. The unstable pattern in deciduous forests comes from a rapid adjustment, attributable to fairly high harvest levels 20 to 50 years into the simulation, from an age-class structure of mostly middle-aged and old stands to one made up of young stands. A further retreat from ETTS-IV harvest levels would be necessary to bring the harvest levels and growing stock into stable patterns over time.

Decline Scenarios

In the Handbook Decline Scenario, the initial harvest pulse is strengthened for about 20 years compared with the Basic Handbook Scenario. After this period the total potential harvest level will be lower than that of the basic scenario. At the end of the simulation period, the difference in potential harvest levels is about 4 million cubic meters per year. An increasing development of the growing stock can be seen in the decline scenario but at a lower level in comparison with the basic scenario.

In the ETTS-IV Decline Scenario, it is only possible to reach ETTS-IV harvest levels during the first 40 years. The growing stock also decreases over time to lower levels than in the basic scenario.

In the Forest Study Decline Scenario it is possible to reach nearly the same growing-stock development as that in the Basic Forest Study Scenario. During the first 65 years of the simulation period, the potential harvest level is lower in the decline scenario. The harvest potential recovers in the decline simulation. Both thinnings and especially final fellings will be reduced in the decline scenario.

In the Forest Study Decline Scenario the growing stock of the basic scenario is not reached for conifers. In addition, there are no possibilities during the first 45 years to reach the harvest levels identified in the basic scenario. Deciduous species reach a slightly lower level of growing stock in the decline scenario, with a decreasing development over time. In spite of the declining growing stock, the potential harvest level also decreases for the first 70 years of the simulation period. At the end of the simulation period the deciduous harvest level recovers to a higher potential than that in the basic scenario. The coppice growing stock in the decline scenario has the same flat and even development as in the basic scenario, with slightly lower potential harvest.

Forest Land Expansion Scenario

After about 40 years, the expanded forest landbase generates a strong increase in total harvest levels. For the remainder of the simulation, harvest level is some 5 to 10 million cubic meters higher than in the basic scenario. For coniferous species the first increase in harvest level comes after about 20 years and the second after 40 years. For deciduous species a slight increase in harvesting starts after about 40 years and continues to increase through the rest of the period, in contrast with a decrease of the deciduous harvest level at the end of the planning period in the Basic Forest Study Scenario.

The increased forest landbase does not change this pattern, although the growing stock is lower for coniferous species and higher for deciduous species than in the basic scenario. Instead of the decrease of the deciduous growing stock over time in the basic scenario there is a slight increase. Coppice is not planted in the expanded forest land.

Summary

There is a good correspondence concerning harvest levels under the three basic scenarios. It is not fully possible to keep the ETTS-IV harvest levels over 100 years. The effects of the forest decline on potential harvests are about 3.5 million cubic meters per year over 100 years. A strong increase of new forest land could generate an additional potential harvest of about 5 million cubic meters per year over 100 years.

Table B.7. France.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	120–156	120–120	120–133	122–146	122–109	122–129	120–128
Fellings[b]							
Year 1	67.4	44.1	44.2	73.8	43.6	38.3	46.6
Year 40	55.0	62.6	60.9	48.3	63.4	53.6	67.6
Year 80	59.8	55.4	55.0	52.6	46.8	57.0	64.4
Coniferous							
Growing stock[a]	145–214	145–144	145–181	146–197	146–126	146–159	145–138
Fellings[b]							
Year 1	34.6	21.2	23.2	37.2	21.2	20.8	25.2
Year 40	31.5	36.3	32.5	28.1	36.2	29.4	41.4
Year 80	33.9	32.3	32.6	30.7	26.1	32.6	36.9
Deciduous							
Growing stock[a]	172–190	172–156	172–163	172–163	172–125	172–148	172–185
Fellings[b]							
Year 1	22.2	10.6	9.6	25.6	10.6	7.6	9.9
Year 40	9.0	13.7	12.8	7.8	13.7	10.1	10.6
Year 80	10.2	8.6	8.3	7.8	7.2	10.2	13.4
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	56.2	57.0	56.7	52.1	53.1	53.2	61.8
Coniferous	31.2	31.7	31.2	29.3	29.6	30.0	35.8
Deciduous	10.5	10.9	10.8	9.5	10.1	9.6	11.3
Coppice	14.5	14.4	14.7	13.3	13.4	13.6	14.7
Growth (m^3 o.b./ha/yr)[c]							
Total	4.6	4.3	4.4	4.2	3.9	4.1	4.1
Coniferous	8.1	7.6	7.8	7.5	6.9	7.3	6.0
Deciduous	4.7	4.5	4.6	4.0	3.9	3.9	4.1
Coppice	2.4	2.2	2.2	2.2	2.0	2.2	2.2
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	120–156	120–120	120–133	122–146	122–109	122–129	120–128
Coniferous	145–214	145–144	145–181	146–197	146–126	146–159	145–138
Deciduous	172–190	172–156	172–163	172–163	172–125	172–148	172–185
Coppice	87–108	87–92	87–92	89–108	89–93	89–103	87–92

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

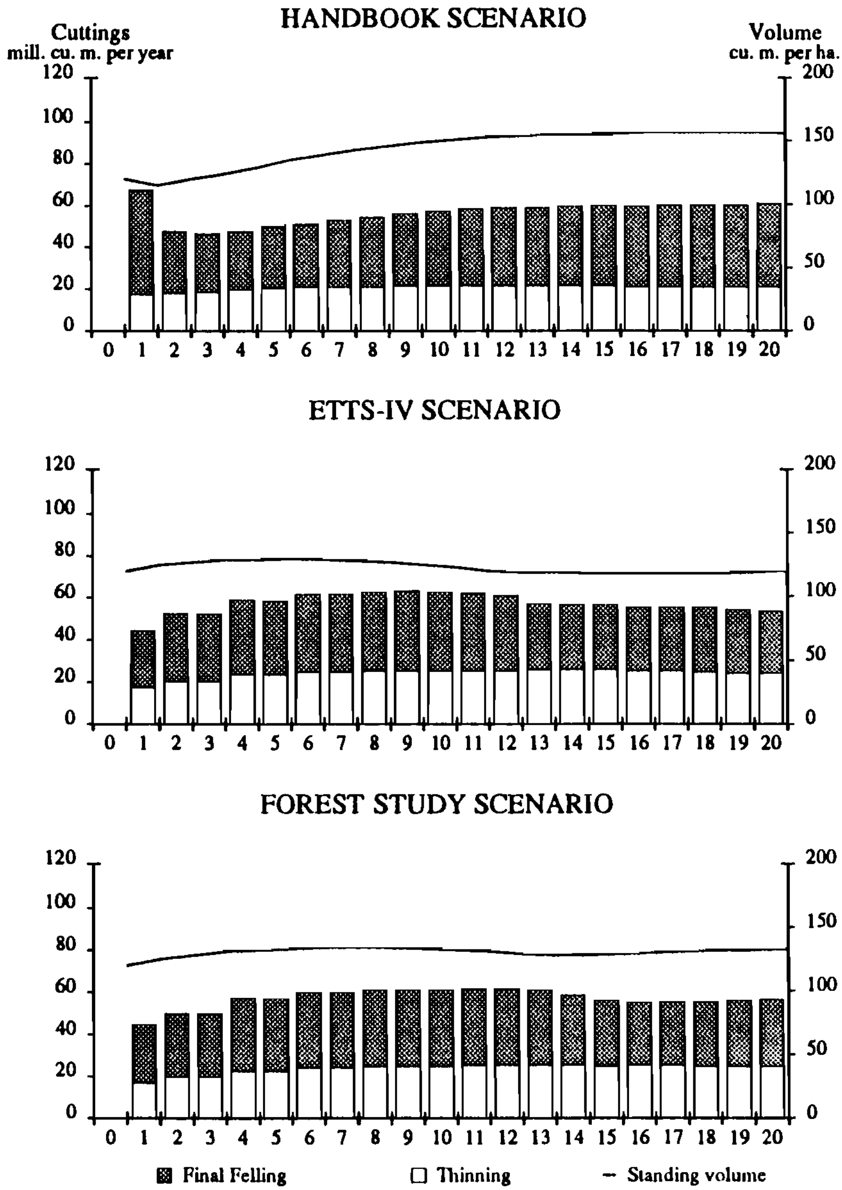


Figure B.46. Projections for total potential harvest and growing stock in France under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 41 million cubic meters o.b.

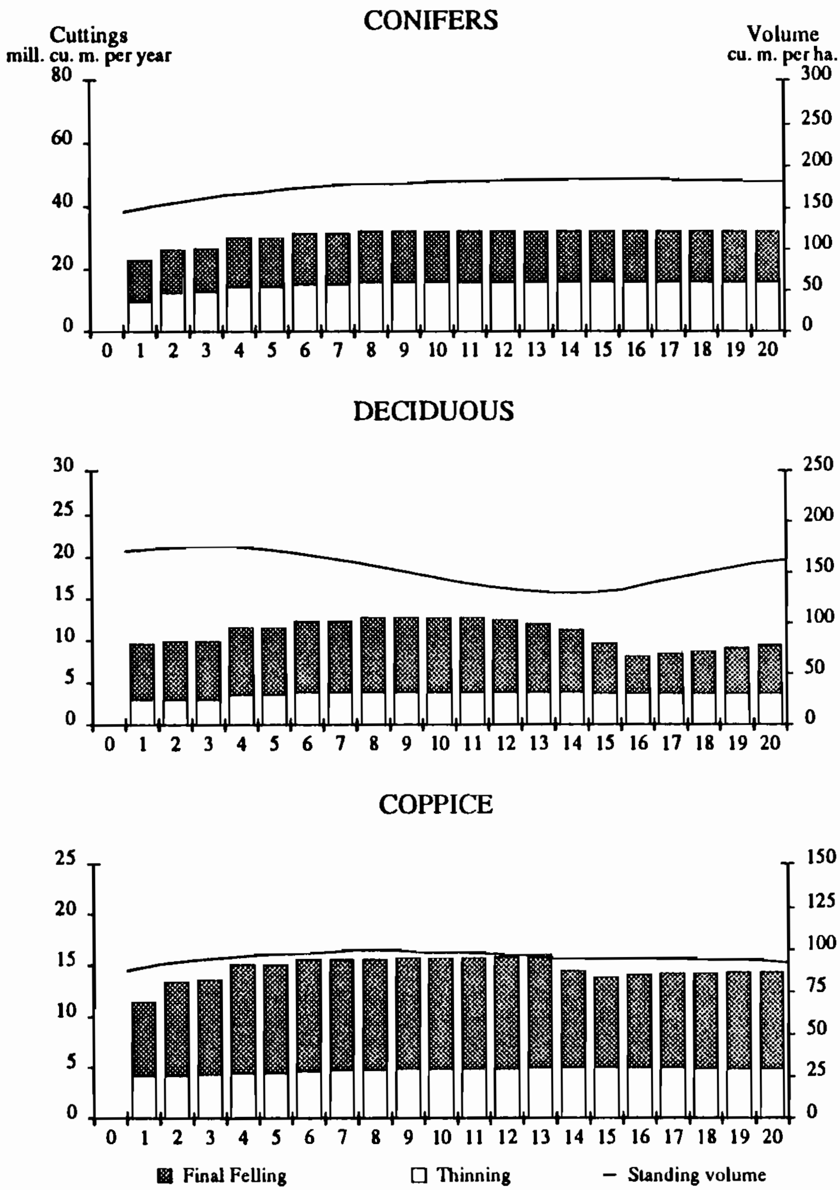


Figure B.47. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in France under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 19 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 22 million cubic meters o.b.

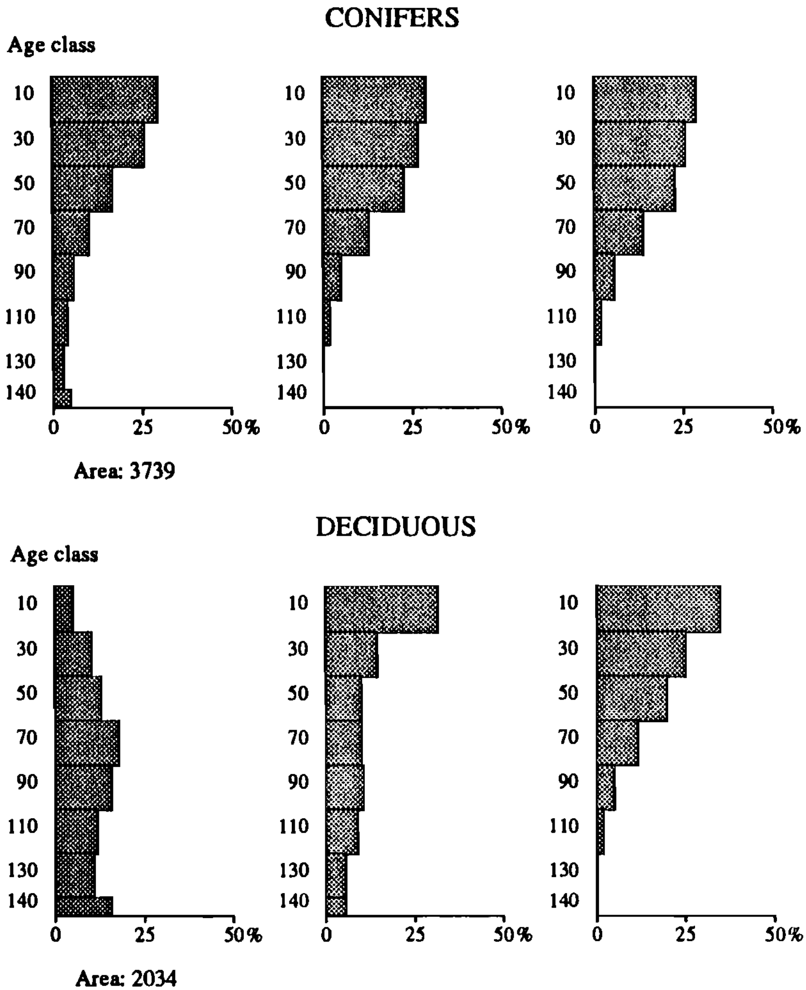


Figure B.48. Age-class distributions in France under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

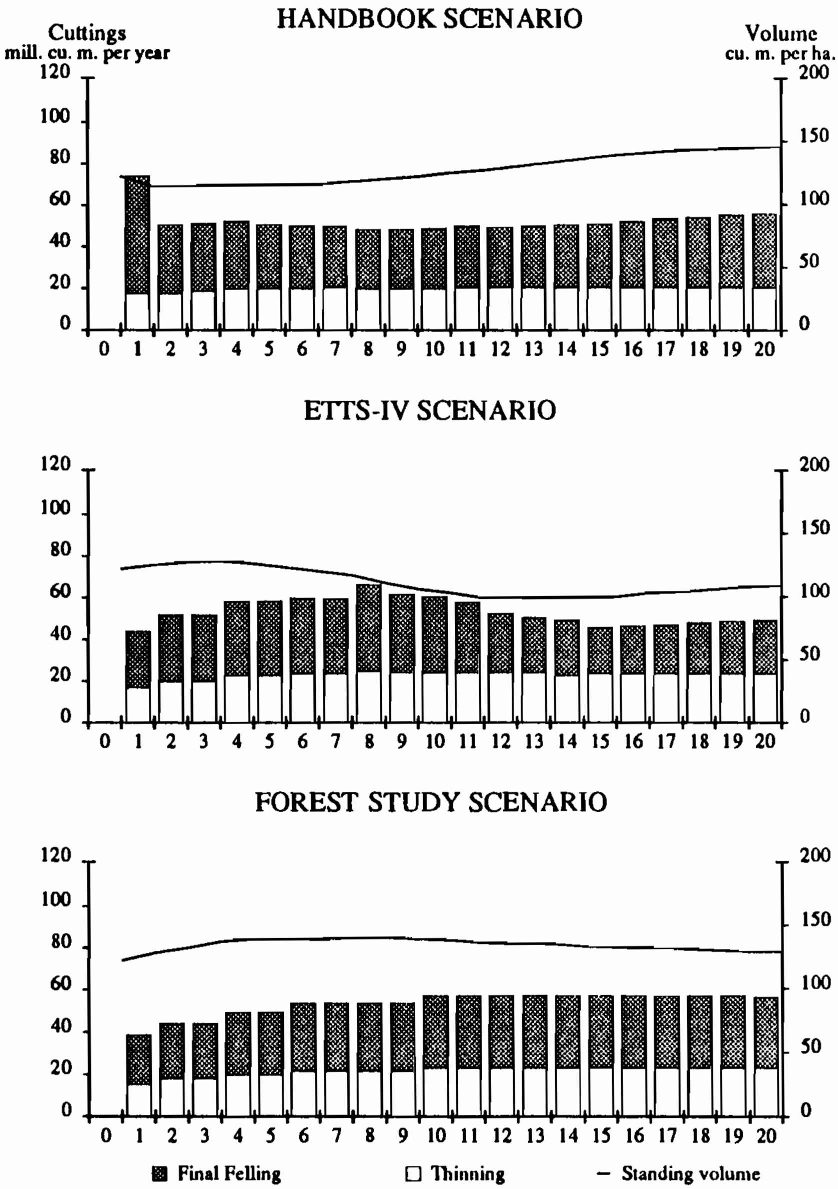


Figure B.49. Projections for total potential harvest and growing stock in France under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 41 million cubic meters o.b.

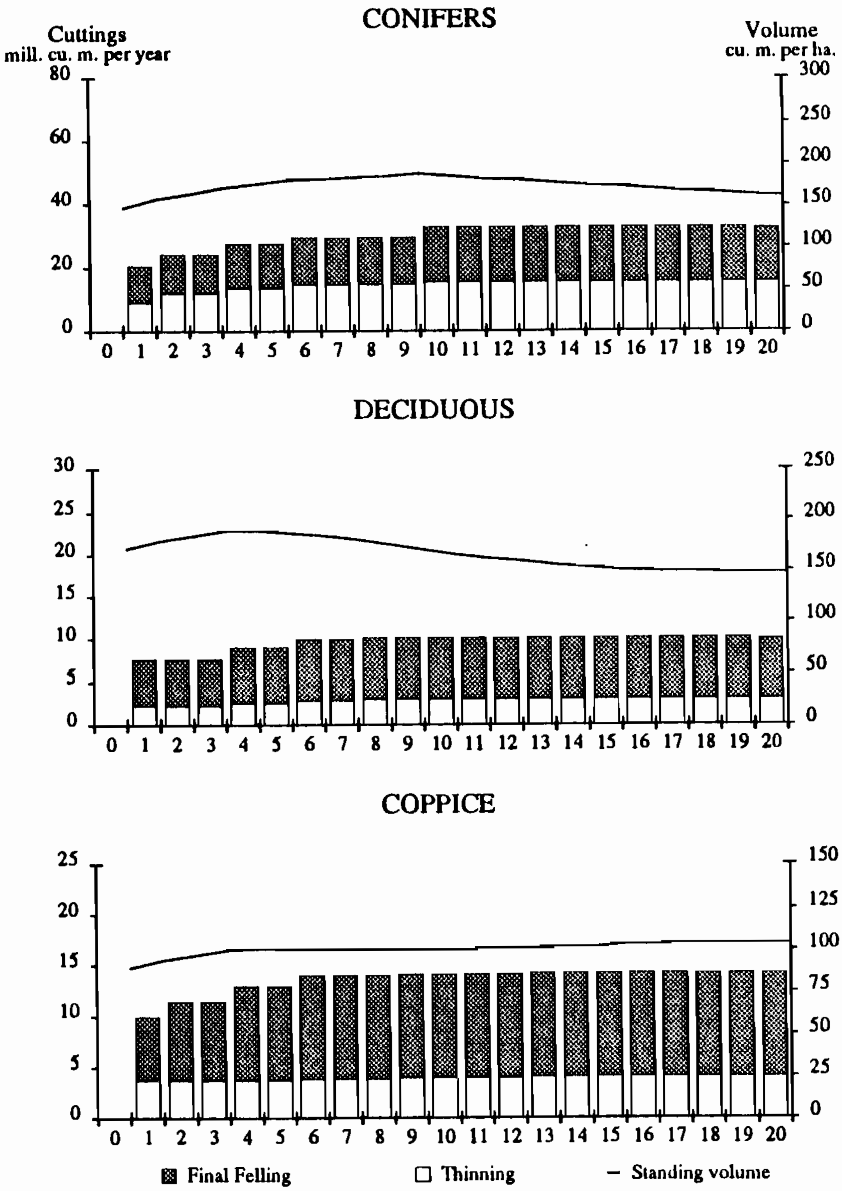


Figure B.50. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in France under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 19 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 22 million cubic meters o.b.

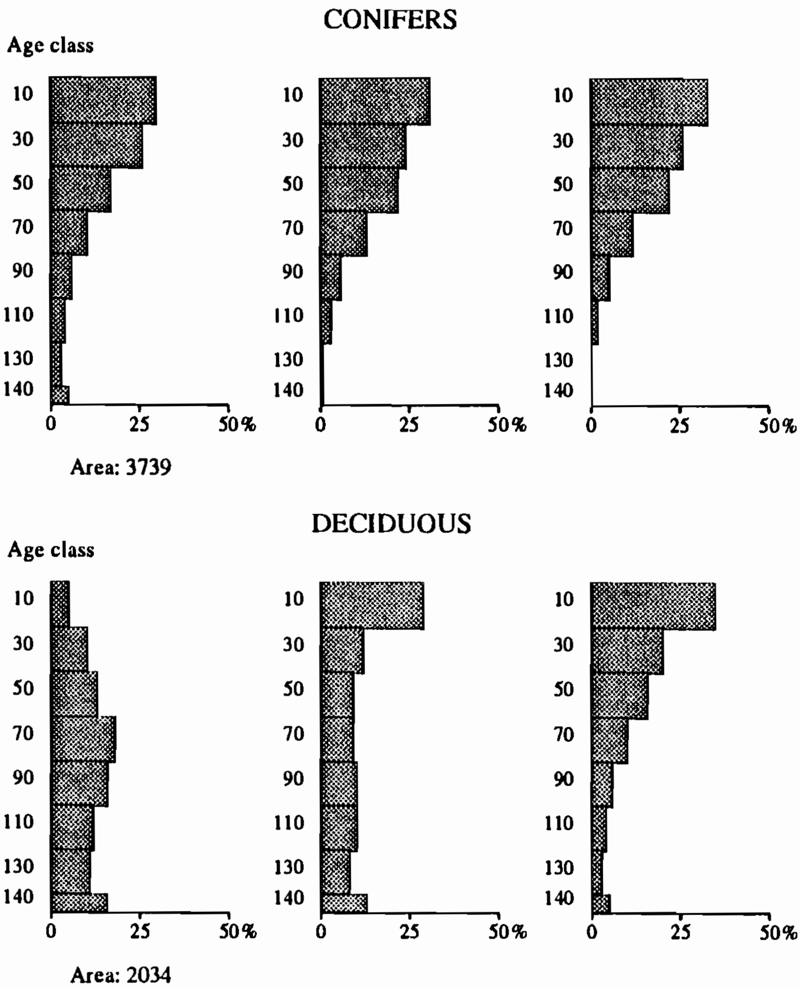


Figure B.51. Age-class distributions in France under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

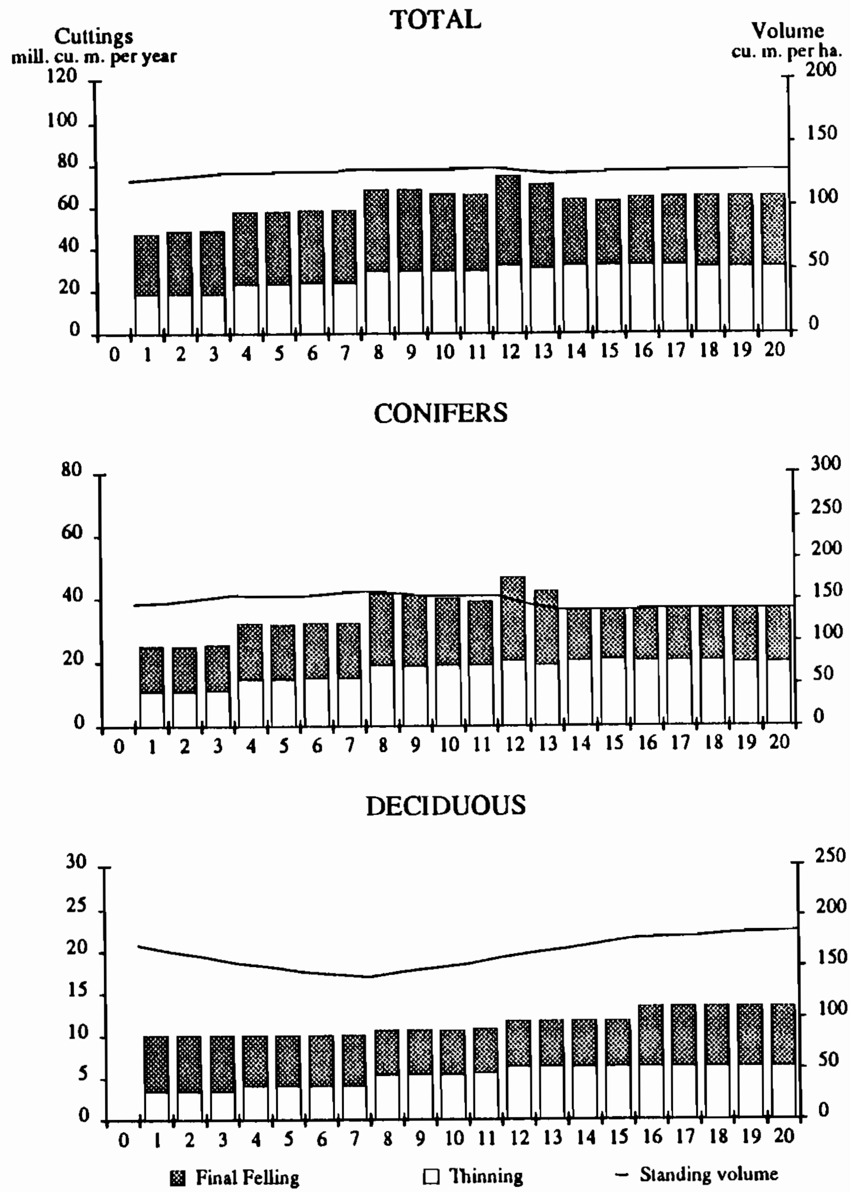


Figure B.52. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in France under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 41 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 19 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 22 million cubic meters o.b.

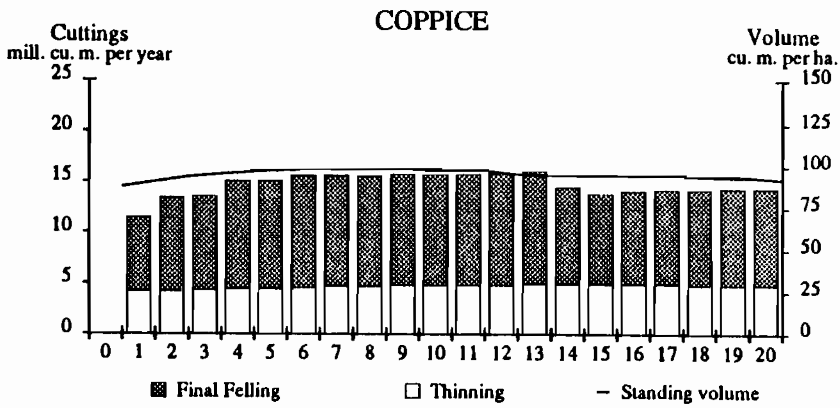


Figure B.53. Projections for potential harvest and growing stock of coppice in France under the Forest Land Expansion Scenario.

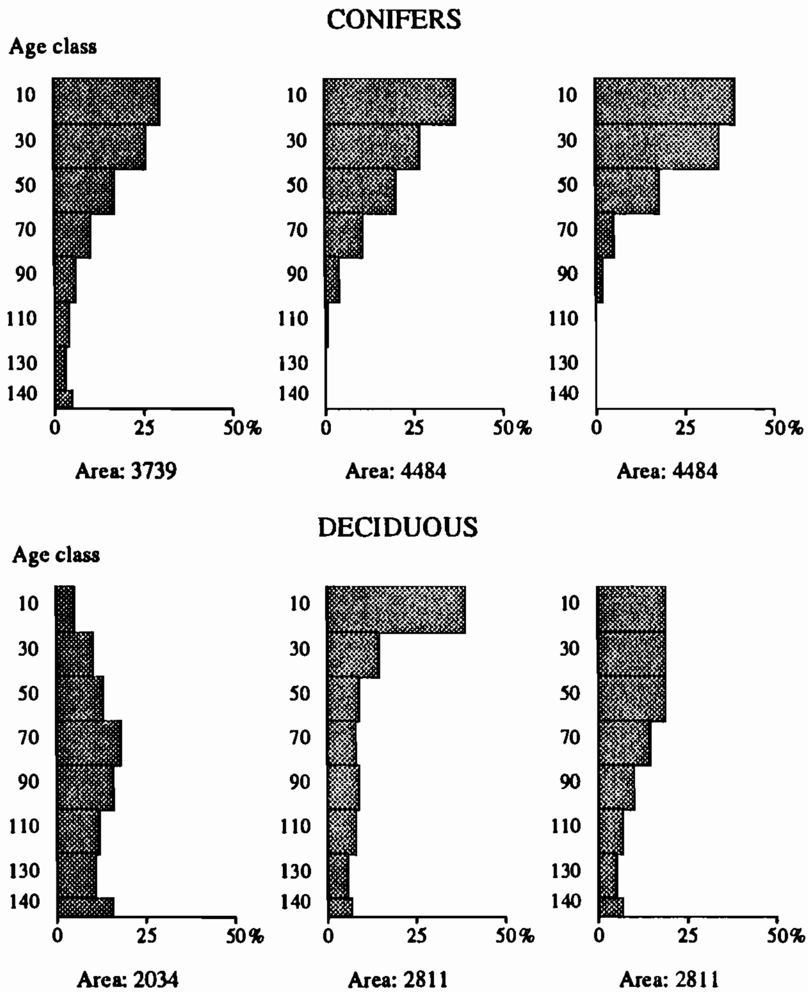


Figure B.54. Age-class distributions in France under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

FRG (Table B.8 and Figures B.55 to B.62)

Basic Scenarios

There is a strong discord between current structure of the FRG forests and a structure that would have evolved under strict handbook silviculture. This is evident in the huge early harvest pulse in the Basic Handbook Scenario. In this scenario, the growing stock remains high at about 270 cubic meters per hectare. ETTS-IV harvest levels are easily taken out, resulting in strong increases in the growing stock up to about 340 cubic meters per hectare. The sustainable harvest level of the Basic Forest Study Scenario is 10.5 million cubic meters per year higher than those of the Basic ETTS-IV Scenario. Overall growing stock stabilizes at 241 cubic meters per hectare. Harvests are concentrated in coniferous forests, where final cuts dominate. The coniferous growing stock is stable at about 260 cubic meters per hectare.

The initial coniferous age-class structure is fairly even but stretches up to 140-year-old stands. By the end of the simulation, only stands up to an age of 100 years can be found. In deciduous forests, final cuts account for about half of the annual harvest, and the growing stock declines slightly. The initial deciduous age-class structure is fairly even, but later on young and middle-aged stands dominate the age-class structure.

Decline Scenarios

The Handbook Decline Scenario generates harvest pulses that are much higher during the first 25 years, in comparison with the basic scenario, after which the potential harvest level is much lower. The total growing stock is also much lower in the decline scenario.

It is nearly possible to maintain the same harvest level in the ETTS-IV Decline Scenario as in the basic scenario. There is a slight decrease in the harvest level at the end of the simulation period. However, with ETTS-IV harvest levels there is a dramatic decrease in the total growing stock by about 120 cubic meters per hectare at the end of the simulation period in comparison with the basic scenario.

According to the Forest Study Decline Scenario, it is possible to keep the same growing-stock development as in the basic scenario, but the even-flow harvest level is lower – by about 12 million cubic meters per year.

Both coniferous and deciduous species will be heavily influenced by forest decline. The decreased harvest potential is mainly in final fellings. Thinnings must be maintained to keep up the vitality of existing forests.

Forest Land Expansion Scenario

The scenario for expansion of the forest landbase is an additional 27,500 hectares per year from 1985 to 2020, bringing the landbase from 7.5 to 8.5 million hectares. About 80 percent of the expansion area is planted with conifers, and 20 percent is established as deciduous stands. With the objective to maintain growing stock (imposed on both the Basic Forest Study Scenario and the Forest Land Expansion Scenario), there is no immediate allowable cut effect. Thus, the first noticeable increase in the harvest level occurs about 35 years into the simulation (period 8), with an overall harvest increase of about 2 million cubic meters per year. A second significant increase is in period 12 (55 years), with an additional several million cubic meters per year. Because most of the forest land expansions are established with conifers, the coniferous group experiences the strongest harvest increase. In the Forest Land Expansion Scenario, the total growing stock climbs slightly, whereas in the Basic Forest Study Scenario, it decreases slowly. This is mainly due to increased growth rate of conifers, despite a continued slow decrease in the deciduous growing stock.

Summary

The Basic Scenarios show that there is a big potential for increased harvest in the future. This can be concluded by comparison with the Basic ETTS-IV and the Basic Forest Study Scenario. The effects of air pollutants are strong. The harvest potential is about 12 million cubic meters per year lower under air pollution conditions. The estimated Forest Land Expansion Scenario will increase the potential harvest level by about 5.5 million cubic meters per year in comparison with the Basic Forest Study Scenario.

Table B.8. FRG.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	224–265	224–339	224–241	224–211	224–219	224–254	224–243
Fellings[b]							
Year 1	74.4	37.2	47.8	99.2	37.2	35.8	48.1
Year 40	44.3	39.5	49.9	35.3	39.9	38.0	52.4
Year 80	47.0	39.5	49.9	35.3	39.5	38.1	56.0
Coniferous							
Growing stock[a]	235–297	235–365	235–260	235–252	235–277	235–273	235–270
Fellings[b]							
Year 1	47.8	25.2	36.0	64.0	25.2	29.2	36.3
Year 40	32.7	29.3	36.7	28.0	29.4	30.0	38.0
Year 80	35.3	29.3	36.7	27.7	29.4	30.0	41.0
Deciduous							
Growing stock[a]	201–195	201–282	201–200	201–124	201–96	201–215	201–182
Fellings[b]							
Year 1	26.6	12.0	11.8	35.2	12.0	6.6	11.8
Year 40	11.6	10.2	13.2	7.3	10.5	8.0	14.4
Year 80	11.7	10.2	13.2	7.6	10.1	8.1	15.0
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	47.7	38.9	49.3	43.6	39.0	37.5	54.9
Coniferous	34.8	28.7	36.5	32.6	28.8	29.8	40.6
Deciduous	12.9	10.2	12.8	11.0	10.2	7.7	14.3
Growth (m^3 o.b./ha/yr)[c]							
Total	6.8	6.4	6.8	5.7	5.2	5.3	6.6
Coniferous	7.4	6.9	7.4	6.6	6.1	6.2	7.1
Deciduous	5.4	5.1	5.4	3.9	3.2	3.4	5.3
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	224–265	224–339	224–241	224–211	224–219	224–254	224–250
Coniferous	235–297	235–365	235–260	235–252	235–277	235–273	235–279
Deciduous	201–195	201–282	201–200	201–124	201–96	201–215	201–180

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

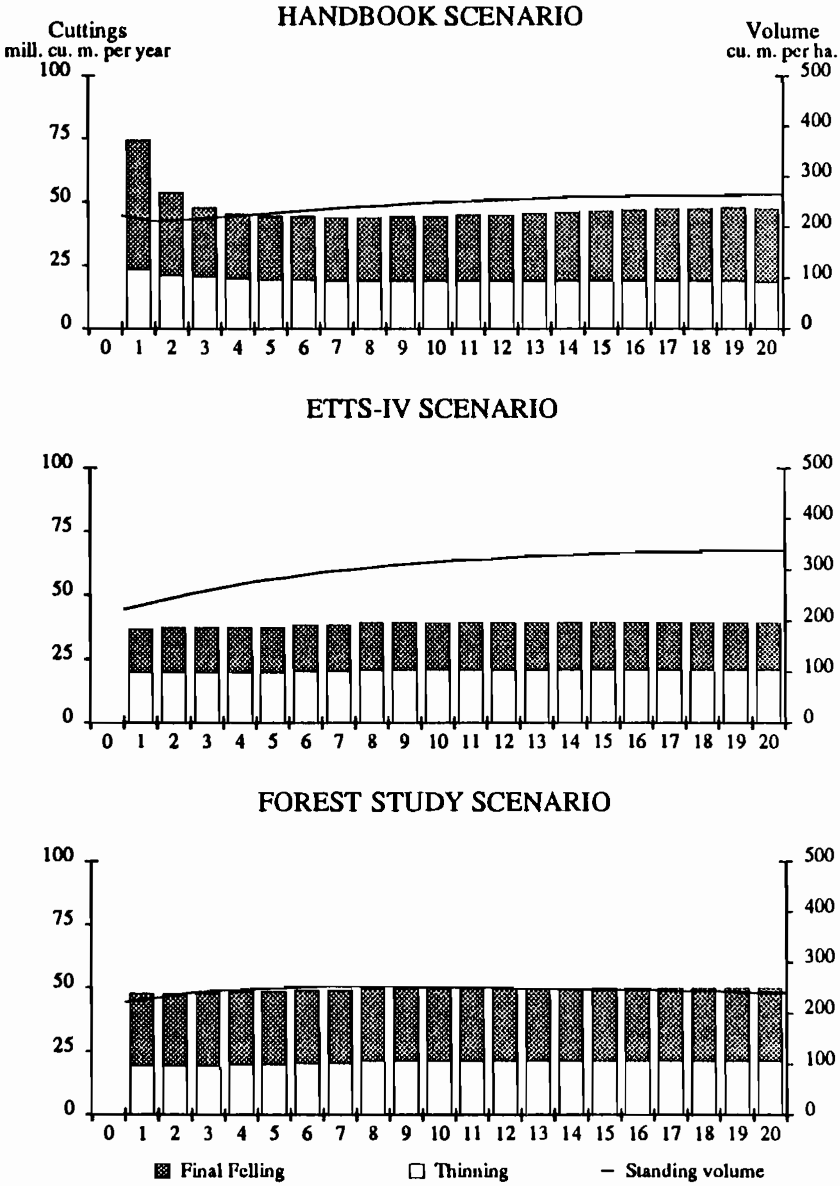


Figure B.55. Projections for total potential harvest and growing stock in the FRG under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 37 million cubic meters o.b.

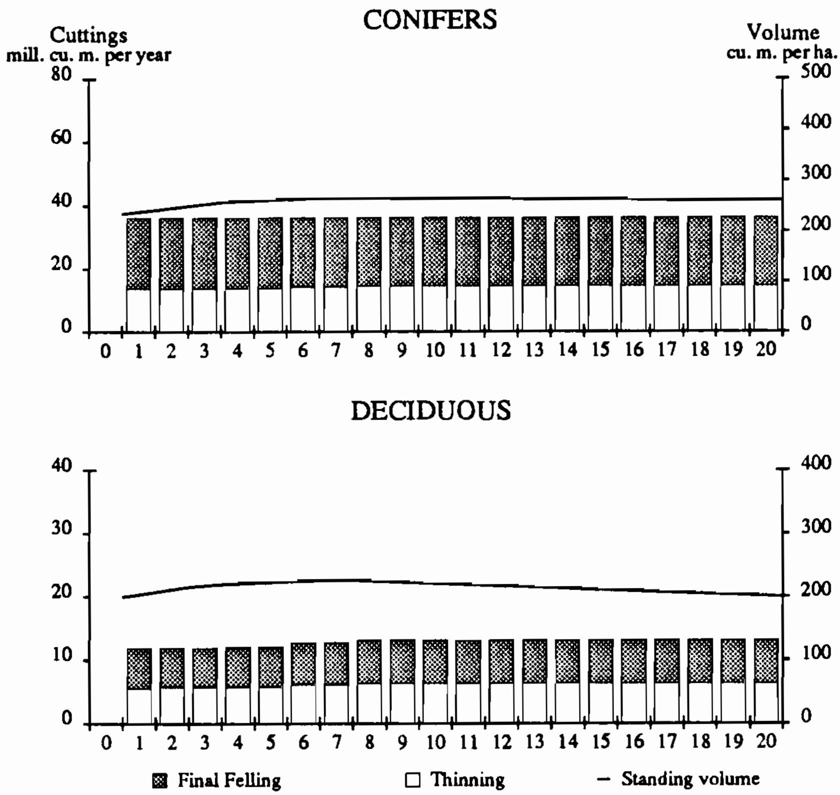


Figure B.56. Projections for total potential harvest and growing stock for coniferous and deciduous species in the FRG under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 25 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 12 million cubic meters o.b.

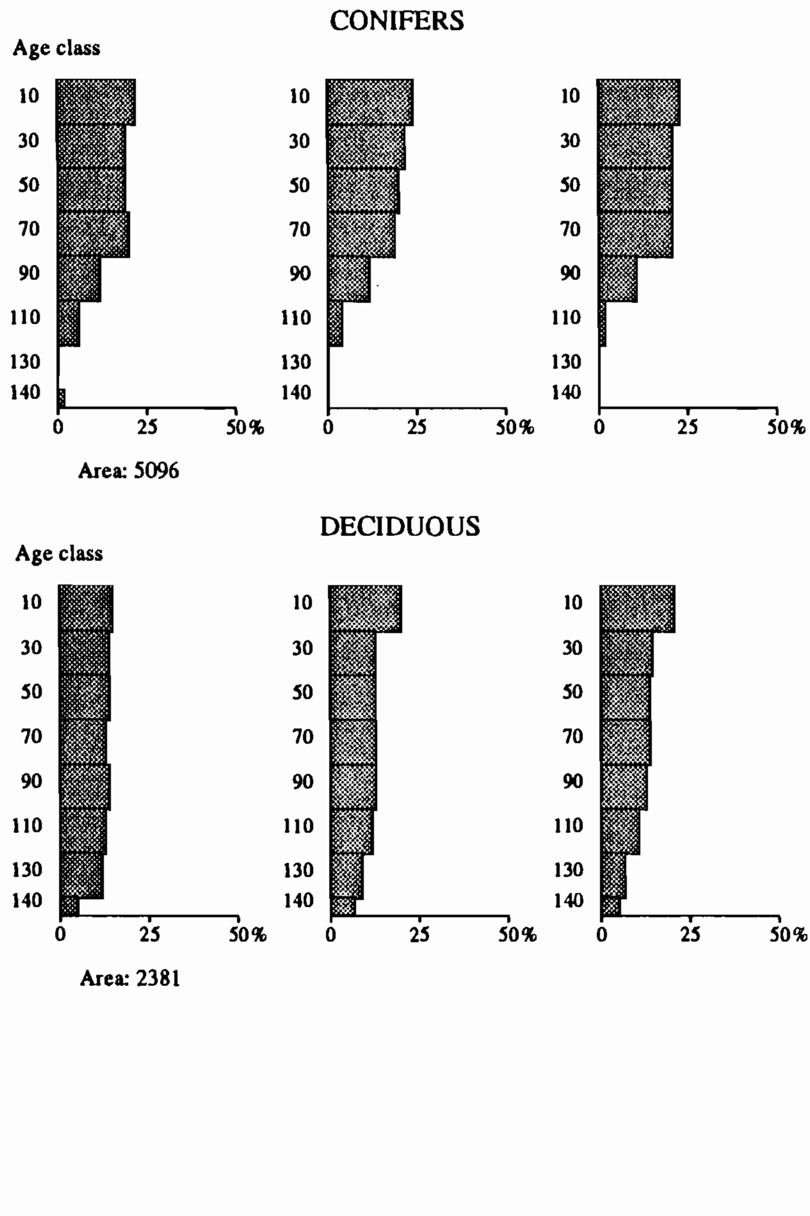


Figure B.57. Age-class distributions in the FRG under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

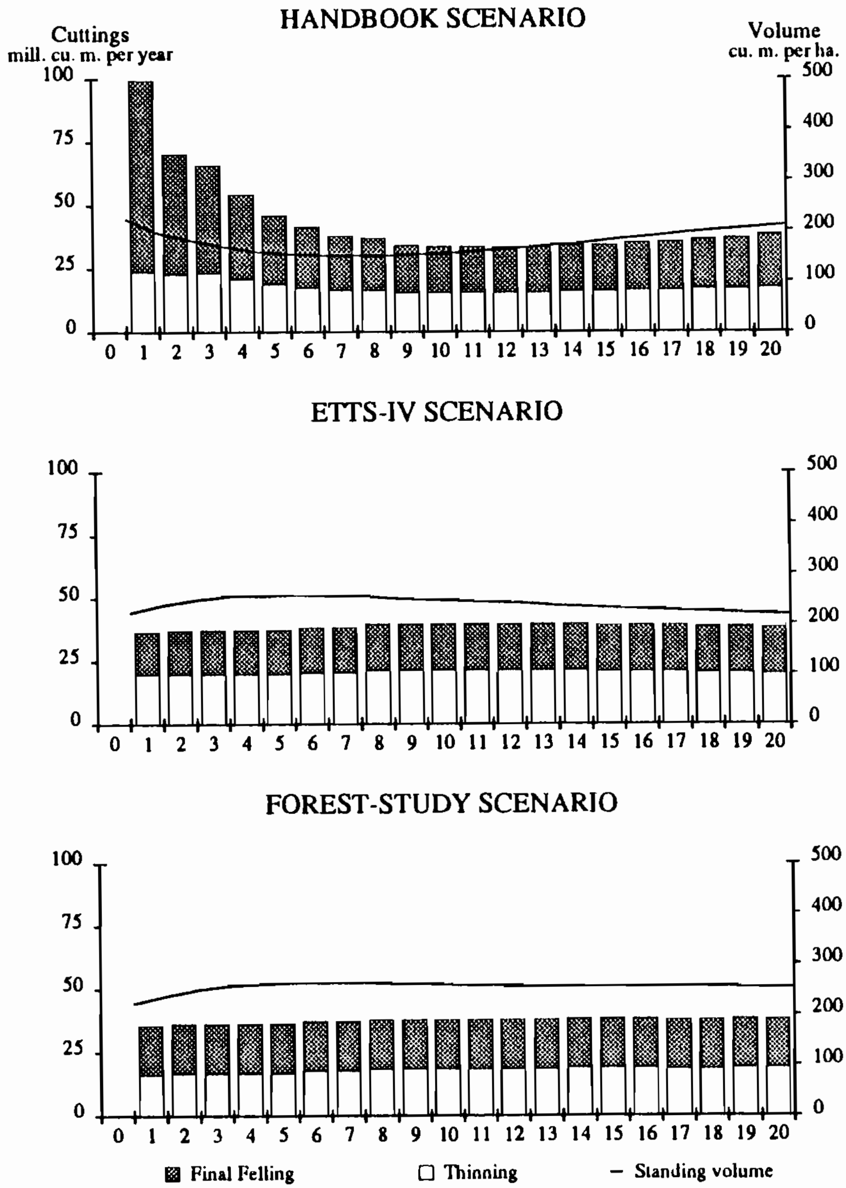


Figure B.58. Projections for total potential harvest and growing stock in the FRG under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 37 million cubic meters o.b.

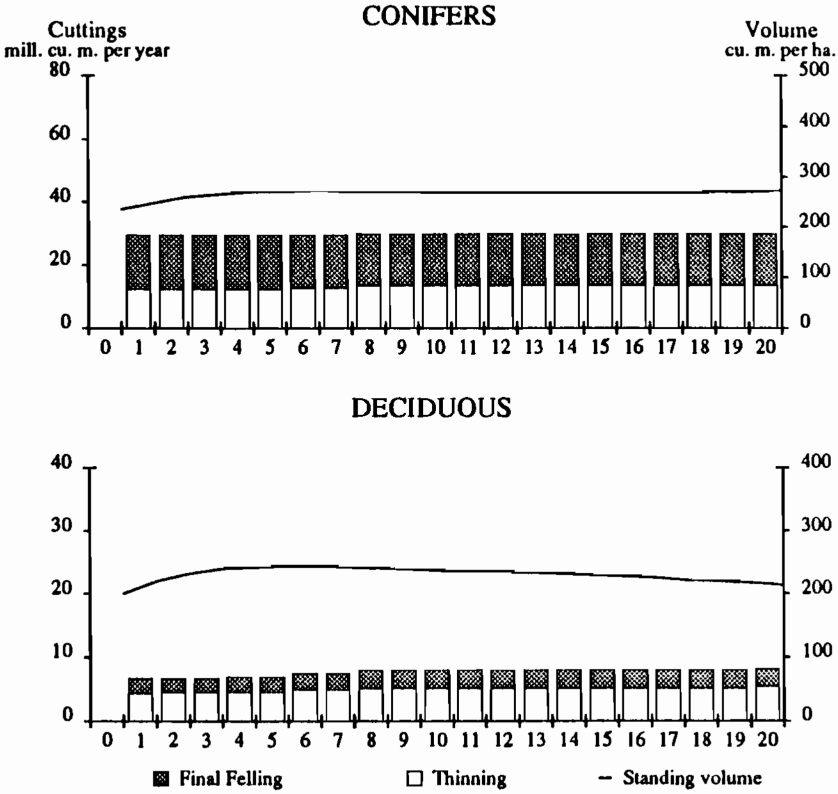


Figure B.59. Projections for total potential harvest and growing stock for coniferous and deciduous species in the FRG under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 25 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 12 million cubic meters o.b.

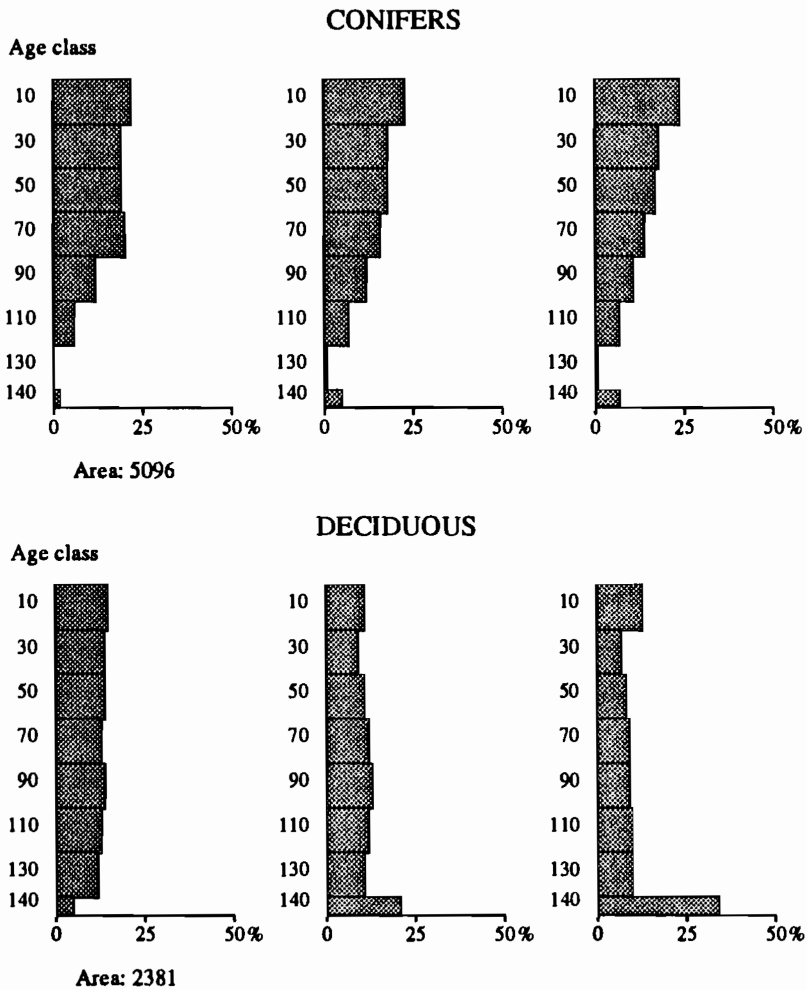


Figure B.60. Age-class distributions in the FRG under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

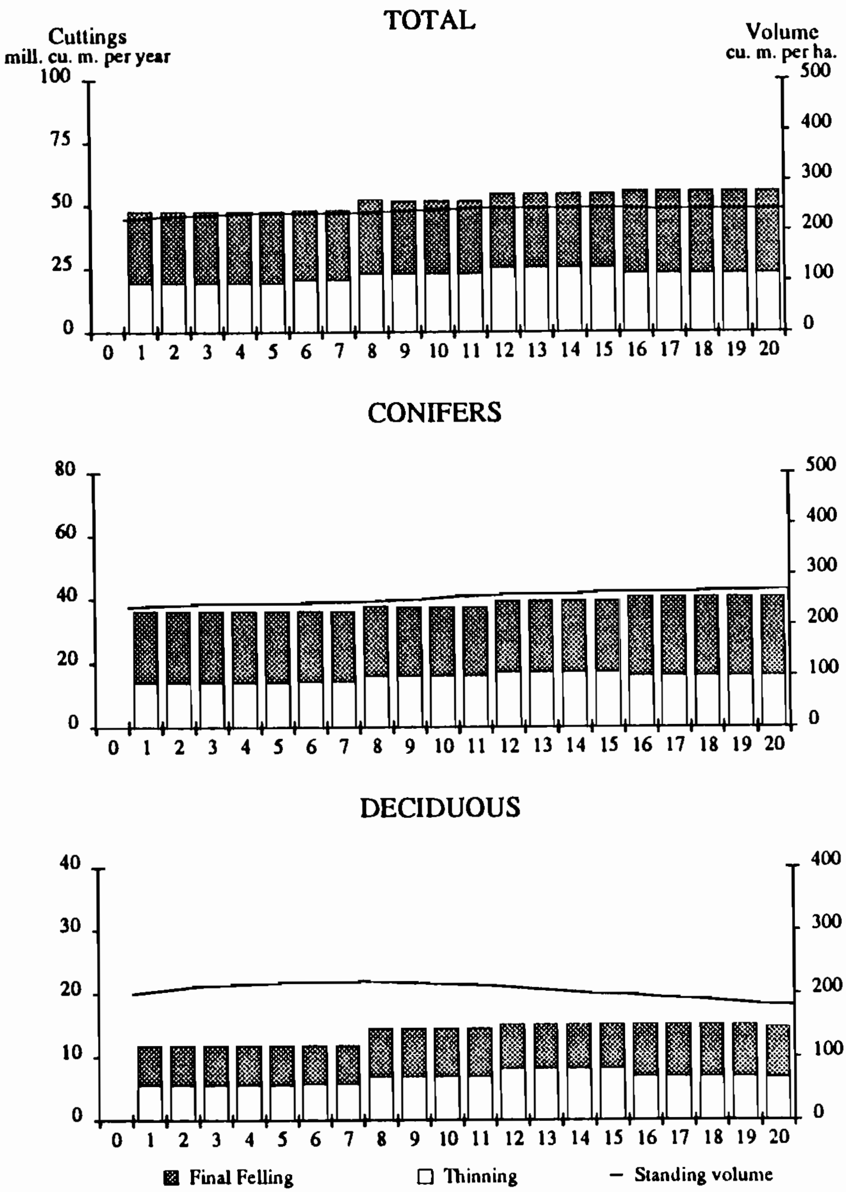


Figure B.61. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in the FRG under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 37 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 25 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 12 million cubic meters o.b.

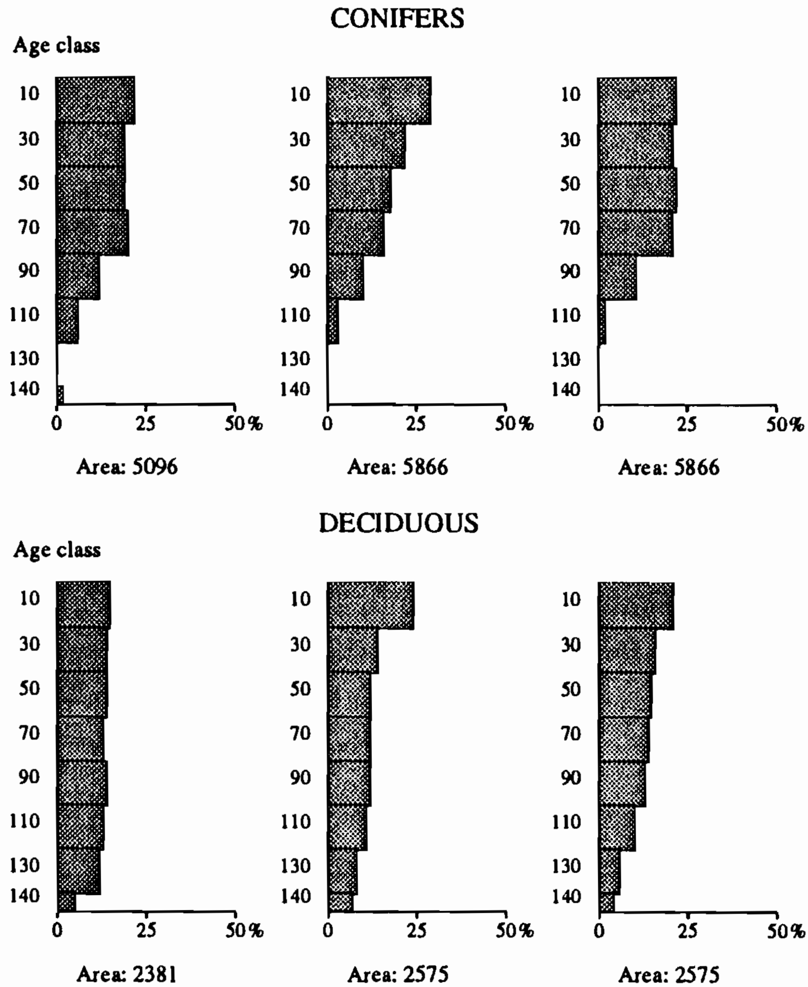


Figure B.62. Age-class distributions in the FRG under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

GDR (Table B.9 and Figures B.63 to B.68)

Basic Scenarios

Results from the Basic Handbook Scenario, with high harvest levels in the early years of the simulation followed by a slow decrease, correspond to an age-class structure with a relatively high proportion of nearly mature stands. ETTS-IV harvest levels are sustainable over the simulation. The Basic Forest Study Scenario, therefore, is similar to the Basic ETTS-IV Scenario. The harvests are dominated by conifers. In addition, growing stocks for both species groups are fairly stable.

Decline Scenarios

The Handbook Decline Scenario, in contrast with the Basic Handbook Scenario, generates a dramatic harvest pulse during the first 20 years. After the pulse there is a pronounced decrease of both the potential harvest level and the growing stock. The total growing stock recovers slightly toward the end of the simulation, but from a low level.

It is not possible to keep the harvest level of the Basic ETTS-IV Scenario during the whole simulation period. At the end there is a decrease of the potential harvest level. Prior to the decreasing potential harvest, there is a dramatic decrease of the growing stock.

In the Basic Forest Study Scenario the total growing stock is kept at a stable level. In the Forest Study Decline Scenario it is possible to generate the same development of the total growing stock as in the basic scenario, but at the expense of the harvest level. The harvest level in the decline scenario is decreased by about 5 million cubic meters per year.

In relative terms the deciduous forest is most affected by decline, but the most pronounced decrease in harvest volumes occurs in coniferous species. The dramatic development of forest resources in the GDR in our decline scenarios is a consequence of the severe pollution situation in the country.

Summary

The scenarios under basic condition give similar results. The effects of forest decline attributed to air pollutants are strong. The decline scenario generates a harvest potential that is 5 million cubic meters per year lower than in the basic scenario.

Table B.9. GDR.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study	Handbook Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	190–224	190–205	190–202	190–153	190–89	190–200	
Fellings[b]							
Year 1	22.3	12.0	13.6	31.7	12.0	13.6	
Year 40	13.2	14.9	14.8	9.3	14.9	8.8	
Year 80	14.4	14.9	14.8	7.3	9.1	8.8	
Coniferous							
Growing stock[a]	181–220	181–186	181–199	181–150	181–90	181–204	
Fellings[b]							
Year 1	15.4	9.7	10.6	19.9	9.7	10.6	
Year 40	10.3	11.9	11.3	7.4	11.9	6.9	
Year 80	11.3	11.9	11.3	5.8	6.5	6.9	
Deciduous							
Growing stock[a]	215–238	215–266	215–209	215–162	215–87	215–188	
Fellings[b]							
Year 1	7.0	2.3	3.0	11.8	2.3	3.0	
Year 40	2.9	3.0	3.5	1.9	3.0	1.9	
Year 80	3.1	3.0	3.5	1.5	2.6	1.9	
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	14.6	14.3	14.6	11.7	12.5	9.7	
Coniferous	11.1	11.5	11.2	9.1	9.8	7.6	
Deciduous	3.5	2.9	3.4	2.6	2.7	2.1	
Growth (m^3 o.b./ha/yr)[c]							
Total	5.8	5.5	5.6	4.0	3.7	3.7	
Coniferous	5.9	5.7	5.7	4.2	3.9	4.0	
Deciduous	5.5	4.9	5.1	3.4	2.9	2.9	
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	190–224	190–205	190–202	190–153	190–89	190–200	
Coniferous	181–220	181–186	181–199	181–150	181–90	181–204	
Deciduous	215–238	215–266	215–209	215–162	215–87	215–188	

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

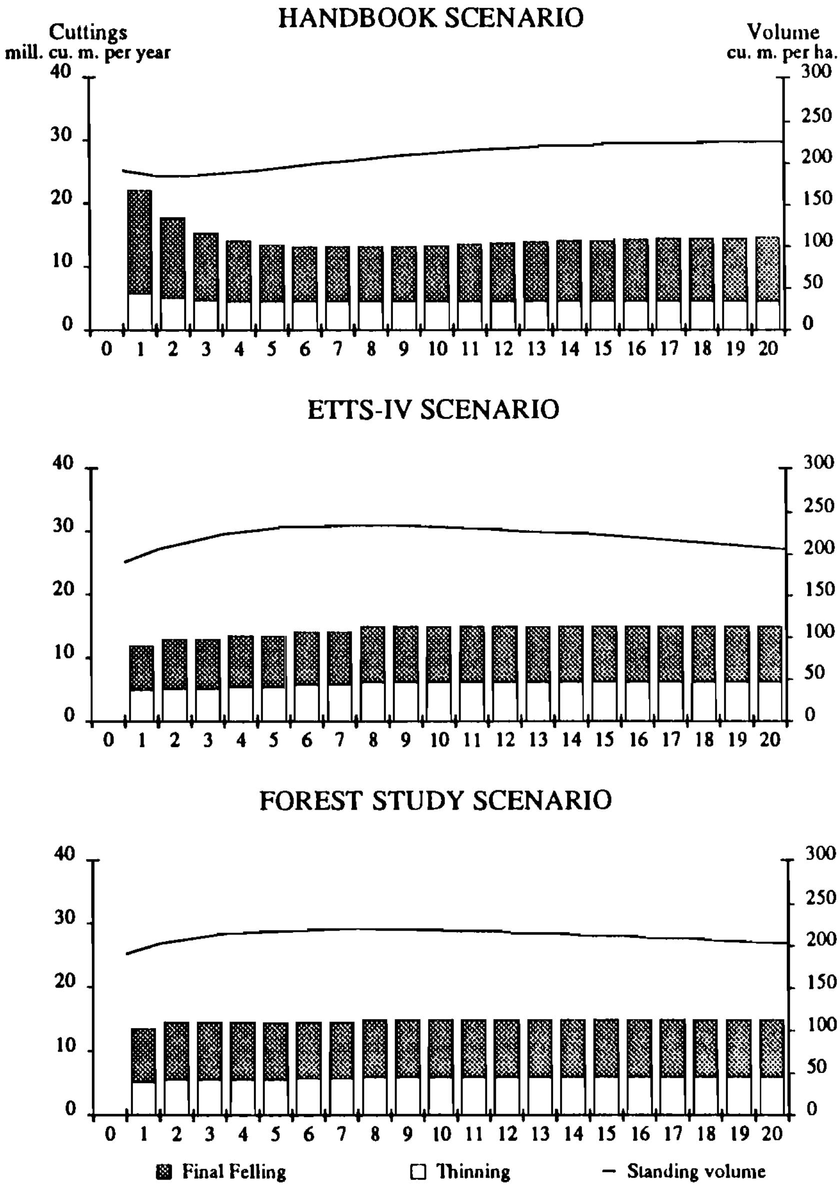


Figure B.63. Projections for total potential harvest and growing stock in the GDR under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 12 million cubic meters o.b.

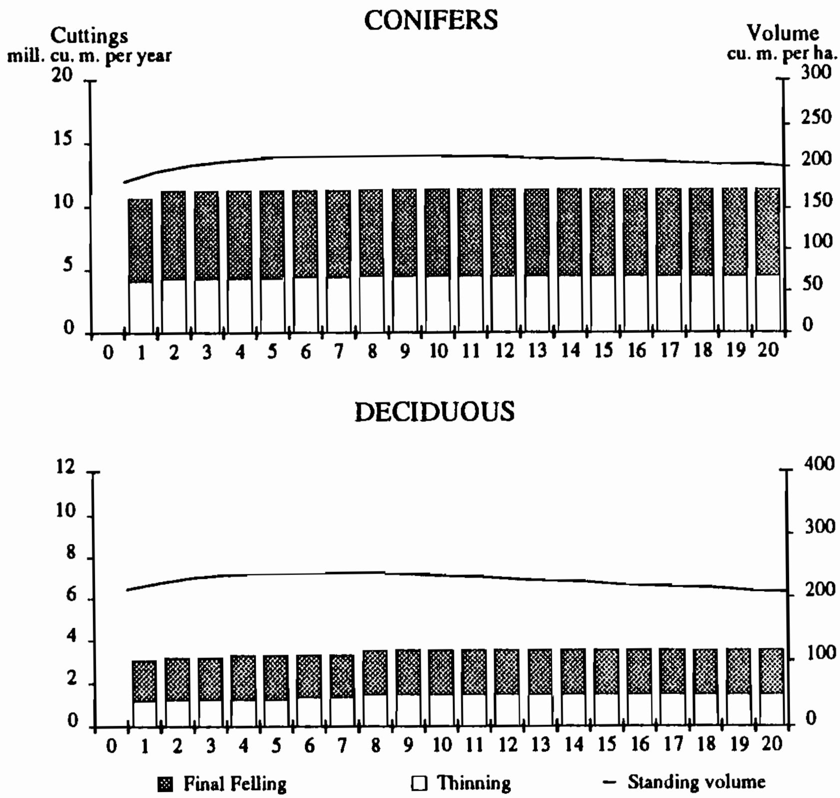


Figure B.64. Projections for total potential harvest and growing stock for coniferous and deciduous species in the GDR under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 10 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 2 million cubic meters o.b.

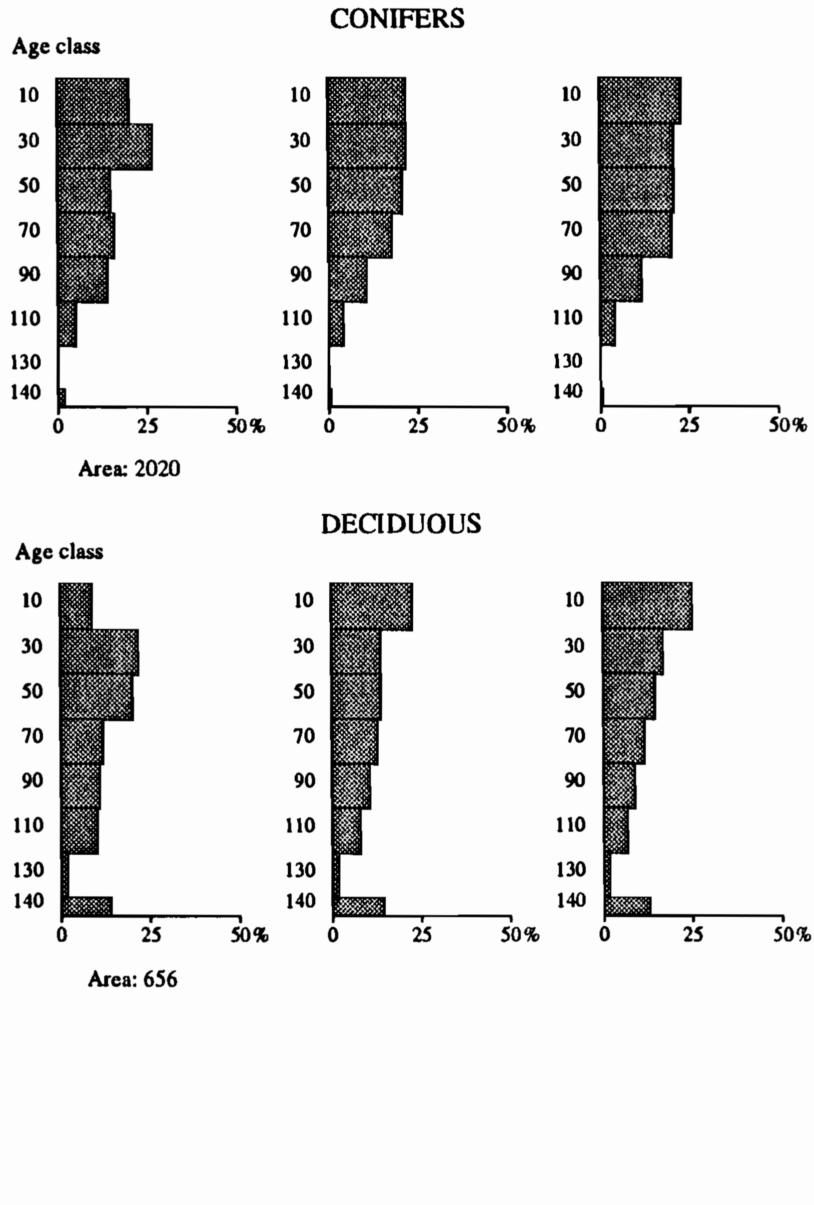


Figure B.65. Age-class distributions in the GDR under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

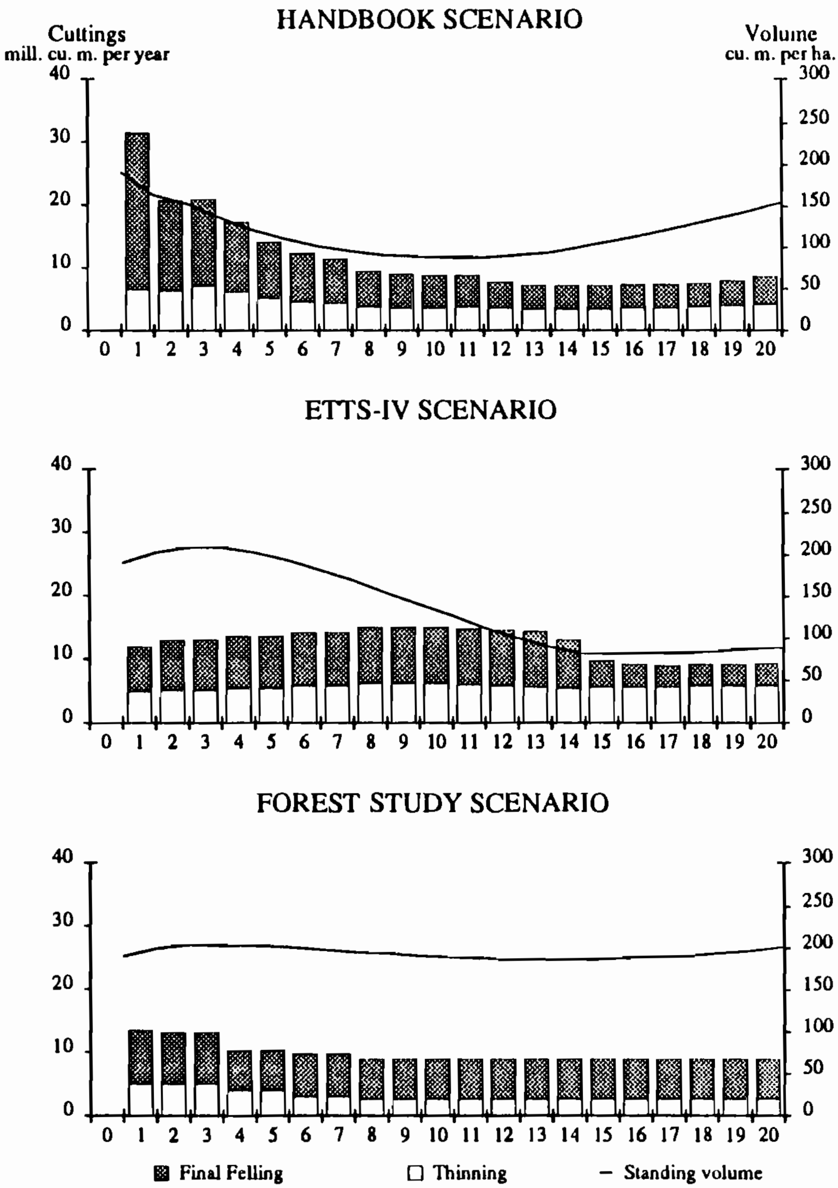


Figure B.66. Projections for total potential harvest and growing stock in the GDR under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 12 million cubic meters o.b.

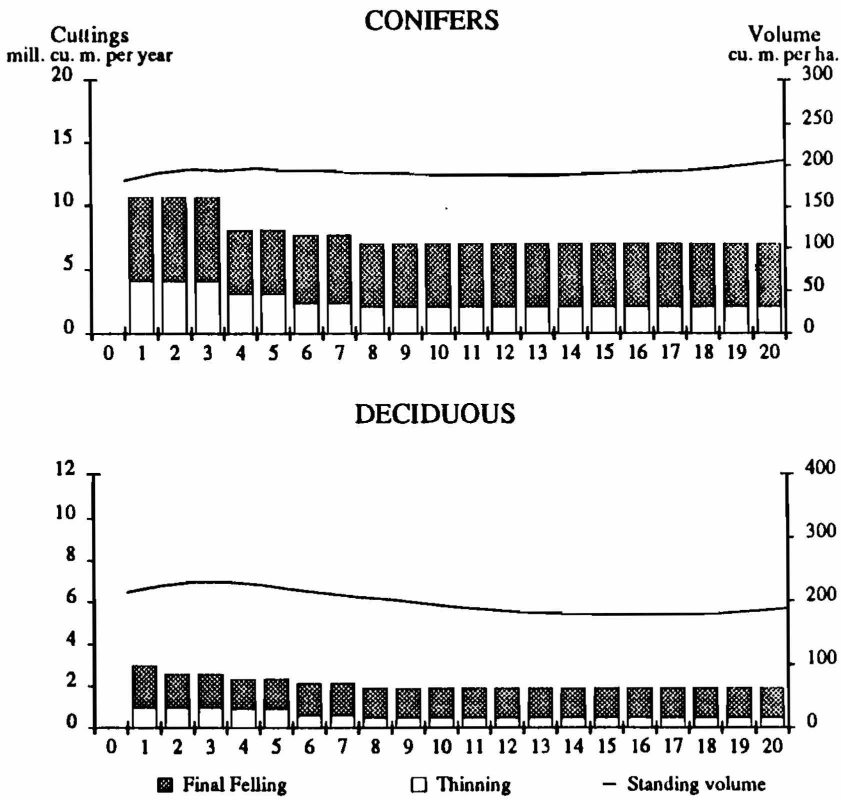


Figure B.67. Projections for total potential harvest and growing stock for coniferous and deciduous species in the GDR under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 10 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 2 million cubic meters o.b.

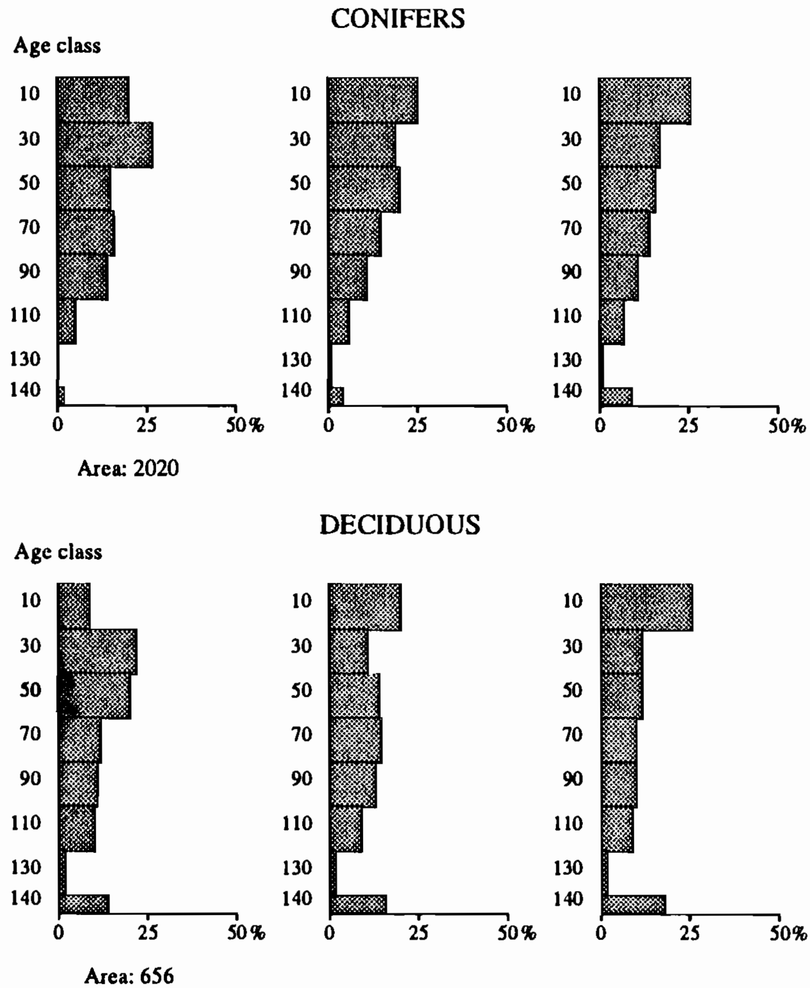


Figure B.68. Age-class distributions in the GDR under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

Greece (Table B.10 and Figures B.69 to B.72)

Basic Scenarios

The forest-inventory data for Greece are so primitive and aggregated that it is impossible to generate a dynamic development of harvest levels and growing stock. Our approach in invoking a Basic Forest Study Scenario results in harvest levels that are similar to present cuttings according to ETTS-IV, with about equal harvests from coniferous and deciduous forests. The growing stock is steadily increasing for both coniferous and deciduous species.

Decline Scenarios

The Forest Study Decline Scenario yields the same development of growing stock as under basic conditions. It is not possible, though, to keep the same harvest level during the first 50 years of the simulation. Later on, the harvesting levels is the same in the two scenarios. The effects of decline are of the same size for both coniferous and deciduous species. No separation between the effects of decline on thinnings and those on final cuts could be made.

Forest Land Expansion Scenario

The simple model concept that had to be used in the simulations for Greece does not permit quantification of the effects of the forest landbase increase.

Summary

The effects of forest decline on the total potential harvest level is rather modest, up to a decreased potential of only 0.2 million cubic meters per year during the whole simulation period. Mean growth figures are low in Greece, especially for deciduous species.

Table B.10. Greece.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]			72–122			72–119	
Fellings[b]							
Year 1			2.8			2.4	
Year 40			2.8			2.6	
Year 80			2.9			2.9	
Coniferous							
Growing stock[a]			136–199			136–195	
Fellings[b]							
Year 1			1.4			1.2	
Year 40			1.3			1.2	
Year 80			1.4			1.4	
Deciduous							
Growing stock[a]			48–92			48–89	
Fellings[b]							
Year 1			1.4			1.2	
Year 40			1.5			1.4	
Year 80			1.5			1.5	
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total			2.9			2.7	
Coniferous			1.4			1.3	
Deciduous			1.5			1.4	
Growth (m^3 o.b./ha/yr)[c]							
Total			2.0			1.8	
Coniferous			3.2			3.0	
Deciduous			1.5			1.4	
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total			72–122			72–119	
Coniferous			136–199			136–195	
Deciduous			48–92			48–89	

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

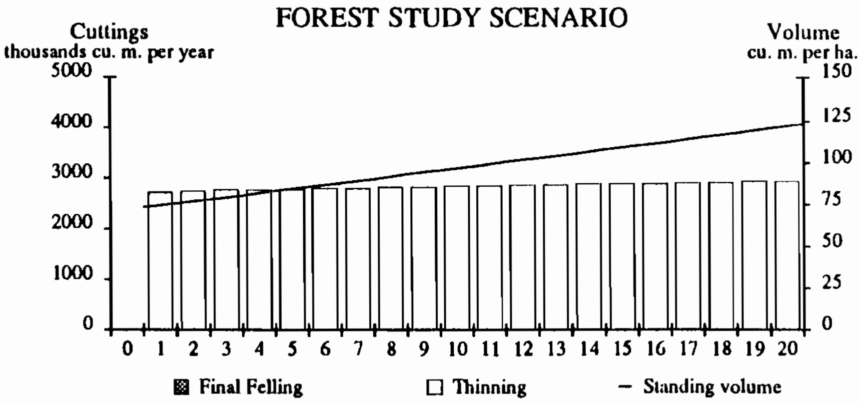


Figure B.69. Projections for total potential harvest and growing stock in Greece under the Basic Forest Study Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 2.8 million cubic meters o.b.

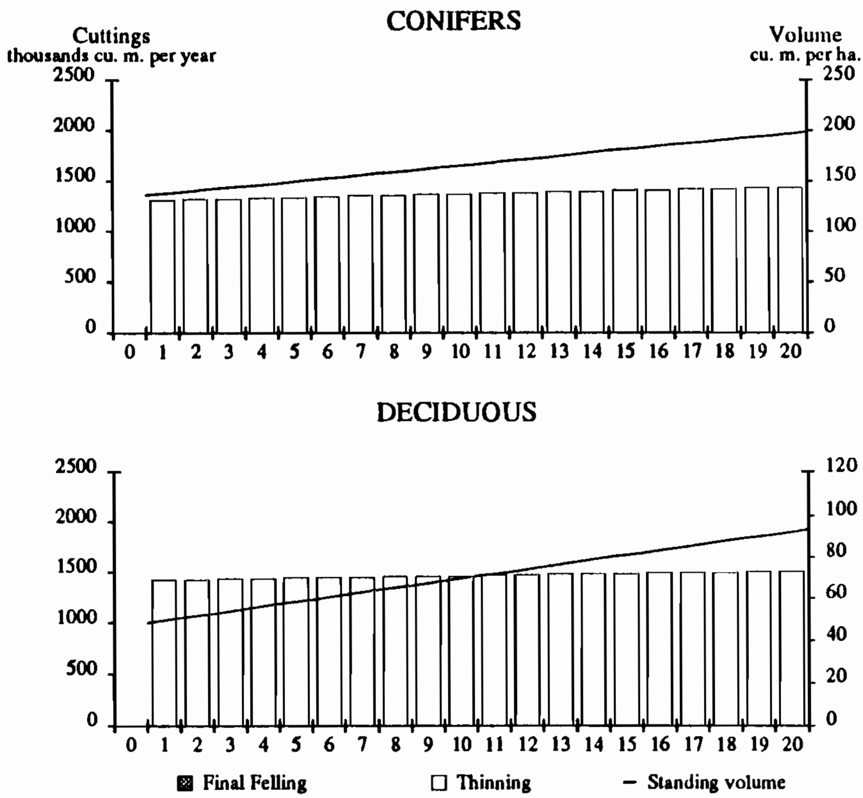


Figure B.70. Projections for total potential harvest and growing stock for coniferous and deciduous species in Greece under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1.8 million cubic meters o.b.

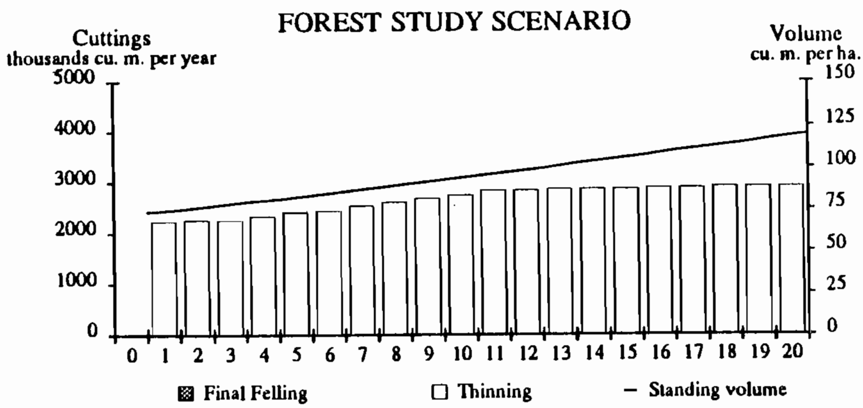


Figure B.71. Projections for total potential harvest and growing stock in Greece under the Forest Study Decline Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 2.8 million cubic meters o.b.

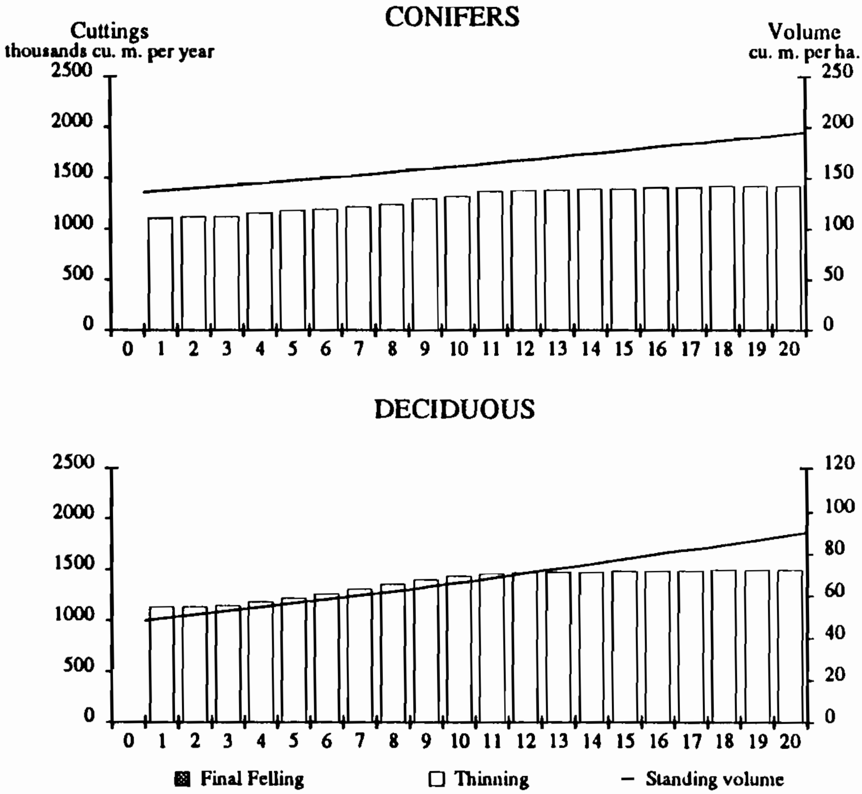


Figure B.72. Projections for total potential harvest and growing stock for coniferous and deciduous species in Greece under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1.8 million cubic meters o.b.

Hungary (Table B.11 and Figures B.73 to B.80)

Basic Scenarios

Hungarian forests do not display a current structure that corresponds to handbook silviculture, as shown by the early harvest pulse in the Basic Handbook Scenario. ETTS-IV harvest levels are possible, but only at the expense of a slightly decreasing growing stock. Thus, the Basic Forest Study Scenario calls for slightly lower harvests during the first 30 years of the simulation, with somewhat more of the harvest coming from final cuts compared with handbook silviculture. Within this harvest, deciduous species strongly dominate. Overall growing stock increases slightly over the simulation, but coniferous stock increases strongly while deciduous stock decreases slightly. Bases for these developments are found in the age-class structures, in which there are increased proportions of older coniferous stands over time starting from a situation with a large amount of young stands.

Decline Scenarios

The Handbook Decline Scenario gives a much stronger harvest pulse during the beginning of the simulation period than the basic scenario. After the pulse there is a strong decline of the potential harvest level during the rest of the simulation period. During the first 35 years there is also a strong decrease in the total growing stock. For the rest of the simulation the total growing stock recovers.

Under decline conditions, it is only possible to keep the ETTS-IV harvest level during the first 60 years. Despite this, the total growing stock declines substantially during these years.

The Forest Study Decline Scenario generates nearly the same development of the total growing stock as the basic scenario. The growing-stock level is, however, associated with a lower harvesting potential of about 3 million cubic meters per year.

A major part of Hungary's forest area bears deciduous species. Therefore, the decline will affect the volume of this species group the most. The decline will cause a decrease of the potential harvest in both final fellings and thinnings, but the decrease will be more evident in the former.

Forest Land Expansion Scenario

The increased forest landbase leads to increased potential harvest after about 25 years. After another increase some 10 years later, the harvest level is about 1.5 million cubic meters per year higher than in the basic scenario. Most of the new harvest is from deciduous species, since the new land is primarily planted with these species.

The total growing stock will have a flat development (as in the basic scenario) but at a lower level. This is also the case for both coniferous and deciduous species.

Summary

The results from the different alternatives under basic conditions are quite similar. Decline attributed to air pollutants strongly influences the total potential harvest. The total potential harvest decreases by 3 million cubic meters per year during the whole simulation period in comparison with the basic conditions. The new landbase could add a potential harvest of 0.8 million cubic meters per year over 100 years.

Table B.11. Hungary.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	182–169	182–185	182–195	182–186	182–143	182–221	182–176
Fellings[b]							
Year 1	15.0	7.6	8.2	19.8	7.6	5.0	8.2
Year 40	8.7	8.8	8.6	5.6	8.9	5.6	10.0
Year 80	8.2	8.8	8.6	5.5	6.0	5.6	10.0
Coniferous							
Growing stock[a]	152–169	152–167	152–221	152–205	152–161	152–232	152–185
Fellings[b]							
Year 1	1.0	0.6	1.0	1.2	0.6	0.6	1.0
Year 40	1.4	1.5	1.1	1.2	1.5	0.9	1.5
Year 80	1.2	1.5	1.1	1.0	1.2	0.9	1.5
Deciduous							
Growing stock[a]	188–168	188–188	188–190	188–182	188–140	188–218	188–174
Fellings[b]							
Year 1	14.0	7.0	7.2	18.4	7.0	4.4	7.2
Year 40	7.3	7.3	7.5	4.4	7.4	4.7	8.5
Year 80	7.0	7.3	7.5	4.5	4.8	4.7	8.5
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	8.8	8.7	8.6	7.4	7.7	5.5	9.4
Coniferous	1.2	1.3	1.1	1.2	1.2	0.9	1.3
Deciduous	7.6	7.4	7.5	6.2	6.5	4.6	8.1
Growth (m^3 o.b./ha/yr)[c]							
Total	5.8	5.8	5.8	4.9	4.8	4.0	5.6
Coniferous	5.4	5.7	5.2	5.4	5.3	4.5	5.2
Deciduous	5.8	5.9	5.9	4.8	4.6	3.9	5.7
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	182–169	182–185	182–195	182–186	182–143	182–221	182–176
Coniferous	152–169	152–167	152–221	152–205	152–161	152–232	152–185
Deciduous	188–168	188–188	188–190	188–182	188–140	188–218	188–174

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

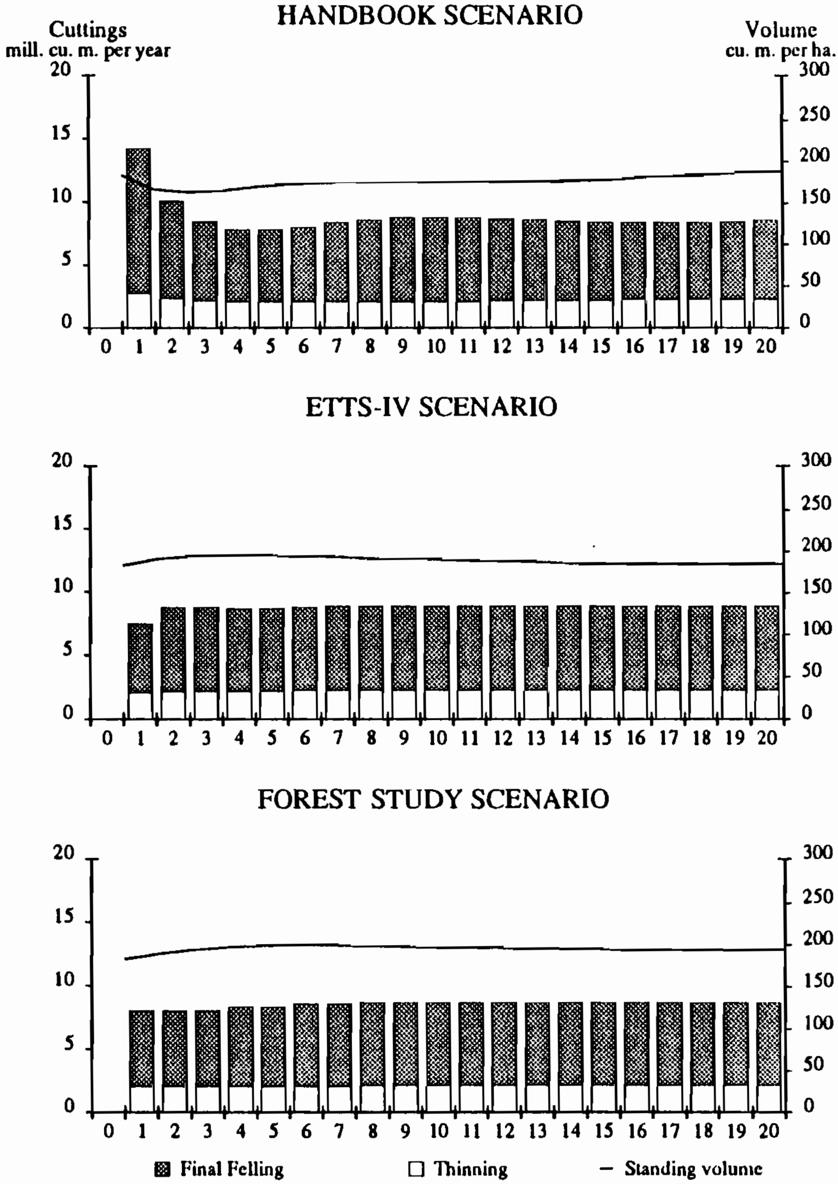


Figure B.73. Projections for total potential harvest and growing stock in Hungary under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.

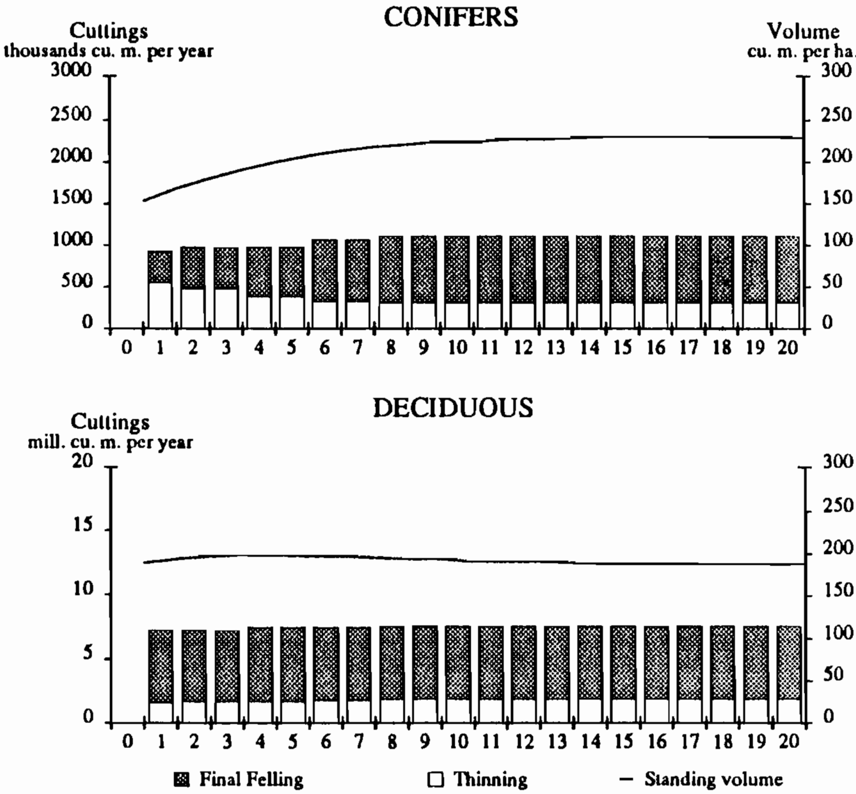


Figure B.74. Projections for total potential harvest and growing stock for coniferous and deciduous species in Hungary under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 7 million cubic meters o.b.

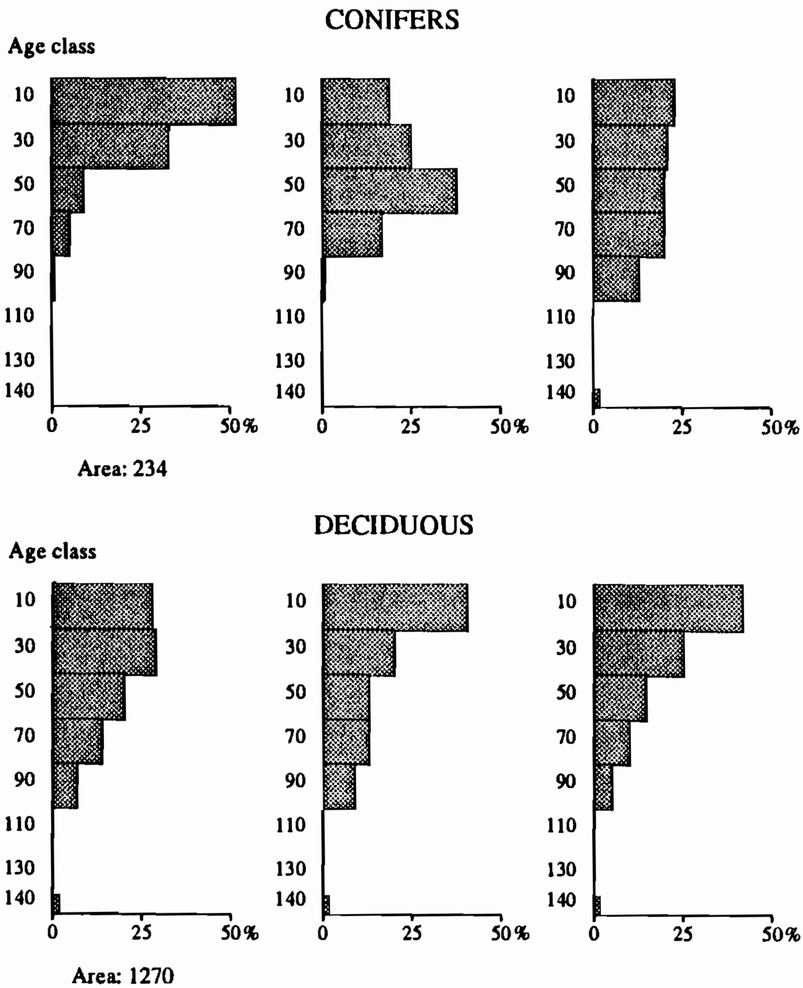


Figure B.75. Age-class distributions in Hungary under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

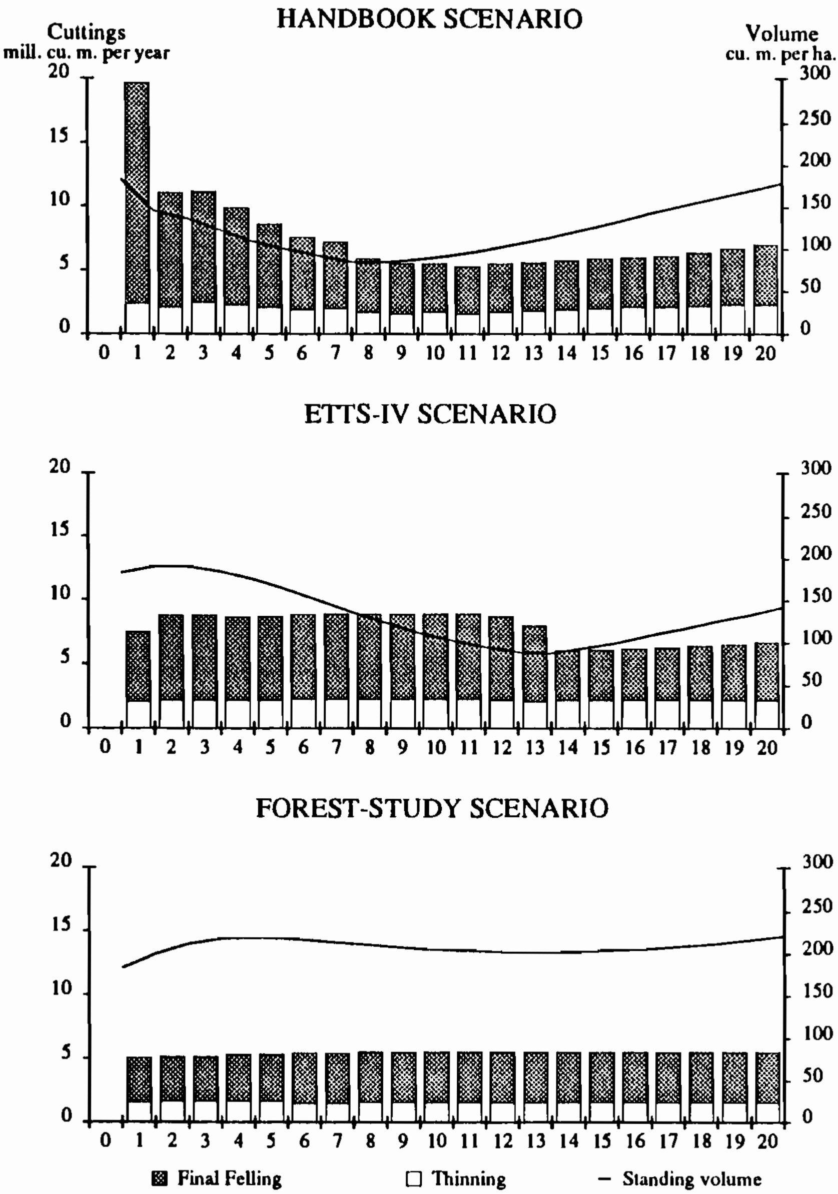


Figure B.76. Projections for total potential harvest and growing stock in Hungary under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.

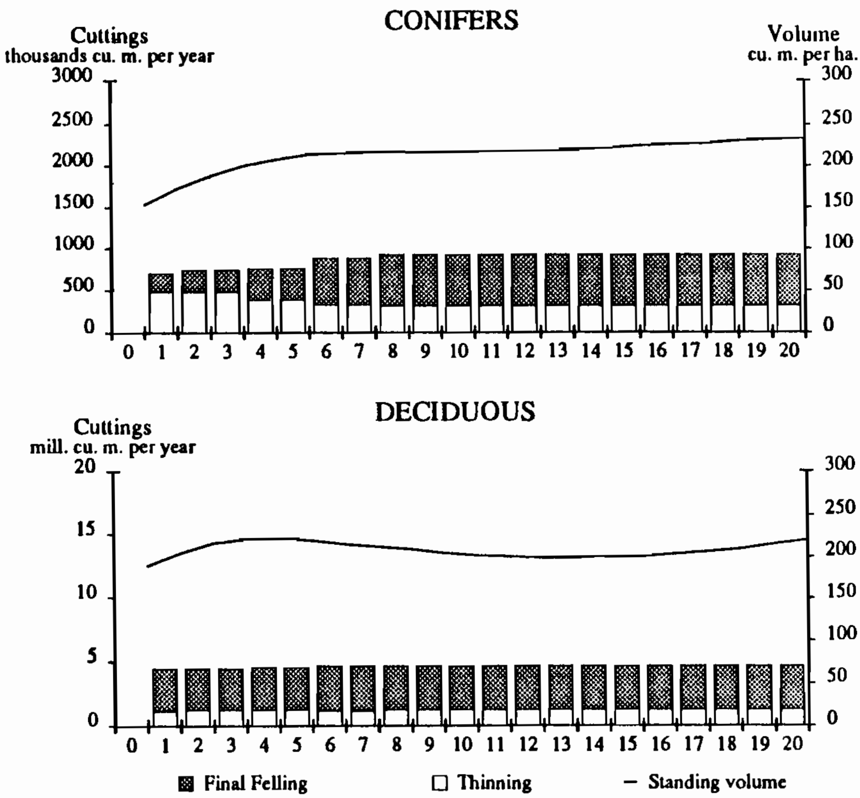


Figure B.77. Projections for total potential harvest and growing stock for coniferous and deciduous species in Hungary under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 7 million cubic meters o.b.

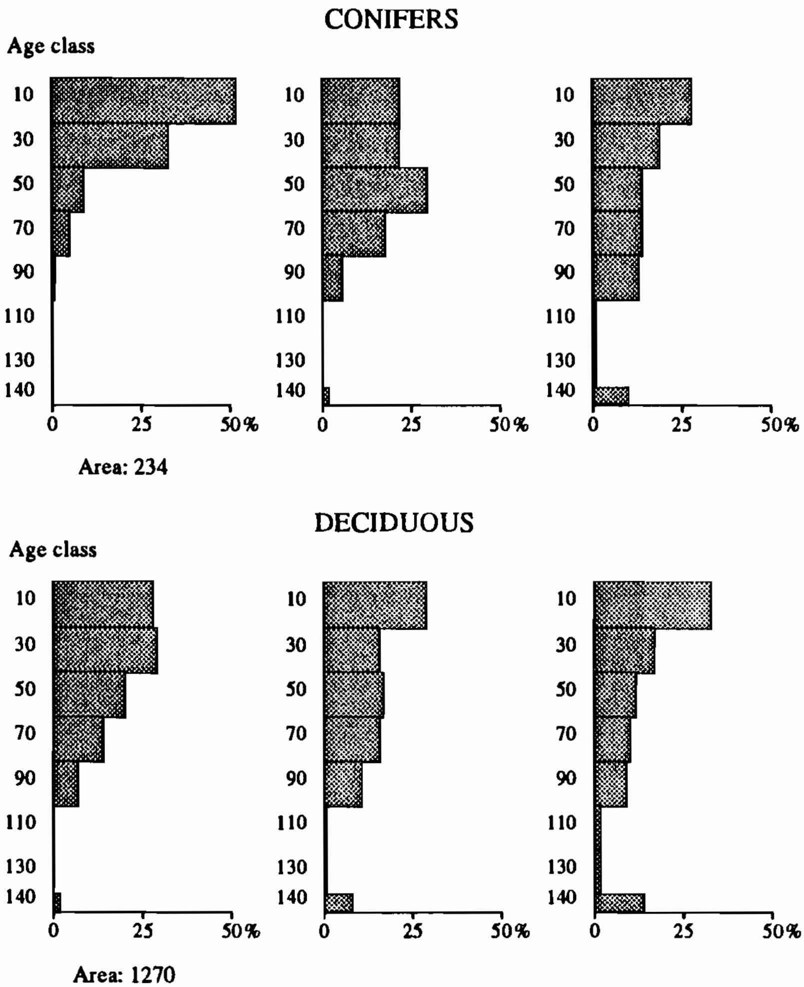


Figure B.78. Age-class distributions in Hungary under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

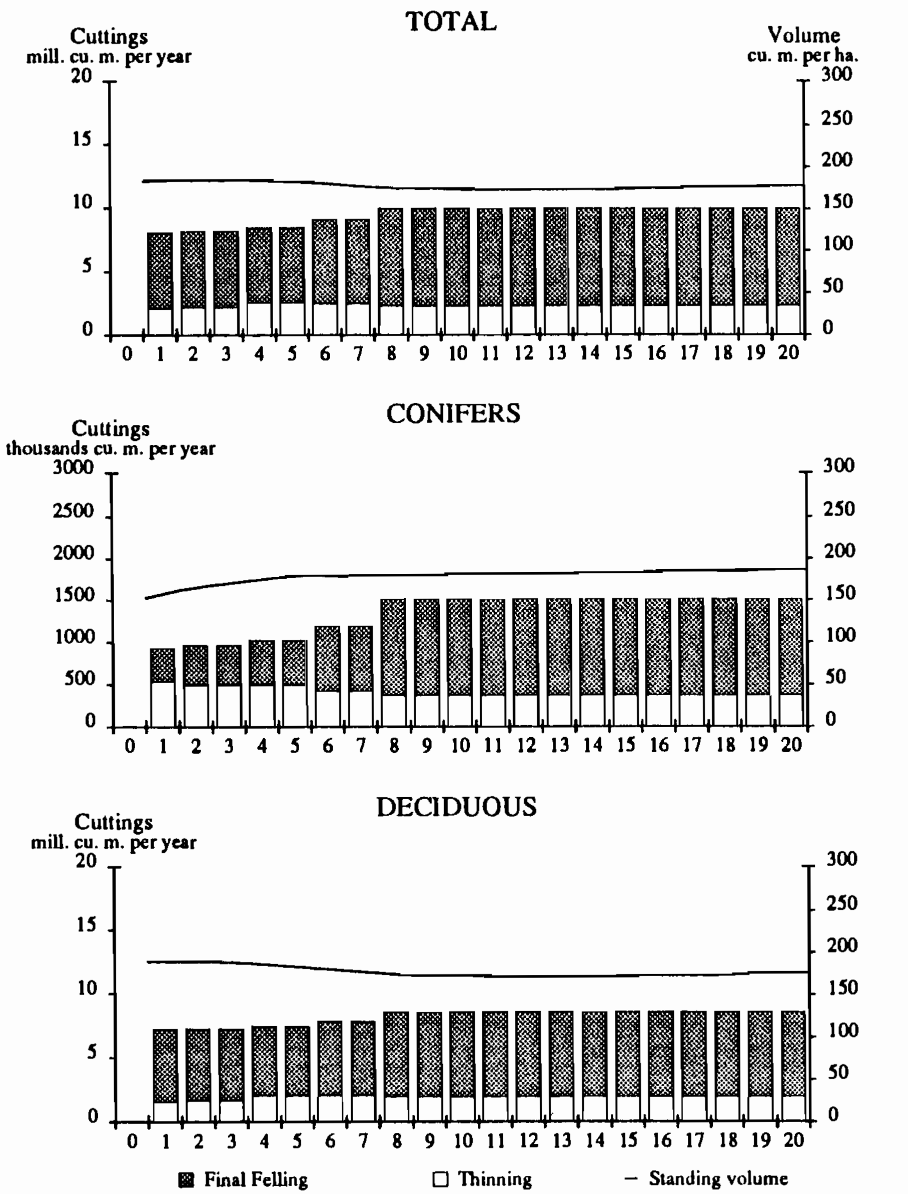


Figure B.79. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Hungary under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 7 million cubic meters o.b.

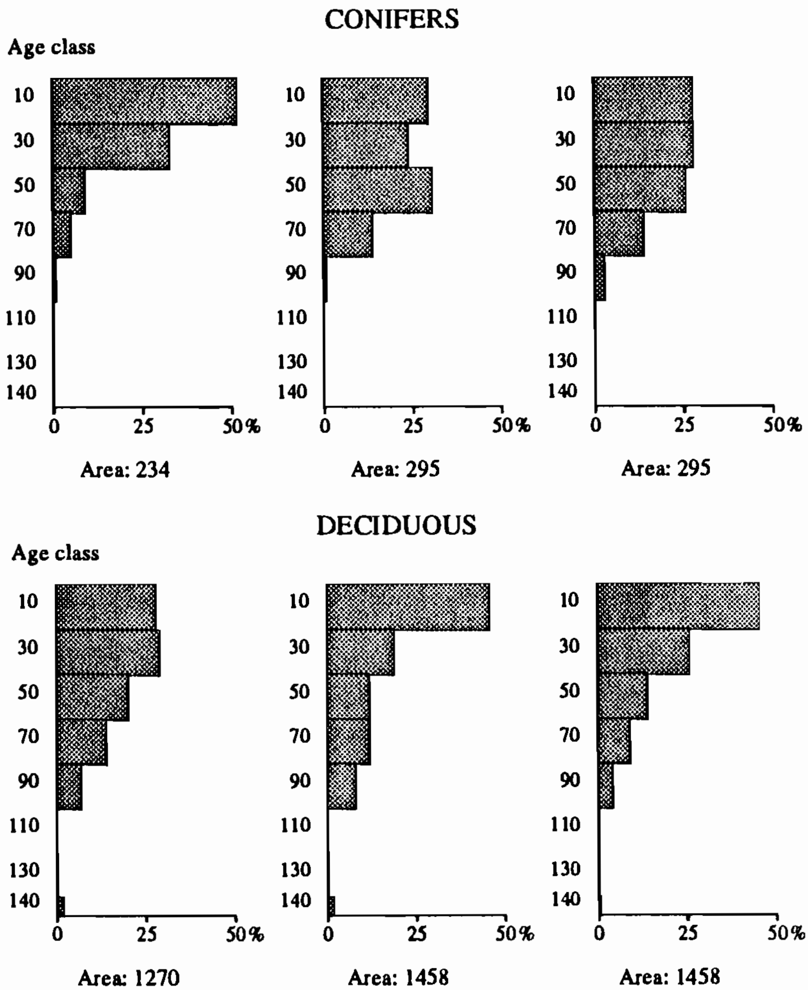


Figure B.80. Age-class distributions in Hungary under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Ireland (Table B.12 and Figures B.81 to B.86)

Basic Scenarios

In the Basic Handbook Scenario, harvests and growing stock (species considered in Ireland are all coniferous) increase to year 40 of the simulation and then decrease, reflecting the initially skewed age-class structure. ETTS-IV harvest levels cannot be sustained, but information provided by Ireland to ETTS-IV includes a strong increase in the forest landbase that we have not accounted for in our basic analyses.

The Basic Forest Study Scenario calls for harvest levels initially lower than those of ETTS-IV, but a level of 2 million cubic meters per year is sustainable over 100 years, while growing stock rises to 256 cubic meters per hectare. Stands less than 20 years old initially dominate the age-class structure. By the end of the simulation the age-class structure displays a comfortable balance. In this scenario, final cuts account for more of the harvest than final cuts in the Basic Handbook Scenario.

Decline Scenarios

The Handbook Decline Scenario gives a result similar to that of the Basic Handbook Scenario. The decline scenario will generate a slightly lower potential harvest level and a lower level of the growing stock. Even in the case of the ETTS-IV scenarios there are strong similarities concerning harvesting levels (and patterns) and the development of the growing stock.

In the Forest Study Decline Scenario, it is possible to keep the same development of the growing stock as in the basic scenario. The potential harvest level in the decline scenario will be slightly decreased, some 0.2 million cubic meters per year lower than that of the basic scenario. This small effect in the decline scenarios is a result of low depositions of air pollutants in Ireland.

Forest Land Expansion Scenario

In Ireland a strong increase of the forest landbase is expected. This expectation is strongly reflected in the future development of the forest resources. In the basic scenario a stable harvest level of about 1.9 million cubic meters per year is established; with the expansion of forest land the harvest level will be doubled in 35 years. After about 65 years the harvest level is three times (6 million cubic meters per year) that of the basic scenario. Due to the large expansion of the forest landbase, the growing stock is at a much lower level in comparison with the basic scenario. The extent of thinnings is much higher in the case of land expansion.

Summary

The handbook alternative gives the highest harvest potential under basic conditions. The harvest level suggested by ETTS-IV can be exceeded on a sustainable basis. The forest decline simulation lowers the potential harvest by 0.2 million cubic meters per year during 100 years. The strong increase expected of the forest landbase of Ireland will generate a tremendous increase of the total potential harvest of some 2.8 million cubic meters per year during the next 100 years.

Table B.12. Ireland.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	102–108	102–28	102–256	102–105	102–26	102–251	102–129
Fellings[b]							
Year 1	1.6	0.6	0.8	1.8	0.6	0.8	1.6
Year 40	2.6	2.1	2.0	2.3	1.7	1.8	4.5
Year 80	1.8	0.9	2.0	1.6	0.8	1.8	7.1
Coniferous							
Growing stock[a]	102–108	102–28	102–256	102–105	102–26	102–251	102–129
Fellings[b]							
Year 1	1.6	0.6	0.8	1.8	0.6	0.8	1.6
Year 40	2.6	2.1	2.0	2.3	1.7	1.8	4.5
Year 80	1.8	0.9	2.0	1.6	0.8	1.8	7.1
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	2.1	1.7	1.9	1.9	1.5	1.7	4.7
Coniferous	2.1	1.7	1.9	1.9	1.5	1.7	4.7
Growth (m^3 o.b./ha/yr)[c]							
Total	7.8	5.4	8.5	7.1	4.9	7.8	5.7
Coniferous	7.8	5.4	8.5	7.1	4.9	7.8	5.7
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	102–108	102–28	102–256	102–105	102–26	102–251	102–129
Coniferous	102–108	102–28	102–256	102–105	102–26	102–251	102–129

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

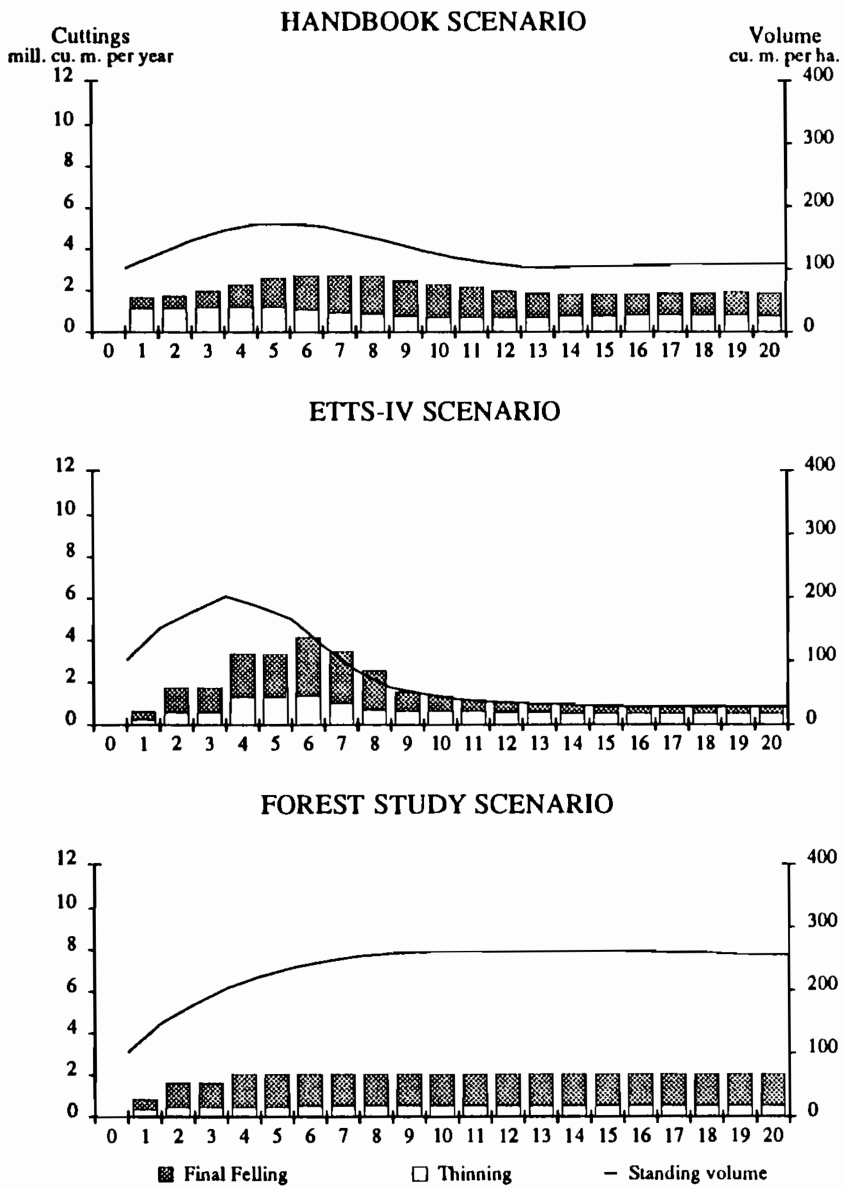


Figure B.81. Projections for total potential harvest and growing stock in Ireland under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.7 million cubic meters o.b.

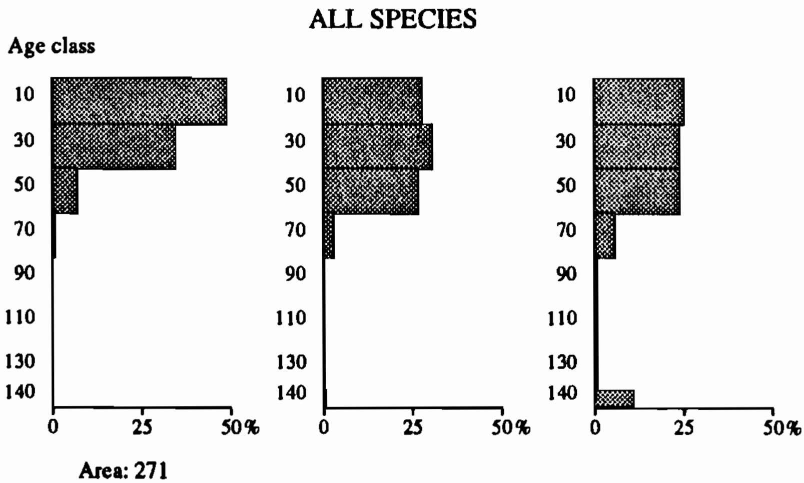


Figure B.82. Age-class distributions in Ireland under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

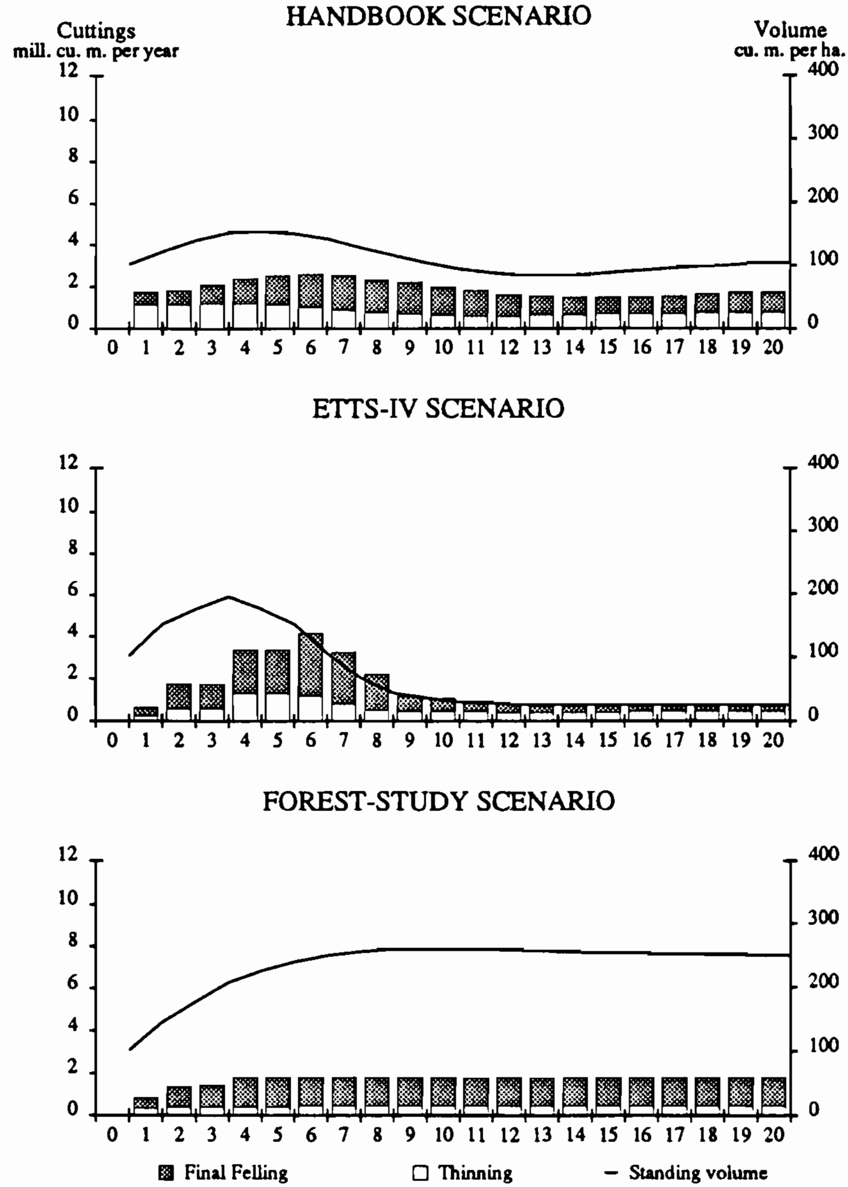


Figure B.83. Projections for total potential harvest and growing stock in Ireland under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.7 million cubic meters o.b.

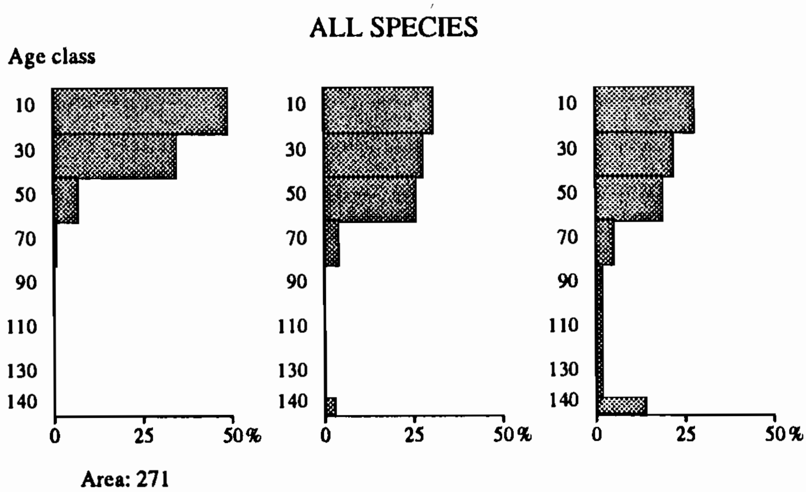


Figure B.84. Age-class distributions in Ireland under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

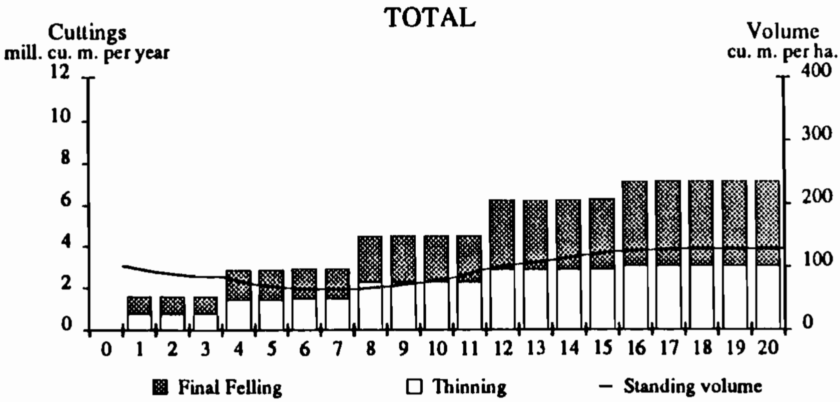


Figure B.85. Projections for total potential harvest and growing stock for total forests in Ireland under the Forest Land Expansion Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.7 million cubic meters o.b.

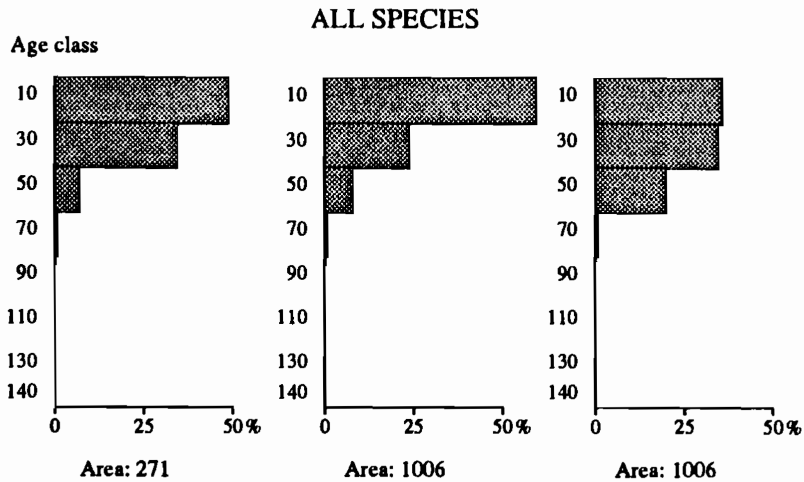


Figure B.86. Age-class distributions in Ireland under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Italy (Table B.13 and Figures B.87 to B.95)

Basic Scenarios

Results from the Basic Handbook Scenario suggest that the structure of Italian forests does not correspond with implementation of handbook silviculture. After the initial harvest pulse, harvest and growing-stock levels remain fairly stable at about 30 million cubic meters per year and 135 cubic meters per hectare, respectively. There is no problem to maintain ETTS-IV harvest levels, but growing stock increases to 338 cubic meters per hectare. The Basic Forest Study Scenario puts harvest levels well above the Basic ETTS-IV Scenario but below those of the Basic Handbook Scenario. The growing stock evolves in the Basic Forest Study Scenario to about 210 cubic meters per hectare, and harvests in high forests have a higher proportion of thinnings in comparison with the Basic Handbook Scenario. The harvests are rather evenly distributed among conifers, hardwoods, and coppices. Harvest levels and growing stocks for all three groups are fairly stable, except for the coppice growing stock which increases from 115 to 192 cubic meters per hectare.

Decline Scenarios

The imbalance between the existing forest structure and handbook silviculture is strongly expressed in the Handbook Decline Scenario. After the initial harvest pulse the potential harvest level is lower in the decline scenario over time in comparison with the basic scenario. The growing-stock level cannot be kept at the same level as in the basic scenario.

The Basic ETTS-IV Scenario gives a strong increase in the growing stock over time and a relatively low harvest level. The ETTS-IV harvest level was based on an old inventory, whereas the Forest Study is based on the new inventory and growth figures that indicate a much higher potential in the Italian forests. Even in the ETTS-IV Decline Scenario there is a strong increase in the growing stock over time, but the level is about 45 cubic meters per hectare lower at the end of the simulation period than in the basic scenario. In spite of the reduction of growing stock, the harvest level has to be reduced in the decline scenario. Thus, in the decline scenario there are no possibilities to keep the harvest level identified in the Basic ETTS-IV Scenario throughout the whole simulation period.

In the Forest Study Decline Scenario the same growing-stock development as in the basic scenario is foreseen through a decrease of the harvest level, about 3.3 million cubic meters per year in comparison with the basic scenario. The effects of the decline will be of about the same order concerning harvests and growing stocks for both deciduous and conifers species. The indicated harvest pattern is more uneven for deciduous species than for conifers. This is an effect of short rotations, especially for poplar trees. The coppice group is less influenced by the decline in comparison with the other two species groups.

Forest Land Expansion Scenario

In the Forest Land Expansion Scenario, the total harvest will start to increase after about 30 years. This process will continue for about 50 years. Thereafter the total harvest level will smooth out. At the end of the simulation period the harvest level is about 2.5 million cubic meters per year higher in comparison with the Basic Forest Study Scenario. The strongest harvest increase is generated by the deciduous species. Deciduous species will be planted on most of the new land (70 percent). The rhythm of the increased harvests is about the same in both coniferous and deciduous species. The development of the total growing stock will not change much with the increased landbase, which is due to the rather short rotation periods. The same can be said about the development of the growing stocks for the two different species groups. Coppices are not established on the new lands, so coppice development is unchanged in this scenario in comparison with the basic alternative. The extent of final cut will increase with the increased landbase. This is a result of new plantations with short rotation periods and limited thinnings.

Summary

There are very good possibilities to exceed the ETTS-IV harvest level under basic conditions. The big differences between the handbook alternative and the Forest Study alternatives suggest that the total potential harvest could be increased even more in the future. Forest decline attributed to air pollutants influences the harvest potential strongly, reducing it by 3.3 million cubic meters per year during 100 years. New forest land will cause an increase of the total potential harvest of 1.7 million cubic meters per year over 100 years.

Table B.13. Italy.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	154–135	154–338	154–208	154–123	154–292	154–221	154–210
Fellings[b]							
Year 1	60.5	9.6	18.0	70.6	9.6	14.8	18.9
Year 40	28.9	12.5	21.2	26.1	12.5	17.9	22.6
Year 80	29.6	12.2	21.0	27.4	12.2	17.7	23.5
Coniferous							
Growing stock[a]	236–227	236–500	236–268	236–204	236–445	236–314	236–239
Fellings[b]							
Year 1	13.8	3.0	5.8	17.8	3.0	4.7	5.9
Year 40	5.9	3.8	6.5	6.0	3.8	5.4	7.0
Year 80	6.4	3.6	6.3	5.5	3.6	5.2	7.6
Deciduous							
Growing stock[a]	172–181	172–408	172–185	172–157	172–309	172–225	172–202
Fellings[b]							
Year 1	10.1	6.2	7.0	13.0	6.2	6.1	7.8
Year 40	8.1	6.5	8.6	7.5	6.5	7.6	9.5
Year 80	8.2	6.4	8.6	7.2	6.4	7.6	9.8
Coppice							
Growing stock[a]	115–82	115–248	115–192	115–78	115–226	115–183	115–192
Fellings[b]							
Year 1	36.6	0.4	5.2	39.8	0.4	4.0	5.2
Year 40	14.9	2.2	6.1	12.6	2.2	4.9	6.1
Year 80	15.0	2.2	6.1	14.7	2.2	4.9	6.1
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	30.7	11.9	20.5	29.8	11.9	17.2	22.2
Coniferous	6.6	3.6	6.2	6.4	3.6	5.1	7.0
Deciduous	8.1	6.3	8.3	7.7	6.3	7.3	9.2
Coppice	16.0	2.0	6.0	15.7	2.0	4.8	6.0
Growth (m^3 o.b./ha/yr)[c]							
Total	6.2	4.3	4.8	5.9	3.9	4.3	4.2
Coniferous	6.0	5.9	6.1	5.6	5.4	5.5	5.0
Deciduous	8.4	8.8	8.7	7.7	7.8	8.1	5.1
Coppice	5.5	2.1	3.0	5.4	1.8	2.4	3.0
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	154–135	154–338	154–208	154–123	154–292	154–221	154–210
Coniferous	236–227	236–500	236–268	236–204	236–445	236–314	236–239
Deciduous	172–181	172–408	172–185	172–157	172–309	172–225	172–202
Coppice	115–82	115–248	115–192	115–78	115–226	115–183	115–192

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

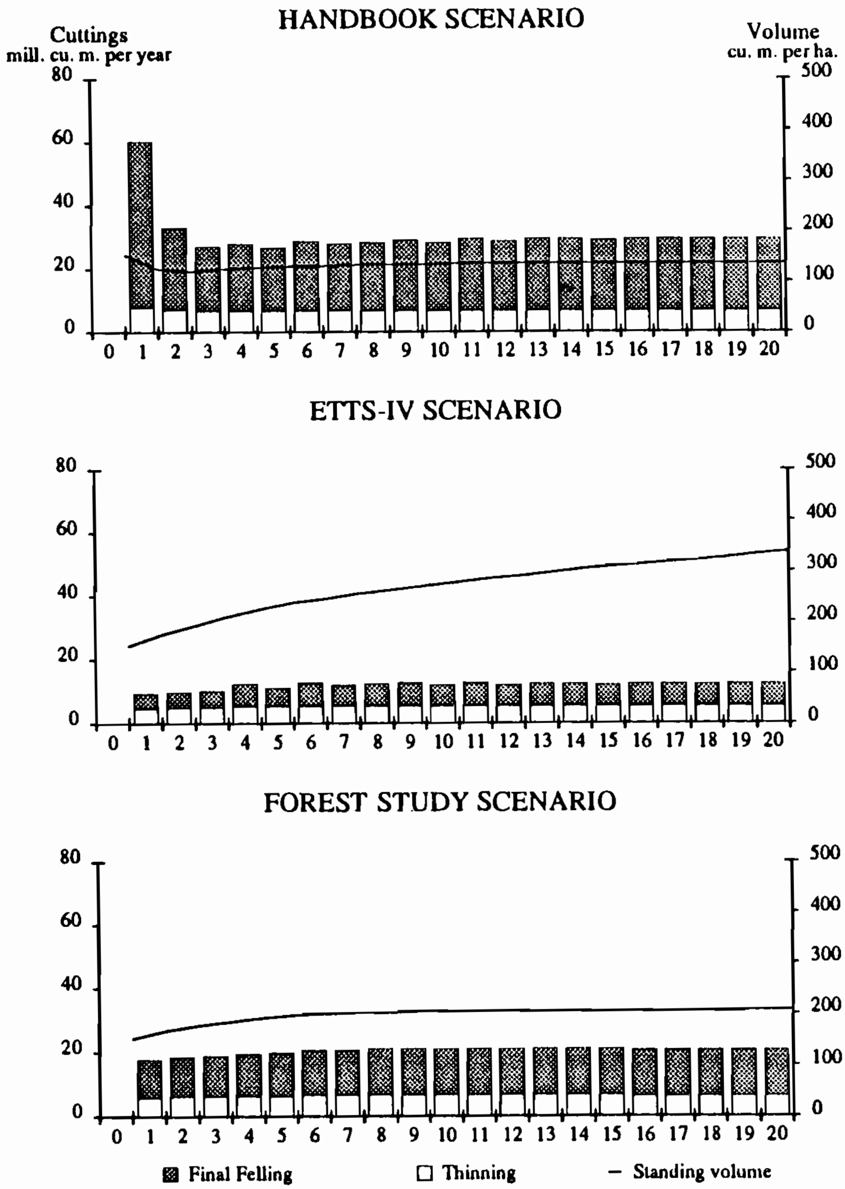


Figure B.87. Projections for total potential harvest and growing stock in Italy under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.

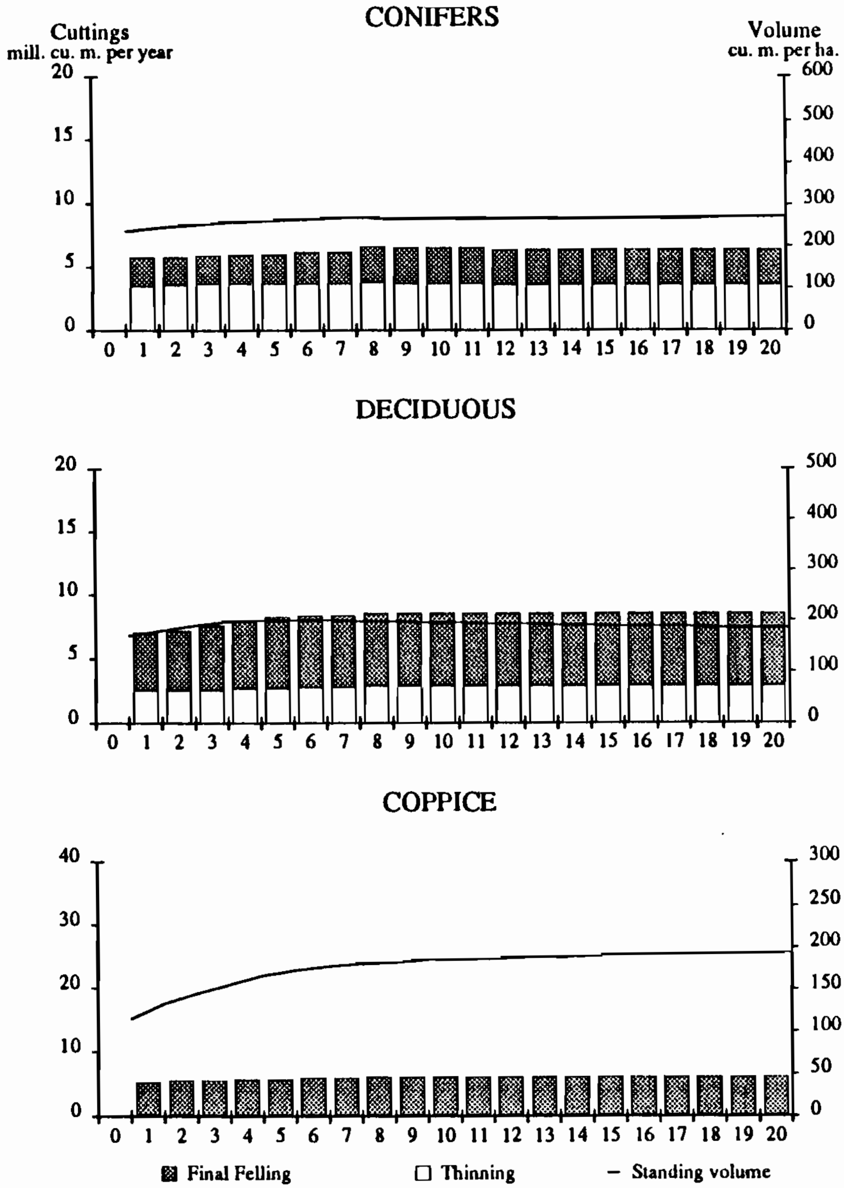


Figure B.88. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Italy under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 2 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 6 million cubic meters o.b.

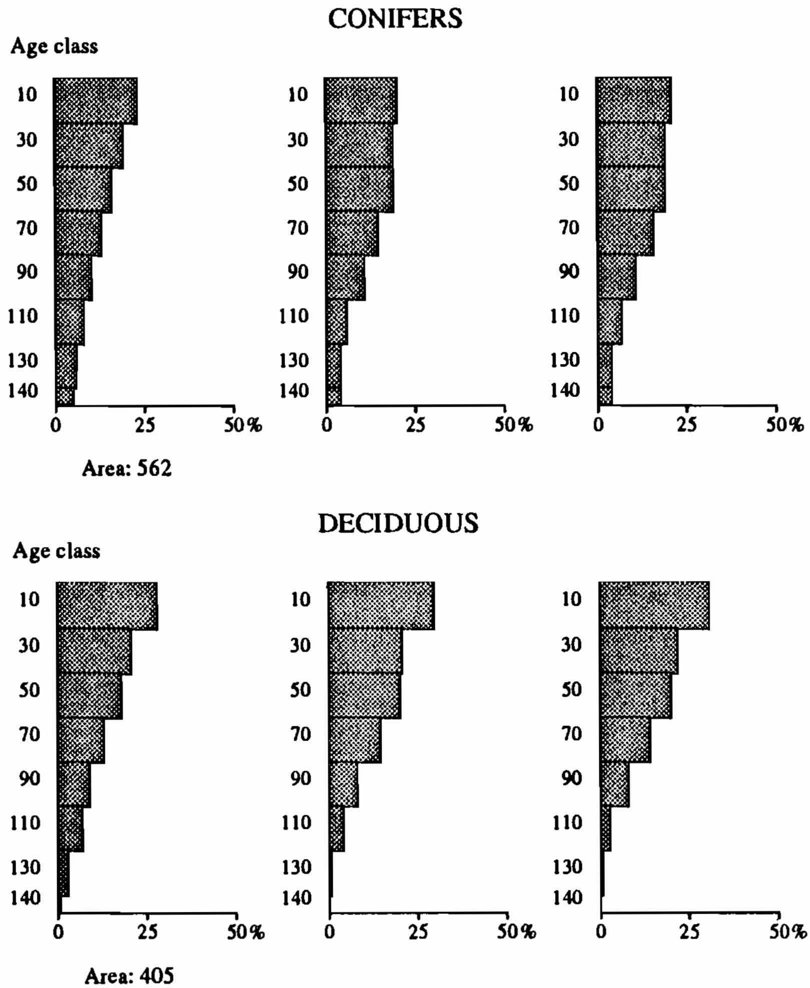


Figure B.89. Age-class distributions in Italy under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

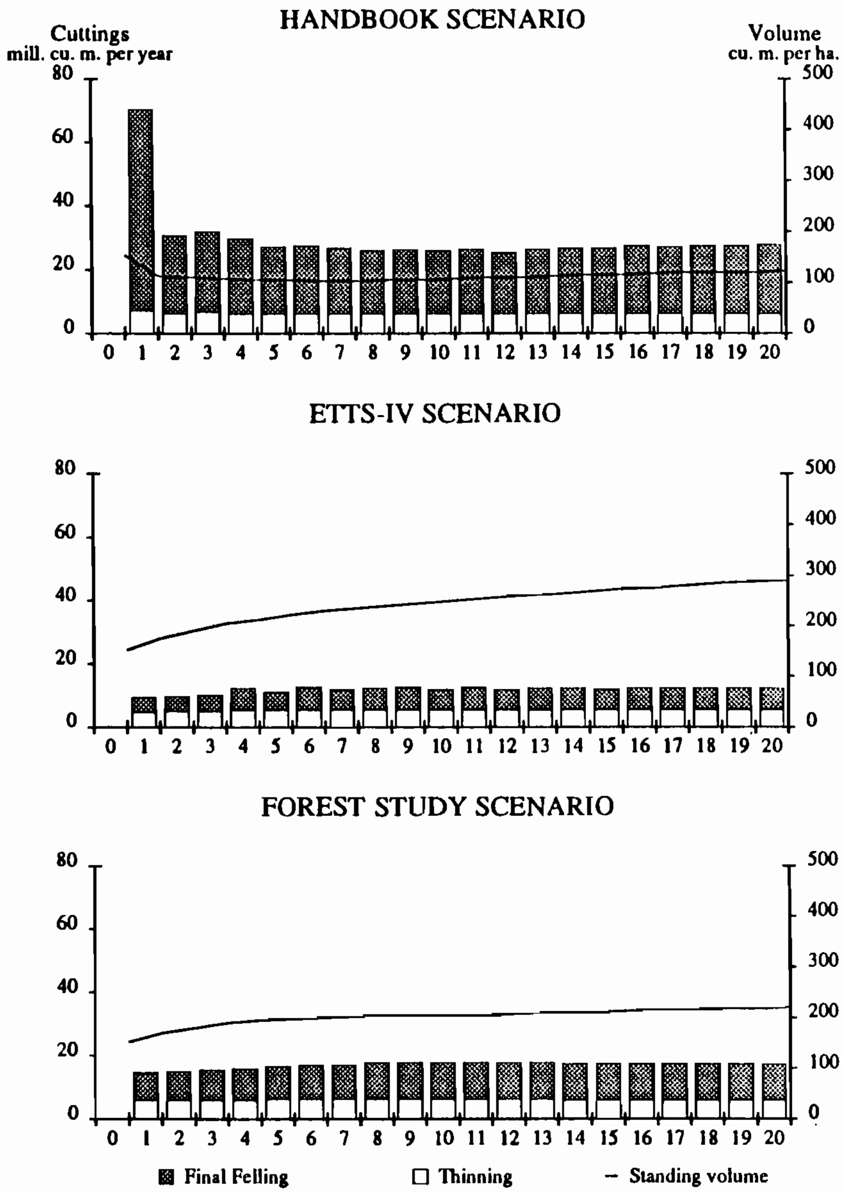


Figure B.90. Projections for total potential harvest and growing stock in Italy under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.

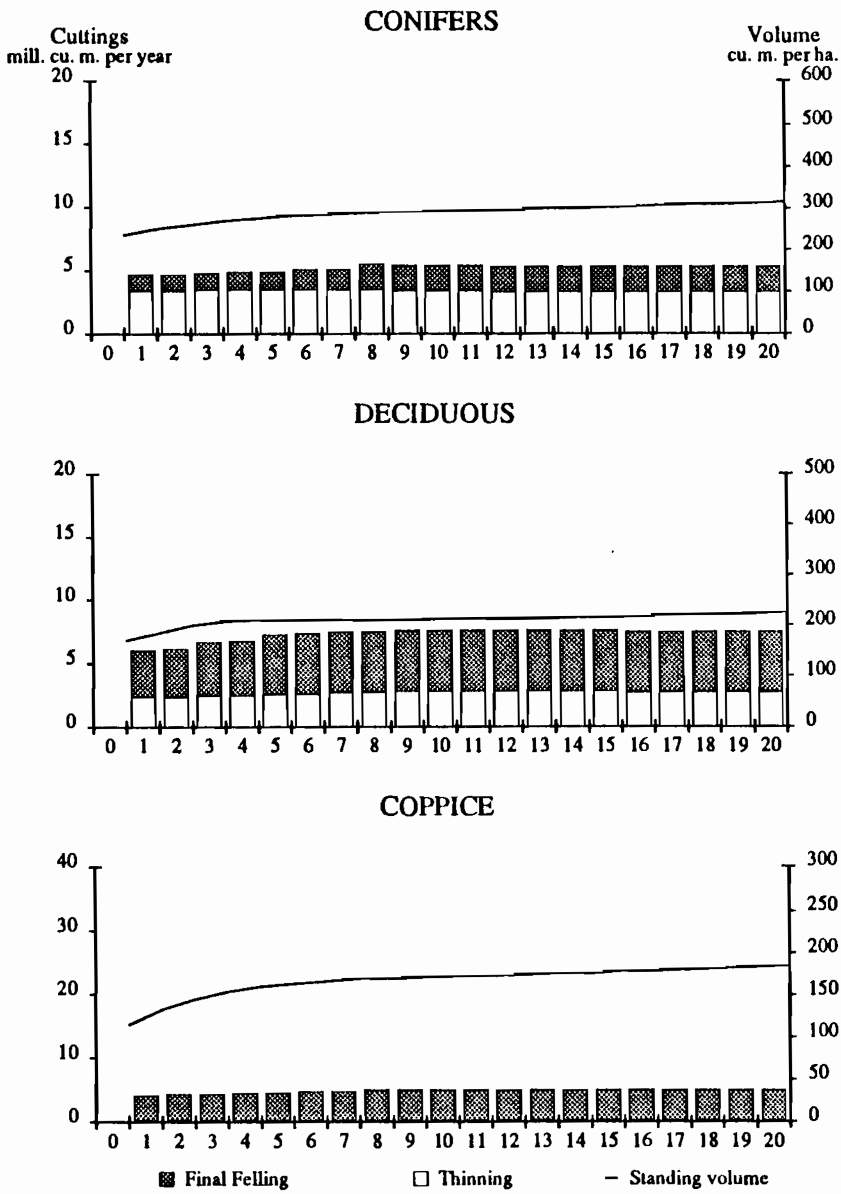
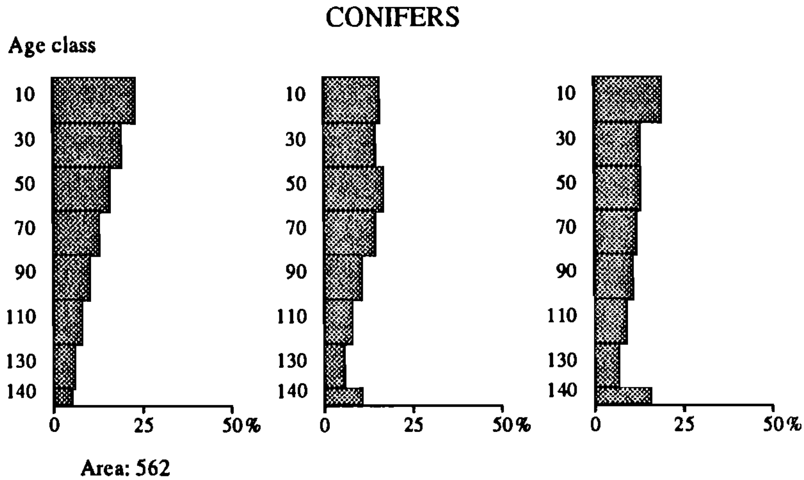


Figure B.91. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Italy under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 2 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 6 million cubic meters o.b.



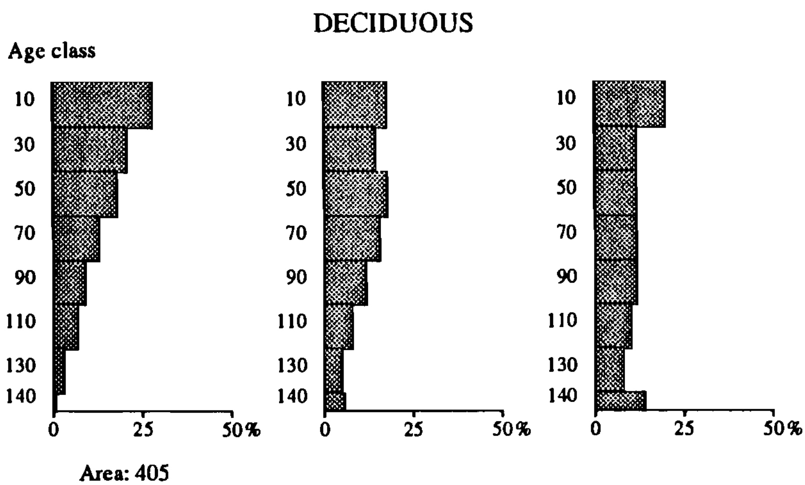


Figure B.92. Age-class distributions in Italy under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

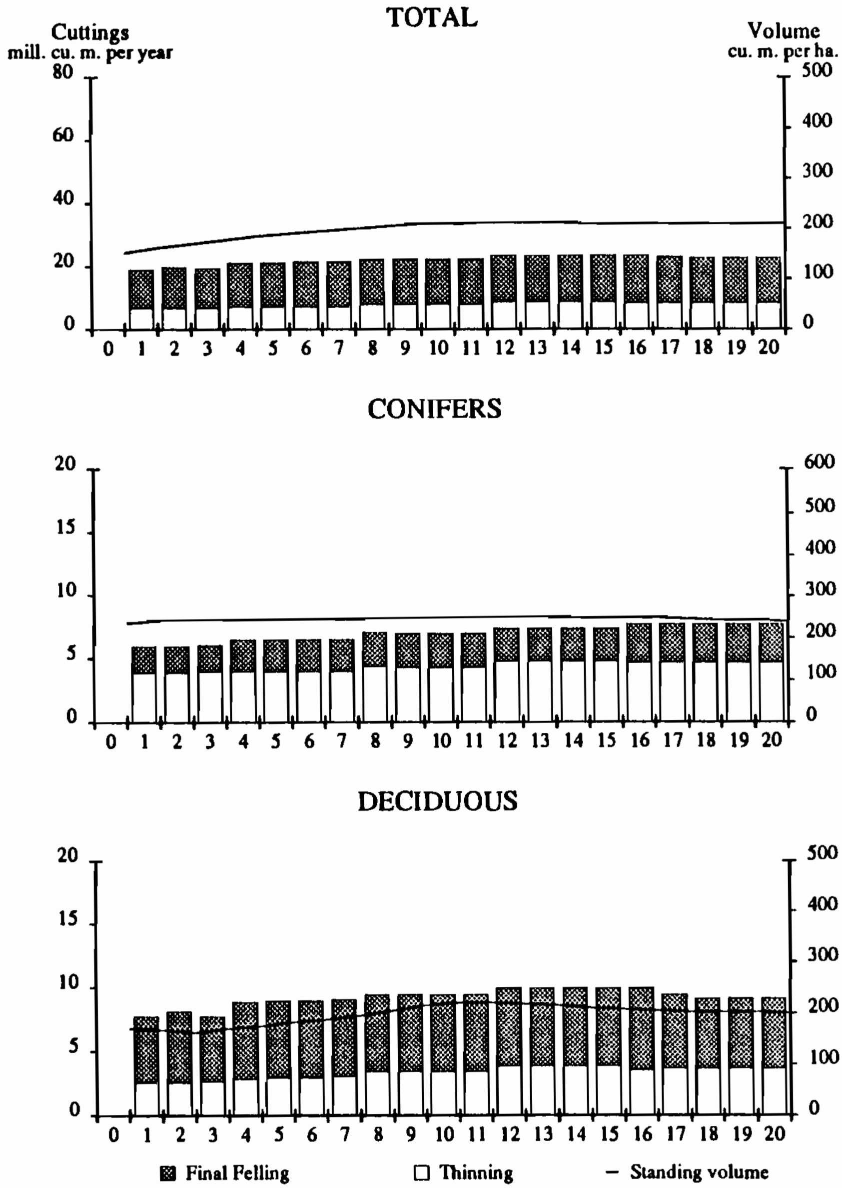


Figure B.93. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Italy under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 2 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 6 million cubic meters o.b.

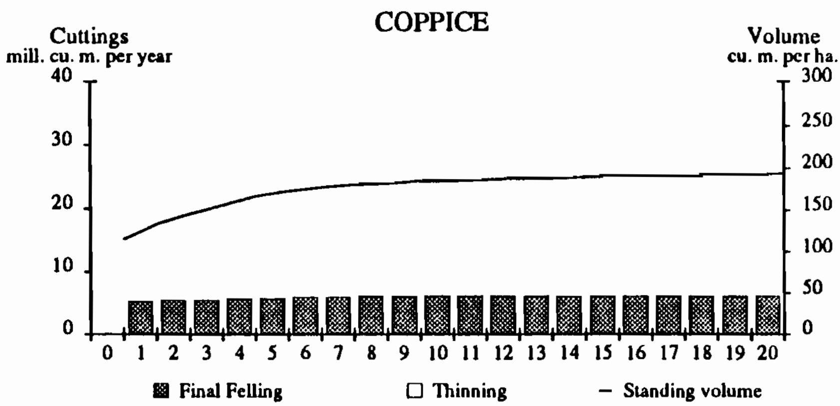


Figure B.94. Projections for potential harvest and growing stock of coppice in Italy under the Forest Land Expansion Scenario.

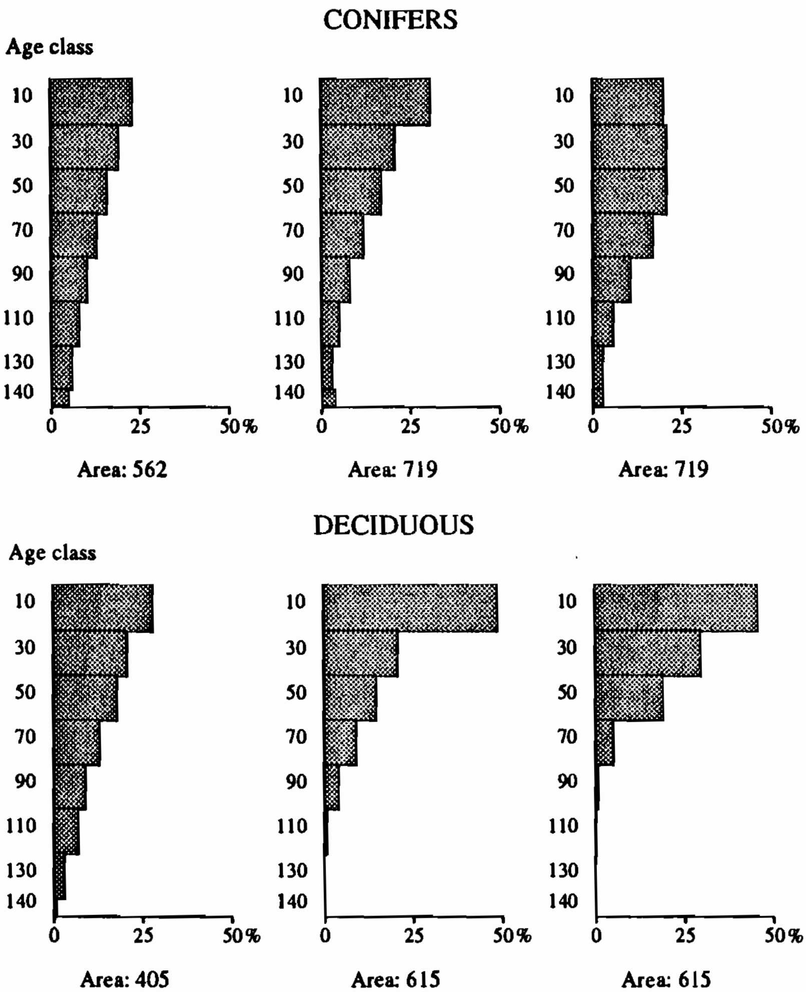


Figure B.95. Age-class distributions in Italy under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Luxembourg (Table B.14 and Figures B.96 to B.103)

Basic Scenarios

Luxembourg's forests have not been managed in the recent past according to handbook silviculture, as the huge harvest peak in the early years of the Basic Handbook Scenario shows. Simultaneously, growing stock has plunged by about 50 percent. While harvests continue to fluctuate over the remainder of the simulation, growing stock increases steadily to about 225 cubic meters per hectare. ETTS-IV harvest levels are not sustainable beyond about 60 years, after which they drop while growing stock builds up to some 190 cubic meters per hectare. The Basic Forest Study Scenario calls for a lower harvest than ETTS-IV for the first 60 years, thus keeping harvest sustainable with a growing stock for both softwoods and hardwoods of some 250 cubic meters per hectare. Harvests, mainly in hardwoods, come less from thinnings in this scenario than in the Basic Handbook Scenario. This is a result of the age-class structure that initially is heavily skewed by large proportions of forest area in old stands. The initial coniferous structure is fairly well balanced, but loses area from older classes with time.

Decline Scenarios

The imbalance between handbook silviculture and the existing forest structure is further emphasized by the Handbook Decline Scenario. Furthermore, in this scenario, the potential harvest is eventually lower in comparison with the basic scenario. The decrease of the total growing stock is also dramatic in the decline scenario in comparison with the basic scenario.

In the ETTS-IV Decline Scenario it is only possible to keep ETTS-IV harvest levels for about 50 years, after which the potential harvest level drops. This is accompanied by a dramatic decrease of the total growing stock (some 90 cubic meters per hectare lower than that of the basic scenario).

In the Forest Study Decline Scenario, it is possible to keep roughly the same level of growing stock as in the basic scenario. However, the potential harvest level has to be lower throughout the whole simulation period in comparison with the basic scenario. The decreased harvest potential is about 0.08 million cubic meters per year. The most dramatic effect of decline on potential harvest levels will occur in deciduous species.

Forest Land Expansion Scenario

In Luxembourg the land increase is small in hectares, but substantial. As a result of the land expansion, the potential harvest will increase over time. The major contribution to this increase comes from coniferous species. At the end of the simulation period, the coniferous harvest will be about double the coniferous harvest in the basic scenario. The harvest level of deciduous species is about the same in the two scenarios.

At the end of the simulation period, the total growing stock will be about the same in the expansion scenario as in the basic one. However, during the first 30 years there is a decrease in the total growing stock (and coniferous growing stock) decreases in comparison with the basic scenario.

The harvest level of deciduous species is roughly the same as that of the basic scenario. This will generate an increasing growing stock of deciduous species, which at the end of the simulation will result in a growing stock of nearly 300 cubic meters per hectare.

Summary

Under basic conditions, there are no possibilities to keep the harvest levels suggested by ETTS-IV for the whole simulation period. Decline attributed to air pollutants will strongly influence (in relative terms) the future total harvest potential. The total harvest potential will thus be decreased by 0.08 million cubic meters per year over the whole simulation period. The increased landbase will generate an additional potential harvest of 0.05 million cubic meters per year during the 100-year period.

Table B.14. Luxembourg.

Variable	Basic Handbook	Basic ETTS-IV	Basic Forest Study	Handbook Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	249–226	249–192	249–254	249–138	249–101	249–270	249–260
Fellings[b]							
Year 1	0.82	0.36	0.24	0.94	0.36	0.16	0.24
Year 40	0.16	0.27	0.23	0.12	0.27	0.17	0.28
Year 80	0.21	0.18	0.23	0.14	0.15	0.17	0.32
Coniferous							
Growing stock[a]	210–242	210–178	210–237	210–212	210–120	210–234	210–206
Fellings[b]							
Year 1	0.10	0.14	0.08	0.12	0.14	0.06	0.08
Year 40	0.07	0.06	0.08	0.05	0.05	0.07	0.13
Year 80	0.08	0.07	0.08	0.05	0.05	0.07	0.17
Deciduous							
Growing stock[a]	261–221	261–197	261–259	261–116	261–95	261–281	261–291
Fellings[b]							
Year 1	0.72	0.22	0.16	0.82	0.22	0.10	0.16
Year 40	0.09	0.21	0.15	0.07	0.22	0.10	0.15
Year 80	0.13	0.11	0.15	0.09	0.10	0.10	0.15
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	0.24	0.25	0.23	0.21	0.23	0.15	0.28
Coniferous	0.08	0.08	0.08	0.07	0.07	0.05	0.13
Deciduous	0.16	0.17	0.15	0.14	0.16	0.10	0.15
Growth (m^3 o.b./ha/yr)[c]							
Total	6.5	6.5	6.6	4.8	5.0	5.0	6.4
Coniferous	9.5	9.1	9.6	8.3	7.5	8.2	8.3
Deciduous	5.6	5.7	5.7	3.7	4.2	4.0	5.4
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	249–226	249–192	249–254	249–138	249–101	249–270	249–260
Coniferous	210–242	210–178	210–237	210–212	210–120	210–234	210–206
Deciduous	261–221	261–197	261–259	261–116	261–95	261–281	261–291

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

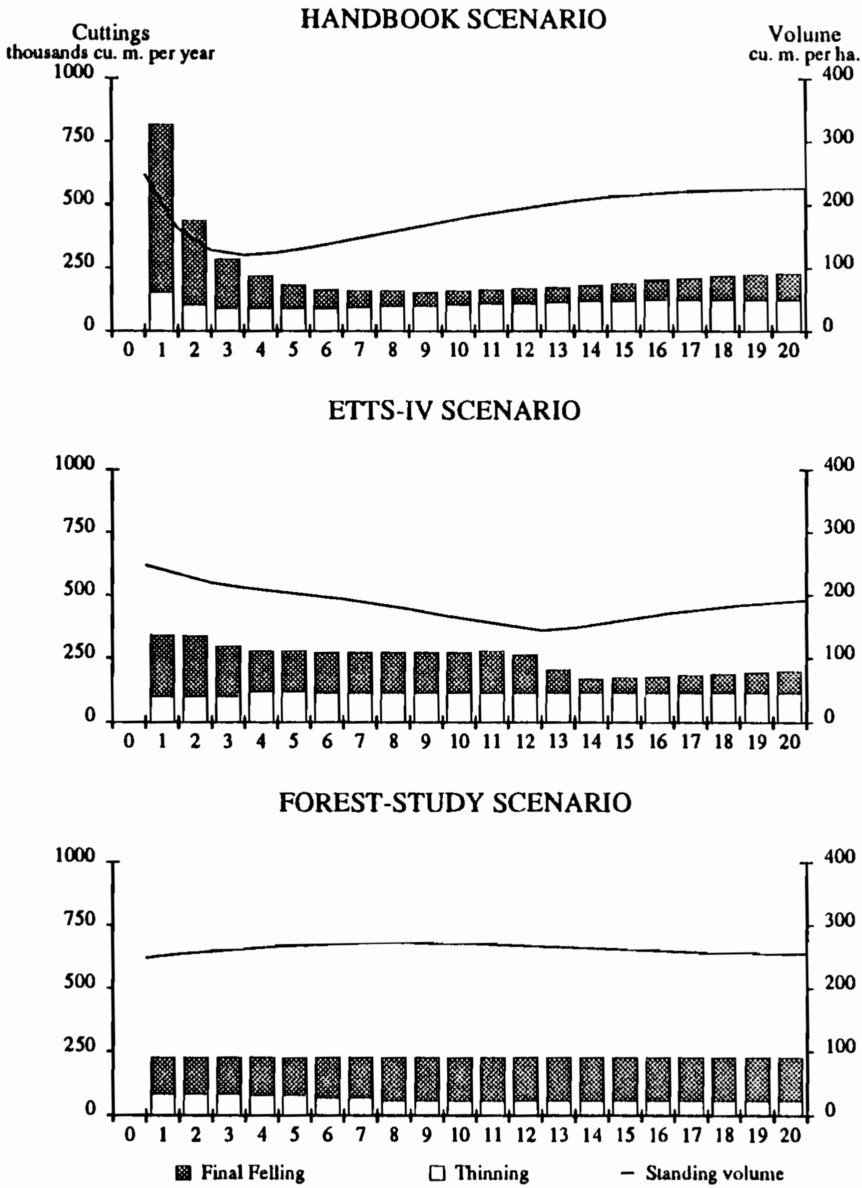


Figure B.96. Projections for total potential harvest and growing stock in Luxembourg under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.3 million cubic meters o.b.

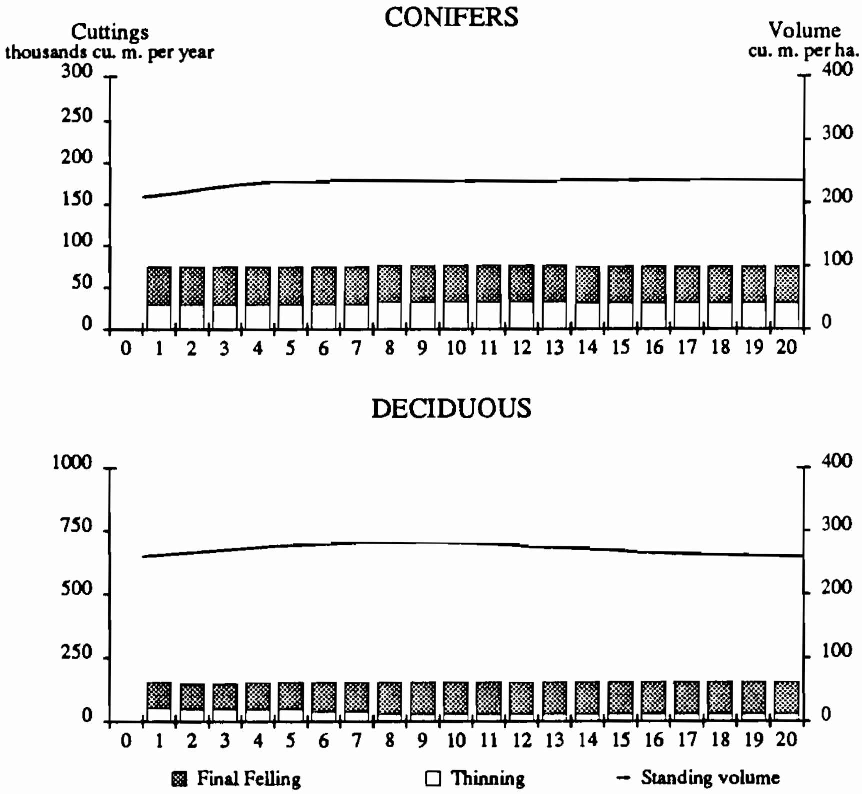


Figure B.97. Projections for total potential harvest and growing stock for coniferous and deciduous species in Luxembourg under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 0.2 million cubic meters o.b.

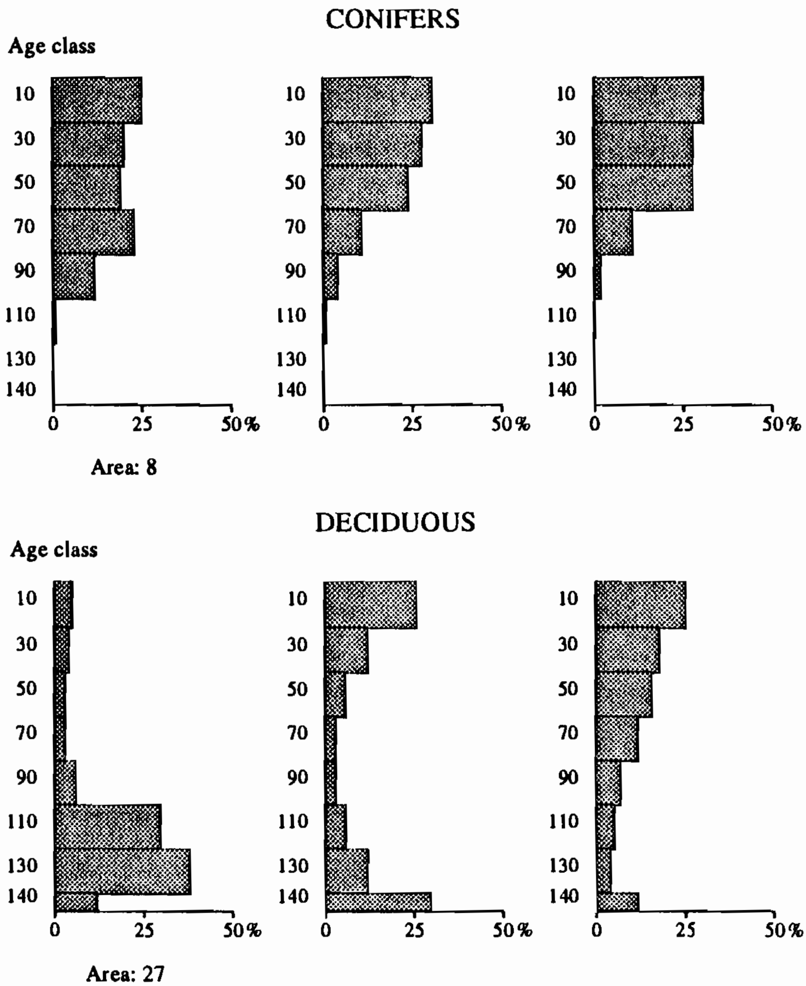


Figure B.98. Age-class distributions in Luxembourg under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

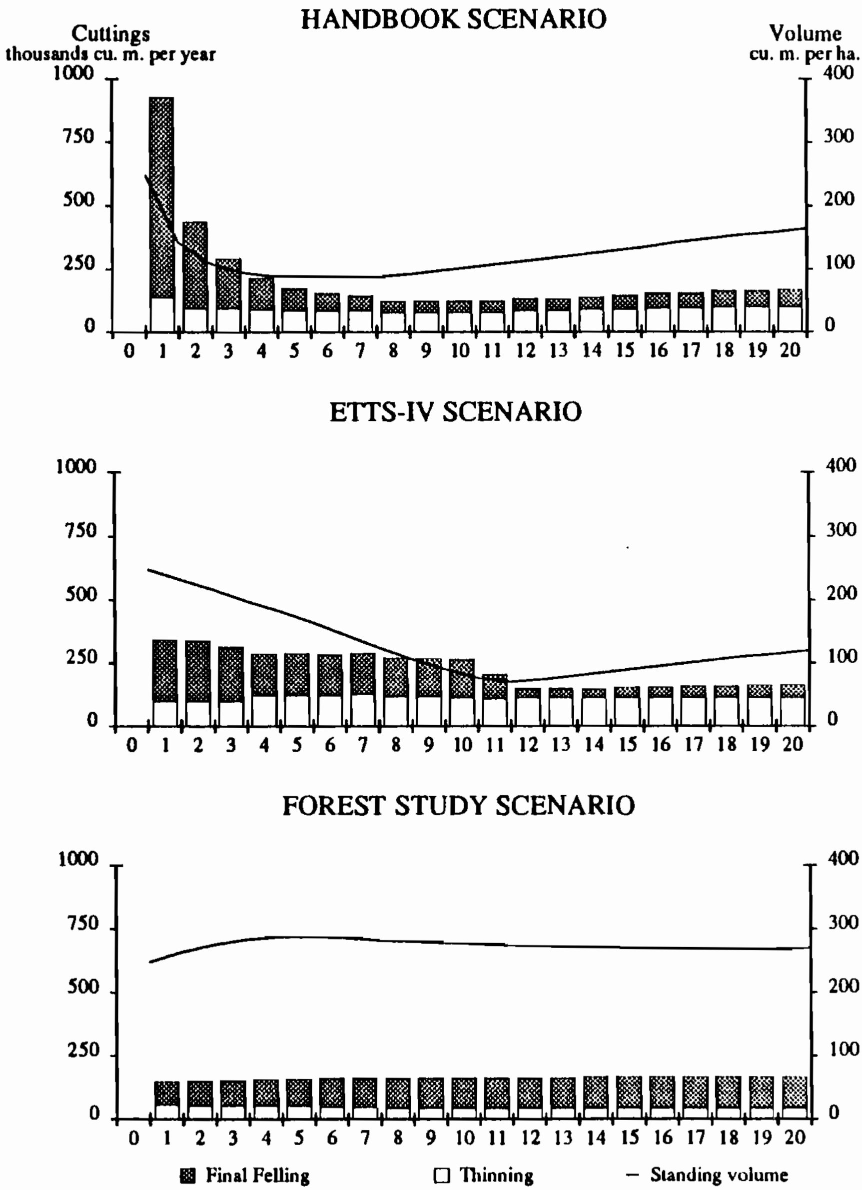


Figure B.99. Projections for total potential harvest and growing stock in Luxembourg under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.3 million cubic meters o.b.

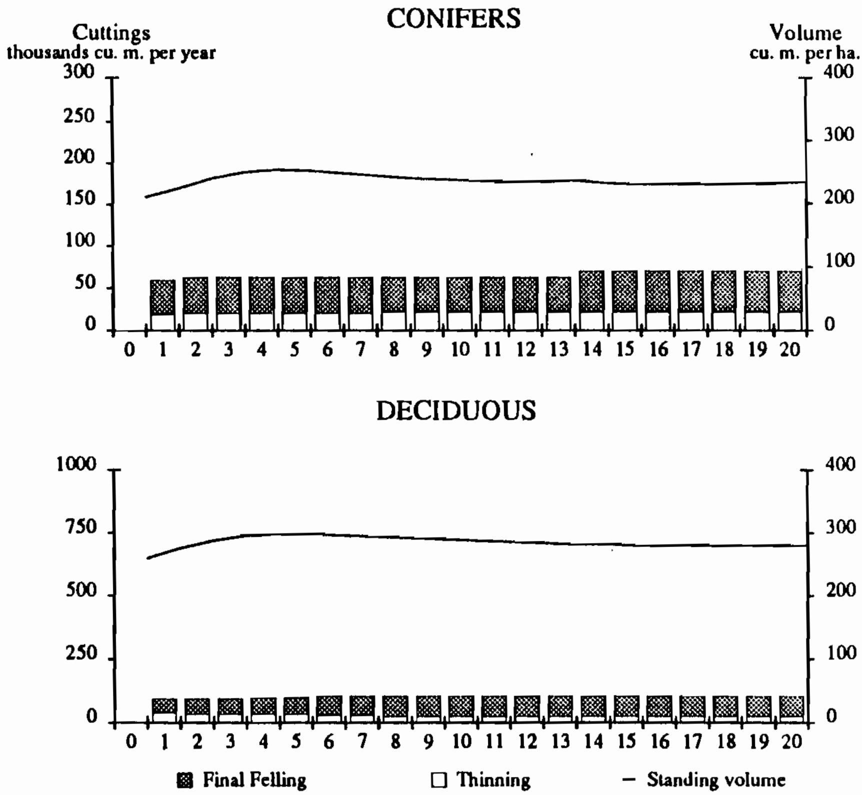


Figure B.100. Projections for total potential harvest and growing stock for coniferous and deciduous species in Luxembourg under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 0.2 million cubic meters o.b.

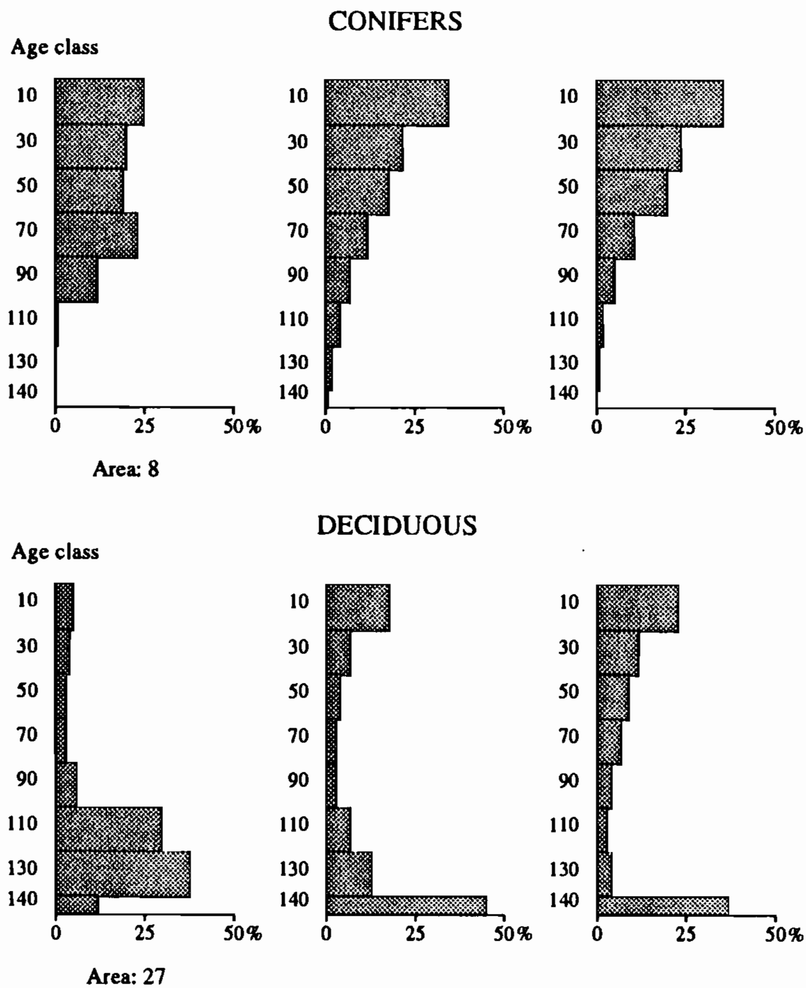


Figure B.101. Age-class distributions in Luxembourg under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

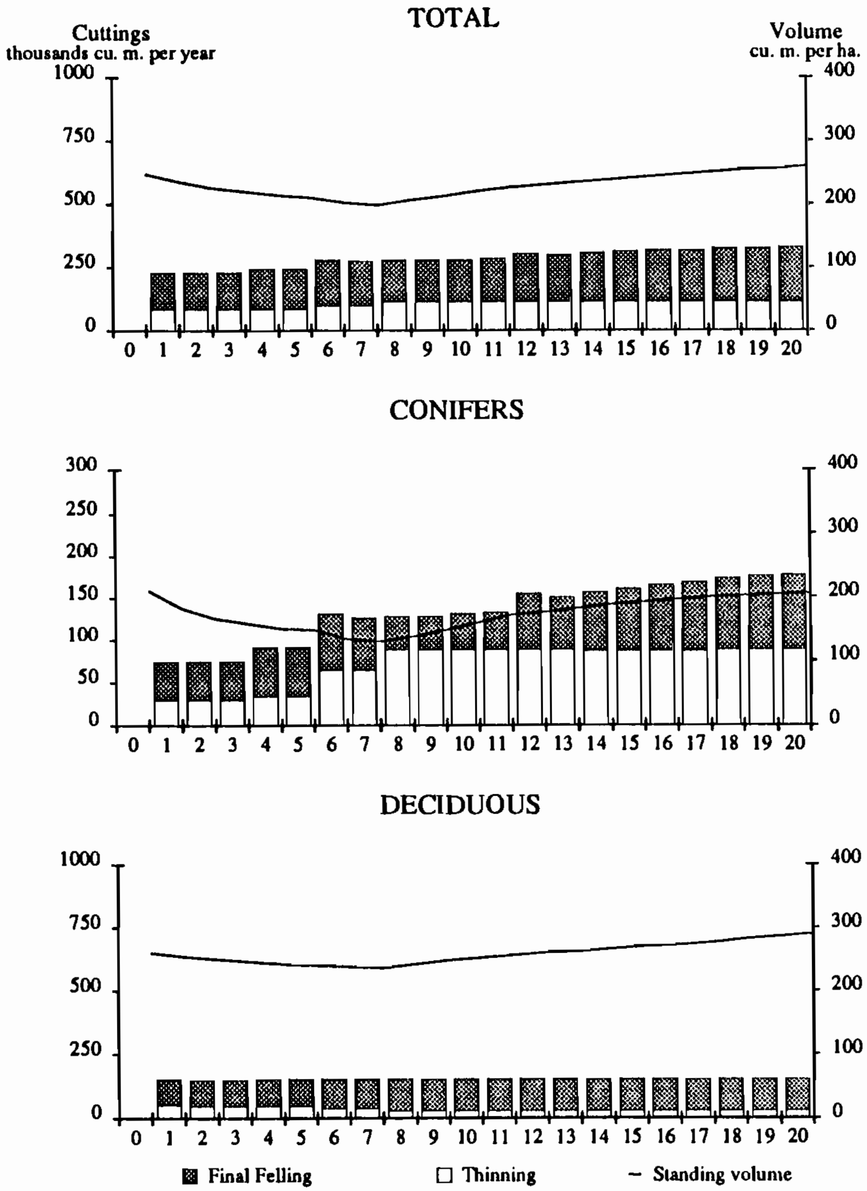


Figure B.102. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Luxembourg under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.3 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 0.1 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 0.2 million cubic meters o.b.

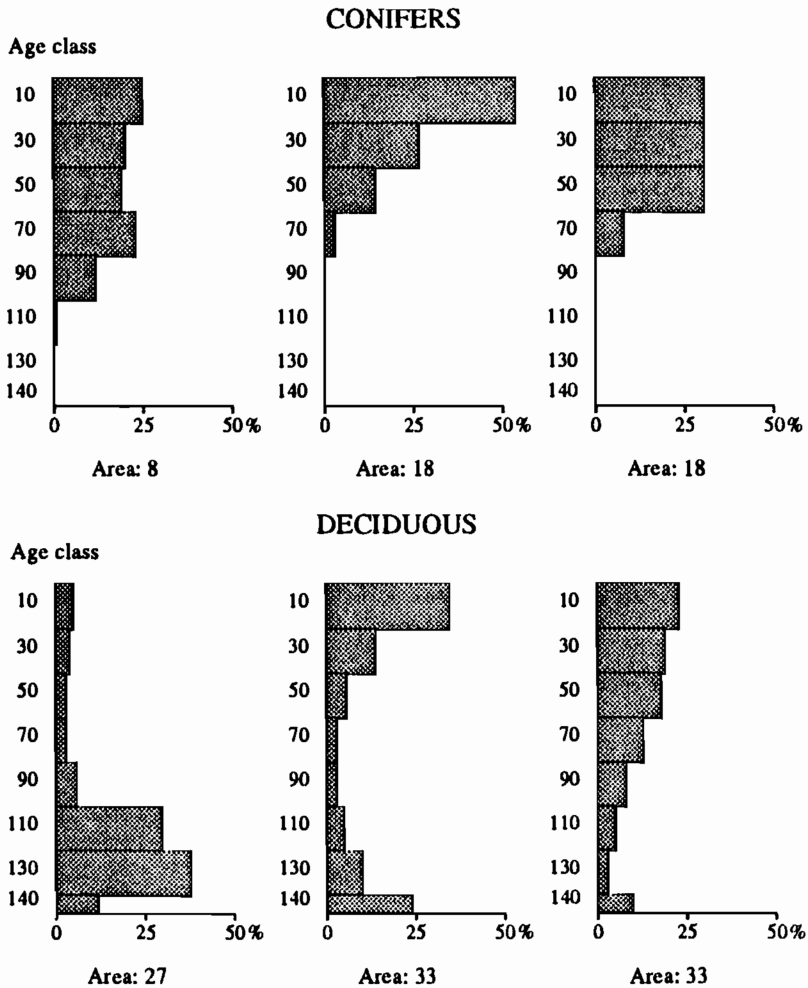


Figure B.103. Age-class distributions in Luxembourg under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Netherlands (Table B.15 and Figures B.104 to B.111)

Basic Scenarios

The existing forest structure appears to have evolved under application of handbook silviculture, as shown by results of the Basic Handbook Scenario. Harvest is more or less stable at about 1 million cubic meters per year, with growing stock increasing from 103 to 156 cubic meters per hectare. The ETTS-IV harvest levels can be maintained, but result in a growing stock that remains low throughout the simulation. The Basic Forest Study Scenario calls for a slightly lower harvest level than the ETTS-IV levels during the first 40 years, permitting the growing stock to rise to 172 cubic meters per hectare by the end of the simulation. The bulk of the annual harvest comes from coniferous stands, and within these mostly from final cuttings. Harvests of both coniferous and deciduous species are stable throughout the planning period, but the deciduous growing stock climbs strongly to more than 200 cubic meters per hectare. Under this scenario, the coniferous age-class structure becomes more balanced, developing from a structure of mostly 20- to 60-year-old stands. The age-class structure of deciduous forests evolves from high proportions of young stands into an even structure in the later part of the simulation.

Decline Scenarios

Forest decline attributed to air pollution disturbs the balance between the existing structure and handbook silvicultural programs. The decline will cause harvest pulses in the beginning of the simulation. After these pulses, the potential harvest level decreases throughout the simulation period. The total growing stock decreases at first, but by the end of the period it recovers to the same level as that in the basic scenario.

ETTS-IV harvest levels cannot be maintained in the case of decline. In the Forest Study Decline Scenario, it is nearly possible to keep the same level of the growing stock as in the basic scenario, but harvests have to be reduced by about 0.2 million cubic meters per year. The deciduous and coniferous species are affected to the same extent concerning relative potential harvest in the decline situation.

Forest Land Expansion Scenario

The increased forest landbase will generate a steady increase in the total harvest level over time. At the end of the planning period, the harvest potential is about 0.2 million higher in comparison with the Basic Forest Study Scenario. Coniferous and deciduous species contribute equally to this increased harvest. The total growing stock and the growing stock of deciduous species will increase over time but stay at lower level in comparison with the basic scenario. The growing stock of conifers has about the same development as in the basic scenario.

Summary

There is a rather good correspondence between the different scenarios under basic conditions. However, the Basic Forest Study Scenario does not reach the harvest level suggested by ETTS-IV. There is a strong forest-decline effect (in relative terms) on the total potential wood supply. The decrease of harvest caused by the decline is about 0.2 million cubic meters per year over 100 years. The addition of new land will generate an increase of the potential harvest of the same size.

Table B.15. Netherlands.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	103–156	103–106	103–172	103–160	103–135	103–169	103–162
Fellings[b]							
Year 1	1.0	1.2	0.8	1.6	0.8	0.6	0.8
Year 40	1.0	1.0	1.0	0.6	1.0	0.8	1.1
Year 80	1.1	1.0	1.0	0.8	0.8	0.8	1.4
Coniferous							
Growing stock[a]	110–153	110–120	110–160	110–160	110–139	110–156	110–159
Fellings[b]							
Year 1	0.6	0.8	0.6	1.0	0.6	0.6	0.6
Year 40	0.7	0.7	0.7	0.5	0.7	0.6	0.7
Year 80	0.8	0.7	0.7	0.6	0.6	0.6	0.9
Deciduous							
Growing stock[a]	87–163	87–71	87–203	87–159	87–125	87–200	87–168
Fellings[b]							
Year 1	0.4	0.4	0.2	0.6	0.2	0.2	0.2
Year 40	0.3	0.3	0.3	0.1	0.3	0.2	0.4
Year 80	0.3	0.3	0.3	0.2	0.2	0.2	0.5
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	1.0	1.0	1.0	0.8	0.9	0.8	1.2
Coniferous	0.7	0.7	0.7	0.6	0.6	0.6	0.8
Deciduous	0.3	0.3	0.3	0.2	0.3	0.2	0.4
Growth (m^3 o.b./ha/yr)[c]							
Total	5.0	4.8	4.9	4.3	4.3	4.0	4.9
Coniferous	4.8	4.8	4.7	4.3	4.2	4.0	4.8
Deciduous	5.5	4.8	5.5	4.3	4.4	4.0	5.2
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	103–156	103–106	103–172	103–160	103–135	103–169	103–162
Coniferous	110–153	110–120	110–160	110–160	110–139	110–156	110–159
Deciduous	87–163	87–71	87–203	87–159	87–125	87–200	87–168

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

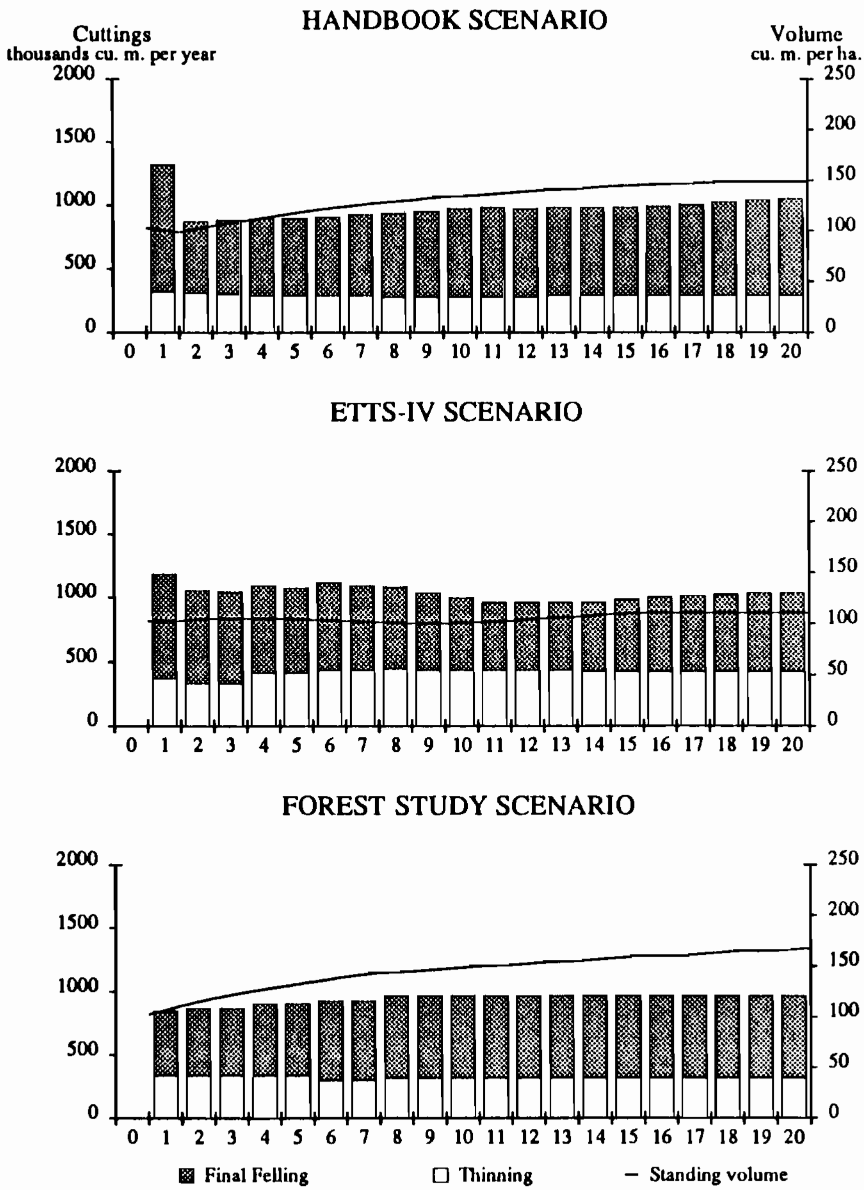


Figure B.104. Projections for total potential harvest and growing stock in the Netherlands under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 1.2 million cubic meters o.b.

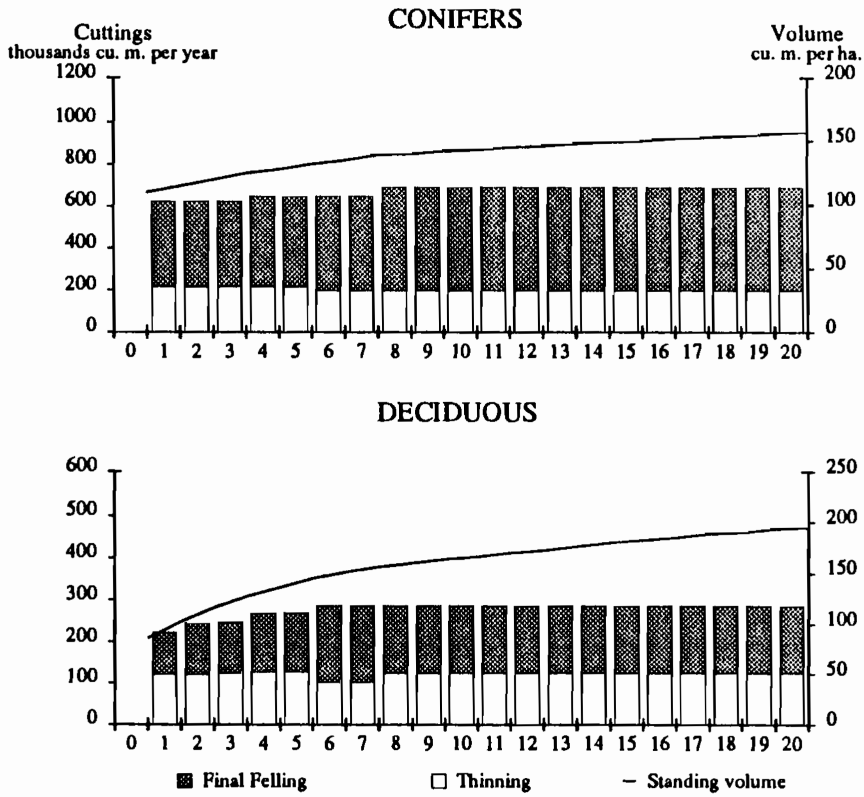


Figure B.105. Projections for total potential harvest and growing stock for coniferous and deciduous species in the Netherlands under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.8 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 0.4 million cubic meters o.b.

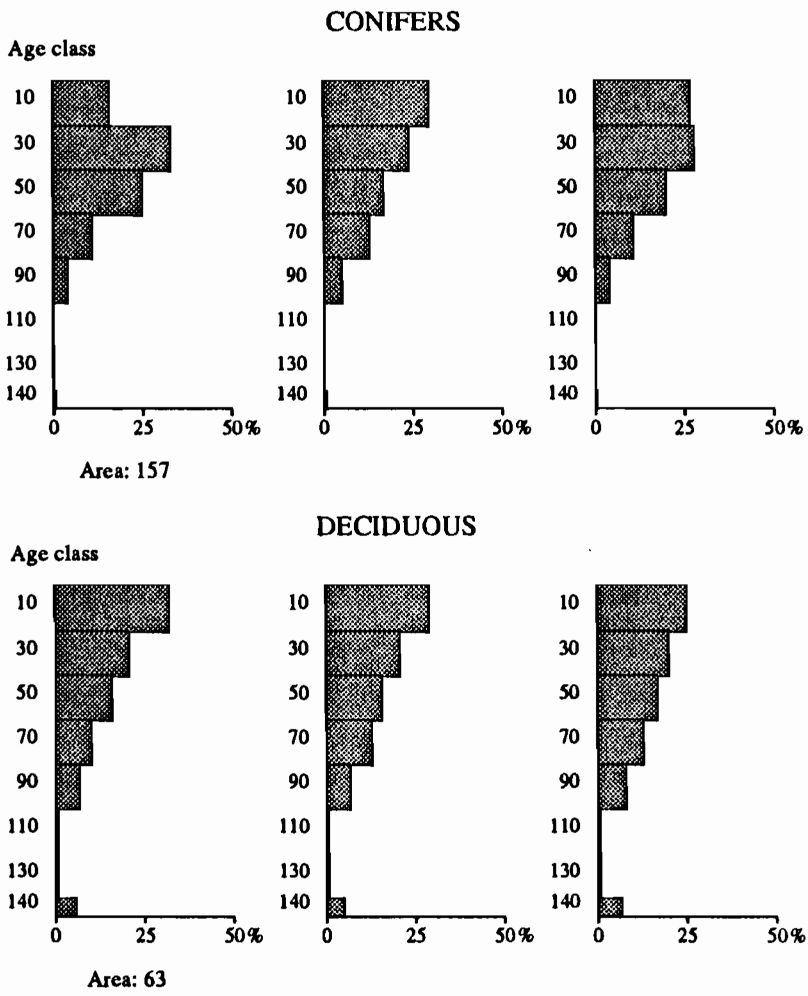


Figure B.106. Age-class distributions in the Netherlands under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

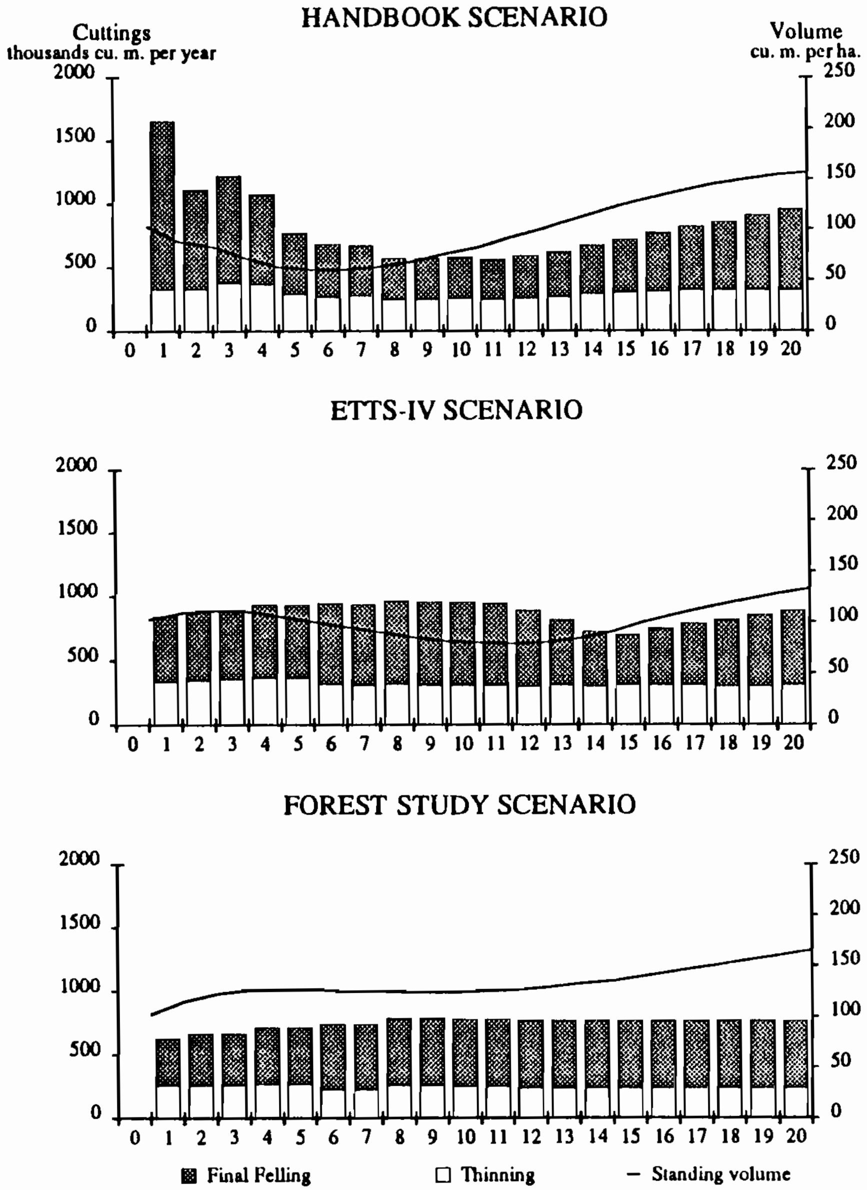


Figure B.107. Projections for total potential harvest and growing stock in the Netherlands under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 1.2 million cubic meters o.b.

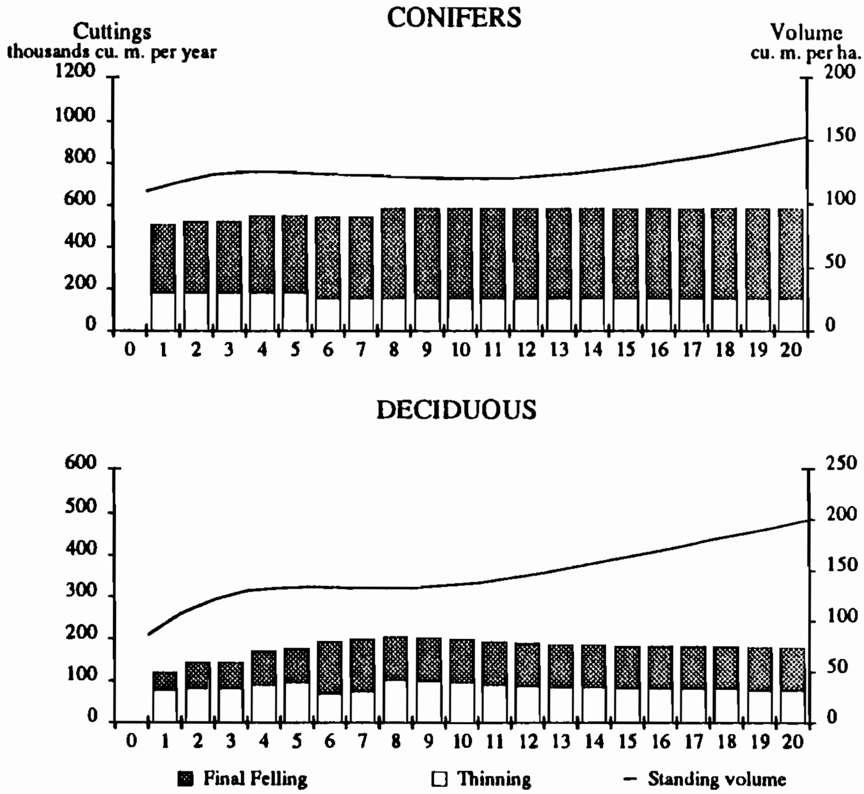


Figure B.108. Projections for total potential harvest and growing stock for coniferous and deciduous species in the Netherlands under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 0.8 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 0.4 million cubic meters o.b.

Figure B.109. Age-class distributions in the Netherlands under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

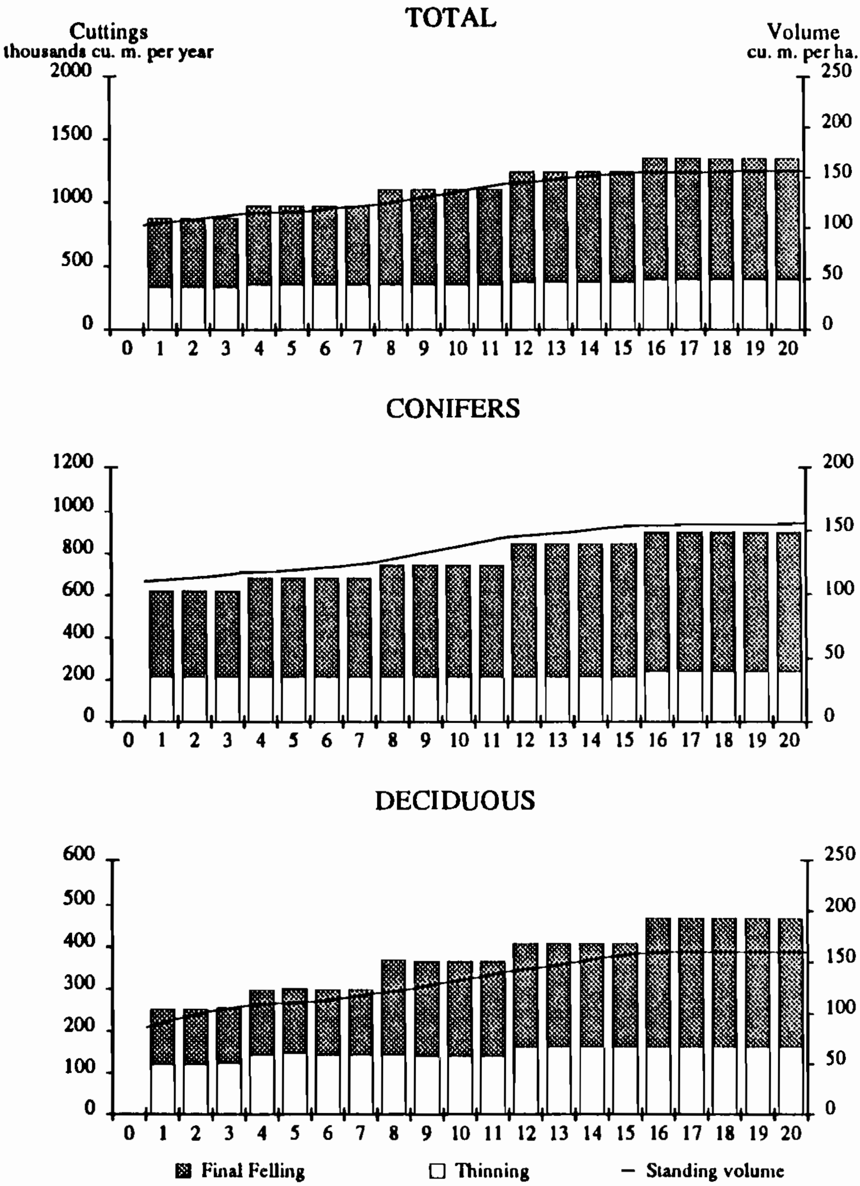


Figure B.110. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in the Netherlands under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 1.2 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 0.8 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 0.4 million cubic meters o.b.

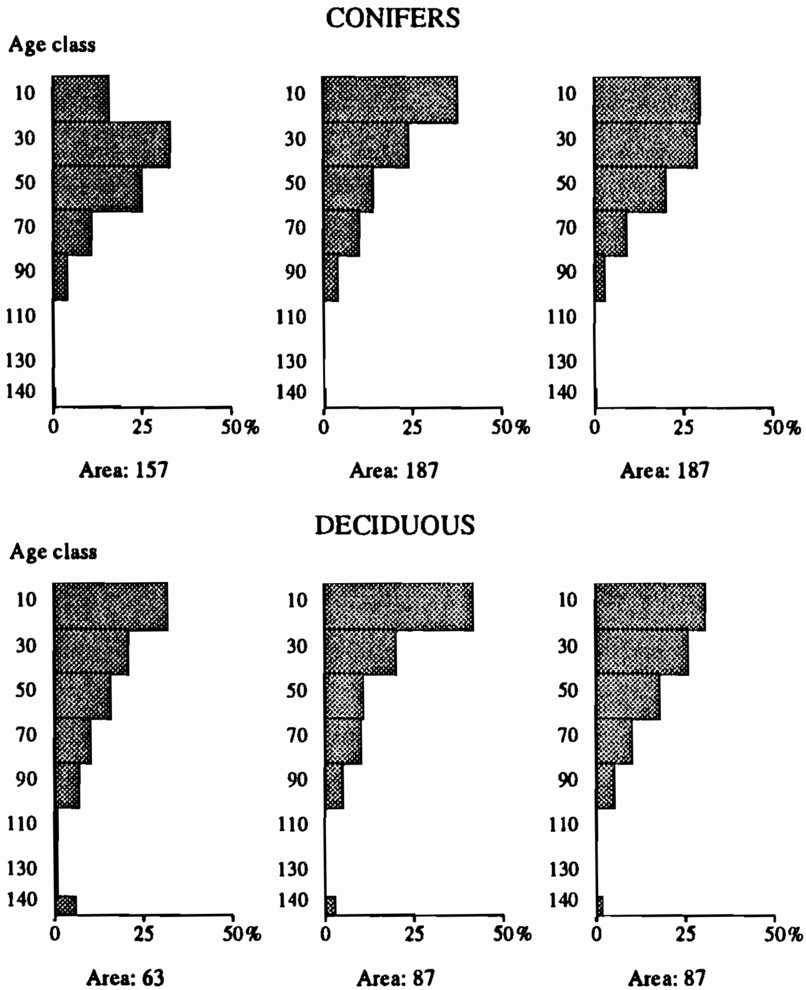


Figure B.111. Age-class distributions in the Netherlands under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Norway (Table B.16 and Figures B.112 to B.115)

Basic Scenarios

The Basic Handbook Scenario indicates a very strong mismatch between handbook silviculture and the initial forest structure. There is no forest-structure or biological constraint in Norway against harvesting at ETTS-IV levels. In fact, carrying out such harvest rates through the simulation period results in a rather high growing stock (from about 100 cubic meters per hectare to about 275 cubic meters per hectare). This would lead to significant problems of forest vitality with increased degrees of competitive stress and overmature stands. Thus, the Basic Forest Study Scenario forces a higher harvest level than the Basic ETTS-IV Scenario by about 40 percent. Even in this case, the growing stock increases to about 225 cubic meters per hectare. This suggests that harvest levels could be pushed even higher without compromising the sustainability of Norway's forest resources. In this case, the age-class structure moves from one with fairly even distribution of all age classes, especially quite mature ones, to one with almost all stands younger than 80 years. Unfortunately, because of the nature of the basic forest-inventory data from Norway, we cannot show separate results for coniferous and deciduous forests.

Decline Scenarios

The Handbook Decline Scenario illustrates a dramatic imbalance between the existing structure of the forest and the silvicultural programs employed. A huge harvest peak occurs in the first period under the decline conditions. During the middle of the simulation period there is a slightly higher harvest potential in the decline scenario than under basic conditions. The potential harvest level has a strong cyclic development, indicating that a structural change in the forest resources is required. At the end of the simulation period there is a decrease in the growing stock in comparison with the basic scenario.

ETTS-IV harvest levels can also be obtained under decline conditions. However, it results in a lower growing stock in comparison with the basic scenario.

In the Forest Study Decline Scenario, it is not possible to achieve the same potential harvest level and growing stock as in the basic scenario. The potential harvest is about 0.8 million cubic meters per year lower.

Summary

There are big differences between individual scenarios under basic conditions. The handbook scenario gives the highest total potential harvest level. The harvest level suggested by ETTS-IV can easily be surpassed, as shown in the Basic Forest Study Scenario. However, in Norway there are big differences between potential and economic (real) wood supply. The effects of forest decline in Norway are less severe than in the other Nordic countries.

Table B.16. Norway.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	83–195	83–272	83–227	83–168	83–248	83–211	
Fellings[b]							
Year 1	45.4	11.0	18.0	68.8	11.0	17.0	
Year 40	17.3	15.9	19.6	19.0	15.9	20.8	
Year 80	28.9	15.9	22.0	28.3	16.0	20.8	
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	23.4	14.9	20.6	24.4	14.9	19.8	
Growth (m^3 o.b./ha/yr)[c]							
Total	5.6	4.8	5.4	5.6	4.5	5.1	
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	83–195	83–272	83–227	83–168	83–248	83–211	

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

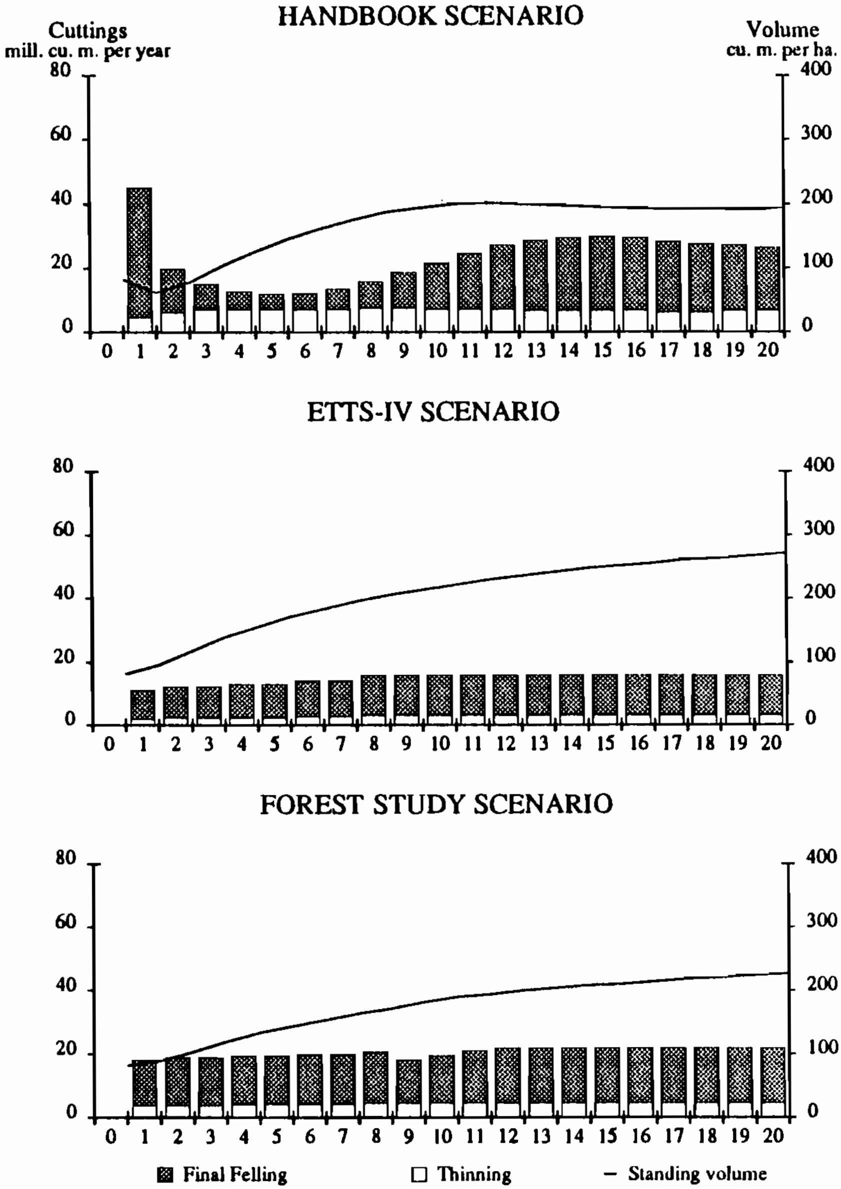


Figure B.112. Projections for total potential harvest and growing stock in Norway under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 11 million cubic meters o.b.

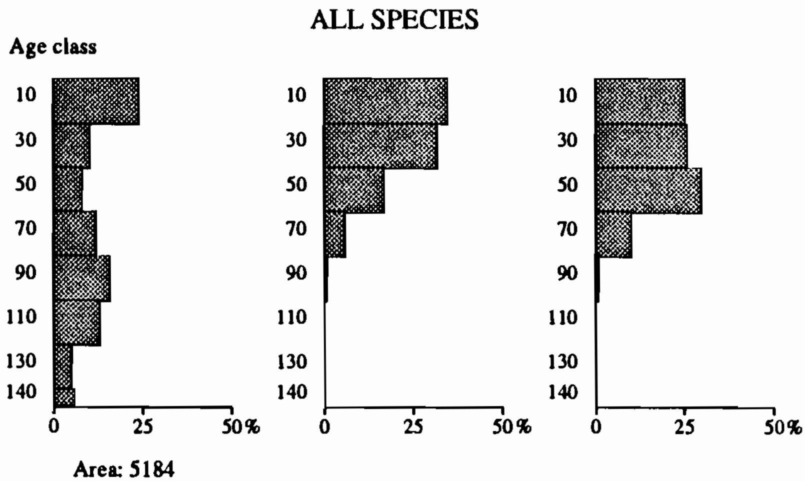


Figure B.113. Age-class distributions in Norway under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

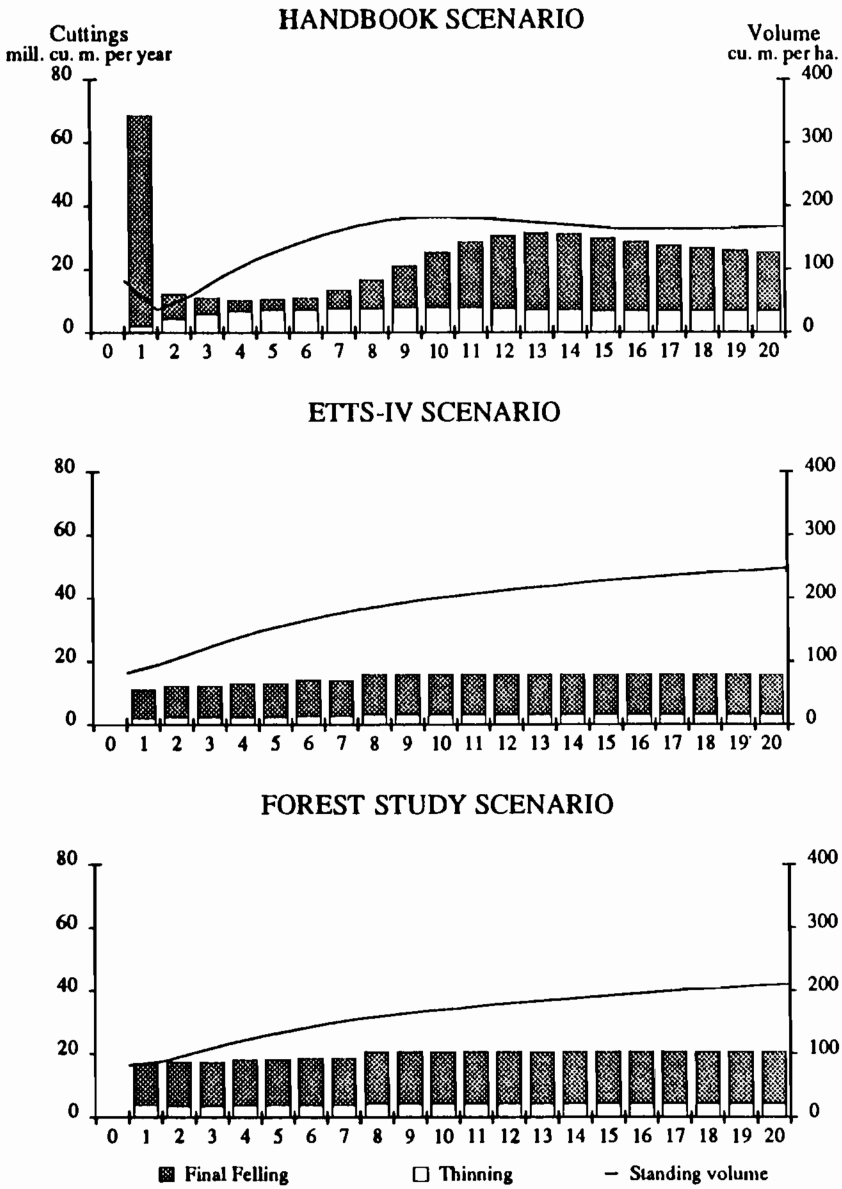


Figure B.114. Projections for total potential harvest and growing stock in Norway under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 11 million cubic meters o.b.

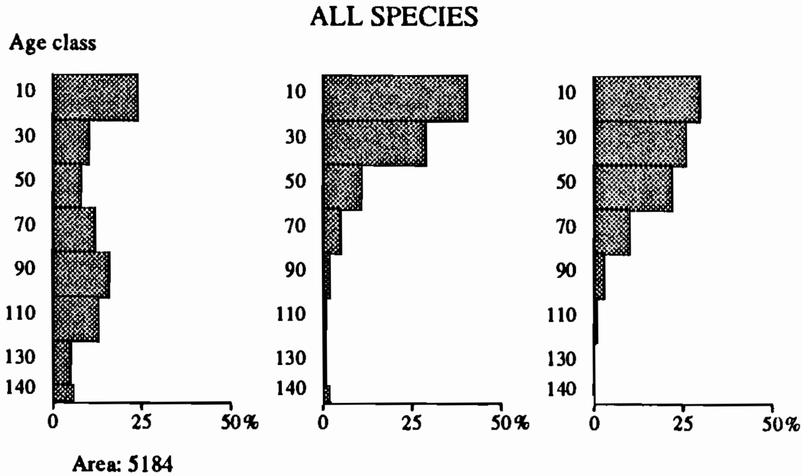


Figure B.115. Age-class distributions in Norway under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

Poland (Table B.17 and Figures B.116 to B.123)

Basic Scenarios

The Basic Handbook Scenario indicates that, in Poland, the existing forest structure has evolved under something close to handbook silviculture. In this scenario, growing stock remains quite stable throughout the simulation at about 190 cubic meters per hectare. ETTS-IV harvest levels are shown to be possible, but growing stock decreases slightly toward the end of the simulation. The Basic Forest Study Scenario has harvest levels roughly equivalent to those of ETTS-IV. Coniferous species dominate the increasing harvests, and the proportion of thinnings, roughly about half the total harvest in the beginning, increases over time. Most deciduous harvest comes from final cuttings. Overall growing stock stabilizes at about 200 cubic meters per hectare, but it increases for coniferous species, while it decreases steadily from 170 to 130 cubic meters per hectare for deciduous species. The decrease for deciduous species results from an initial age-class structure weighted heavily with middle-age classes, developing to a structure with more area in the low-volume young classes. The initial age-class distribution for conifers, which is concentrated on younger and middle-age classes, gains a more even structure late in the simulation, but maybe with too much area in older stands.

Decline Scenarios

The balance between existing forest structure and silviculture programs is disturbed in the decline scenario. The Handbook Decline Scenario generates higher harvest levels during the first 30 years of the simulation period. Later there is a strong decrease of the potential harvest level in the decline situation, and the growing stock is also negatively affected.

Only during the first 70 years in the decline situation is it possible to follow the harvest level of ETTS-IV. The total growing stock is much lower in the decline scenario than in the basic scenario, dropping to a level of about 100 cubic meters per hectare at the end of the period. In the Forest Study Decline Scenario, growing stock is kept at the same level as in the basic scenario, but potential harvest levels must be reduced by about 11 million cubic meters per year in comparison with the basic scenario. The strongest effect of decline takes place in coniferous species.

Forest Land Expansion Scenario

Poland has expressed a desire to increase its forest landbase in the future, primarily by conversion of abundant agricultural land. The increased landbase results in a slight increase of the potential harvest after about 25 years and through the rest of the planning period. The dominating part of the increased harvest comes from coniferous species. Total and coniferous growing stocks follow the same pattern as in the Basic Forest Study Scenario. In deciduous species a decrease in the growing stock is expected, although less pronounced than in the basic scenario.

Summary

The Basic Handbook Scenario gives the highest harvest potential under basic conditions. As expected, with the high depositions of air pollutants in Poland, the total harvest potential is strongly affected in the decline scenarios. The decline reduces the total potential harvest by about 11 million cubic meters per year during 100 years.

Table B.17. Poland.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	163–194	163–199	163–196	163–150	163–94	163–217	163–204
Fellings[b]							
Year 1	37.0	25.4	25.6	32.0	25.4	13.0	25.6
Year 40	34.3	31.7	31.8	30.8	31.7	22.0	32.4
Year 80	34.4	31.7	31.8	21.0	29.6	22.1	32.4
Coniferous							
Growing stock[a]	162–201	162–213	162–214	162–161	162–101	162–242	162–219
Fellings[b]							
Year 1	29.6	20.4	20.6	24.8	20.4	10.6	20.6
Year 40	27.6	24.9	24.6	25.9	24.9	16.8	25.4
Year 80	28.5	24.9	24.6	17.9	25.0	16.9	25.4
Deciduous							
Growing stock[a]	168–170	168–145	168–126	168–108	168–65	168–120	168–145
Fellings[b]							
Year 1	7.4	5.0	5.0	7.2	5.0	2.4	5.0
Year 40	6.7	6.8	7.2	4.9	6.8	5.2	7.0
Year 80	5.9	6.8	7.2	3.1	4.6	5.2	7.0
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	33.9	30.2	30.4	28.7	29.5	19.4	30.9
Coniferous	27.5	23.7	23.6	23.5	23.8	14.8	24.2
Deciduous	6.4	6.5	6.8	5.2	5.7	4.6	6.7
Growth (m^3 o.b./ha/yr)[c]							
Total	4.6	4.2	4.2	3.5	3.0	3.0	4.1
Coniferous	4.7	4.3	4.3	3.7	3.2	3.2	4.2
Deciduous	3.9	3.7	3.8	2.6	2.5	2.3	3.6
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	163–194	163–199	163–196	163–150	163–94	163–217	163–204
Coniferous	162–201	162–213	162–214	162–161	162–101	162–242	162–219
Deciduous	168–170	168–145	168–126	168–108	168–65	168–120	168–145

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

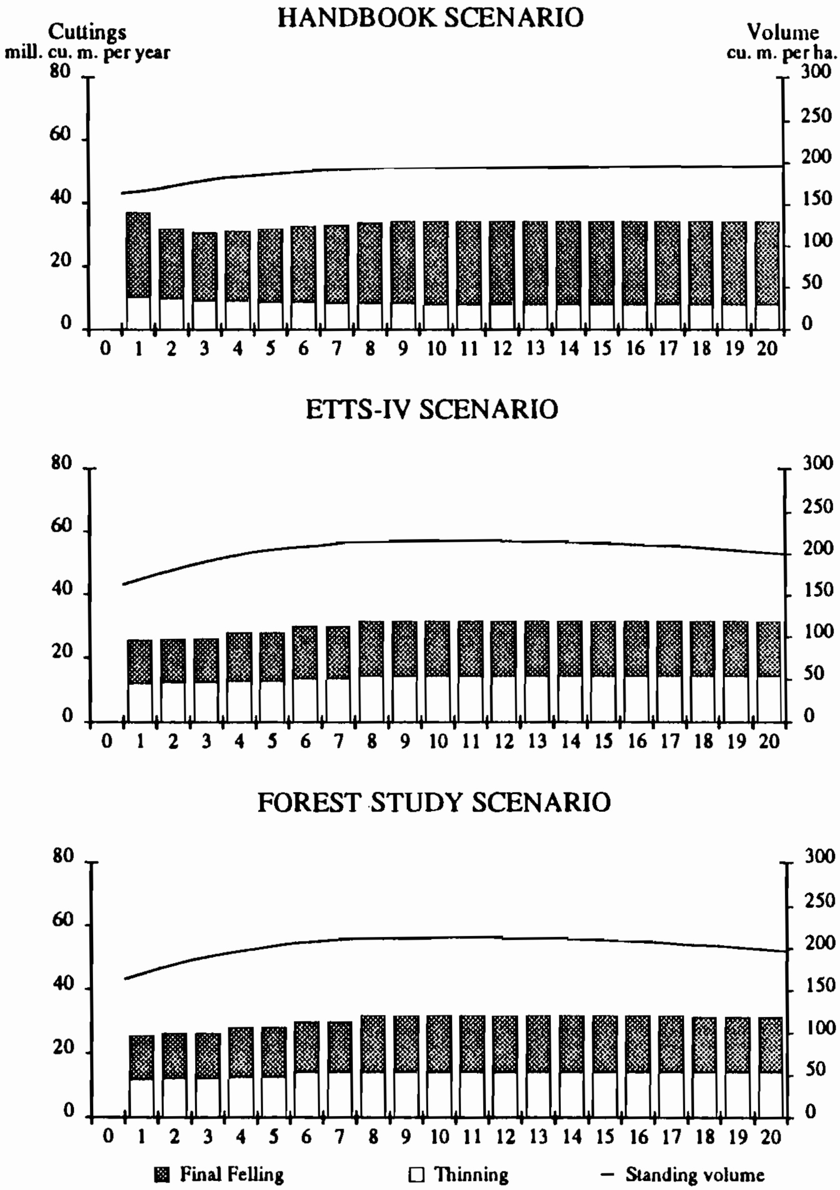


Figure B.116. Projections for total potential harvest and growing stock in Poland under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 25 million cubic meters o.b.

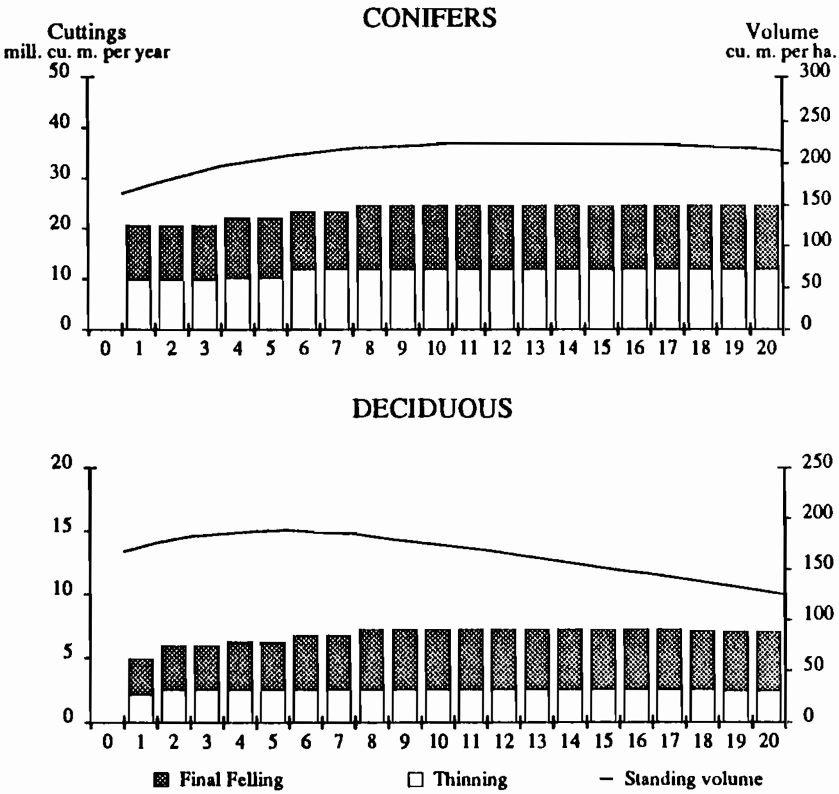


Figure B.117. Projections for total potential harvest and growing stock for coniferous and deciduous species in Poland under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 20 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

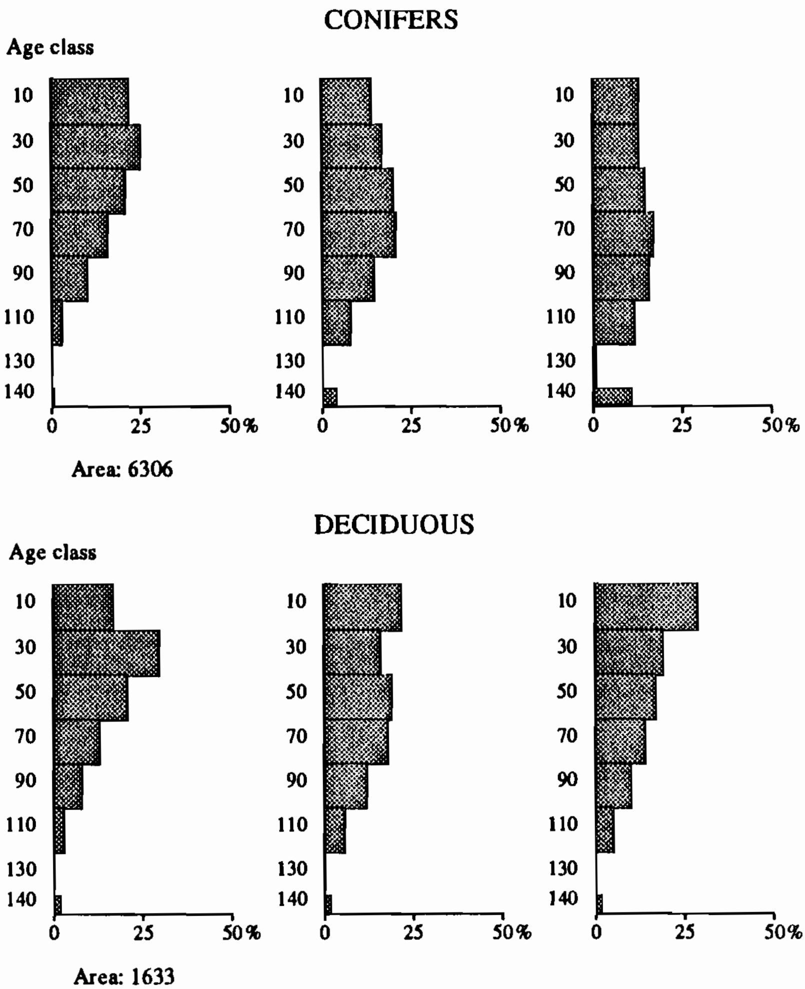


Figure B.118. Age-class distributions in Poland under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

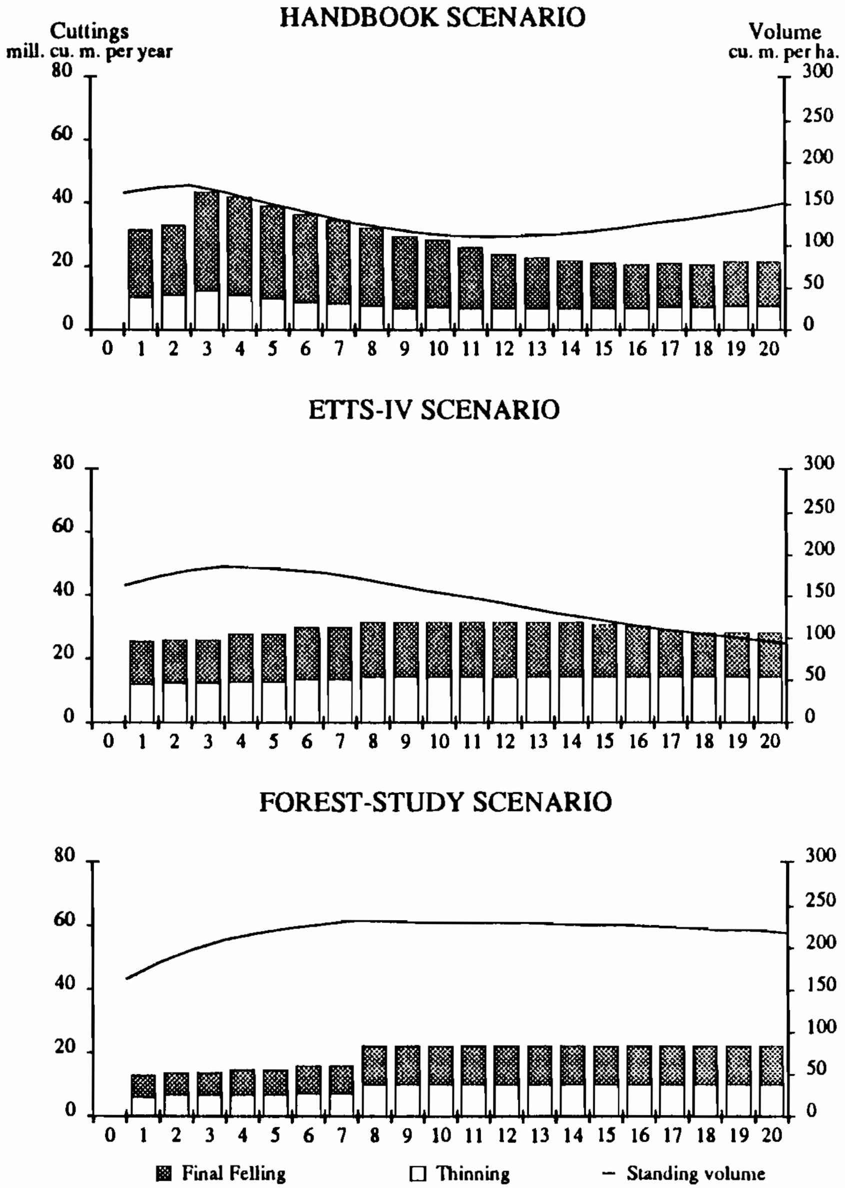


Figure B.119. Projections for total potential harvest and growing stock in Poland under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 25 million cubic meters o.b.

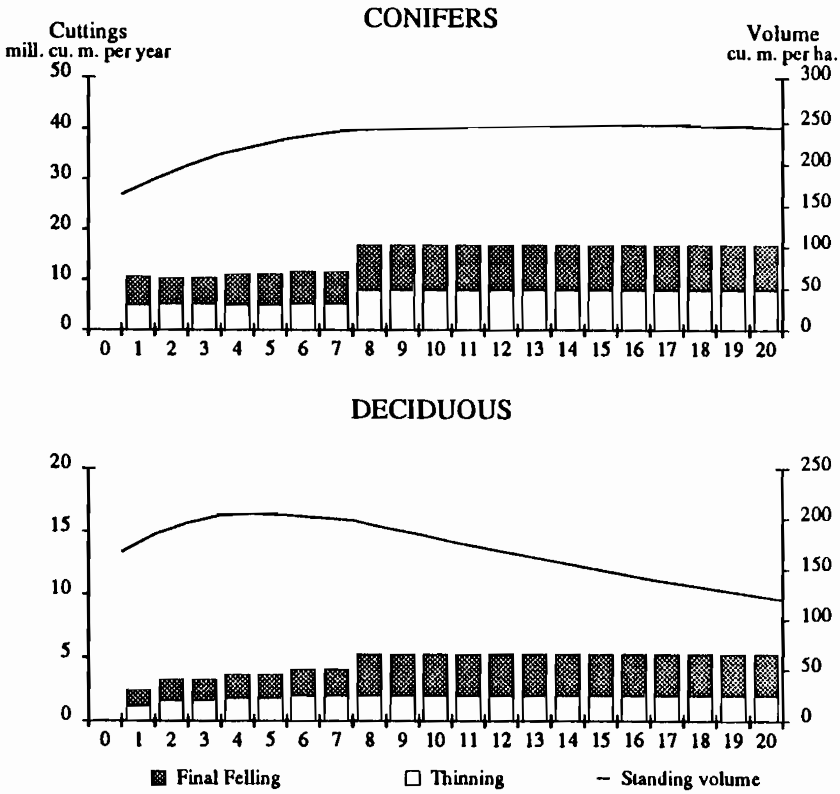


Figure B.120. Projections for total potential harvest and growing stock for coniferous and deciduous species in Poland under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 20 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

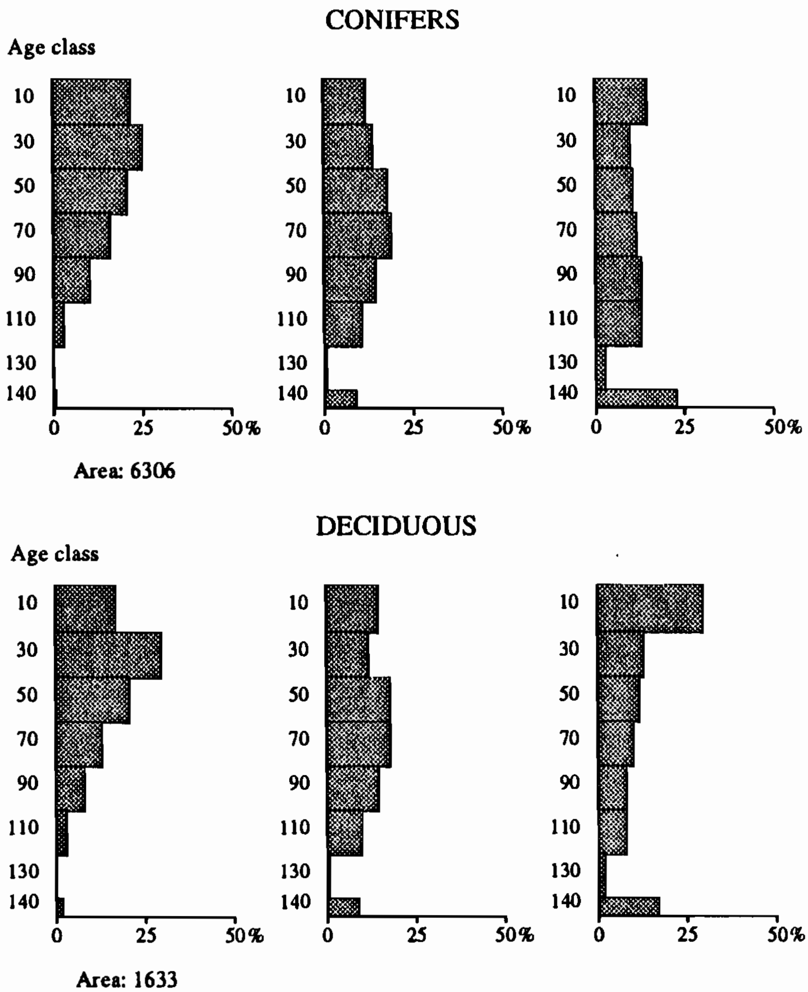


Figure B.121. Age-class distributions in Poland under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

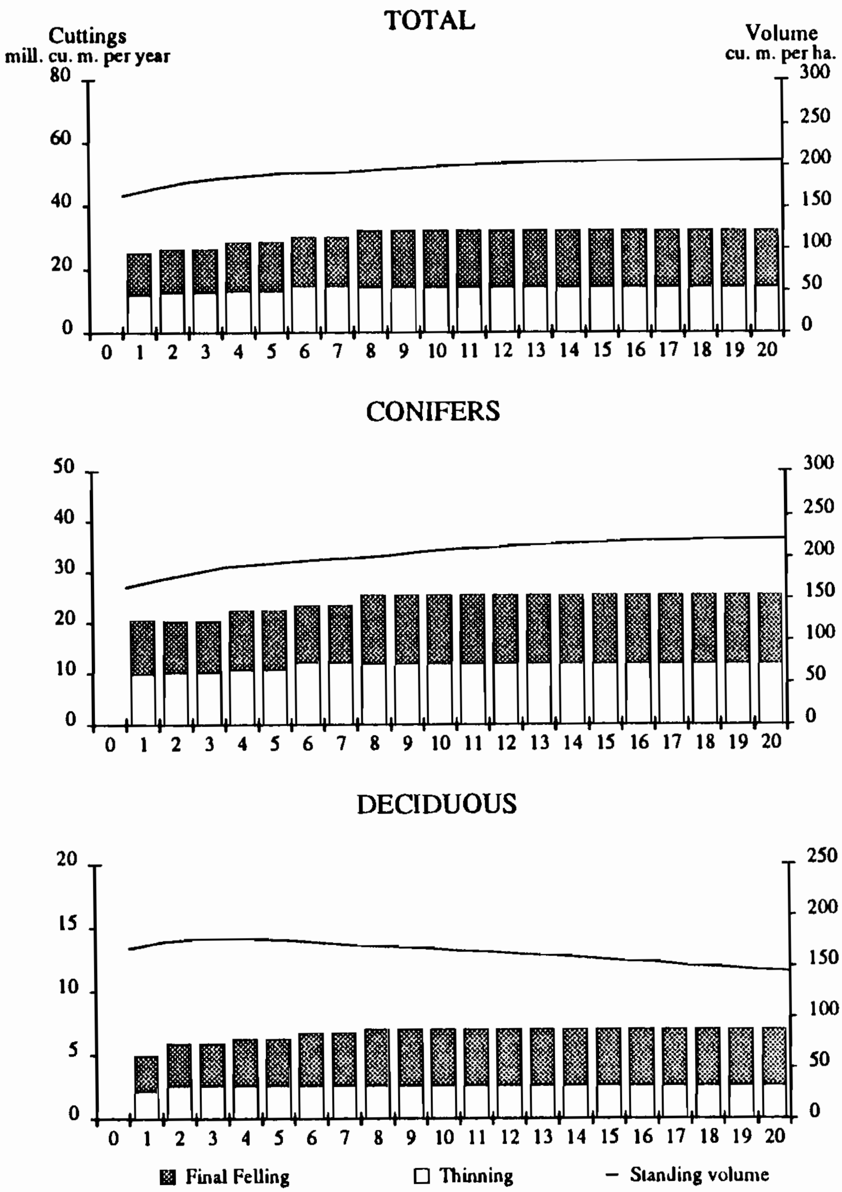


Figure B.122. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Poland under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 25 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 20 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 5 million cubic meters o.b.

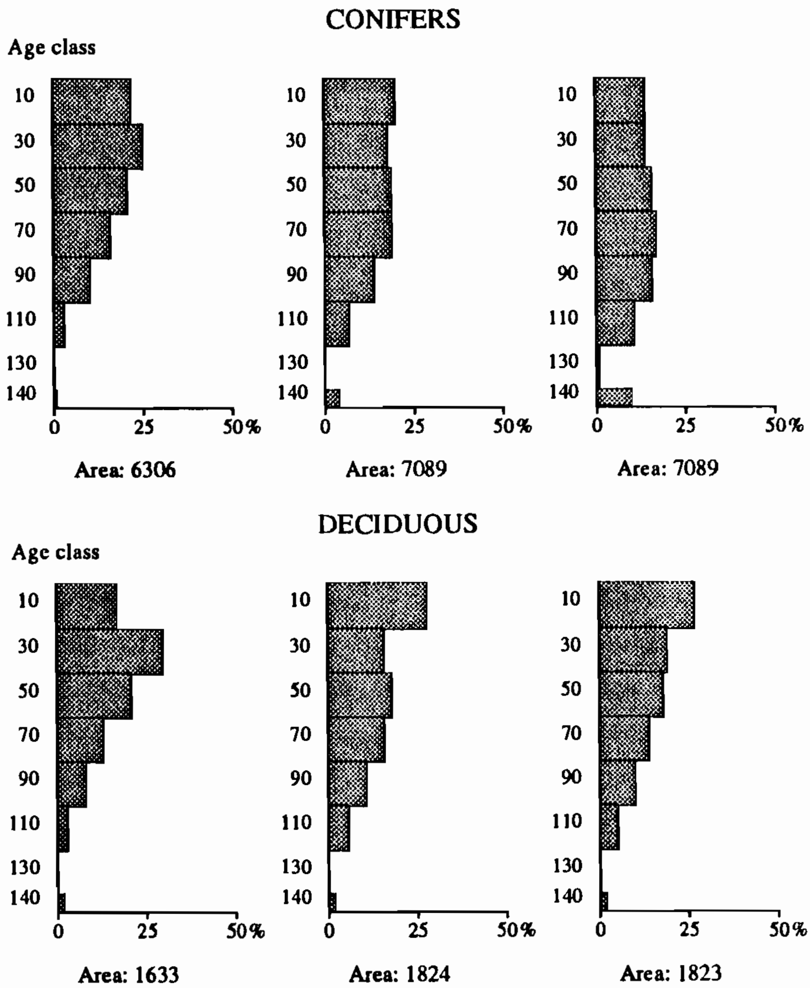


Figure B.123. Age-class distributions in Poland under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Portugal (Table B.18 and Figures B.124 to B.131)

Basic Scenarios

The development of harvest levels and growing stock in Portugal is unique among the European countries. Implementation of the Basic Handbook Scenario produces unstable, rather cyclic patterns, starting from very low levels in the first period of the simulation. This can be explained by Portugal's recent establishment of huge areas of new plantations of both coniferous and deciduous species, and especially of eucalyptus. Since the rotation period for eucalyptus is very short, a cyclic pattern is expected. The implementation of handbook silviculture produces pulses in the harvest, at least for one cycle in coniferous species but for several cycles in deciduous species. Ultimately, though, the harvests begin to stabilize, as does growing stock.

It is not possible to maintain ETTS-IV harvest levels beyond the first 30 years into the simulation. This may result from the increase of the forest landbase in the projections provided to ETTS-IV, while our model for Portugal maintains a constant landbase for the basic scenarios. The Basic Forest Study Scenario features harvest levels below those of ETTS-IV, but our objectives to stabilize the harvest pattern over time and to maintain or increase growing stock are reached for both coniferous and deciduous forests. Total harvest stabilizes at about 8 million cubic meters per year, rather equally distributed between coniferous and deciduous species. Growing stock for both types holds steady, slightly below 200 cubic meters per hectare. Notably, all harvests in Portugal are taken as final cuts.

Decline Scenarios

The cyclic development of the potential harvests from the Basic Handbook Scenario shows up also in the Handbook Decline Scenario. The growing stock levels and developments are about the same in the two scenarios, but the potential harvest level must be substantially reduced in the decline scenario by about 1.25 million cubic meters per year. The reduced harvest potential of both deciduous and coniferous species occurs at the beginning of the simulation period. The strongest effects of decline are visible in deciduous species.

In the ETTS-IV Decline Scenario, a cyclic harvesting pattern is at hand during the first half of the planning period. In the Forest Study Decline Scenario, the harvest level in the later part of the simulation is 2 million cubic meters per year lower than the harvest level of the Basic Forest Study Scenario.

Forest Land Expansion Scenario

The effects of the Forest Land Expansion Scenario on the total potential harvest will start from the beginning of the planning period. The total potential harvest level is about 4.5 million cubic meters per year higher than in the basic scenario at the end of the planning period. The increased landbase generates about the same increase of potential harvest in coniferous and deciduous species. For deciduous species the effects on the potential harvest occur after about 10 years, as a result of the short rotation periods for eucalyptus.

The increased landbase leads to strong increases in the total growing stock during the planning period. However, neither coniferous nor deciduous growing stocks will not reach the same level as the level in the Basic Forest Study Scenario.

Summary

There are rather big differences between the scenarios under the basic conditions. It is not possible to reach the harvest level suggested by ETTS-IV, mainly because a land increase is included in ETTS-IV which is not accounted for in our basic scenarios. The other reason is that forestry in Portugal is in an expansion phase. The total potential harvest will be influenced by decline caused by air pollutants. The most affected species group is deciduous. In the decline scenario, the total potential harvest is reduced by 1.5 million cubic meters per year over 100 years. The estimated land increase adds 2.8 million cubic meters per year over the whole simulation period to the potential harvest.

Table B.18. Portugal.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	90–153	90–117	90–188	90–156	90–98	90–178	61–171
Fellings[b]							
Year 1	2.4	6.6	3.0	8.8	8.6	3.0	3.2
Year 40	7.0	8.1	8.1	8.0	8.8	6.5	11.2
Year 80	9.6	8.9	8.1	6.2	7.6	6.1	12.6
Coniferous							
Growing stock[a]	102–164	102–128	102–189	102–149	102–112	102–174	102–162
Fellings[b]							
Year 1	1.8	5.4	1.8	7.8	7.4	1.8	2.0
Year 40	3.5	4.0	4.3	4.6	4.9	4.1	5.6
Year 80	5.0	5.1	4.3	4.0	4.4	3.7	6.8
Deciduous							
Growing stock[a]	61–127	61–90	61–187	61–172	61–64	61–189	61–171
Fellings[b]							
Year 1	0.6	1.2	1.2	0.8	1.4	1.2	1.2
Year 40	3.5	4.1	3.8	3.4	3.9	2.4	5.6
Year 80	4.6	3.8	3.8	2.2	3.2	2.4	5.8
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	8.5	9.3	7.5	7.3	8.4	6.0	10.3
Coniferous	4.5	5.2	4.1	4.3	4.8	3.7	5.4
Deciduous	4.0	4.1	3.4	3.0	3.6	2.3	4.9
Growth (m^3 o.b./ha/yr)[c]							
Total	6.4	6.5	6.0	5.6	5.8	4.9	5.7
Coniferous	4.9	5.2	4.8	4.6	4.8	4.2	4.1
Deciduous	9.9	9.6	9.0	7.9	8.2	6.5	8.8
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	90–153	90–117	90–188	90–156	90–98	90–178	61–171
Coniferous	102–164	102–128	102–189	102–149	102–112	102–174	102–162
Deciduous	61–127	61–90	61–187	61–172	61–64	61–189	61–171

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

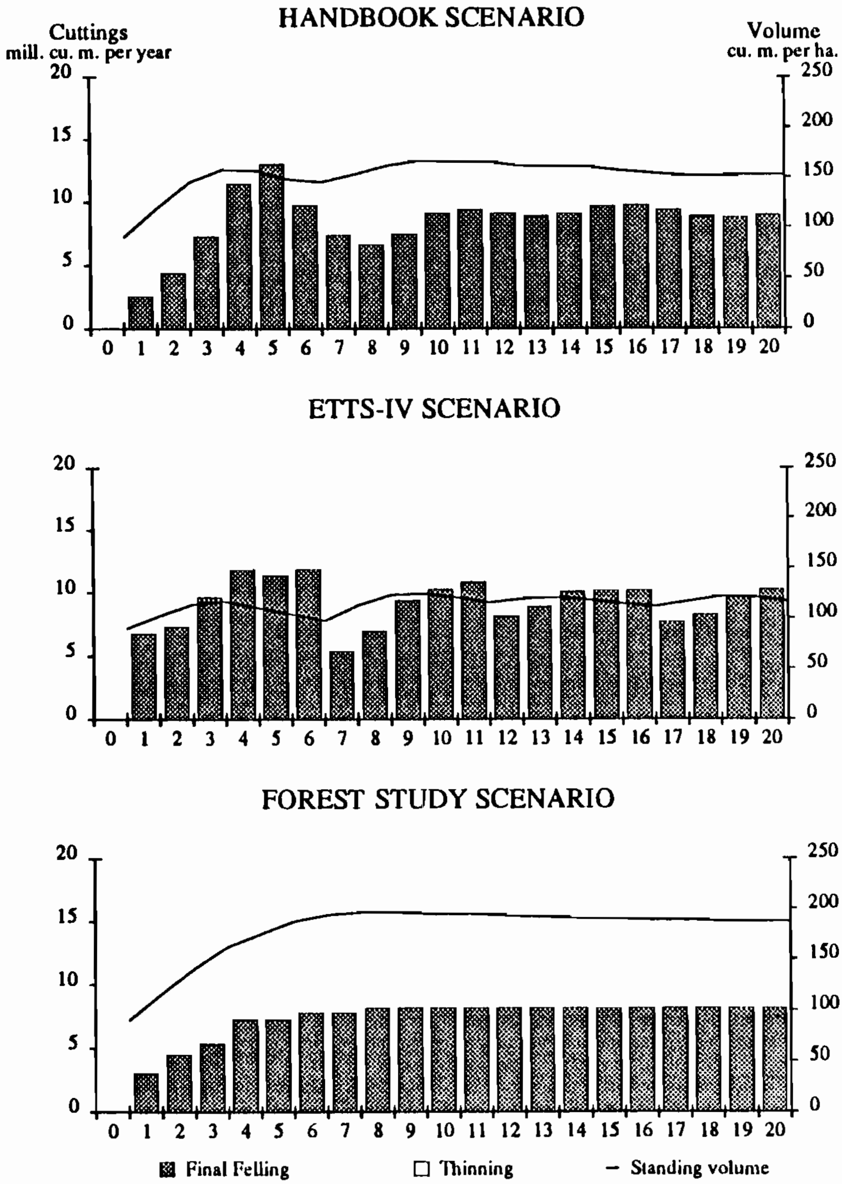


Figure B.124. Projections for total potential harvest and growing stock in Portugal under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 11 million cubic meters o.b.

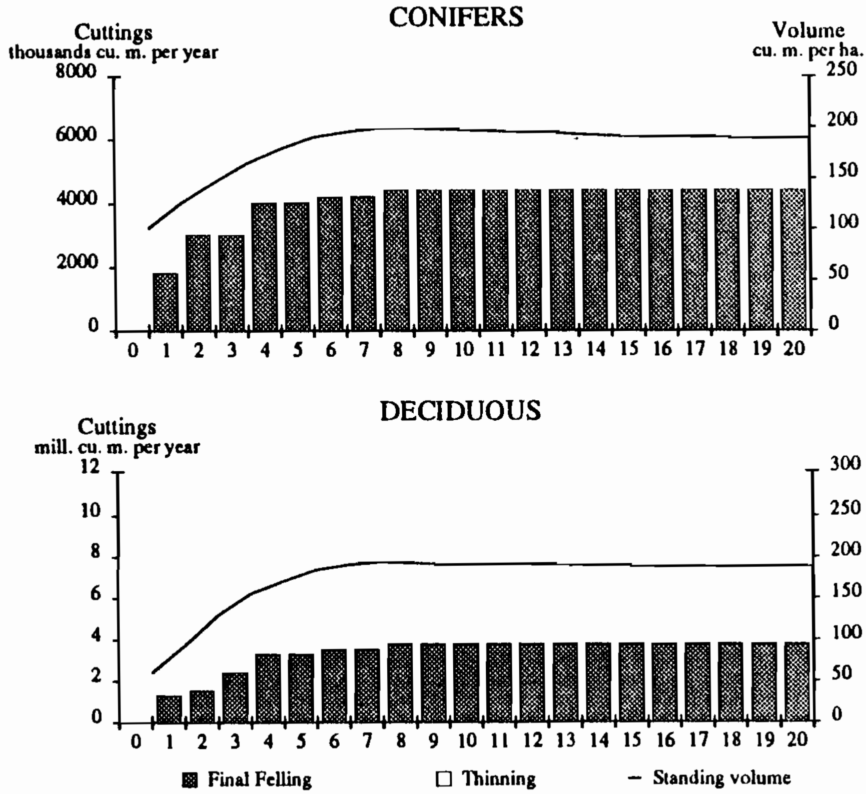


Figure B.125. Projections for total potential harvest and growing stock for coniferous and deciduous species in Portugal under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 7 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 4 million cubic meters o.b.

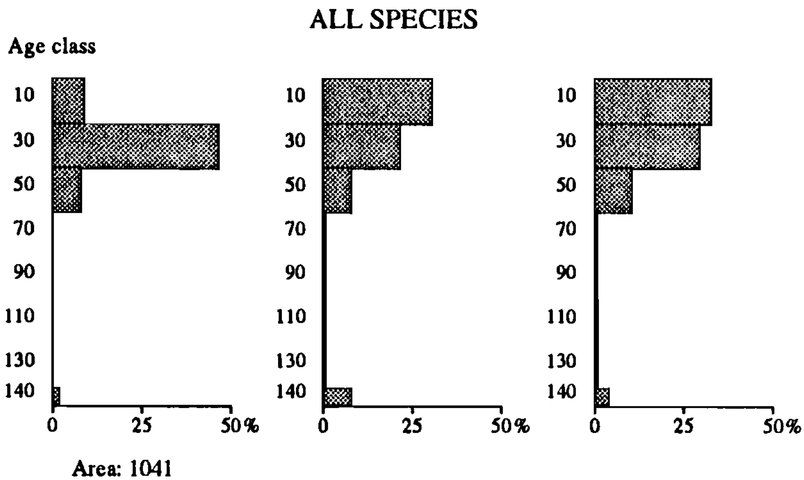


Figure B.126. Age-class distributions in Portugal under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

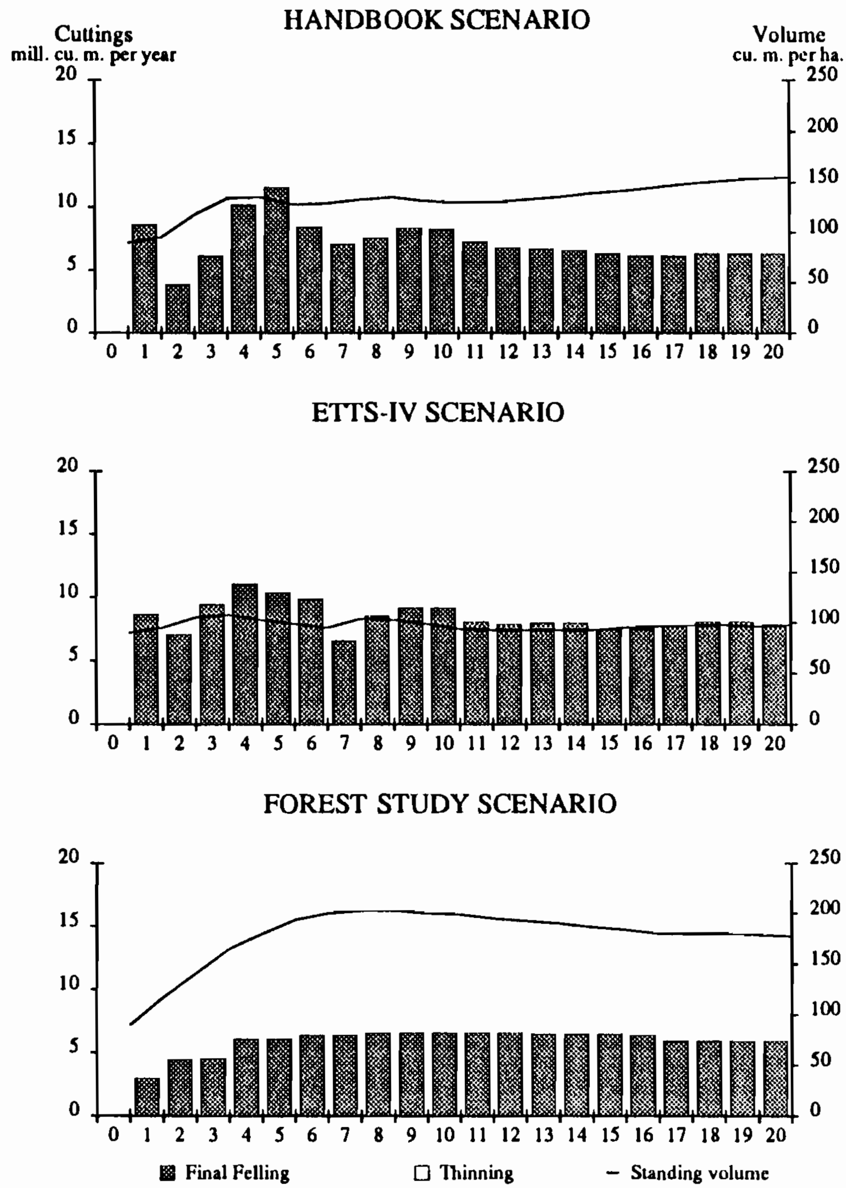


Figure B.127. Projections for total potential harvest and growing stock in Portugal under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 11 million cubic meters o.b.

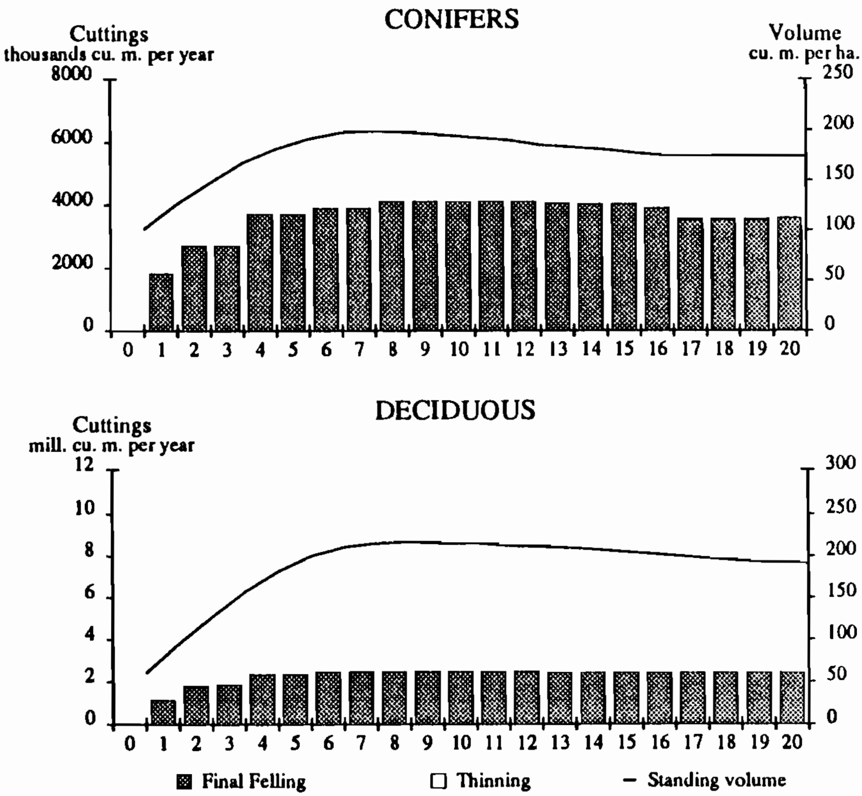


Figure B.128. Projections for total potential harvest and growing stock for coniferous and deciduous species in Portugal under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 7 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 4 million cubic meters o.b.

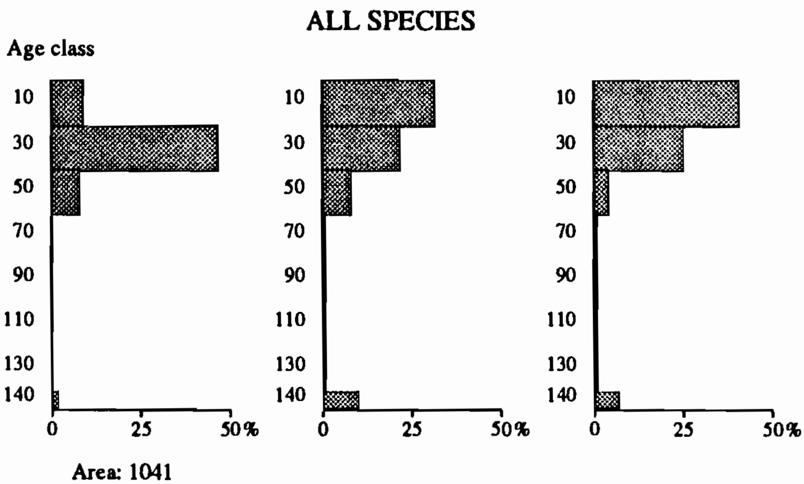


Figure B.129. Age-class distributions in Portugal under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

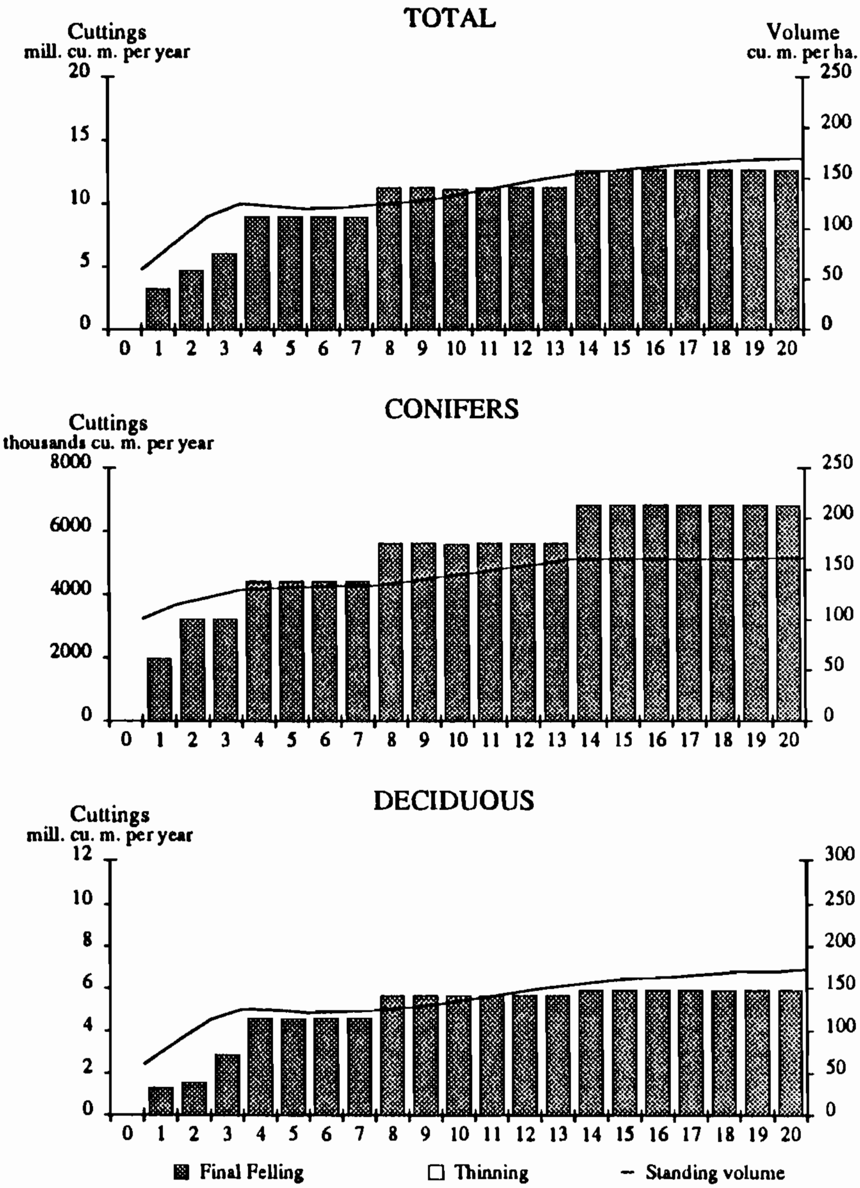


Figure B.130. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Portugal under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 11 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 7 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 4 million cubic meters o.b.

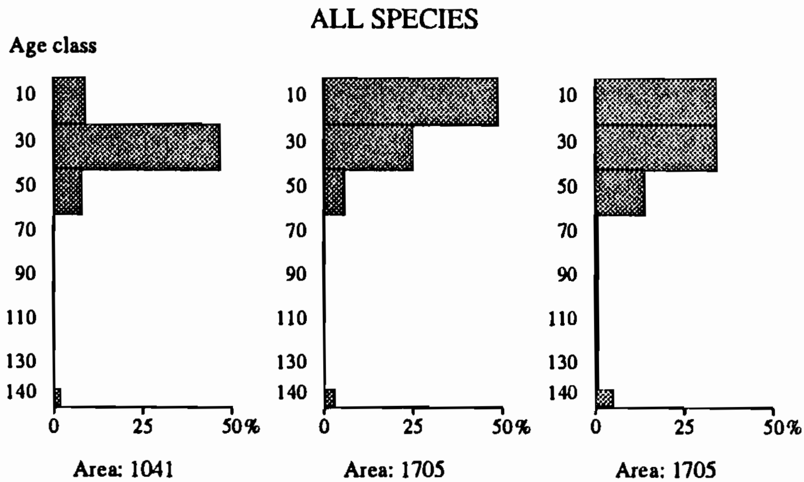


Figure B.131. Age-class distributions in Portugal under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Romania (Table B.19 and Figures B.132 to B.137)

Basic Scenarios

Handbook silviculture has not been practiced recently in Romania. This is clearly shown in the Basic Handbook Scenario by the huge harvest pulse resulting from a mismatch between implementation of handbook silviculture and the initial forest structure. After a first reaction, the potential harvests and the mean growing stock increase steadily, the latter reaching a level of about 240 cubic meters per hectare. ETTS-IV harvest levels are easily realizable, but result in a strong increase of the growing stock to about 370 cubic meters per hectare. In the Basic Forest Study Scenario, harvest levels are higher, about 40 million cubic meters per year, with a larger proportion of thinnings than in the Basic Handbook Scenario. Deciduous species account for some 60 percent of the harvests. The deciduous harvest levels need to be reduced somewhat after 60 years, but the coniferous harvest level remains stable throughout the simulation. The overall growing stock is stabilized at about 225 cubic meters per hectare; the coniferous species, at nearly 300 cubic meters per hectare; and the deciduous, at 210 cubic meters per hectare. Both the coniferous and deciduous age-class structures are developing into structures without stands of more than 100 years of age.

Decline Scenarios

In the Handbook Decline Scenario, there is a strengthened harvesting pulse in the beginning of the simulation period with higher harvest levels during the first periods. Later, the potential harvest level is about the same as in the basic scenario, though the extent of thinnings is much higher in the case of decline. The higher potential harvest levels and the higher proportion of thinnings in the decline scenario can be explained by the changed silvicultural programs implemented under these conditions. To keep the forests vital, it is necessary to increase the extent of thinnings over time, resulting in a lower mean growing stock.

In the ETTS-IV Decline Scenario, it is possible to keep ETTS-IV harvest levels throughout the simulation, but only with a reduction of growing stock by about 100 cubic meters per hectare during the simulation period.

In the Forest Study Decline Scenario the mean growing stock cannot be preserved at the same levels as in the Basic Forest Study Scenario. The difference is about 37 cubic meters per hectare at the end of the simulation period. Neither is it possible in the decline scenario to maintain the harvest levels identified in the basic scenario. The growing stock of conifers is lower in the decline scenario, but the harvest levels are about the same in the two scenarios. The proportions of thinnings and final fellings of conifers is also about the same in the two scenarios. The strongest effects of decline are on deciduous species. The deciduous growing stock is about 50 cubic meters per hectare lower in the decline scenario by the end of the simulation period. The harvest levels of all species groups are much lower throughout the simulation period in comparison with the basic scenario.

Summary

Under basic conditions, there are good possibilities to exceed the harvest levels identified by ETTS-IV. The results for the Basic Handbook Scenario and the Basic Forest Study Scenario are similar. Forest decline will reduce the total potential harvest by about 3.8 million cubic meters per year throughout the simulation period. The growth for coniferous species appears higher in the Handbook Decline Scenario than in the other scenarios, probably because the management program employed in this scenario keeps the growing stock low and the coniferous area concentrated on the lower age classes. In fact, the growth rates are at the highest for these classes. This implies that the handbook silvicultural program is not well defined.

Table B.19. Romania.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	174–237	174–366	174–226	174–160	174–263	174–189	
Fellings[b]							
Year 1	85.0	20.6	39.6	110.2	20.4	33.8	
Year 40	32.0	28.0	41.8	35.2	28.6	37.3	
Year 80	39.6	28.0	39.5	38.8	28.1	36.9	
Coniferous							
Growing stock[a]	237–361	237–517	237–292	237–203	237–456	237–276	
Fellings[b]							
Year 1	33.0	7.8	16.0	42.8	7.8	15.8	
Year 40	11.9	11.2	17.1	17.7	11.4	17.4	
Year 80	16.0	11.2	17.2	19.3	11.5	17.3	
Deciduous							
Growing stock[a]	163–207	163–348	163–212	163–156	163–199	163–157	
Fellings[b]							
Year 1	51.2	12.2	23.0	64.8	12.2	17.4	
Year 40	17.8	16.0	24.0	15.6	16.3	19.2	
Year 80	21.9	16.0	21.6	17.4	16.0	19.0	
Coppice							
Growing stock[a]	92–108	92–129	92–150	92–89	92–135	92–147	
Fellings[b]							
Year 1	0.8	0.6	0.6	2.6	0.4	0.6	
Year 40	2.3	0.8	0.7	1.9	0.9	0.7	
Year 80	1.7	0.8	0.7	2.1	0.6	0.6	
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	39.2	26.5	40.2	44.0	26.7	36.4	
Coniferous	15.3	10.5	16.9	21.0	10.7	17.0	
Deciduous	22.2	15.2	22.7	20.8	15.3	18.8	
Coppice	1.7	0.8	0.6	2.2	0.7	0.6	
Growth (m^3 o.b./ha/yr)[c]							
Total	6.9	6.2	7.0	6.9	5.2	6.0	
Coniferous	9.6	8.5	9.7	11.1	8.0	9.7	
Deciduous	6.3	5.9	6.5	5.4	4.4	4.9	
Coppice	3.1	1.8	1.7	3.8	1.7	1.7	
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	174–237	174–366	174–226	174–160	174–263	174–189	
Coniferous	237–361	237–517	237–292	237–203	237–456	237–276	
Deciduous	163–207	163–348	163–212	163–156	163–199	163–157	
Coppice	92–108	92–129	92–150	92–89	92–135	92–147	

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

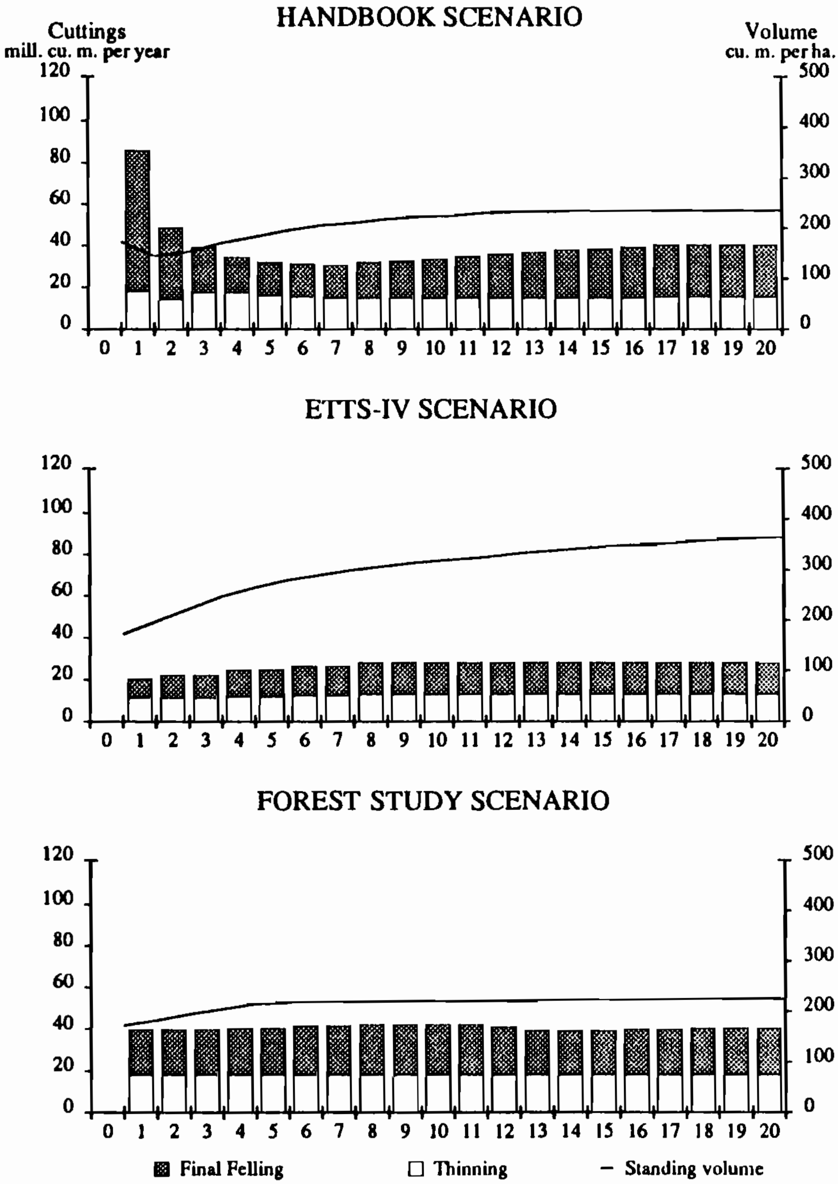


Figure B.132. Projections for total potential harvest and growing stock in Romania under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 21 million cubic meters o.b.

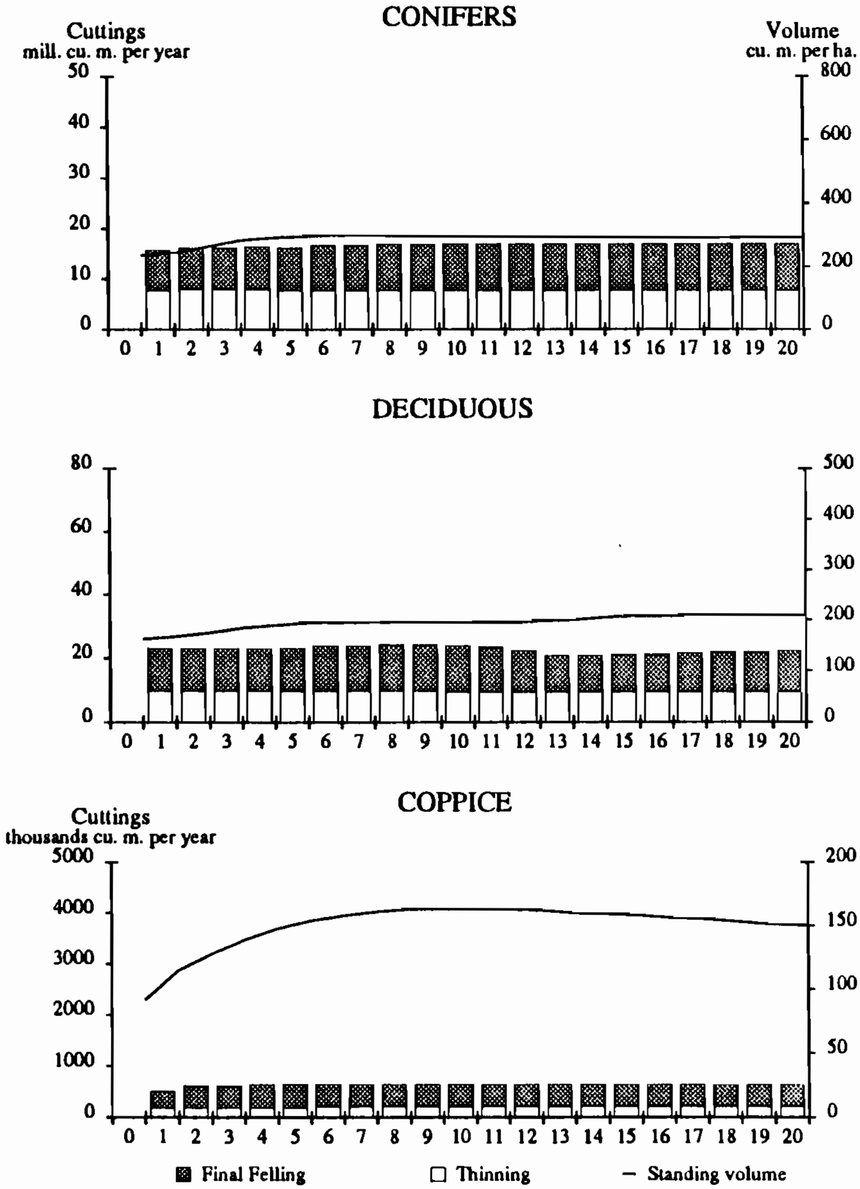


Figure B.133. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Romania under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 13 million cubic meters o.b.

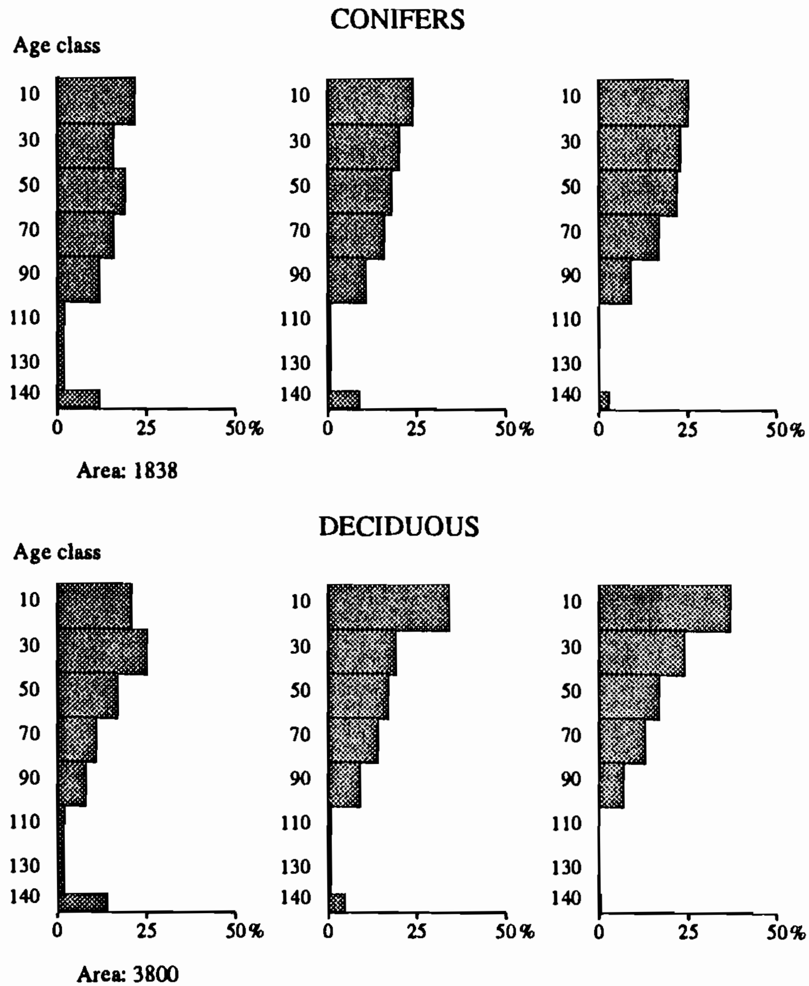


Figure B.134. Age-class distributions in Romania under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

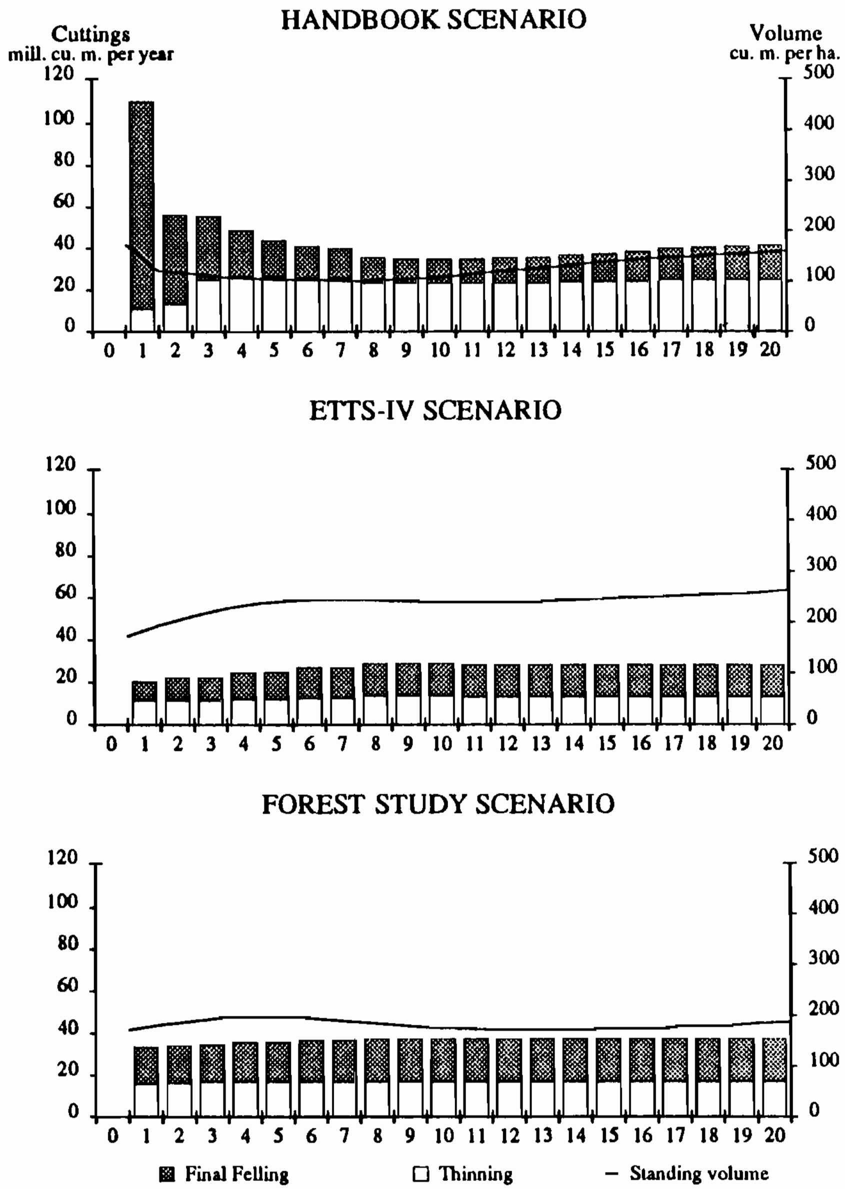


Figure B.135. Projections for total potential harvest and growing stock in Romania under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 21 million cubic meters o.b.

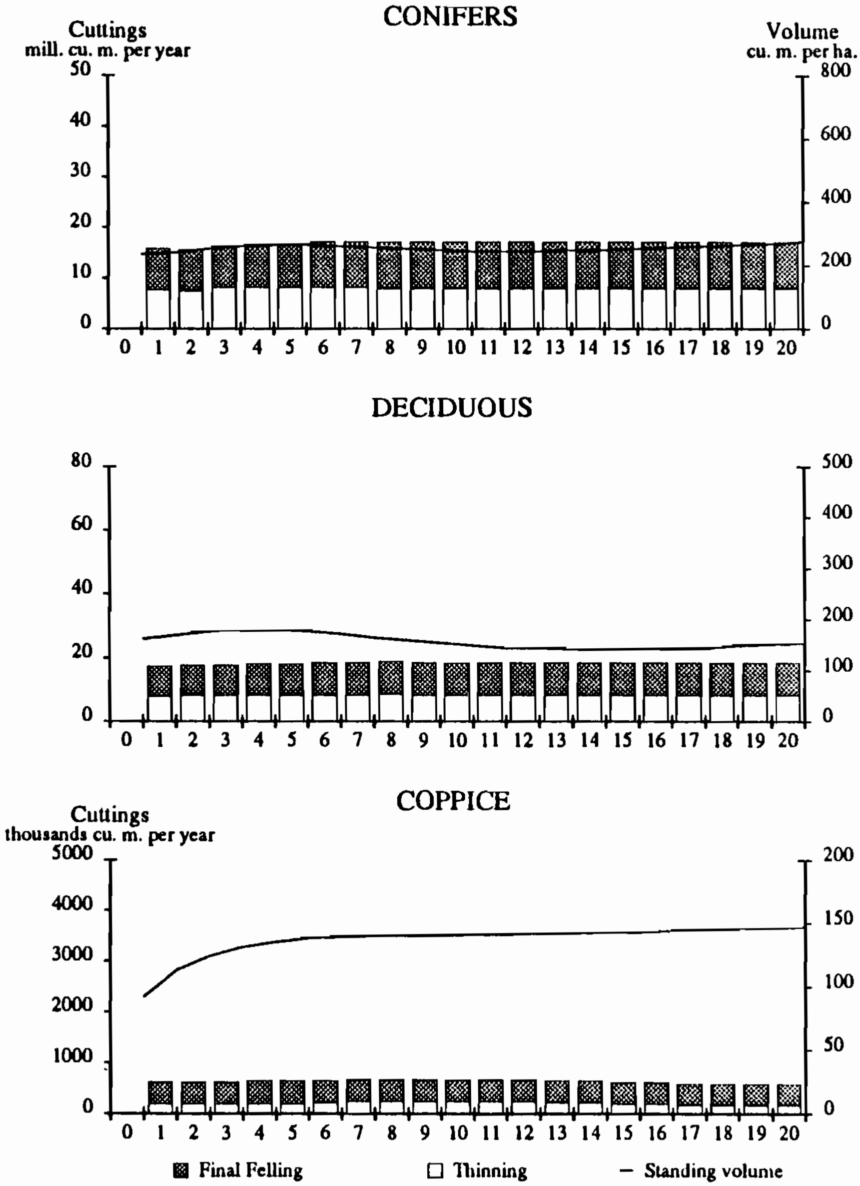


Figure B.136. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Romania under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 8 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 13 million cubic meters o.b.

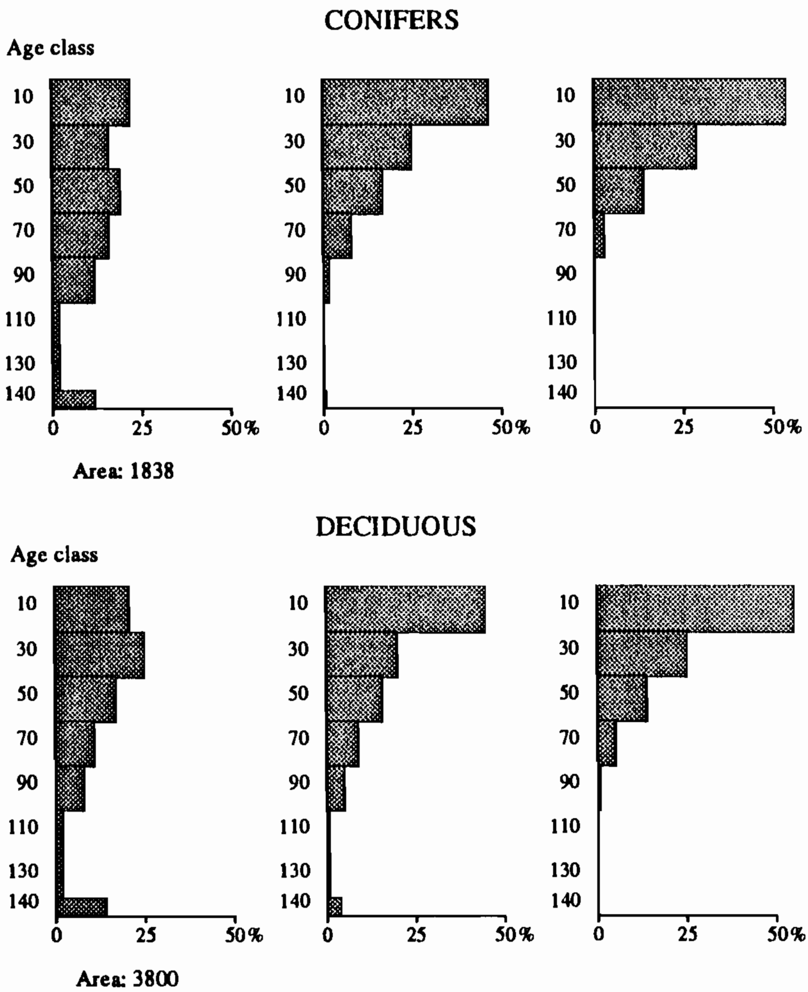


Figure B.137. Age-class distributions in Romania under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

Spain (Table B.20 and Figures B.138 to B.141)

Basic Scenario

Because of limitations in the basic inventory data, Spain's forest resources had to be analyzed using a diameter-distribution model instead of an area-based model. This concept is used even though many of Spain's forests are managed on an area basis. Moreover, it is not possible to generate either a Basic Handbook Scenario or a Basic ETTS-IV Scenario. This is because we have not been able to produce a stable simulation over 100 years by invoking handbook silviculture, and we have not been able to determine a credible way to arrange the harvest rules in the diameter classes when the total harvest is set to ETTS-IV levels. Therefore, we present only one basic scenario for Spain, the Basic Forest Study Scenario, which has a strong flavor of handbook silviculture. The harvests for Spain register entirely as thinnings.

According to the Basic Forest Study Scenario the total harvest in Spain is higher than the ETTS-IV levels, growing from 14 to 22 million cubic meters per year over time. About two-thirds of the harvest is coniferous, and coppice represents only a small portion. Harvests for the coniferous and deciduous species groups increase substantially over the simulation period. The mean growing stock also increases dramatically but is still relatively low compared with many other countries; by the end of the simulation period, it levels off or declines for all three species groups.

Forest Land Expansion Scenario

The expected future of increase of the forest landbase in Spain is large. This is reflected in the harvest potentials of the expansion scenario. The increase of the harvest level starts immediately in the simulation and increases steadily over time to 25 million cubic meters per year, compared with 20 million cubic meters per year in the basic scenario. The increased harvests come from both coniferous and deciduous species. The coppice harvest is not influenced by the expansion scenario.

The mean growing stock in the expansion scenario increases slightly over time, but to a lower level than in the basic scenario. Concerning coniferous species, the development and level of the growing stock are about the same in the two scenarios. This situation can be explained by the fact that the structure of the coniferous forests will not be changed by the increased area. In deciduous species, the level of the mean growing stock is much lower in the expansion scenario. The growing stock of coppice is not influenced by the increased forest landbase.

Summary

It has not been possible to quantify the effects of forest decline in Spain. The expansion of forest land will generate increased harvest potentials in comparison with the basic conditions by about 2.1 million cubic meters per year throughout the simulation period.

Table B.20. Spain.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]			68–131				75–98
Fellings[b]							
Year 1			14.2				14.6
Year 40			16.2				17.8
Year 80			21.6				25.2
Coniferous							
Growing stock[a]			61–109				67–100
Fellings[b]							
Year 1			9.2				9.4
Year 40			10.4				11.7
Year 80			13.8				15.6
Deciduous							
Growing stock[a]			112–260				124–95
Fellings[b]							
Year 1			4.8				5.0
Year 40			5.4				5.7
Year 80			7.4				9.2
Coppice							
Growing stock[a]			36–86				36–86
Fellings[b]							
Year 1			0.2				0.2
Year 40			0.4				0.4
Year 80			0.4				0.4
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total			17.9				20.0
Coniferous			11.4				12.6
Deciduous			6.1				7.0
Coppice			0.4				0.4
Growth (m^3 o.b./ha/yr)[c]							
Total			3.8				3.0
Coniferous			3.0				2.9
Deciduous			8.3				3.3
Coppice			3.6				3.6
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total			68–131				75–98
Coniferous			61–109				67–100
Deciduous			112–260				124–95
Coppice			36–86				36–86

[a] In m^3 o.b./ha; yr0–yr100.
[b] In mill. m^3 o.b./yr.
[c] Average for the simulations over 100 years.

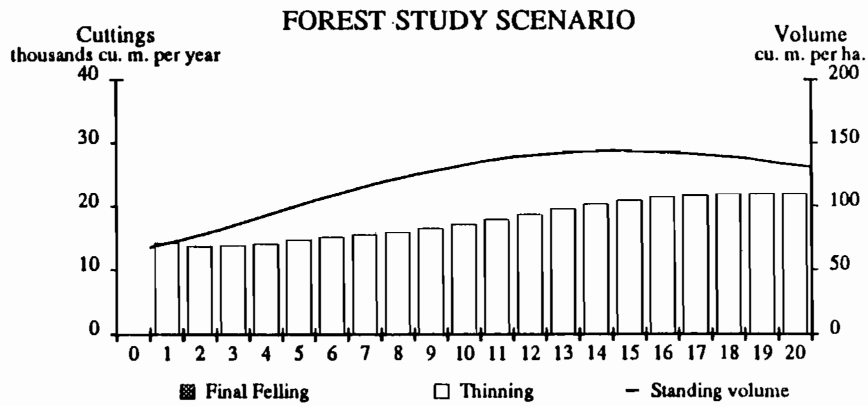


Figure B.138. Projections for total potential harvest and growing stock in Spain under the Basic Forest Study Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 13 million cubic meters o.b.

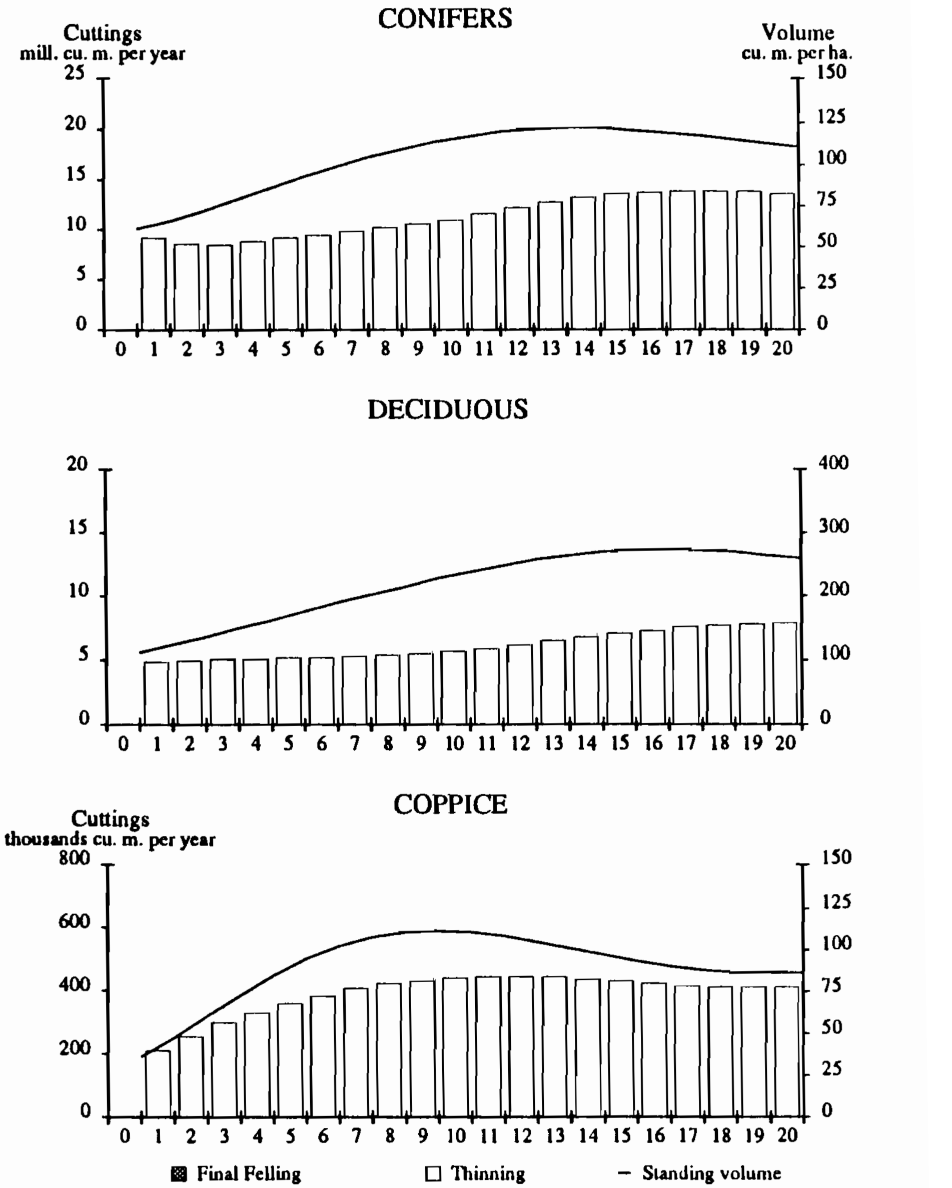


Figure B.139. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Spain under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 9 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 4 million cubic meters o.b.

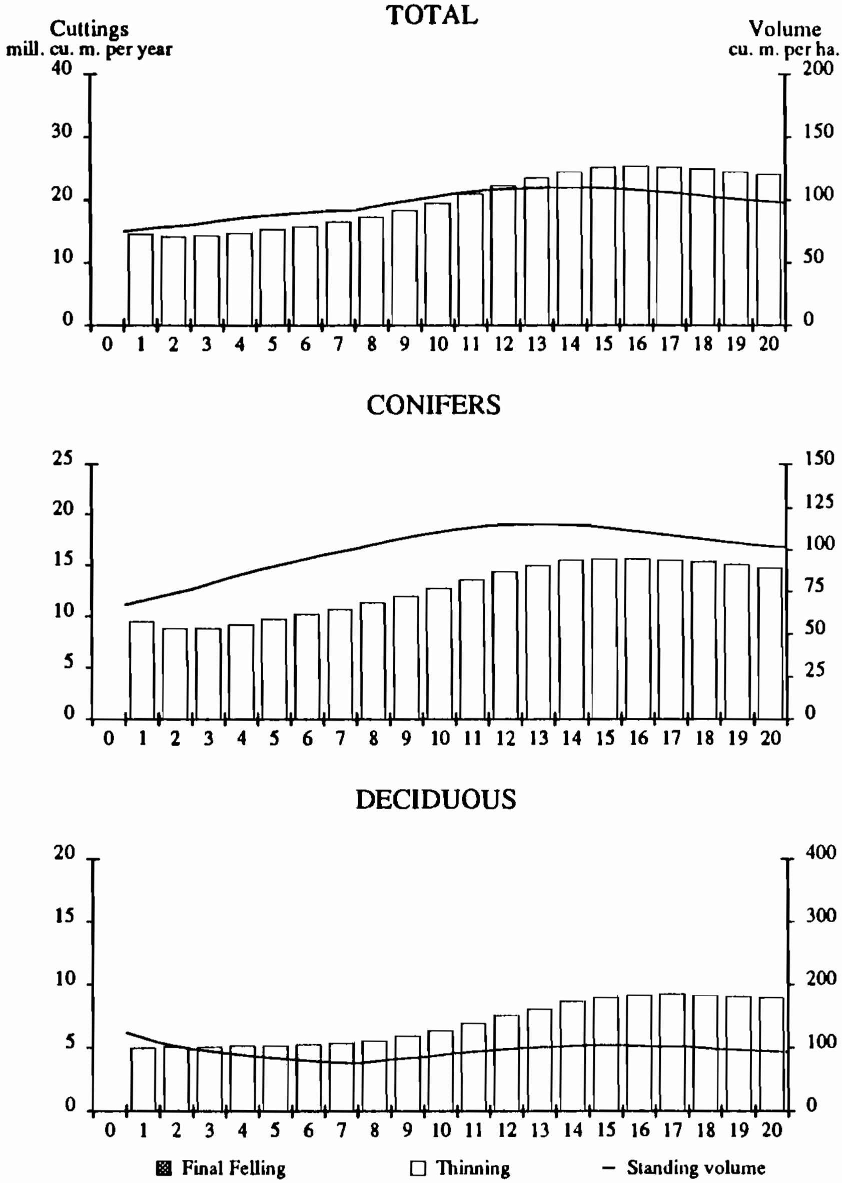


Figure B.140. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Spain under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 13 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 9 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 4 million cubic meters o.b.

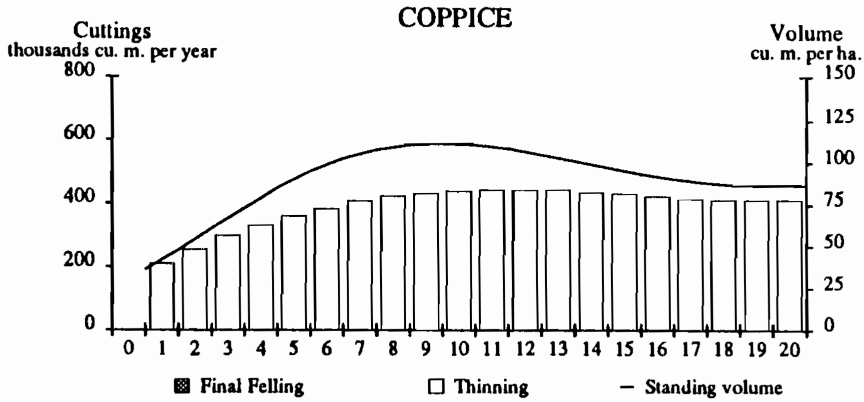


Figure B.141. Projections for total potential harvest and growing stock of coppice in Spain under the Forest Land Expansion Scenario.

Sweden (Table B.21 and Figures B.142 to B.149)

Basic Scenarios

Because of a large amount of mature and overmature forests in Sweden, implementation of handbook silviculture results in huge harvests in the early periods of the simulation. ETTS-IV harvest levels can easily be reached, with a continuous increase in average growing stock from about 100 cubic meters per hectare to roughly 150 cubic meters per hectare. The Basic Forest Study Scenario results closely match the Basic ETTS-IV Scenario, mainly because the information provided by Sweden to the ETTS-IV compilation is based on quantitative analyses structured much like those of the Forest Study.

Coniferous harvests are very stable over the entire simulation period, but deciduous harvests are much higher in the first 20 years; later they stabilize to a lower sustainable level. This results from the high proportions of older deciduous stand areas in the initial age-class structure for deciduous forests. It is also associated with the fact that a large part of deciduous harvests are taking place in coniferous wood stands, which in this study are classified as coniferous stands.

Decline Scenarios

The imbalance between actual forest structure and handbook silviculture in the Basic Handbook Scenario is strengthened in the Handbook Decline Scenario. During the middle of the simulation period, the potential harvest level is the same in the two scenarios, but by the end of the simulation period the potential harvest level is lower in the decline scenario. The growing stock is about 35 cubic meters per hectare lower in the decline scenario at the end of the simulation period.

Under decline conditions, the harvest level suggested by ETTS-IV can be yielded only during the first 30 years. The growing stock is also affected by the decline, reaching a level about 23 cubic meters per hectare lower at the end of the simulation period than under basic conditions. The same total growing-stock level can be achieved in the Forest Study Decline Scenario as in the Basic Forest Study Scenario, but only with a total potential harvest level of about 5.8 million cubic meters per year lower. From a potential harvest point of view, the coniferous species are most affected by the decline, mainly because this species group dominates the growing stock in Sweden.

Forest Land Expansion Scenario

The increased landbase will generate a slight increase of the harvest potential for most of the planning period. The dominating part of the increased harvest comes from coniferous species. The total growing stock will develop both at the same level and with the same pattern as those in the Basic Forest Study Scenario. For conifers the growing stock will be slightly higher with an increased landbase.

Summary

The Basic ETTS-IV Scenario and the Basic Forest Study Scenario give the same results. Under basic conditions, the handbook scenario generates the lowest total potential harvest level. The potential harvest level is rather strongly affected by decline conditions, with reductions close to 6 million cubic meters per year during the whole simulation period. The increased landbase generates an additional total potential harvest of 2.3 million cubic meters per year.

Table B.21. Sweden.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	101–171	101–147	101–147	101–132	101–122	101–137	101–136
Fellings[b]							
Year 1	148.8	57.2	57.2	165.7	57.2	45.2	63.2
Year 40	55.1	76.1	76.1	57.4	74.8	74.6	80.5
Year 80	75.2	77.3	77.3	74.6	75.6	73.4	80.8
Coniferous							
Growing stock[a]	103–174	103–153	103–153	103–138	103–130	103–147	103–144
Fellings[b]							
Year 1	135.1	50.1	50.1	151.3	50.1	41.1	54.1
Year 40	47.7	67.8	67.8	50.0	67.9	64.8	72.0
Year 80	65.6	67.7	67.7	67.2	67.7	64.8	71.2
Deciduous							
Growing stock[a]	82–147	82–92	82–92	82–76	82–54	82–51	82–74
Fellings[b]							
Year 1	13.7	7.1	7.1	14.4	7.1	4.1	9.1
Year 40	7.4	8.3	8.3	7.4	6.9	9.8	8.5
Year 80	9.6	9.6	9.6	7.4	7.9	8.6	9.6
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	70.7	75.6	75.6	72.0	74.6	69.8	77.9
Coniferous	62.1	66.1	66.1	64.2	66.2	61.1	67.9
Deciduous	8.6	9.5	9.5	7.8	8.4	8.7	10.0
Growth (m^3 o.b./ha/yr)[c]							
Total	3.7	3.7	3.7	3.4	3.4	3.4	3.7
Coniferous	3.7	3.7	3.7	3.4	3.4	3.4	3.6
Deciduous	4.2	4.1	4.1	3.2	3.3	3.4	4.0
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	101–171	101–147	101–147	101–134	101–124	101–139	101–148
Coniferous	103–174	103–153	103–153	103–139	103–130	103–147	103–155
Deciduous	82–147	82–92	82–92	82–81	82–57	82–54	82–95

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

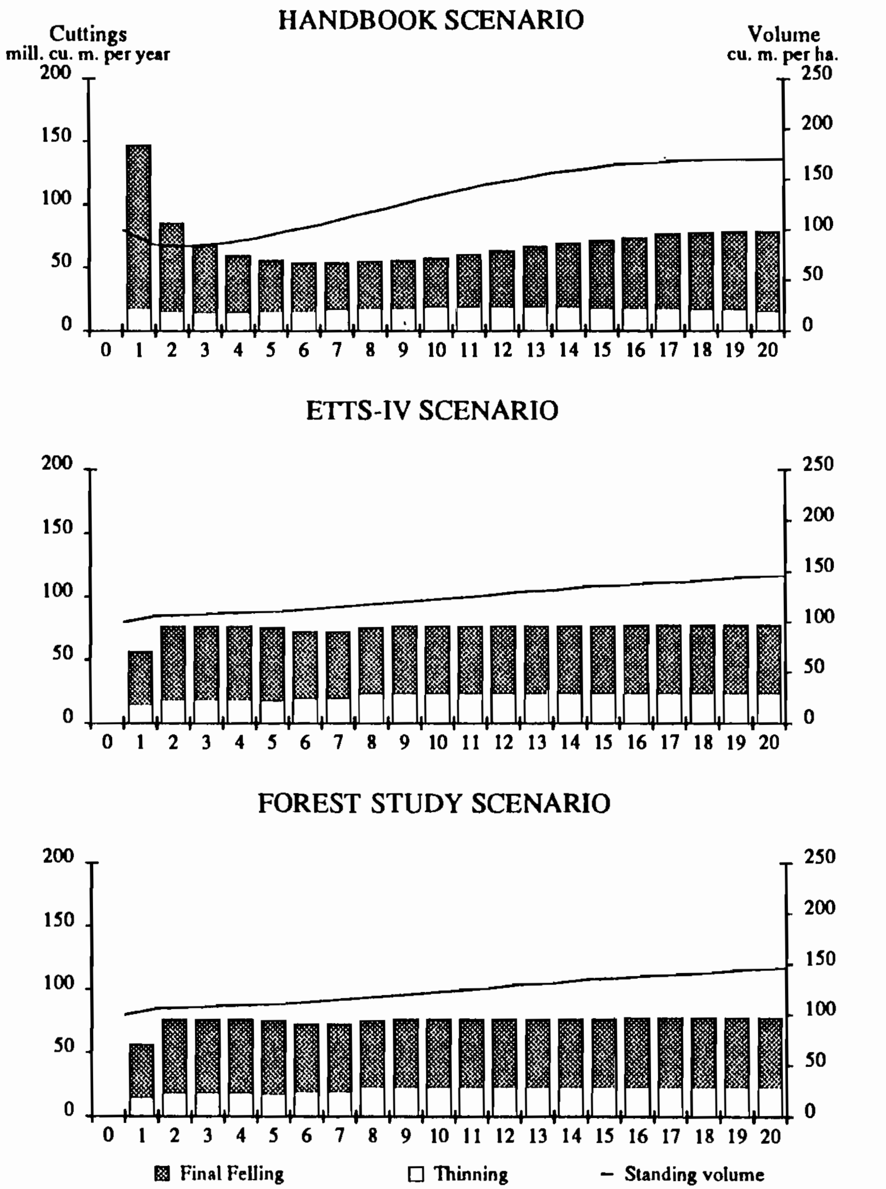


Figure B.142. Projections for total potential harvest and growing stock in Sweden under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 57 million cubic meters o.b.

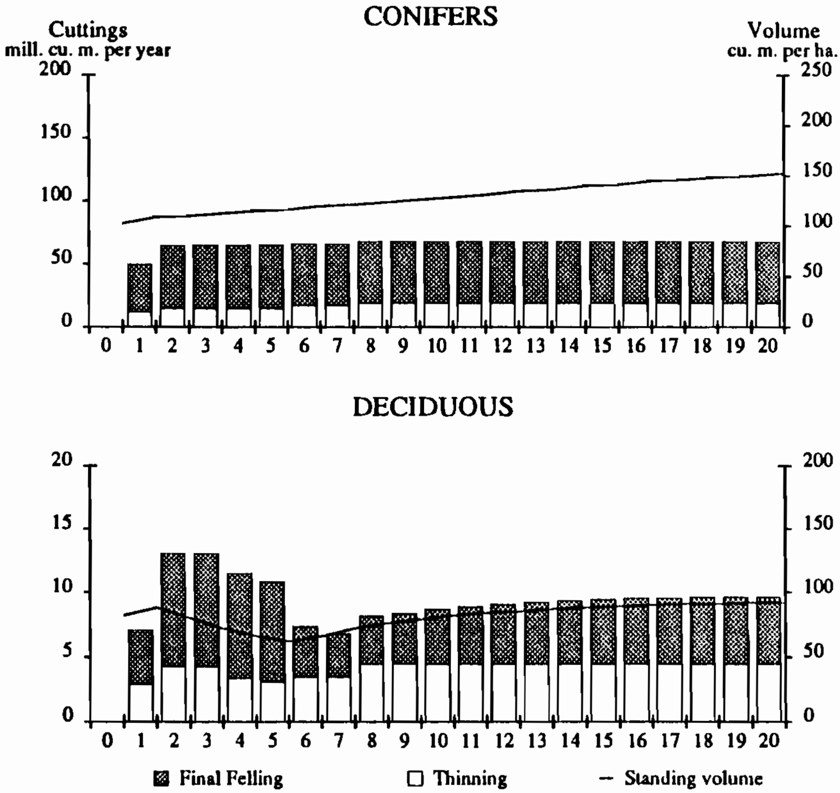


Figure B.143. Projections for total potential harvest and growing stock for coniferous and deciduous species in Sweden under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 50 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 7 million cubic meters o.b.

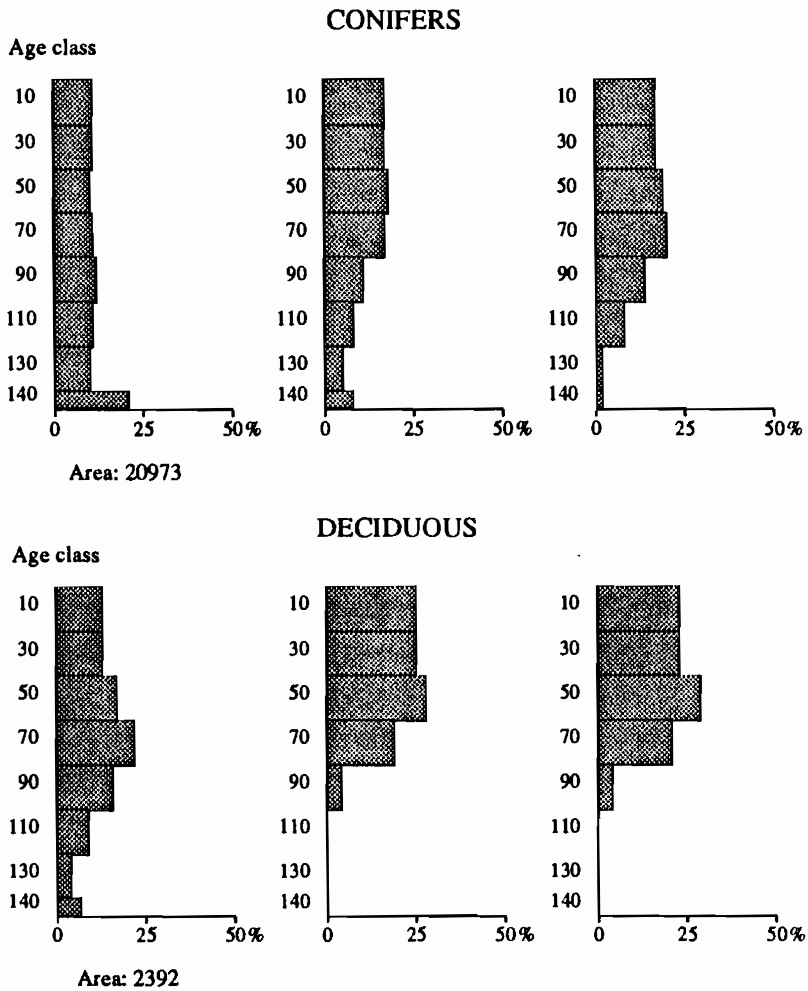


Figure B.144. Age-class distributions in Sweden under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

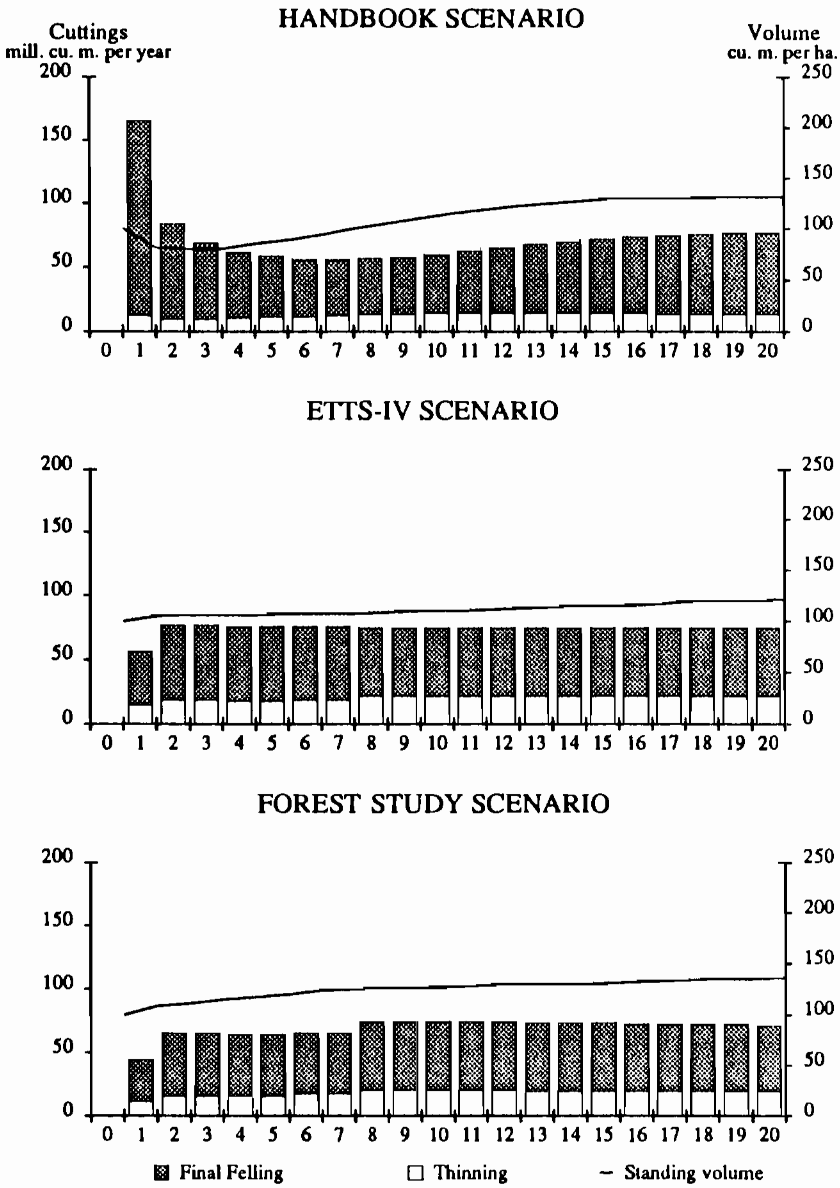


Figure B.145. Projections for total potential harvest and growing stock in Sweden under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 57 million cubic meters o.b.

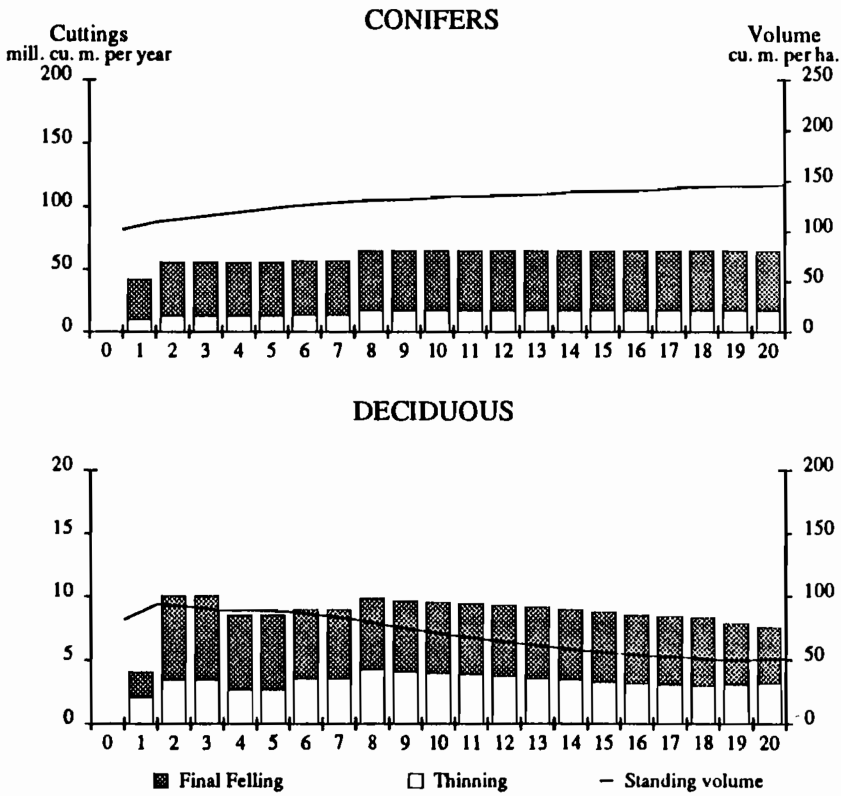


Figure B.146. Projections for total potential harvest and growing stock for coniferous and deciduous species in Sweden under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 50 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 7 million cubic meters o.b.

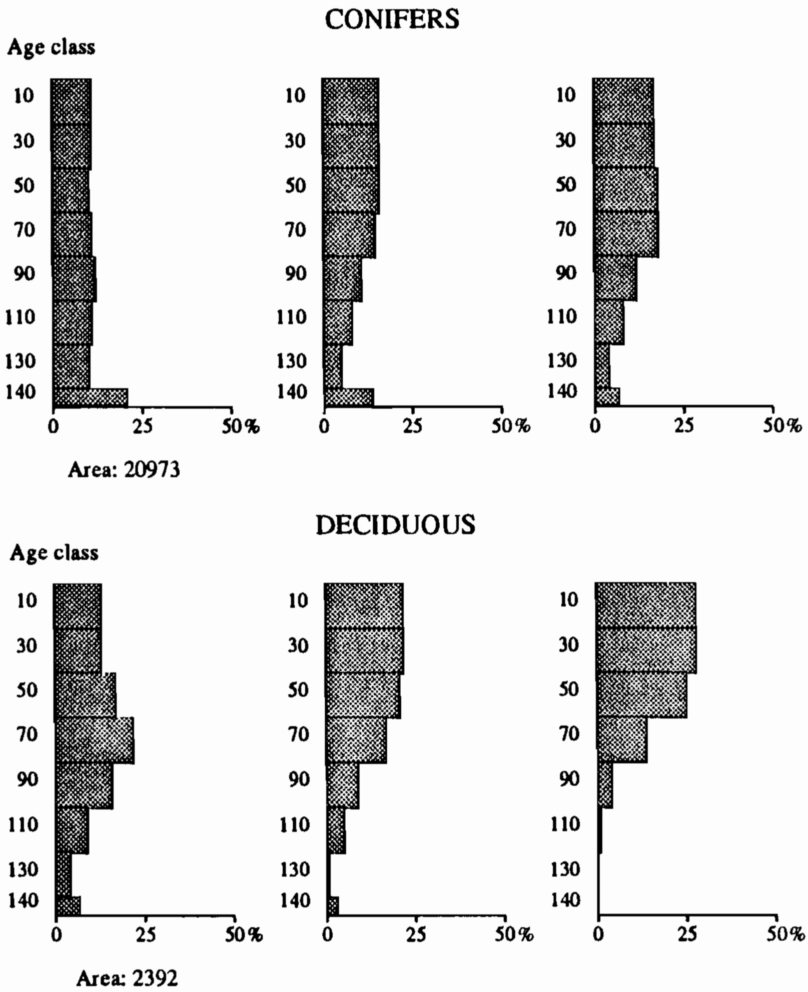


Figure B.147. Age-class distributions in Sweden under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

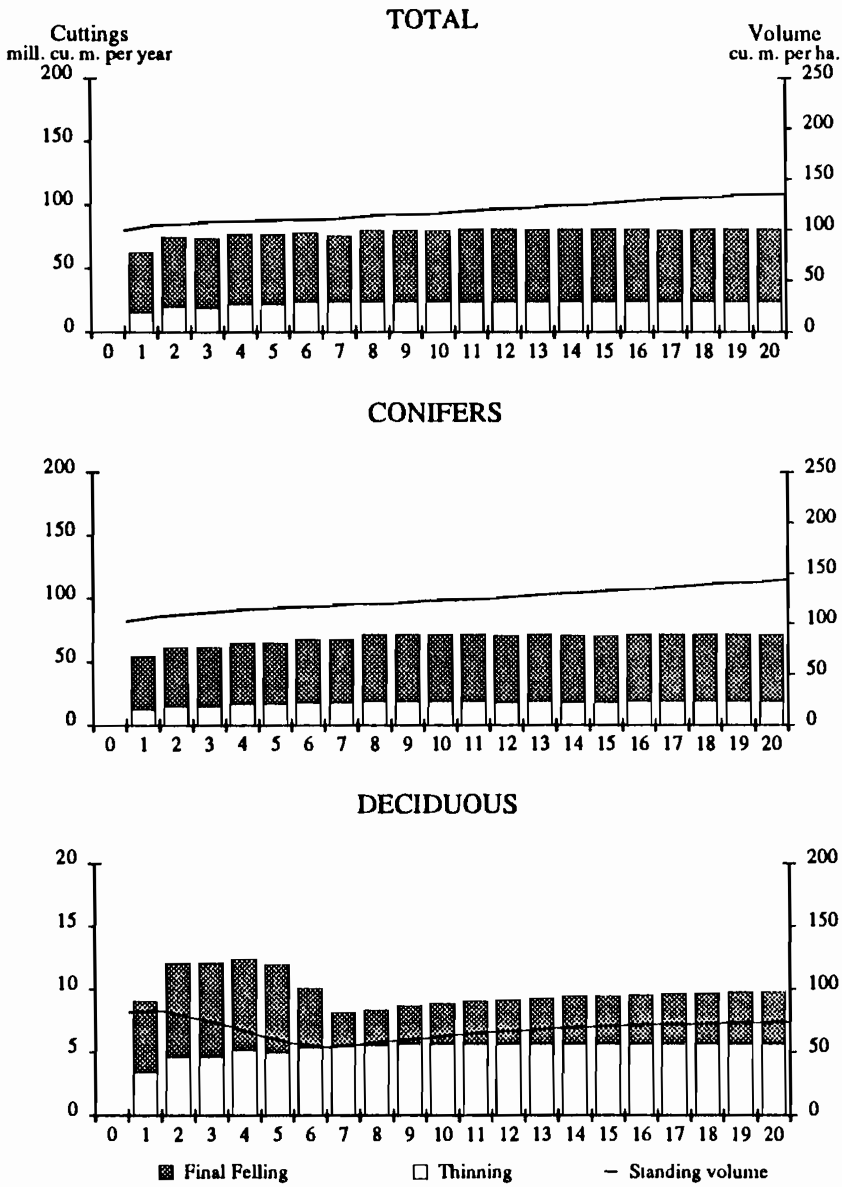


Figure B.148. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Sweden under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 57 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 50 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 7 million cubic meters o.b.

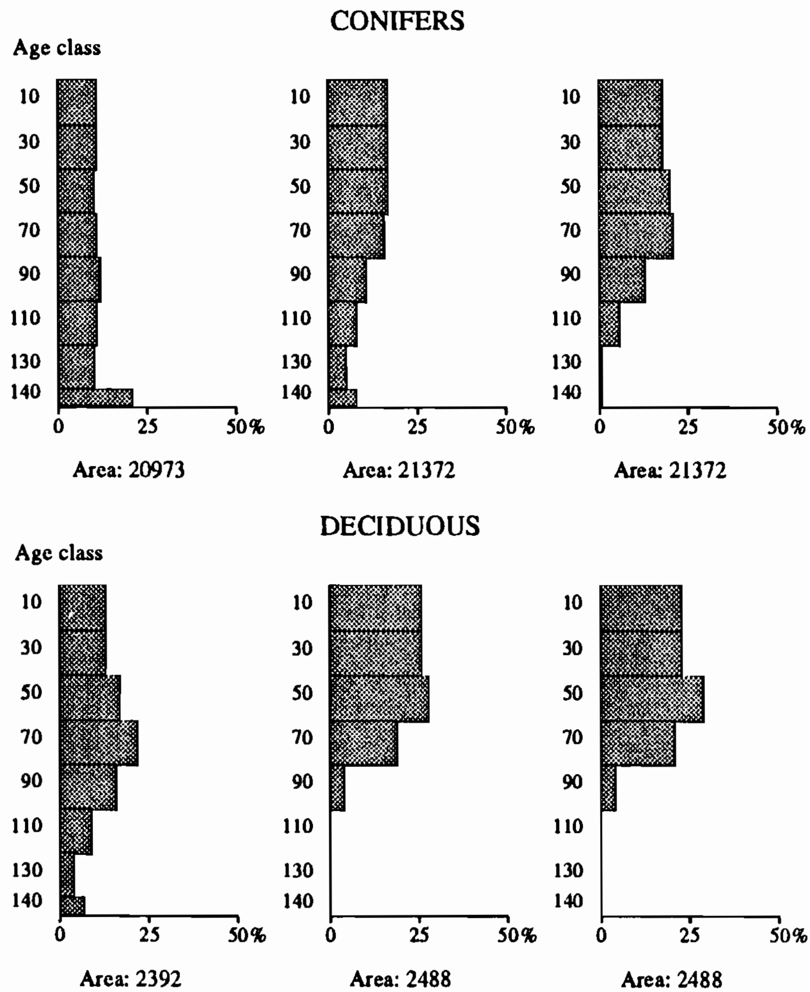


Figure B.149. Age-class distributions in Sweden under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Switzerland (Table B.22 and Figures B.150 to B.157)

Basic Scenarios

The Basic Handbook Scenario shows no correspondence between handbook silviculture and the initial forest structure of Switzerland. After huge harvests in the initial periods, harvests stabilize at about 7 million cubic meters per year, with a steady increase of growing stock to about 345 cubic meters per hectare. ETTS-IV harvest levels can easily be realized, with the mean growing stock increasing to about 500 cubic meters per hectare, an extremely high level. Under such conditions, harvests must surely be increased.

The ETTS-IV submission from Switzerland was based on old information. The Basic Forest Study Scenario calls for much higher harvest levels, bringing the overall growing stock down to about 330 cubic meters per hectare by the end of the simulation. Most of these harvests come from final cuts in coniferous stands. The mean growing stock of conifers declines over the simulation, from approximately 400 cubic meters per hectare to 300 cubic meters per hectare, while that of deciduous shows an opposite pattern. Old stands dominate the coniferous age-class structure at the beginning of the simulation, but the age-class structure evens out over time – explaining the high harvest potential and the self-decline of the growing stock. The initial deciduous age-class structure permits an increasing growing stock over time.

Decline Scenarios

The early harvest pulse is strengthened in the Handbook Decline Scenario. The potential harvest level is lower throughout the whole simulation period (after the pulses) in comparison with the basic scenario. The mean level of the growing stock is also lower in the decline scenario, about 150 cubic meters per hectare lower at the end of the period studied, in comparison with the basic scenario.

The harvest levels of ETTS-IV are possible to achieve in the decline scenario. However, such harvest levels strongly influence the level of the total growing stock, which in the decline scenario are about 140 cubic meters per hectare lower than those of the Basic ETTS-IV Scenario.

It is possible to keep the level of the growing stock identified in the Basic Forest Study Scenario stable in the decline case. Nevertheless, harvest levels are heavily influenced in the decline situation, being reduced by about 2.4 million cubic meters per year in comparison with the basic scenario. The potential harvest of coniferous species is most affected by the decline. The reduction of potential harvests strongly influences the levels of final cuts in both coniferous and deciduous stands.

Forest Land Expansion Scenario

The increased forest landbase of Switzerland generates slight impacts on the potential harvest, mainly as a result of the rather long rotation periods in this country with the increase of the forest landbase. It is possible to have a more stable development of the total growing stock at about the same level as in the basic scenario. This is also valid for coniferous species. Concerning deciduous growing stock, the mean level is lower but with the same development pattern as in the basic scenario.

Summary

Under the basic conditions, the harvest levels suggested by ETTS-IV can be realized. Decline caused by air pollutants is expected to influence future harvest potentials rather strongly. With decline, total harvest potential will decrease by 2.4 million cubic meters per year throughout the whole simulation period. The estimated increase of the forest landbase will add 0.1 million cubic meters per year to the total harvest potential throughout the 100 years in comparison with the basic scenario.

Table B.22. Switzerland.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	364–346	364–504	364–330	364–191	364–359	364–401	364–323
Fellings[b]							
Year 1	18.4	4.8	7.0	23.6	4.8	4.6	7.1
Year 40	6.9	5.7	7.7	6.2	5.7	5.3	7.5
Year 80	6.7	5.7	7.7	4.6	5.7	5.3	8.2
Coniferous							
Growing stock[a]	409–351	409–572	409–296	409–211	409–460	409–426	409–326
Fellings[b]							
Year 1	16.9	3.4	5.6	21.5	3.4	3.6	5.7
Year 40	5.2	4.0	6.2	4.5	4.0	4.2	6.0
Year 80	4.8	4.0	6.2	3.4	4.0	4.2	6.4
Deciduous							
Growing stock[a]	260–334	260–348	260–408	260–144	260–125	260–343	260–319
Fellings[b]							
Year 1	1.5	1.4	1.4	2.1	1.4	1.0	1.4
Year 40	1.7	1.7	1.5	1.7	1.7	1.1	1.5
Year 80	1.9	1.7	1.5	1.2	1.7	1.1	1.8
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	7.7	5.7	7.6	7.4	5.7	5.2	7.7
Coniferous	6.0	4.0	6.1	5.8	4.0	4.1	6.1
Deciduous	1.7	1.7	1.5	1.6	1.7	1.1	1.6
Growth (m^3 o.b./ha/yr)[c]							
Total	7.3	6.9	7.0	5.5	5.5	5.4	5.9
Coniferous	7.8	7.3	7.3	6.1	6.1	5.9	6.5
Deciduous	6.2	6.2	6.2	4.1	4.1	4.3	4.8
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	364–346	364–504	364–330	364–191	364–359	364–401	364–323
Coniferous	409–351	409–572	409–296	409–211	409–460	409–426	409–326
Deciduous	260–334	260–348	260–408	260–144	260–125	260–343	260–319

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

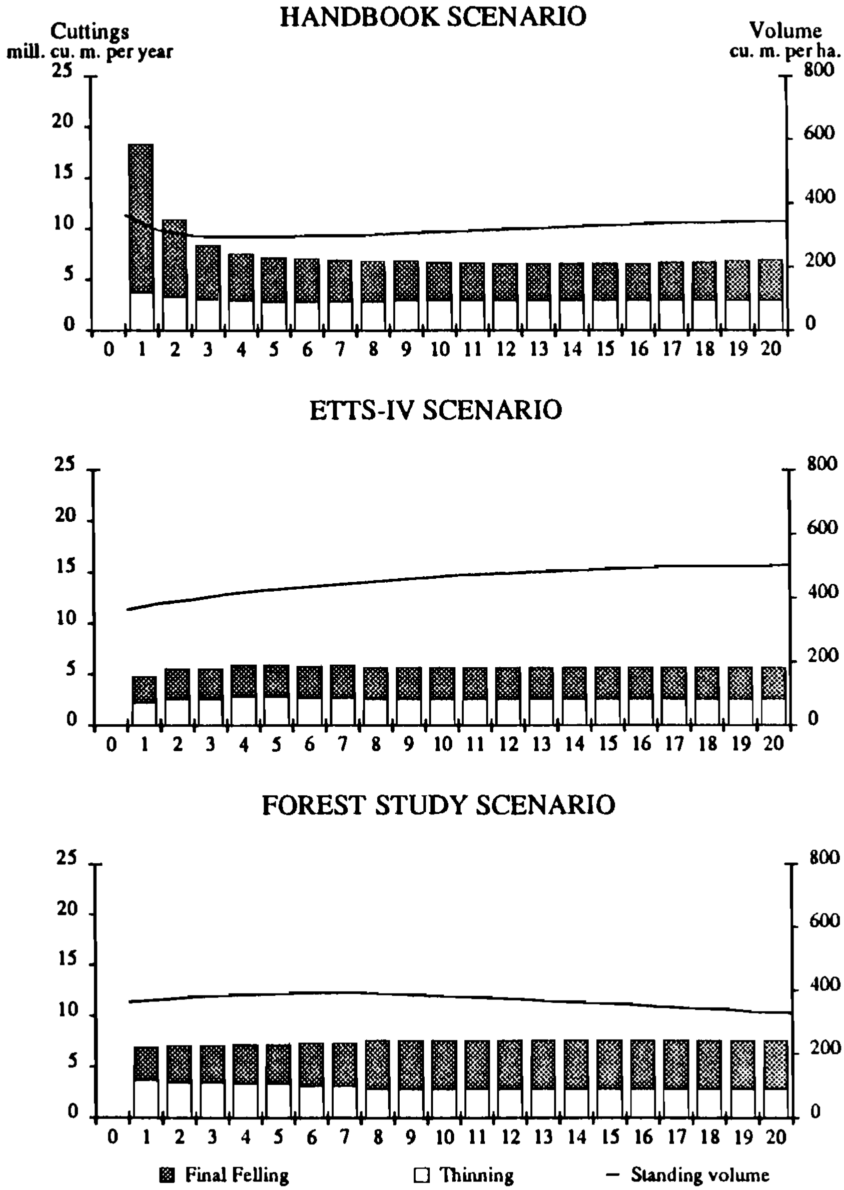


Figure B.150. Projections for total potential harvest and growing stock in Switzerland under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 4.8 million cubic meters o.b.

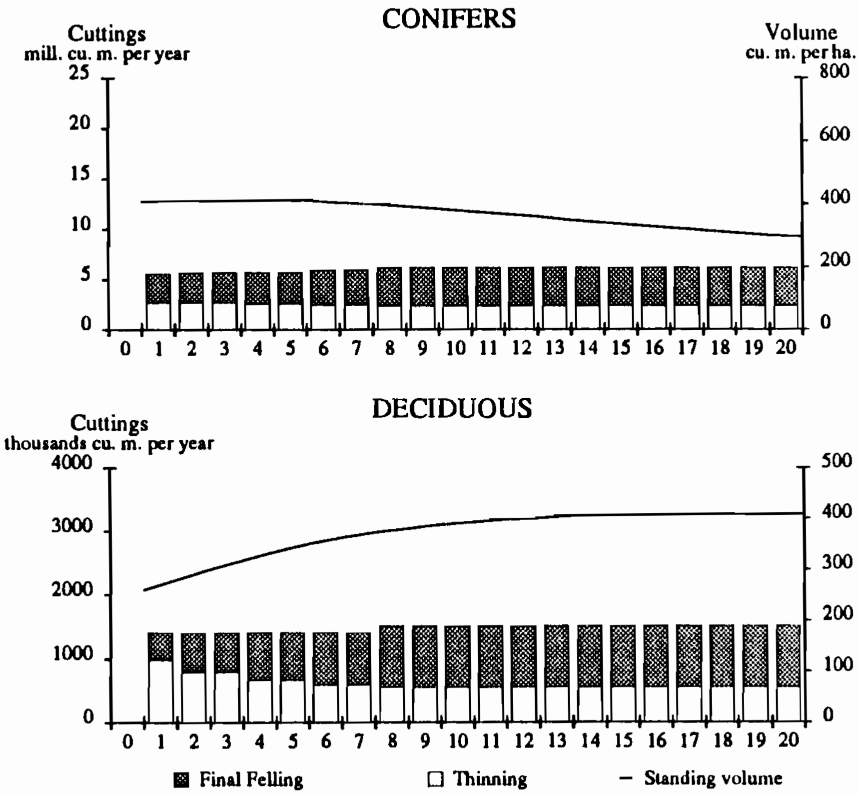


Figure B.151. Projections for total potential harvest and growing stock for coniferous and deciduous species in Switzerland under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 3.4 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1.4 million cubic meters o.b.

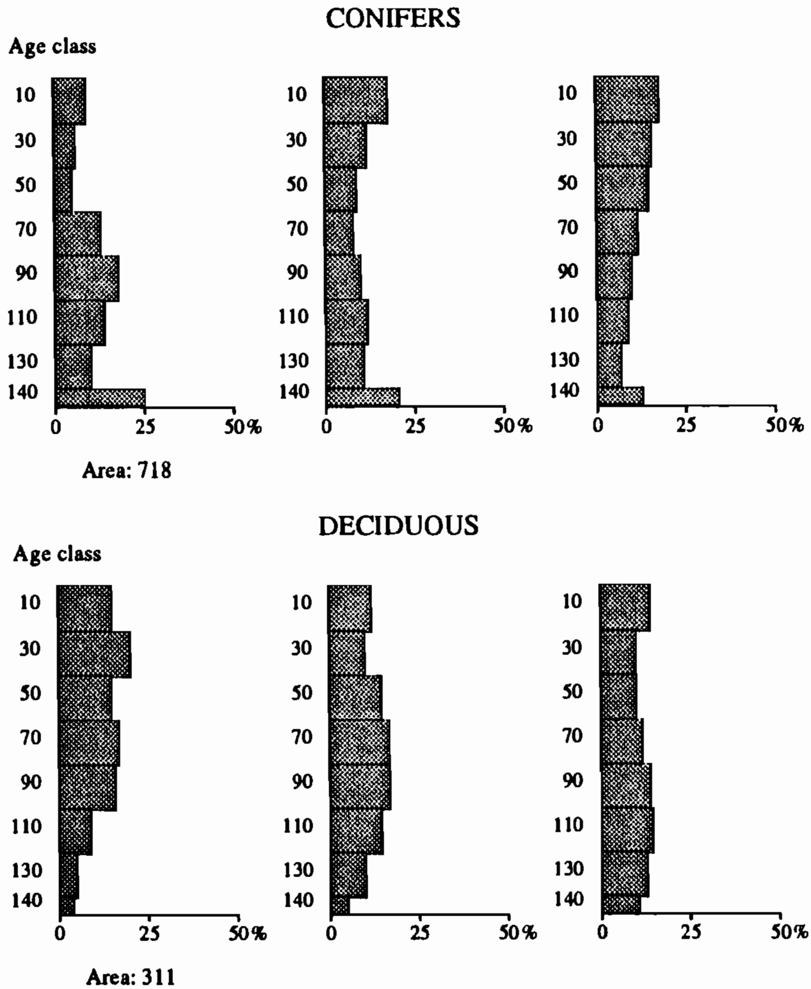


Figure B.152. Age-class distributions in Switzerland under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

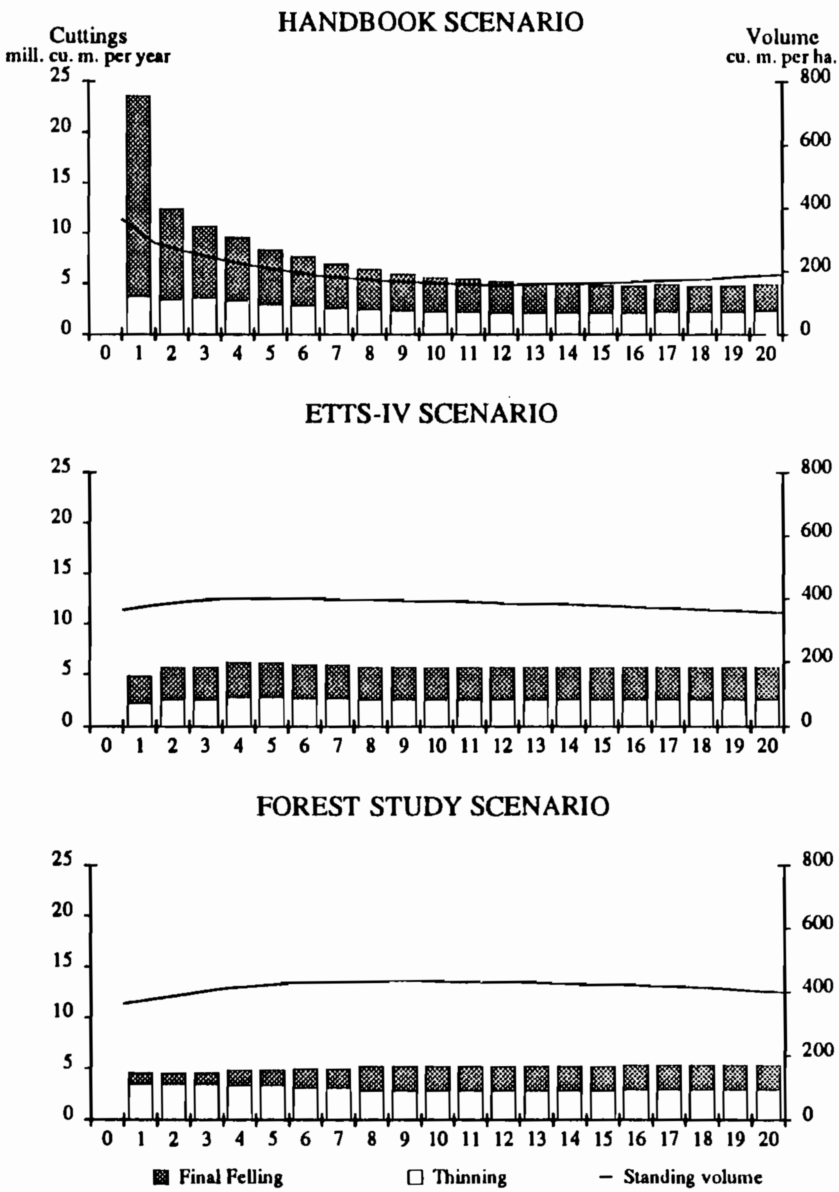


Figure B.153. Projections for total potential harvest and growing stock in Switzerland under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 4.8 million cubic meters o.b.

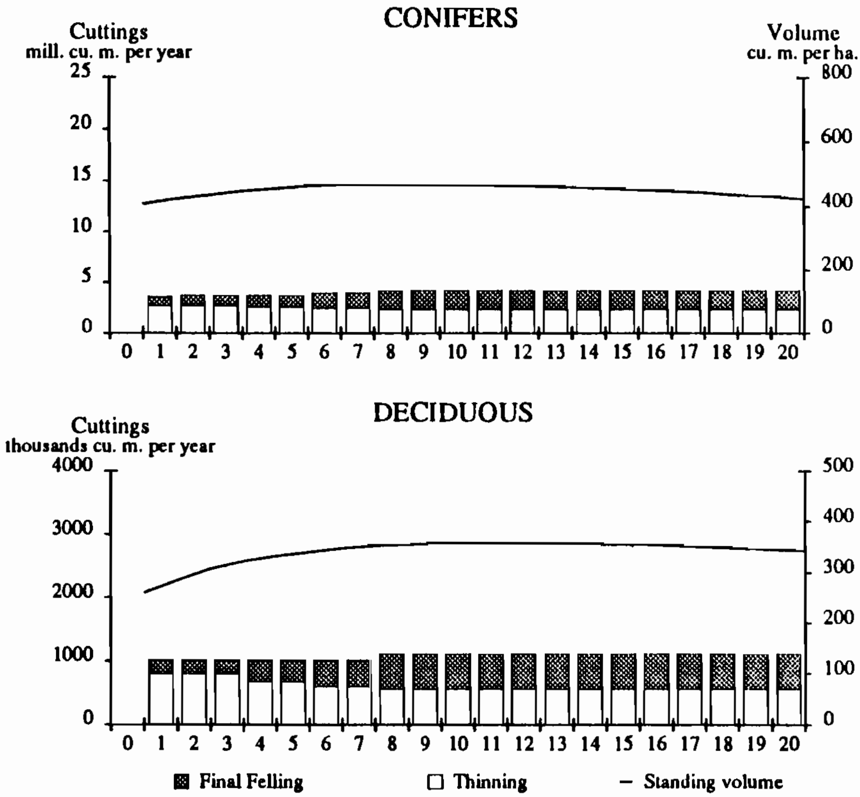


Figure B.154. Projections for total potential harvest and growing stock for coniferous and deciduous species in Switzerland under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 3.4 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1.4 million cubic meters o.b.

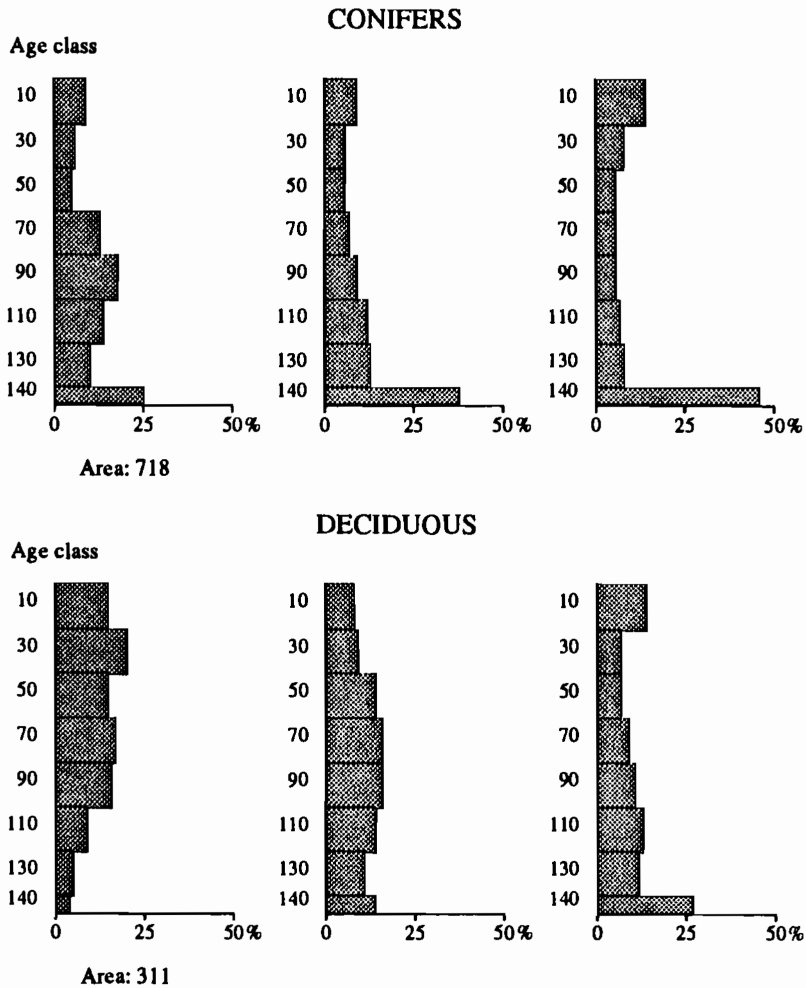


Figure B.155. Age-class distributions in Switzerland under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

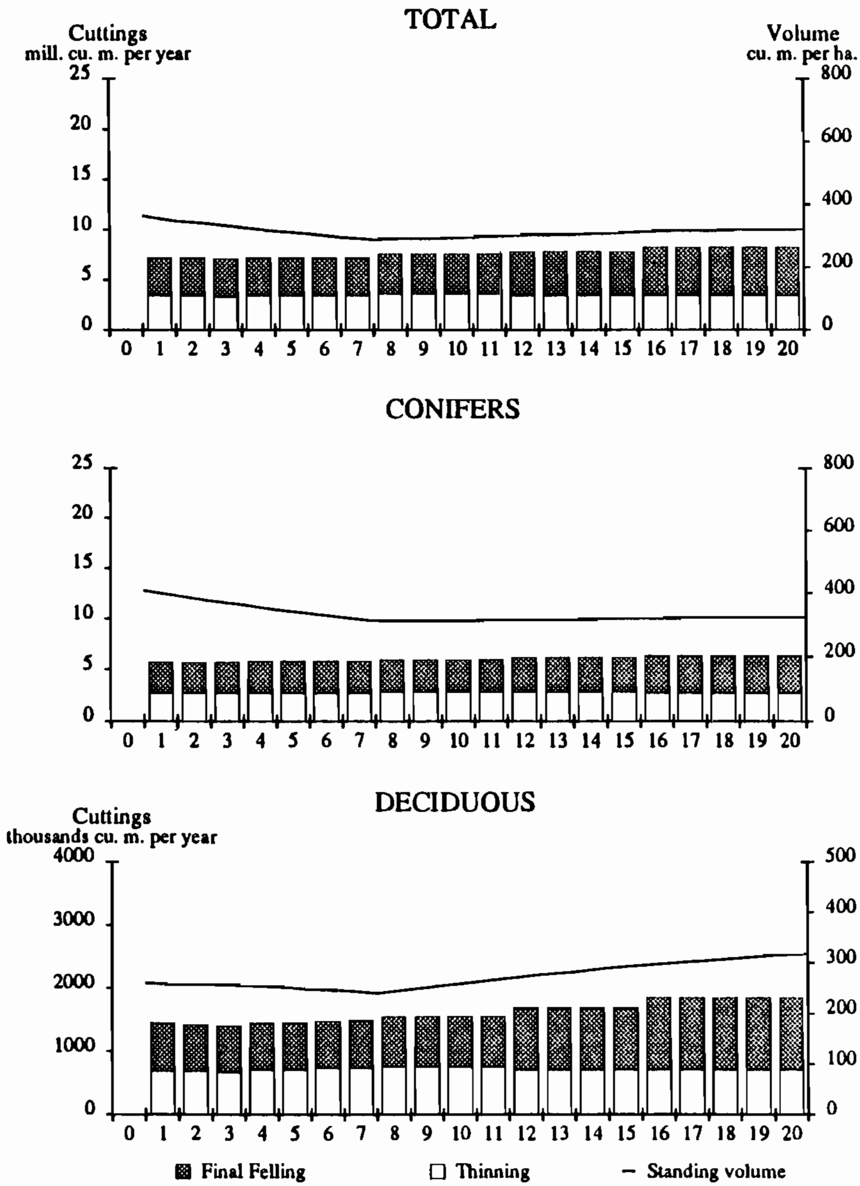


Figure B.156. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Switzerland under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 4.8 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 3.4 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1.4 million cubic meters o.b.

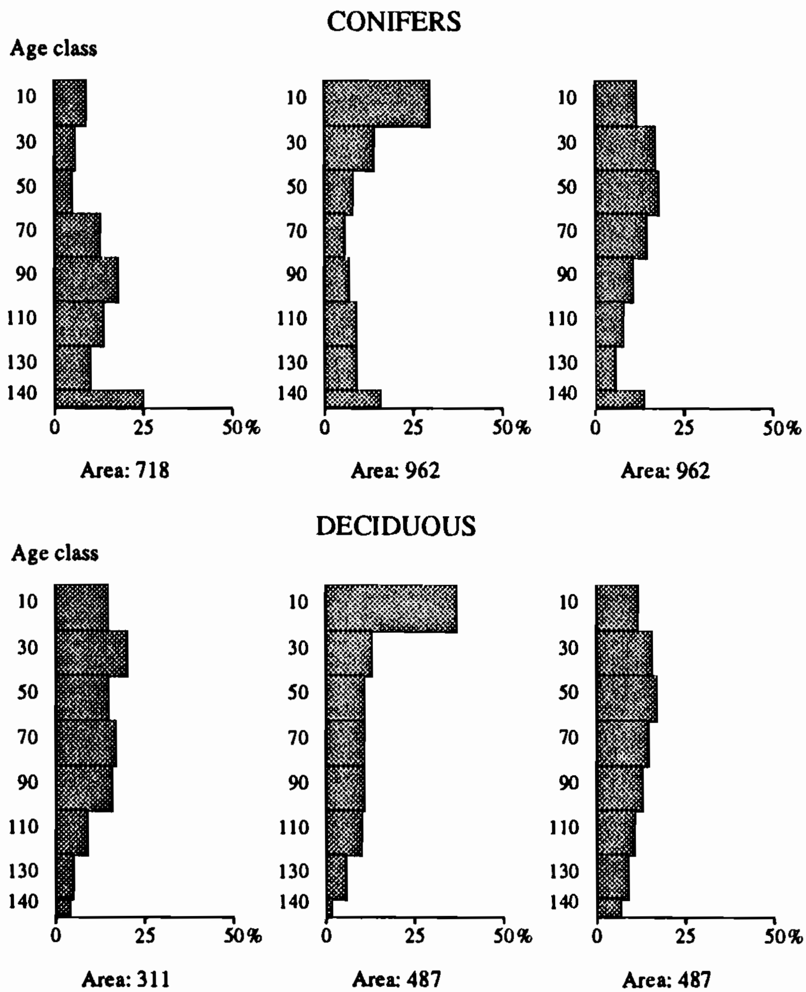


Figure B.157. Age-class distributions in Switzerland under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Turkey (Table B.23 and Figures B.158 to B.161)

Basic Scenario

The inventory data for Turkey are so primitive and aggregated that it is impossible to generate a dynamic development of the harvest levels and growing stock. The Basic Forest Study Scenario approach results in harvest levels that slightly exceed those of ETTS-IV approach, with about half the harvest coming from coniferous forests and a quarter each from deciduous and coppice forests. The growing stocks for the coniferous and deciduous groups increase steadily to almost 150 and 250 cubic meters per hectare, respectively, while the mean growing stock of coppice is steady at a low level of about 18 cubic meters per hectare.

Decline Scenario

The calculation of decline effects are rough due to the model approach employed. It is possible in the decline scenario to maintain the level of growing stock as identified in the basic scenario, but then the total potential harvest level has to be reduced by about 2.9 million cubic meters per year in comparison with the basic scenario. The deciduous species group is most affected by the decline.

Summary

Decline causes a reduction of the total potential harvest of about 2.9 million cubic meters per year during the whole simulation period. Deciduous species have a higher growth rate in comparison with coniferous species. In general, the total growth rate is very low in Turkey in comparison with other countries.

Table B.23. Turkey.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]			58–80			58–84	
Fellings[b]							
Year 1			26.8			23.8	
Year 40			34.8			32.4	
Year 80			34.8			31.8	
Coniferous							
Growing stock[a]			104–147			104–156	
Fellings[b]							
Year 1			12.2			10.2	
Year 40			20.1			19.2	
Year 80			20.1			18.9	
Deciduous							
Growing stock[a]			160–243			159–259	
Fellings[b]							
Year 1			6.8			5.8	
Year 40			6.9			5.4	
Year 80			6.9			5.1	
Coppice							
Growing stock[a]			18–18			18–18	
Fellings[b]							
Year 1			7.8			7.8	
Year 40			7.8			7.8	
Year 80			7.8			7.8	
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total			27.0			24.1	
Coniferous			12.3			11.0	
Deciduous			6.9			5.3	
Coppice			7.8			7.8	
Growth (m^3 o.b./ha/yr)[c]							
Total			1.9			1.8	
Coniferous			2.8			2.6	
Deciduous			5.9			4.9	
Coppice			0.8			0.8	
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total			58–80			58–84	
Coniferous			104–147			104–156	
Deciduous			160–243			159–259	
Coppice			18–18			18–18	

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

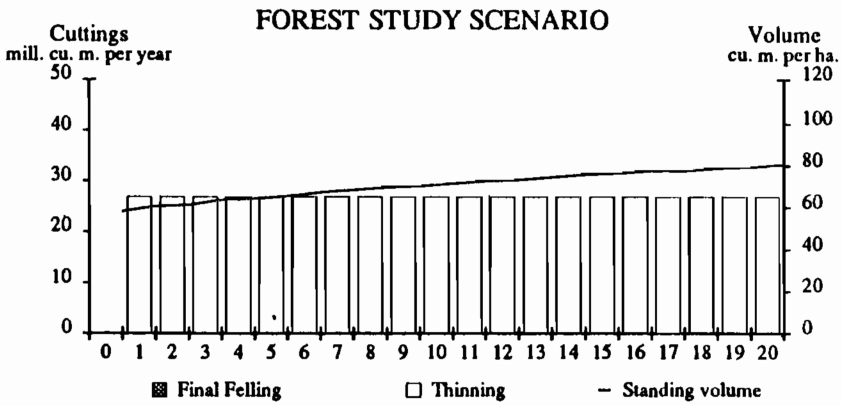


Figure B.158. Projections for total potential harvest and growing stock in Turkey under the Basic Forest Study Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 20 million cubic meters o.b.

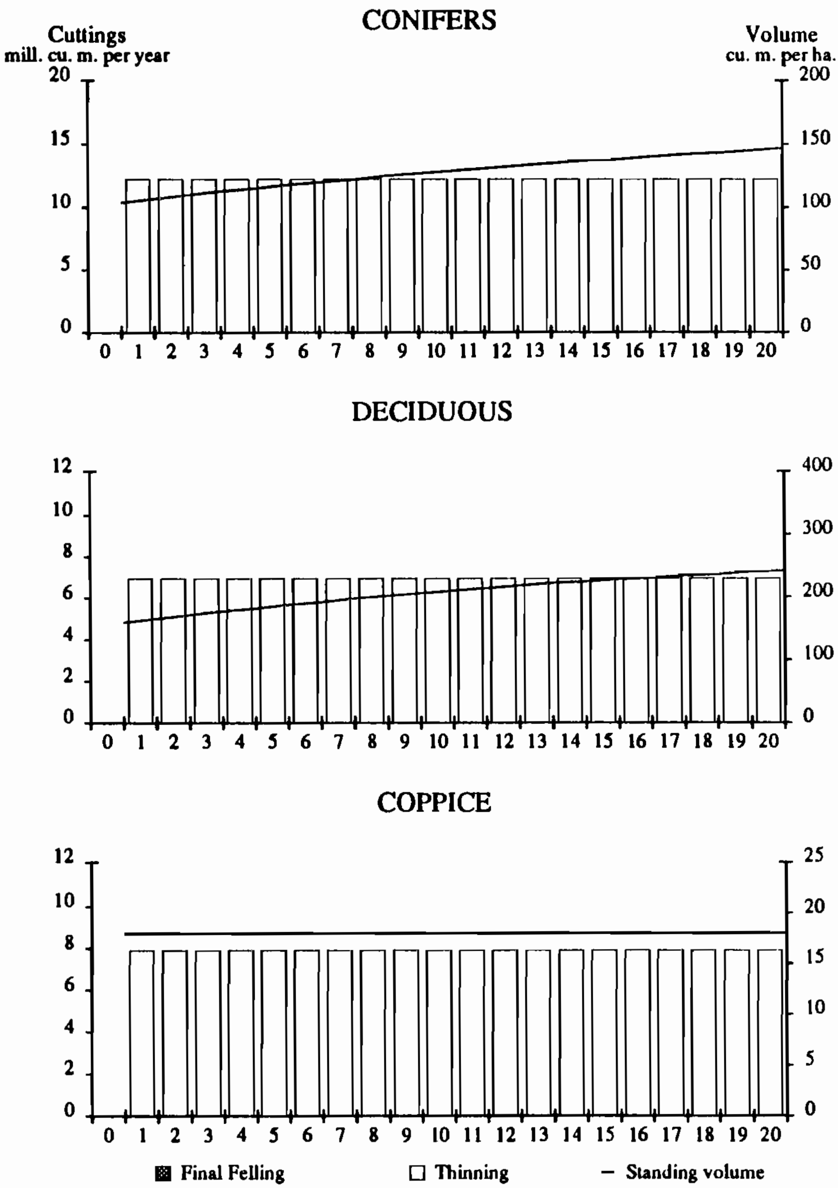


Figure B.159. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Turkey under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 12 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 8 million cubic meters o.b.

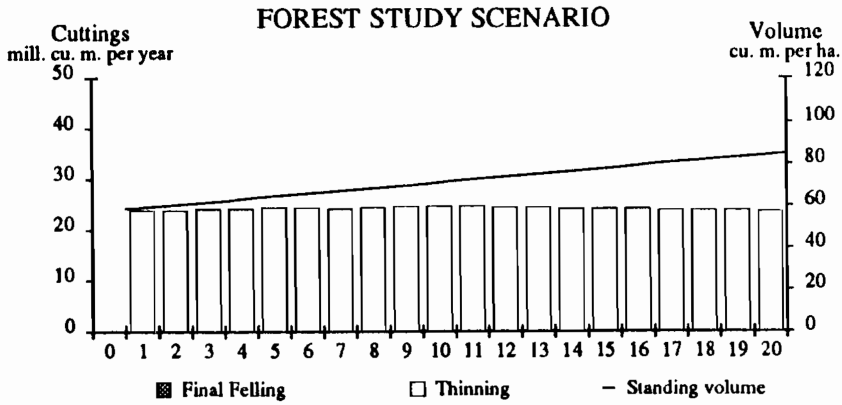


Figure B.160. Projections for total potential harvest and growing stock in Turkey under the Forest Study Decline Scenario. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 20 million cubic meters o.b.

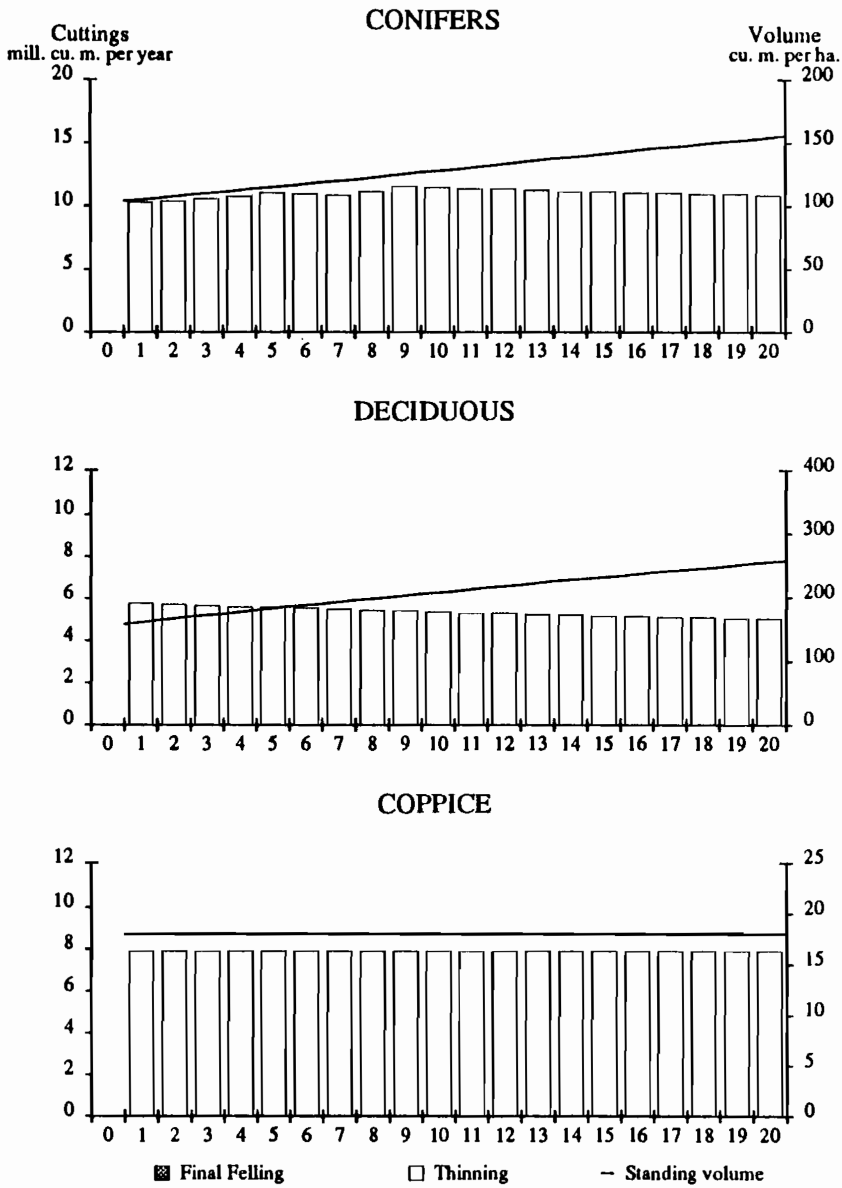


Figure B.161. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Turkey under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 12 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 8 million cubic meters o.b.

UK (Table B.24 and Figures B.162 to B.169)

Basic Scenarios

The structure of forest resources in the UK matches closely what would be expected from implementation of handbook silviculture, as results from the Basic Handbook Scenario show. There is no significant harvest pulse in the first periods. The harvest level rises steadily for about 60 years to a stable level of approximately 15 million cubic meters per year. Over the entire simulation, and especially during the first half, the growing stock increases from 108 cubic meters per hectare to 209 cubic meters per hectare. ETTS-IV harvest levels cannot be reached during the first 20 years, but can be achieved later in the simulation. This is because the information provided by the UK to ETTS-IV already incorporates an increase in the forest landbase, but this condition is not reflected in our basic analyses, which maintain a fixed forest landbase. In the Basic ETTS-IV Scenario, the growing stock develops much the same as in the Basic Handbook Scenario.

The Basic Forest Study Scenario evens out the harvest levels over the first half of the simulation period, yielding a total harvest higher than in the case of the Basic ETTS-IV Scenario. In the Basic Forest Study Scenario a higher proportion of the annual harvest during the first 50 years comes from final cuts (mainly coniferous) compared with the Basic Handbook Scenario. Whereas coniferous harvests double during the first 30 years and then stabilize, deciduous harvests are stable throughout the entire simulation. The growing stock develops smoothly in the Basic Forest Study Scenario, from about 110 cubic meters per hectare to 240 cubic meters per hectare. Over time, the deciduous age-class structure shifts from one rather evenly distributed over all age classes, although with a shortage in the youngest class, to one with mostly young age classes. For coniferous species, the initial peak in the young classes is leveled out over time.

Decline Scenarios

In the Handbook Decline Scenario, we see a strong harvest pulse in the beginning of the simulation period. Later the potential for total harvest and the growing stock are much lower throughout the simulation period in the decline case.

It is not possible to keep the ETTS-IV harvest levels in the decline case. The total harvest level will be much lower. In addition, there is a strong reduction (some 85 cubic meters per hectare) of the growing stock in the decline scenario.

In the Forest Study Decline Scenario, it is possible to keep the growing-stock level identified in the Basic Forest Study Scenario, but only with a harvest level that is lowered by about 3.6 million cubic meters per year.

The potential harvest of coniferous species is most affected by the decline. However, in relative terms, coniferous and deciduous species are affected to the same extent. The reduction of potential harvests is expressed mostly in the levels of final fellings.

Forest Land Expansion Scenario

A strong increase of the forest landbase generates strong effects on the potential harvests. The total potential harvest level at the end of the simulation period is close to 25 million cubic meters per year, in the Forest Land Expansion Scenario. The dominating part of the increased harvests comes from coniferous species, since 80 percent of the new land is planted with coniferous species In the later part of the period, there is also an increase of the potential deciduous harvests.

The development of the total and coniferous growing stocks is similar in the basic and expansion scenarios. For deciduous species growing stock is lower with land expansion, and its development pattern is decreasing or stable over time.

Summary

It is possible under basic conditions to exceed the potential harvest levels suggested by ETTS-IV. The decline scenario will strongly influence the mean potential harvest level. The reduction caused by the decline is about 3.6 million cubic meters per year over 100 years in the Forest Study scenarios.

The strong increase estimated of the forest landbase generates an additional total mean potential of about 4.2 million cubic meters per year during 100 years.

Table B.24. UK.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	108–209	108–229	108–241	108–181	108–143	108–265	108–237
Fellings[b]							
Year 1	11.2	4.8	8.2	20.2	4.8	4.8	9.8
Year 40	15.0	16.3	14.7	9.5	10.5	11.0	16.6
Year 80	14.9	11.9	14.6	12.7	8.7	10.8	24.0
Coniferous							
Growing stock[a]	83–218	83–122	83–237	83–198	83–52	83–268	85–276
Fellings[b]							
Year 1	5.4	3.8	5.2	9.0	3.8	2.8	6.4
Year 40	12.0	15.2	11.6	7.5	9.4	9.1	12.8
Year 80	11.3	10.8	11.5	10.3	7.6	8.9	19.8
Deciduous							
Growing stock[a]	159–188	159–466	159–250	159–143	159–345	159–256	162–127
Fellings[b]							
Year 1	5.8	1.0	3.0	11.2	1.0	2.0	3.4
Year 40	3.0	1.1	3.1	2.0	1.1	1.9	3.8
Year 80	3.6	1.1	3.1	2.4	1.1	1.9	4.2
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	13.8	12.0	13.3	11.2	9.4	9.7	17.5
Coniferous	10.4	10.9	10.2	8.6	8.3	7.8	13.6
Deciduous	3.4	1.1	3.1	2.6	1.1	1.9	3.9
Growth (m^3 o.b./ha/yr)[c]							
Total	8.2	7.5	8.3	6.6	5.2	6.6	7.4
Coniferous	9.0	8.4	9.1	7.5	5.8	7.6	8.2
Deciduous	6.3	5.1	6.4	4.4	3.9	4.3	5.1
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	108–209	108–229	108–241	108–181	108–143	108–265	108–237
Coniferous	83–218	83–122	83–237	83–198	83–52	83–268	85–276
Deciduous	159–188	159–466	159–250	159–143	159–345	159–256	162–127

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

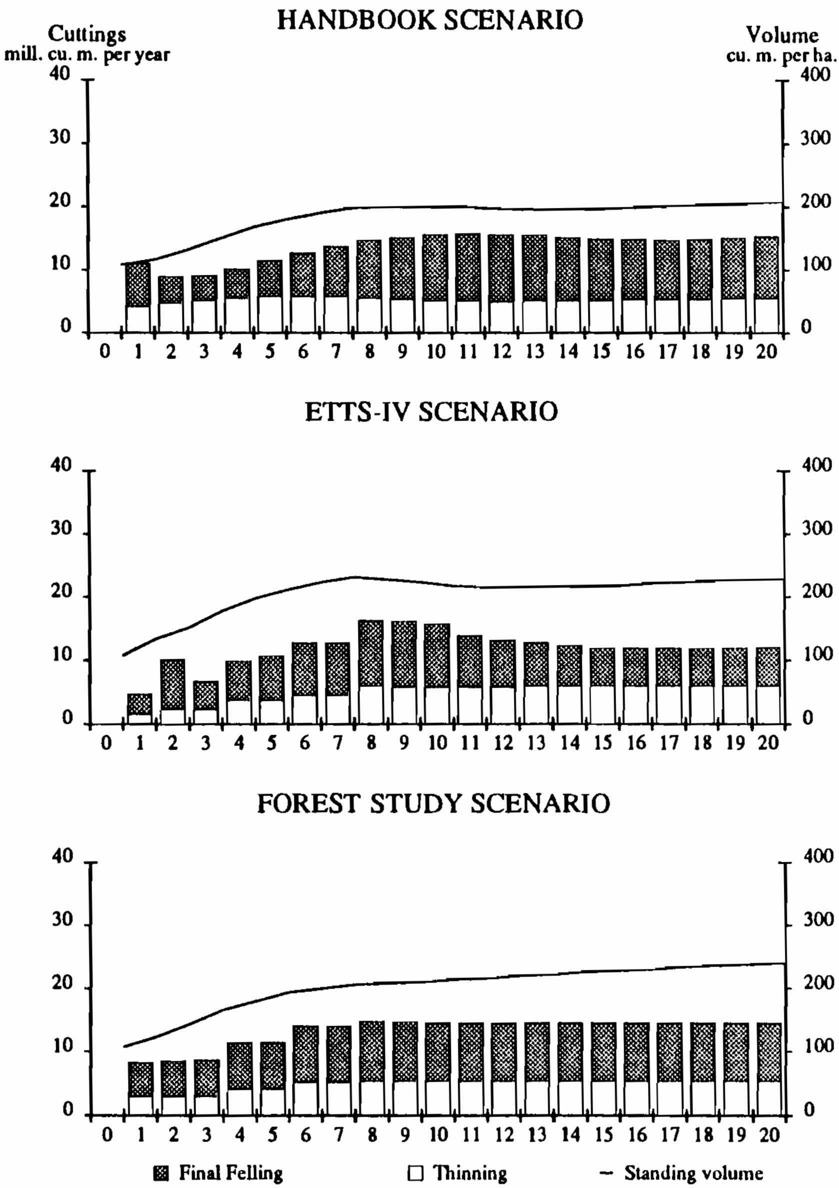


Figure B.162. Projections for total potential harvest and growing stock in the UK under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 4.6 million cubic meters o.b.

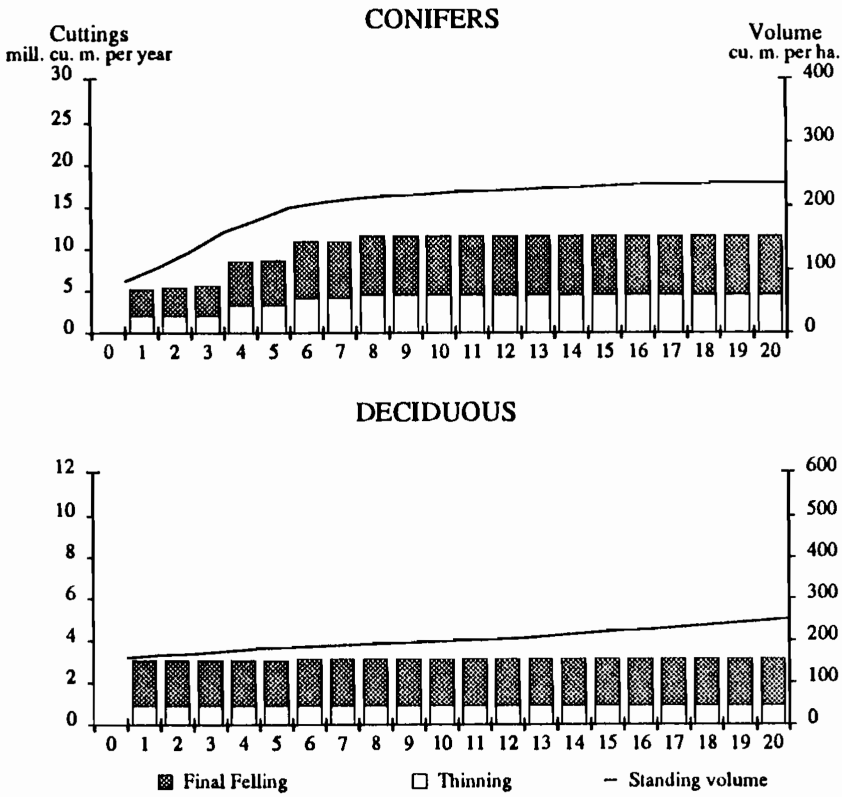


Figure B.163. Projections for total potential harvest and growing stock for coniferous and deciduous species in the UK under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 3.6 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.

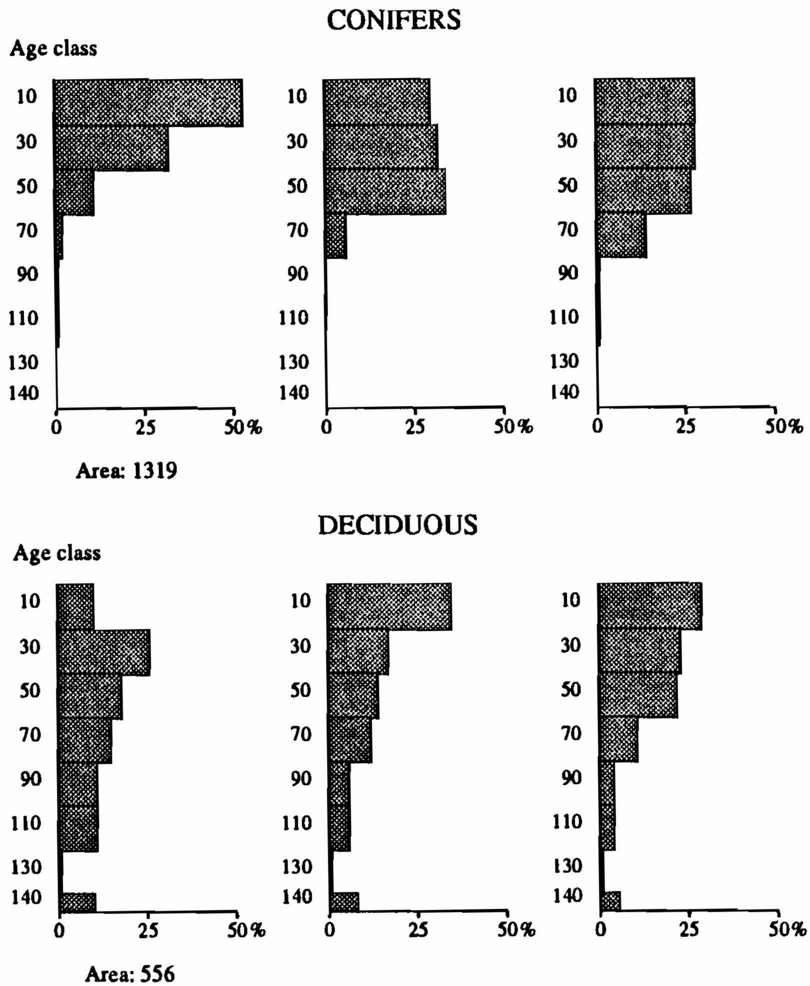


Figure B.164. Age-class distributions in the UK under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

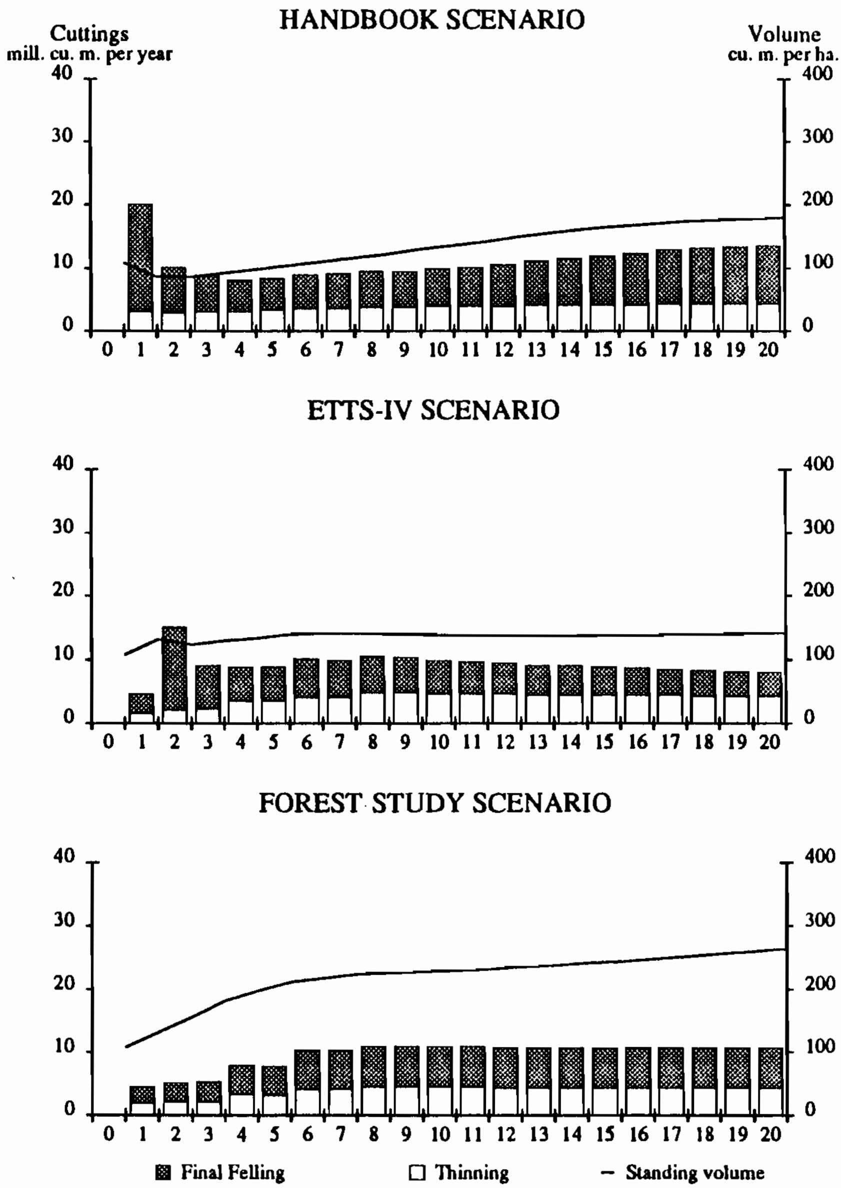


Figure B.165. Projections for total potential harvest and growing stock in the UK under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 4.6 million cubic meters o.b.

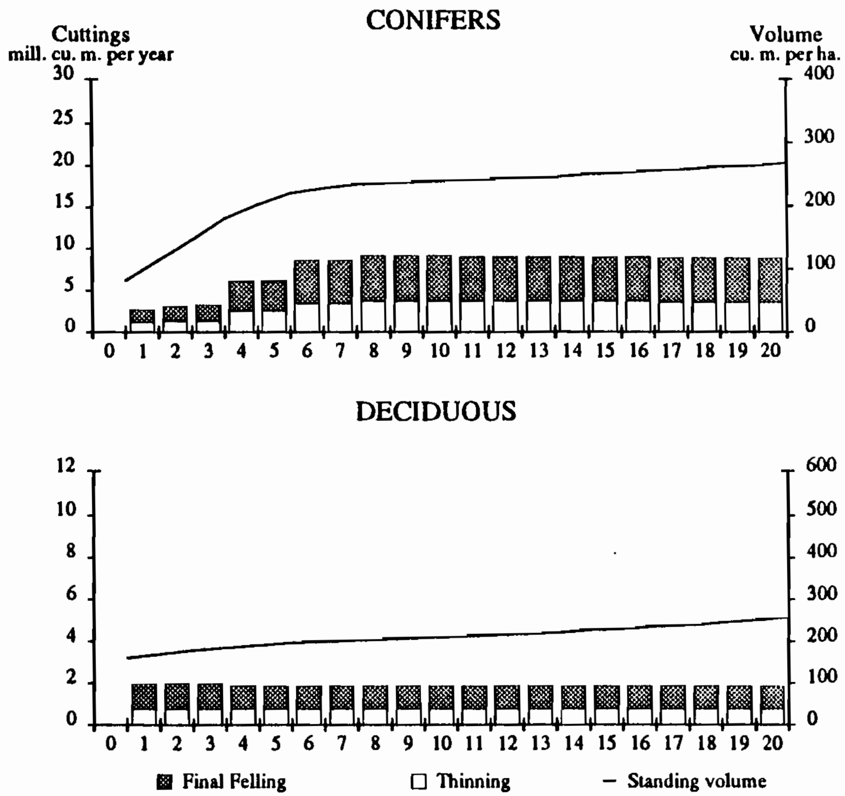


Figure B.166. Projections for total potential harvest and growing stock for coniferous and deciduous species in the UK under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 3.6 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.

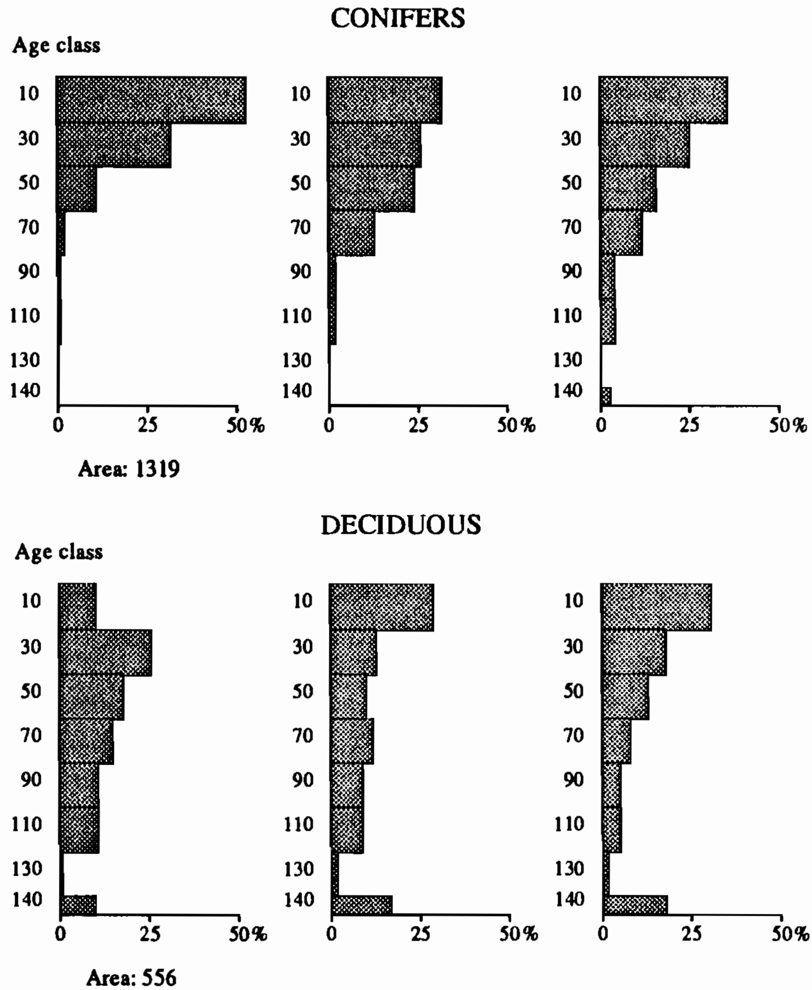


Figure B.167. Age-class distributions in the UK under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

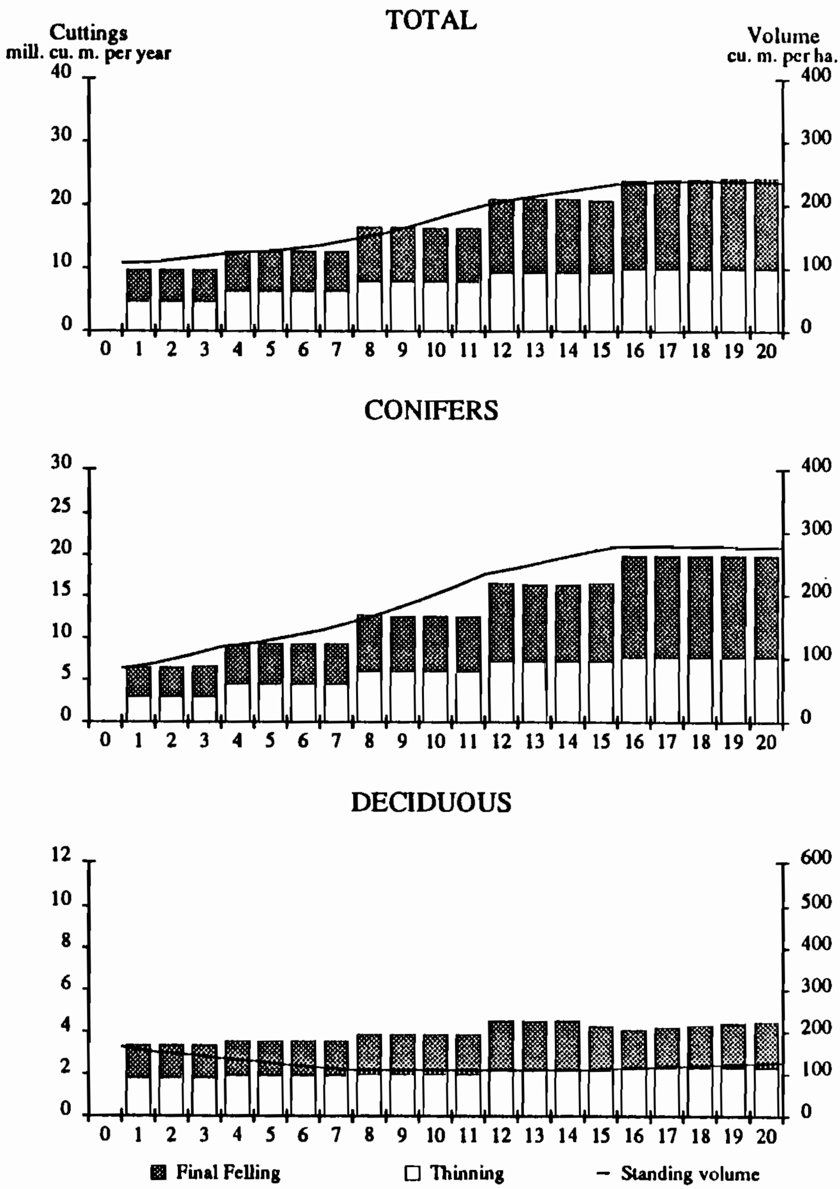


Figure B.168. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in the UK under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 4.6 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 3.6 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 1 million cubic meters o.b.

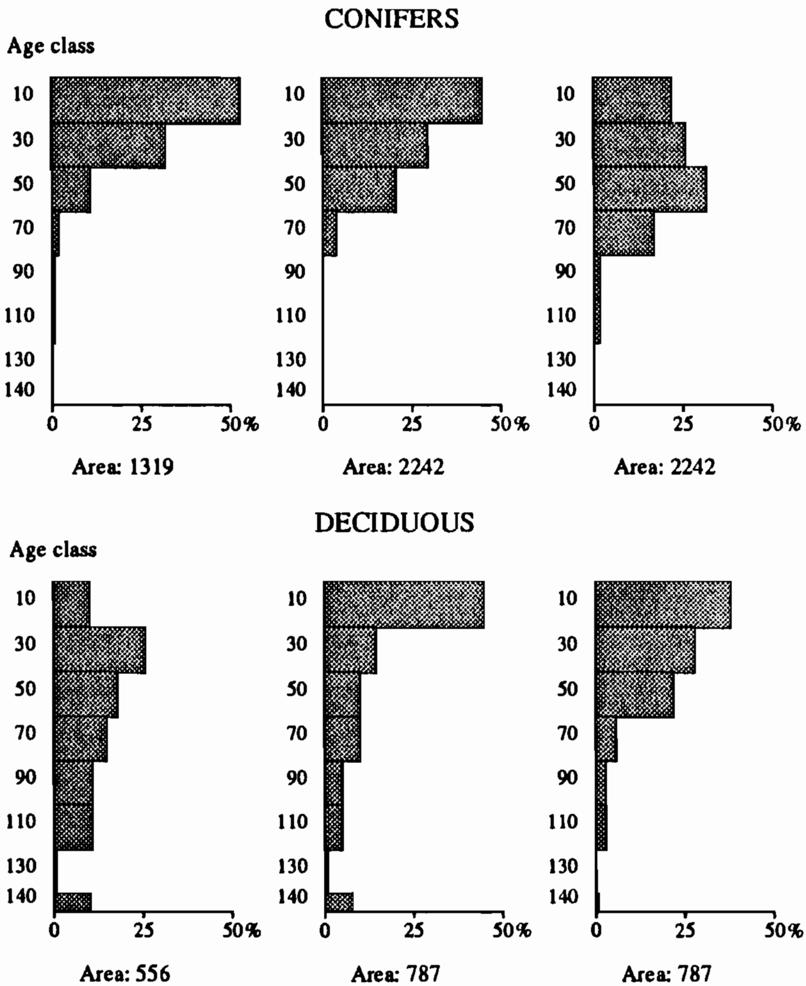


Figure B.169. Age-class distributions in the UK under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.

Yugoslavia (Table B.25 and Figures B.170 to B.178)

Basic Scenarios

The Yugoslavian forests are somewhat out of balance with handbook silviculture, as is evident from the modest early harvest pulse under the Basic Handbook Scenario. The total harvest level stabilizes at about 24 million cubic meters per year, while the mean growing stock increases steadily to 200 cubic meters per hectare. ETTS-IV harvest levels can be maintained only through the first half of the simulation. However, the development of growing stock under the Basic ETTS-IV Scenario is close to that implied by the Basic Handbook Scenario. The growing stock is brought to a slightly higher level with the Basic Forest Study Scenario, where it is possible to keep a harvest level of about 23 million cubic meters per year throughout the simulation.

A large part of the Yugoslavian forests are inadequately described. These forests are thus modeled using our "simple approach," which means that there is only one basic simulation. In turn this simulation is merged into all the basic scenarios. All cuttings from these poorly described forests are registered as thinnings in the simulations. Thus, the proportion of thinnings in the total harvests is shown to be high. Harvests of both coniferous and deciduous species are very stable over time in the Basic Forest Study Scenario, and growing stocks increase steadily. This is also explained by the preponderance of poorly described forests for which the simulations are very "stiff." Turning to the age-class structure development for even-aged stand areas, the coniferous species display an evolution from a structure of mostly young age classes to one of mostly older classes. This notably affects harvests and the mean growing stock, but the effects are damped by the combination of stands with differentiated age structure. The age-class structure for the deciduous species evolves differently, from a pattern of middle-aged stands to one that is fairly evenly distributed.

Decline Scenarios

In the Handbook Decline Scenario, the harvest pulse of the first period is accentuated. After about 35 years, the potential total harvest level decreases continuously over time in comparison with the basic scenario. This decrease continues for about 40 years, and at the end of the simulation period the potential harvest levels are about the same in the two scenarios. In the decline scenario, there is no possibility to maintain the level of the growing stock identified in the basic scenario. In the ETTS-IV Decline Scenario, it is not possible to maintain ETTS-IV harvest levels for the first half of the simulation period. In addition, the mean growing stock is lower than that in the basic scenario.

In the Forest Study Decline Scenario it is not possible to maintain the same growing-stock level as identified in the Basic Forest Study Scenario. Even with lower levels of growing stock, harvests are reduced in comparison with the basic scenario by about 2.8 million cubic meters per year. The decrease is evident more in the beginning of the simulation period. The coppice species group is most affected by the decline. Coppice shows reduction of both growing-stock and harvest levels in the decline scenario. Harvest of deciduous species is mainly affected in the first 40 years of the simulation period. For this species group, the growing-stock level is also lower at the end of the simulation period in the case of decline. The situation is the same for coniferous species, for which the difference between growing stocks in the two scenarios is about 60 cubic meters per hectare.

Forest Land Expansion Scenario

With an increased forest landbase, there is an increase in the harvest potential throughout the simulation period. However, this increase is relatively low in comparison with the size of the land expansion. This is a result of the relatively low growth rate in this region. The total growing stock is slightly lower in the expansion scenario than in the basic scenario.

The strongest effects on harvest levels by land expansion is achieved in coppice. This strong effect can be explained by the short rotation periods for coppice forests. The harvest potential of conifers is also increased by the land expansion, although not as strong as for coppice. The growing stock of conifers is lower with the increased forest landbase in comparison with the Basic Forest Study Scenario. Potential harvests of the deciduous species group is hardly affected by the land expansion, because of a low degree of new deciduous stands on the forest land expansions.

Summary

The total harvest levels in the handbook and ETTS-IV scenarios are about the same for both basic and decline conditions. The decline attributed to air pollutants causes a reduction of the total potential harvest of about 2.8 million cubic meters per year over 100 years in comparison with the basic scenario. The rather large expansion of the forest landbase does not generate a corresponding strong increase of the total potential harvest level. The increase is only 0.3 million cubic meters per year during 100 years in comparison with the basic scenario. This can be explained by the fact that many of the forests were poorly described.

Table B.25. Yugoslavia.

Variable	Basic Hand-book	Basic ETTS-IV	Basic Forest Study	Hand-book Decline	ETTS-IV Decline	Forest Study Decline	Forest Land Expansion
Selected data on harvests and growing stock							
Total							
Growing stock[a]	138–200	138–199	138–206	138–173	138–173	138–187	138–199
Fellings[b]							
Year 1	31.2	20.6	22.6	43.0	19.8	18.0	22.8
Year 40	23.8	28.4	23.4	22.4	28.9	20.9	23.8
Year 80	23.5	23.6	23.4	23.8	24.0	21.3	23.8
Coniferous							
Growing stock[a]	191–355	191–368	191–376	191–295	191–306	191–317	187–325
Fellings[b]							
Year 1	4.2	3.8	3.8	5.4	4.2	4.0	3.8
Year 40	4.3	4.0	3.9	5.3	5.1	4.8	4.3
Year 80	4.2	3.9	3.9	4.9	4.7	4.4	4.2
Deciduous							
Growing stock[a]	192–260	192–255	192–260	192–230	192–226	192–232	193–259
Fellings[b]							
Year 1	13.4	10.8	10.8	14.8	9.6	9.0	10.8
Year 40	11.3	13.4	11.3	10.7	13.4	10.8	11.3
Year 80	10.9	10.8	11.3	10.7	10.8	11.6	11.3
Coppice							
Growing stock[a]	54–56	54–52	54–61	54–51	54–48	54–73	54–65
Fellings[b]							
Year 1	13.6	6.0	8.0	22.8	6.0	5.0	8.0
Year 40	8.2	11.0	8.2	6.4	10.4	5.3	8.2
Year 80	8.4	8.9	8.2	8.2	8.5	5.3	8.3
Summary of results							
Potential harvest (mill. m^3 o.b./yr)[c]							
Total	24.2	24.2	23.2	24.7	24.2	20.4	23.5
Coniferous	4.2	3.9	3.8	5.0	3.9	4.4	4.1
Deciduous	11.4	11.6	11.2	11.3	11.6	10.8	11.2
Coppice	8.6	8.7	8.2	8.4	8.7	5.2	8.2
Growth (m^3 o.b./ha/yr)[c]							
Total	3.6	3.6	3.6	3.4	3.4	3.0	3.4
Coniferous	4.6	4.5	4.5	4.5	4.4	4.4	4.1
Deciduous	3.9	4.0	3.9	3.6	3.6	3.5	3.8
Coppice	2.8	2.8	2.7	2.7	2.6	1.9	2.6
Development of growing stock (m^3 o.b./ha; yr0–yr100)							
Total	138–200	138–199	138–206	138–173	138–173	138–187	138–199
Coniferous	191–355	191–368	191–376	191–295	191–306	191–317	187–325
Deciduous	192–260	192–255	192–260	192–230	192–226	192–232	193–259
Coppice	54–56	54–52	54–61	54–51	54–48	54–73	54–65

[a]In m^3 o.b./ha; yr0–yr100.
[b]In mill. m^3 o.b./yr.
[c]Average for the simulations over 100 years.

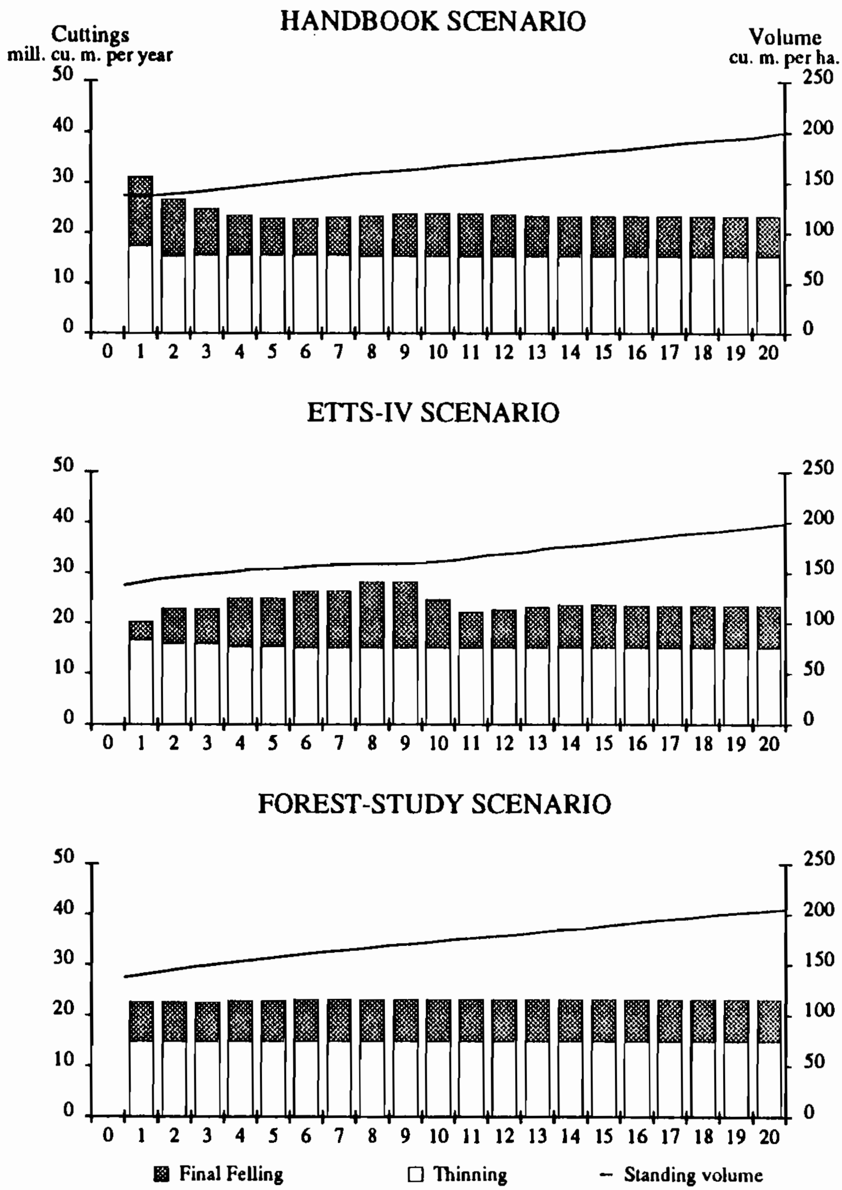


Figure B.170. Projections for total potential harvest and growing stock in Yugoslavia under the basic scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 20 million cubic meters o.b.

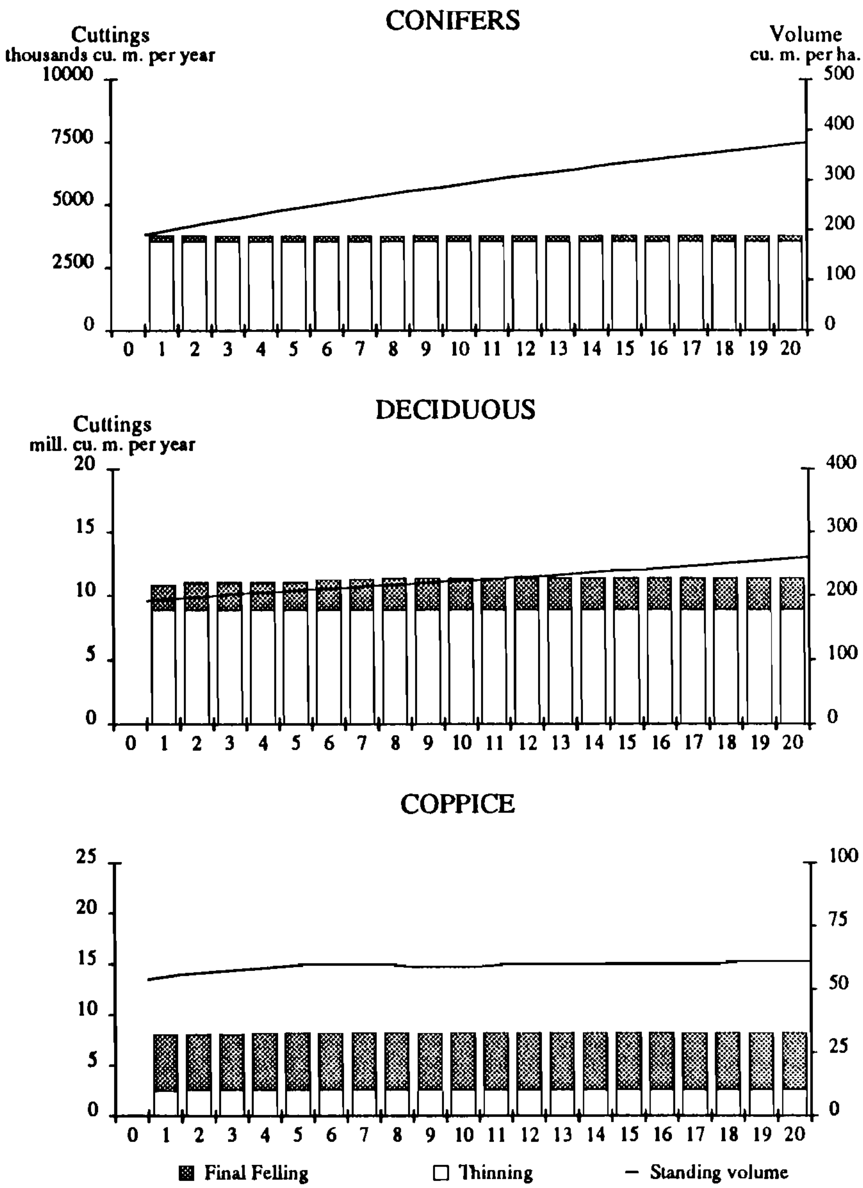


Figure B.171. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Yugoslavia under the Basic Forest Study Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 6 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 14 million cubic meters o.b.

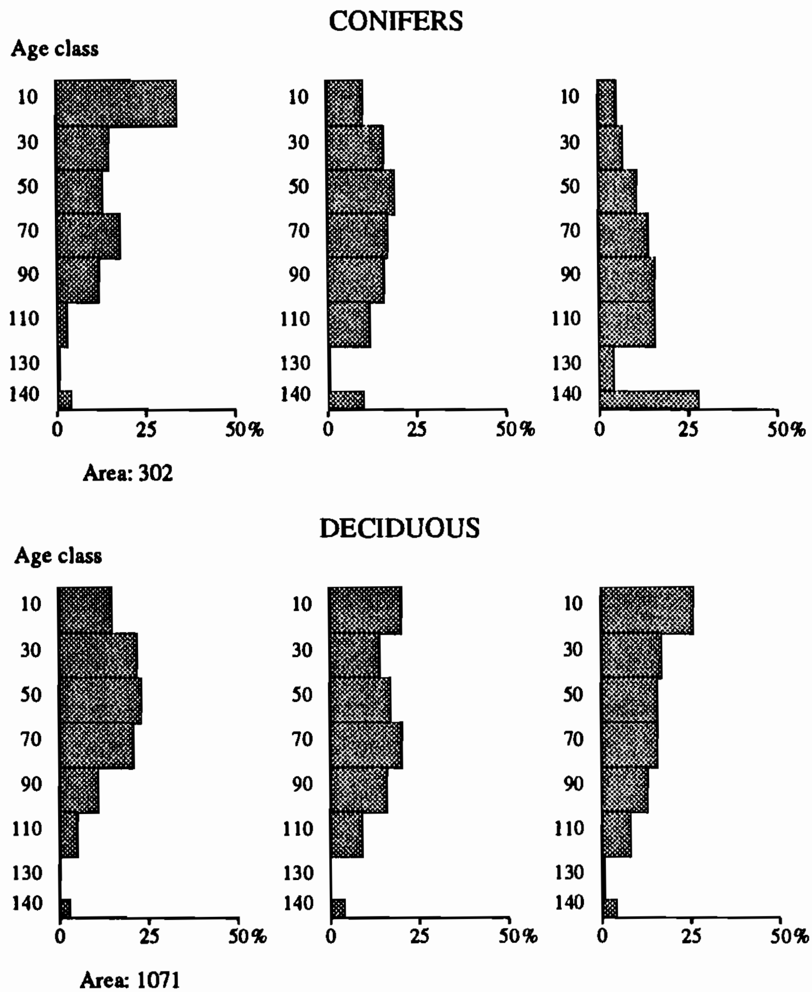


Figure B.172. Age-class distributions in Yugoslavia under the Basic Forest Study Scenario for year 0, 35, and 75, respectively.

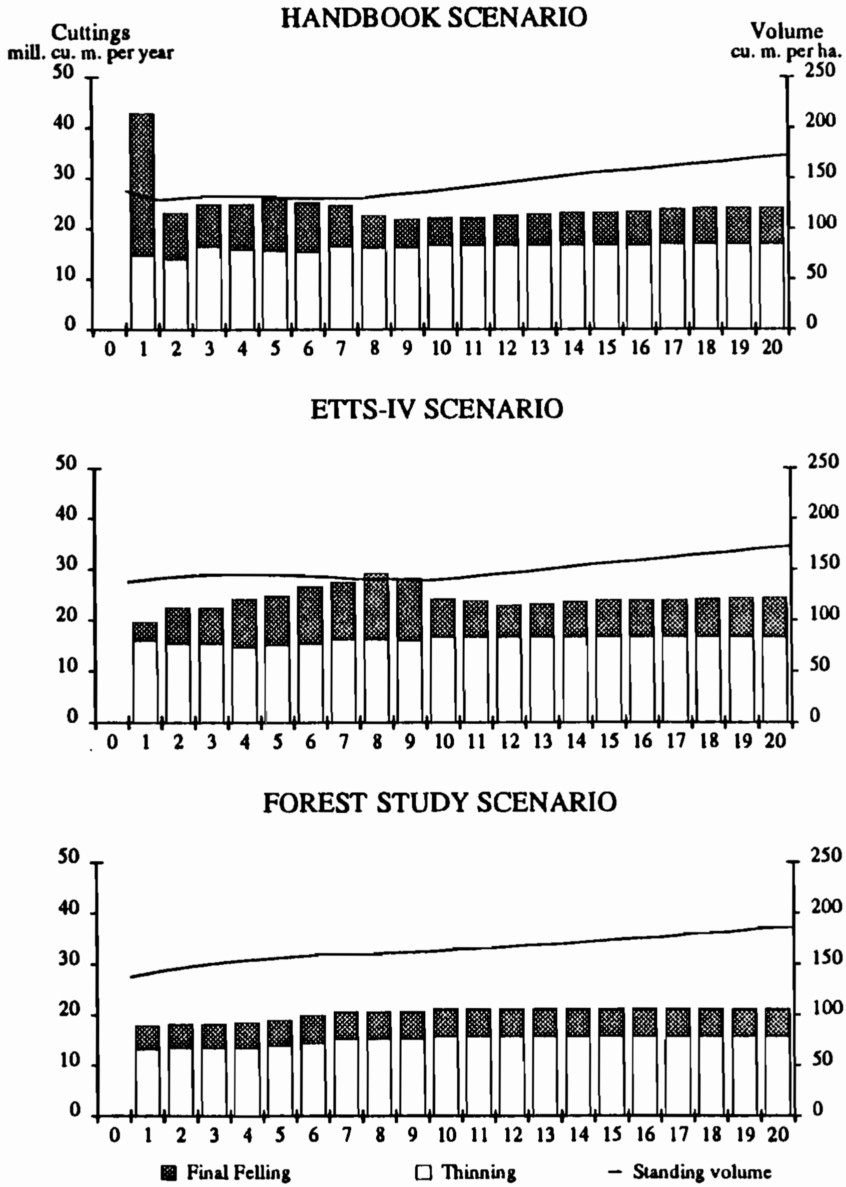


Figure B.173. Projections for total potential harvest and growing stock in Yugoslavia under the decline scenarios. Fellings in the early 1980s according to ETTS-IV (UN, 1986), 20 million cubic meters o.b.

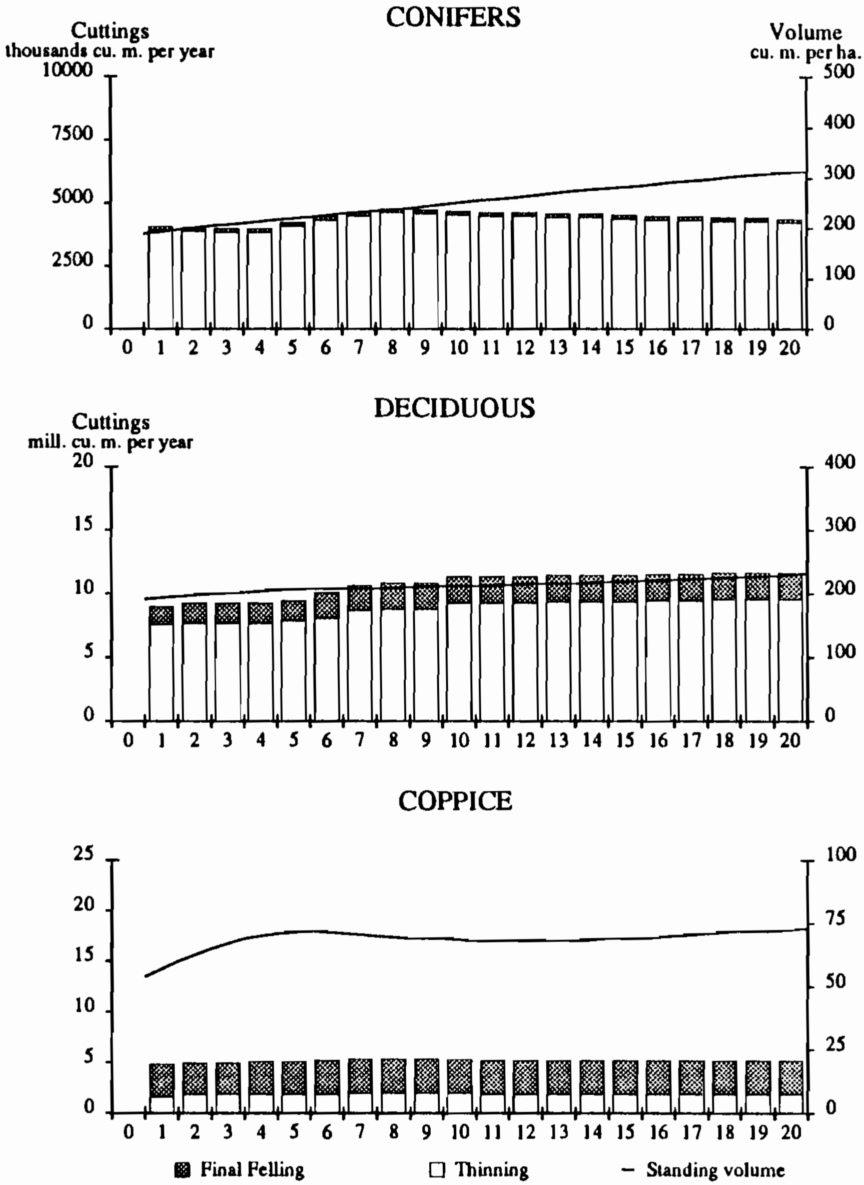


Figure B.174. Projections for total potential harvest and growing stock for coniferous, deciduous, and coppice species in Yugoslavia under the Forest Study Decline Scenario. Coniferous fellings in the early 1980s according to ETTS-IV (UN, 1986), 6 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 14 million cubic meters o.b.

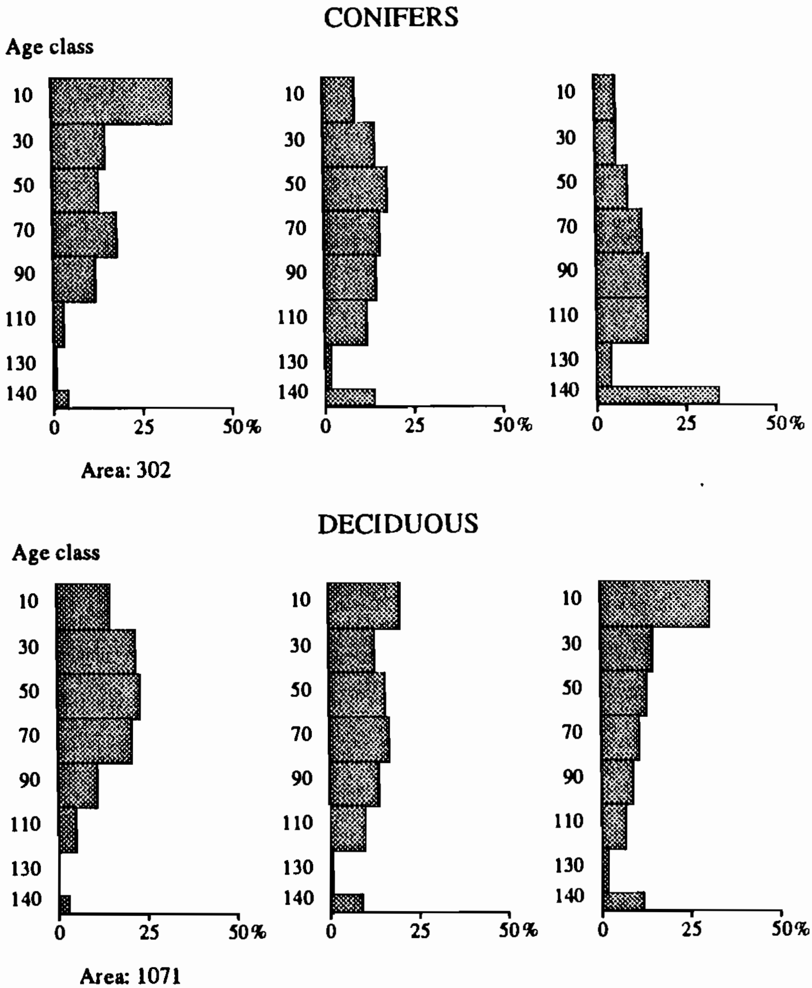


Figure B.175. Age-class distributions in Yugoslavia under the Forest Study Decline Scenario for year 0, 35, and 75, respectively.

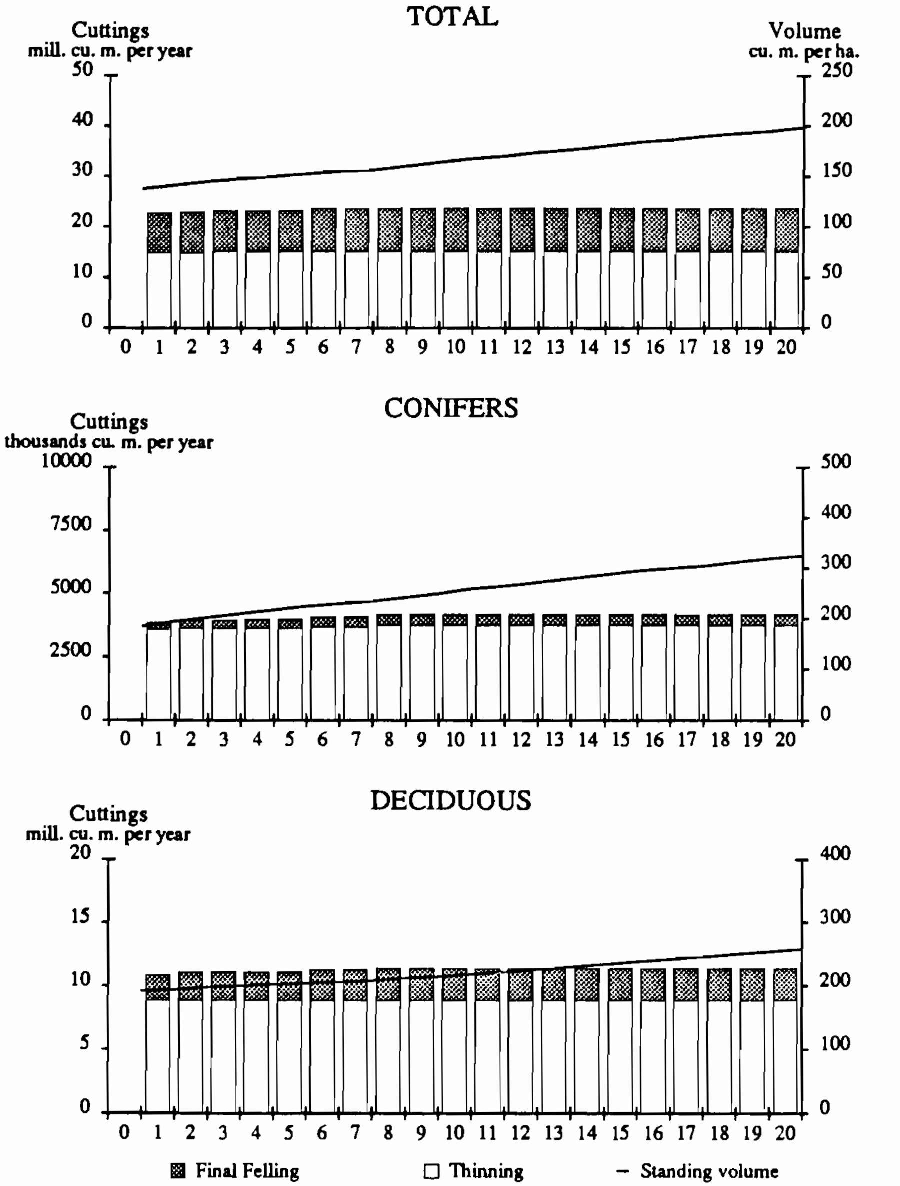


Figure B.176. Projections for total potential harvest and growing stock for total, coniferous, and deciduous species in Yugoslavia under the Forest Land Expansion Scenario. Total fellings in the early 1980s according to ETTS-IV (UN, 1986), 20 million cubic meters o.b.; coniferous fellings in the early 1980s according to ETTS-IV, 6 million cubic meters o.b.; deciduous fellings in the early 1980s according to ETTS-IV, 14 million cubic meters o.b.

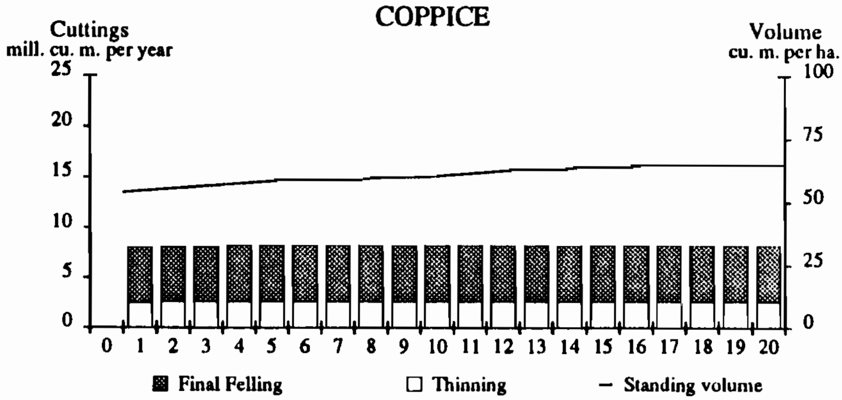


Figure B.177. Projections for potential harvest and growing stock of coppice in Yugoslavia under the Forest Land Expansion Scenario.

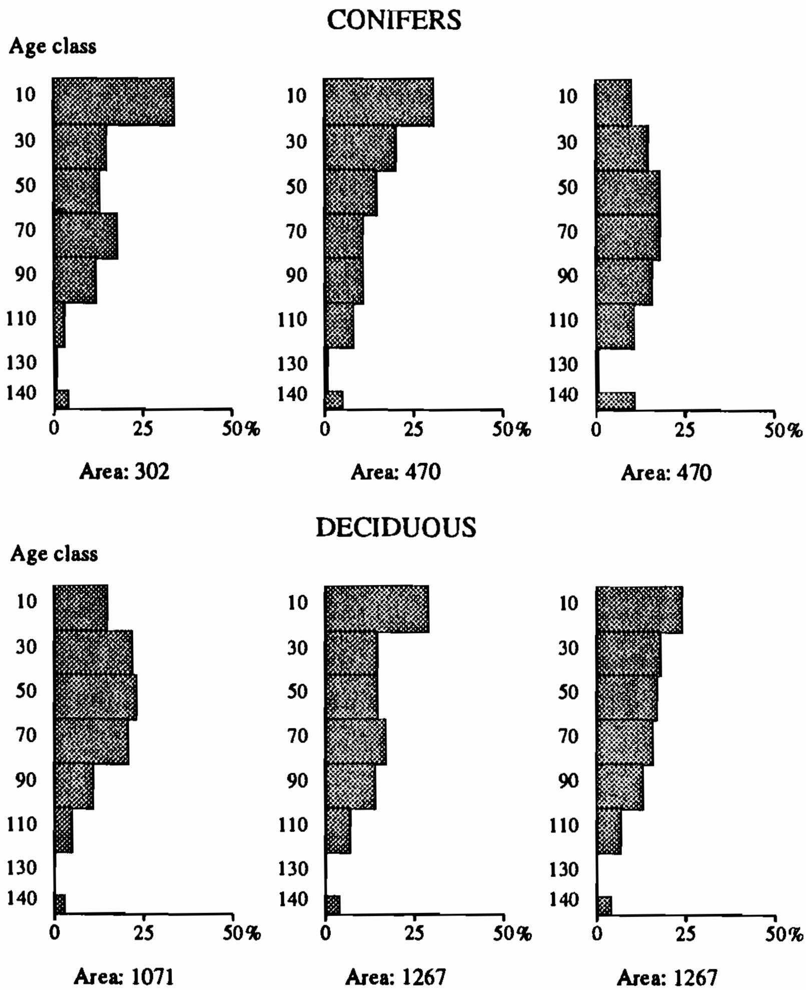


Figure B.178. Age-class distributions in Yugoslavia under the Forest Land Expansion Scenario for year 0, 35, and 75, respectively.