Forest Potentials and Policy Implications: A Summary of a Study of Eastern and Western European Forests by the International Institute for Applied Systems Analysis

Sten Nilsson, Ola Sallnäs, and Peter Duinker

EXECUTIVE REPORT 17
February 1991

Sten Nilsson
Biosphere Dynamics Project, International Institute for Applied Systems Analysis, and College of Forestry, Swedish University of Agricultural Sciences
Ola Sallnäs
College of Forestry, Swedish University of Agricultural Sciences
Peter Duinker
School of Forestry, Lakehead University, Thunder Bay, Ontario, Canada

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 LAXENBURG, AUSTRIA

International Standard Book Number 3-7045-0104-2

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Cover design by Martin Schobel

Printed by Novographic, Vienna, Austria

Foreword

National timber-assessment studies based on dynamic models are well developed in some European countries, but 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 the development of 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 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 European site studies. The IIASA forest study has had as one major objective 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 goals, regional actions to achieve national goals, and national actions to achieve 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 for Agricultural Sciences, where much of the work was done. We are also indebted to the approximately 120 collaborating organizations and individuals throughout Europe that assisted in the work.

In particular we are indebted to the Forest Study Advisory Committee, which provided advice, encouragement and support over the course of this study. The members of this committee are: Dr. Michael Apsey, Chairman, Council of Forest Industries of British Columbia, Vancouver, Canada; Prof. Gordon Baskerville, Faculty of Forestry, University of New Brunswick, Fredericton, Canada; Dr. Bela Berdar, President, Pilis Park Forest, Visegrad, Hungary; Dr. Albert Böckenförde, Manager, International Projects, Feldmühle, Düsseldorf, Germany; Dr. Radovan Chrast, Centre for the Environment, Bratislava, CSFR; Minister of Forests, Academician A.S. Isaev, Chairman, GOSKOMLES USSR State Forest Committee, Moscow, USSR; Prof. Riccardo Morandini, Director, Istituto Sperimentale per la Silvicultura, Arezzo, Italy; Mr. Tim Peck, Director, ECE/FAO Agriculture and Timber Division, Palais des Nations, Geneva, Switzerland; Prof. Lennart Schotte (Committee Chairman), President, The Royal Swedish Academy of Agriculture and Forestry, Stockholm, Sweden; Dr. Heinrich Schmutzenhofer, IUFRO Secretary, IUFRO, Vienna, Austria; Prof. A.Z. Shvidenko, All-Union Scientific Research Information Center for Forest Resources, USSR State Forest Committe, Moscow, USSR; Mr. Thomas Stemberger, Präsidentenkonferenz der Landwirtschaftskammern Österreichs, Vienna, Austria; Prof. Harald Thomasius, Technische Universität Dresden, Tharandt, Germany; Mr. Håkan Vestergren, Vice-president, STORA, Falun, Sweden.

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Summary and Conclusions

The IIASA Forest Study, begun in 1986 as part of IIASA's Biosphere Dynamics Project, addresses the question of the long-term development of forests in Western and Eastern Europe and the European USSR. This report deals with 25 countries in Western and Eastern Europe which are listed on page 4 of the report. (A similar report on forest in the European USSR is in preparation.) The major objectives of the study are to:

(1) Gain an objective view of potential future developments of the forest resources of Europe.

(2) Build a number of alternative and consistent scenarios about potential future developments and their effects on the forest sector, international trade, and society in general.

(3) Illustrate the effects of:

- (a) Forest decline caused by air pollutants;
- (b) Existing and changed silvicultural strategies; and
- (c) Expansion of the forest landbase.

(4) Identify meaningful policy options, including institutional, technological, and research/monitoring responses that should be pursued to deal with these effects.

The basic approach was to assemble detailed country-by-country databases in European forest resources, and link them to a matrix-type simulation model, which is described on pages vii and viii. The model generates scenarios of growing-stock and timber-harvest levels 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 included in the simulation model by taking into account depositions, critical loads for air pollutants (sensitivity to air pollutants) and resulting damage cycles and growth losses. Although the model is relatively simple, it is conservative in the sense that it understates the effects of air pollutants in two main respects: The decline effects are only based on sulfur and nitrogen emissions; and emissions are assumed to drop to zero after the year 2000, which is unlikely.

Major findings for forests in Western and Eastern Europe include:

- A comparison of the 100-year average harvests with actual numbers in 1987 shows that there is a potential to increase long-term sustainable harvests by about 110 million cubic meters per year, and that the Nordic countries and the original EEC-countries (EEC-9) have the most potential to strengthen their role as wood suppliers in the region. This calculation does not take into account any effects of air pollutants.
- This is unlikely to be achieved because of the loss of potential harvests caused by air pollutants expected to be emitted in Europe up to 2000–2005. Our estimate is that this loss will be about 16 percent of the total potential harvests under conditions of no air pollution effects, or about 85 million m^3/year averaged over 100 years.
- The regions most affected by forest decline attributed to air pollutants are the Eastern and the Central (Austria and Switzerland) Regions, followed by EEC-9.
- The anticipated expansion of forest land in Europe (assuming no pollution-induced decline) will generate an increase in the total timber harvest potential of some 25 million m^3/year, averaged over 100 years, with about 70 percent of this increase taking 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 m^3/year by 2010.
- If the decline caused by air pollutants is taken into account the deficit amounts to about 130 million m^3/year.
- Even complete elimination of air pollutant damage will not be enough to entirely eliminate stress on European forests; inappropriate implementation of good silvicultural practice has also contributed to the decline visible today. Hence improvements in implementing basic forest management are also required.
- The major conclusion of the study is that the problem of air pollutant damage to European forests is both serious and immediate. Its solution

will require a concerted and cooperative effort by all countries involved. While improved silviculture practices can mitigate the damage visible today, and should be implemented, this alone will not eliminate the serious threat to European forests.

Modeling Methodology

A matrix-type simulation model was built to generate various scenarios of the development of forest resources and potential wood supply in Europe under different assumptions about future forest decline rates and characteristics, silvicultural practices, and forest land expansion policies in Europe. Since there are different forest structures among the countries of Europe, we had to employ three different model concepts founded on different assumptions.

Area-Based Approach

In the area-based approach, specific forest types in our study are described by age and standing volume. The different forest types are characterized by country, region, owner, forest structure (high forest, coppice, etc.), and species. Site class was used as a additional separating variable when supporting data were available. The model is based on a structure developed by Sallnäs (1990).

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 mean volume per stem. Dynamics are introduced via transition of stems between the diameter classes. Forest types were characterized using the same criteria as in the area-based approach except that site class could not be used owing to insufficient data. A more detailed description of this approach is found in Houllier (1989).

Simplified Approach

Owing to problems of data quantity and quality, use of the two approaches described above was not possible for Greece, Turkey, and some parts of Yugoslavia. In these cases, potential harvests were estimated 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.

Modeling Forest Decline Attributed to Air Pollutants

To incorporate decline effects in our forest simulators, the description scheme or matrix of the forest was expanded by two variables: decline class, and sensitivity class. In addition, the transition rates were made changeable over time. Changed silvicultural regimes were also incorporated into the models, in terms of shorter rotations, increased intensity in thinnings and enlarged regeneration.

The RAINS model, used to generate deposition estimates in our calculations, is documented in the IIASA/Kluwer book *The RAINS Model of Acidification: Science and Strategies in Europe*, J. Alcamo, R. Shaw, and L. Hordijk, eds.

The RAINS model itself, with a comprehensive user's manual, can be obtained from IIASA. The model requires an IBM XT, AT, 386 or compatible machine with a core memory of 640 KB DOS and disk space of 4–8 MB, depending on the modules installed. A co-processor is highly recommended but not essential. The operating system is DOS3.X or above, and the graphic display requires an EGA, VGA, CGA, or Hercules card.

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Forest Potentials and Policy Implications: A Summary of a Study of Eastern and Western European Forests by the International Institute for Applied Systems Analysis

1. Background

Because the forests of Europe are so important in many different ways, forest decline attributed to air pollution has become 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 outwardly 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: upsets 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 (for example, due to increased incidence of insect outbreaks); loss of recreationally significant 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 (there are declining forests throughout the European continent), the scale of each instance of decline is local to regional. The forests themselves are different from region to region (because of ecological and silvicultural differences), making them differently susceptible to air pollution and other stressors. The spectrum of air pollutants differs from region to region. Forest declines can be found in all countries of Europe, but many forests do not display signs of decline while some others have been all but obliterated by air pollution. Strategies to combat undesirable impacts of forest decline must be fitted to the local or regional scales, but they also must be set firmly in an international context to take into account such matters as transboundary air pollution and trade in raw materials.

Most of those who recognize the gravity of the problem are calling for immediate mitigative actions. It is clear, however, 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. For example, reduced capital investments are likely to affect labor and employment. Thus there is a strong call for international and regional cooperation in any efforts to combat the expected consequences 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 (stand) scale. The systems whose future we are most concerned about here, however, are regional (for example, forest-management units administered by governments or companies), national (national economies), and international (European Economic Community). Those who are faced with solving 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 European forests over the past several centuries have given us the forests we have today. 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 would design and implement solutions to the problem of forest decline must face the difficulties of coordinating 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 fairly the myriad of competing interests, with various strengths, in equitable problem resolution.

2. The IIASA Forest Study

Within the IIASA 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 to:

(1) Gain an objective view of potential future developments of the forest resources of Europe.
(2) Build a number of alternative and consistent scenarios about potential future developments and their effects on the forest sector, international trade, and society in general.
(3) Illustrate the effects of:
   (a) Forest decline caused by air pollutants;
   (b) Existing and changed silvicultural strategies; and
   (c) Expansion of the forest landbase.
(4) 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 built to generate various scenarios of the development of forest resources and wood supply under different assumptions about silvicultural practices, air pollution, and forest-land expansion policies. A detailed country-by-country database on European forest resources has been assembled by the Forest Study to link with the simulation model. The model generates scenarios of growing-stock and timber-harvest volumes over time by country (and subregions of a country), species group, and age, making it possible to undertake a general timber-supply assessment.

3. Methods

Since there are different forest structures among the countries of Europe, we had to employ different model concepts founded on different assumptions. The two main forest-model concepts we used are: (1) the unit area and its characteristics and (2) the tree and its characteristics.

The countries are grouped as they are by the ECE (UN, 1986):

Nordic:	Finland, Norway, Sweden
EEC-9:	Belgium, Denmark, France, former Federal Republic of Germany,[1] Ireland, Italy, Luxembourg, Netherlands, United Kingdom
Central:	Austria, Switzerland
Southern:	Greece, Portugal, Spain, Turkey, Yugoslavia
Eastern:	Bulgaria, Czechoslovakia, former German Democratic Republic,[1] Hungary, Poland, Romania

3.1 Area-based approach

Using concepts of the unit area, specific forest types in the study are described by age and standing volume. A matrix defined by about ten intervals for the volume dimension and 6–15 intervals for the age dimension is created. The forest state is then depicted by an area distribution over this matrix. Dynamics in terms of volume increment are expressed as transitions of areas between specific fixed states in the matrix.

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

[1] We have been forced to report former Federal Republic of Germany and former German Democratic Republic individually. The reason is that all available information for validation of our results are based on the aggregation of countries as presented here.

in volume between the cells, after which 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 be regarded as expressing the intensity and quality of regeneration efforts.

In the area-based approach, the different forest types are characterized by country; region; owner; forest structure (for example, high forest, coppice); and species. Site class was used as an additional separating variable when supporting data were available. The model concept is presented in more detail by Sallnäs (1990).

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 mean volume per stem. Dynamics are introduced via transition of stems between the diameter classes. Forest types are characterized using the same criteria as in the area-based approach except that site class could not be used due to insufficient data. A more detailed description of this approach is found in Houllier (1989).

3.3 Simple approach

We tried to use these two basic model structures for all countries in Europe. Due to problems of data quantity and quality, this was not possible for Greece, Turkey, and some parts of Yugoslavia. In these cases, our 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.

4. Modeling Forest Decline Attributed to Air Pollutants

In generating model input data concerning forest decline attributed to air pollutants, we have tried to be as quantitative as possible. Our first task was to calculate the distribution of the forests of each country over several

Table 1. Target loads for sulfur and nitrogen deposition used in the forest-decline scenarios. Data are grams of substance per m^2 per year.

Substance	Conifers			Deciduous		
sensitivity	Low	Medium	High	Low	Medium	High
Sulphur[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 the Beijer Institute (Chadwick and Kuylenstierna, 1988) based on critical loads set by ECE (UN-ECE, 1988).
[b]Target loads for nitrogen are the same as critical loads set by ECE (UN-ECE, 1988).

sensitivity classes with respect to sulfur and nitrogen depositions. The sensitivity classes are based on capabilities of forest soils to buffer against acidification from deposition of sulfur and nitrogen compounds. Highly sensitive sites have low buffering capacity; low-sensitivity sites have high buffering capacity.

Specific *critical loads* and *target levels* of sulfur and nitrogen deposition have been assigned to the individual sensitivity classes. The difference between critical and target loads is defined this 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. Target loads are less restrictive with respect to deposition loads in that they incorporate consideration for other pollution-control factors, such as economic ones.

Critical loads for sulfur and nitrogen have been defined by the United Nations Economic Commission for Europe (UN-ECE, 1988). Target loads for sulfur have been proposed at levels somewhat higher than the ECE critical loads by the Beijer Institute Center for Resource Assessment and Management, University of York, United Kingdom. The target loads we have used for nitrogen are the same as critical loads set by ECE (1988). The following analyses are based on the target loads presented in *Table 1*.

By combining the Forest Study database 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 sulfur dioxide (SO_2) and nitrogen oxides (NO_x) as announced officially by individual governments (end of 1988). Basic calculations were carried out at the country level, and

Table 2. Exposure of European forests to significant amounts of air pollutants. Data for sulphur and nitrogen are percentages of the total forest area where target loads for the pollutants are exceeded. Data for ozone are based on diurnal concentration distributions April–September 1986.

Pollutant/ Forest type/ Period	Region Nordic	EEC-9	Central	Southern	Eastern
Sulphur					
Coniferous					
1985	59	88	98	62	98
2000	48	76	93	84	98
Deciduous					
1985	19	34	50	18	84
2000	7	24	46	40	76
Nitrogen					
Coniferous					
1985–2000	75	83	100	34	76
Deciduous					
1985–2000	52	55	86	21	47
Ozone					
1985–2000	1–2×CL	1.5–2.0×CL	2.0–2.5×CL	n.a.	1.5–2.5×CL

n.a. = not available due to insufficient data.
CL = critical load.
Source: Nilsson and Posch, 1989.

the results (*Table 2*) used as input to our timber-assessment models. These results show that existing and planned pollution-abatement strategies will not be effective in reducing risk to forests from pollutants. In the year 2000, most of the European forests still will have depositions exceeding critical loads for SO_2, NO_x, NH_3, and ozone (O_3).

Researchers in Berlin have developed an elaborate tool called PEMU (Bellman *et al.*, 1988) for analysis of cause-effect relations between air pollution and forest-stand condition. Input data to the PEMU-system are based on field observations made since the early 1960s at a set of test sites along emission gradients. This analytical tool has been employed in estimating the decline effects on forests if depositions exceed target loads. Whereas the cause-effect relations for the PEMU-system have been properly quantified only for sulfur depositions with specific background depositions of nitrogen on pine stands, preliminary results from a new spruce-decline model indicate the same basic results as for pine.

Results from the PEMU-system are expressed in terms of damage cycle and growth losses. The expression *damage cycle* needs explanation. The international criterion for monitoring forest decline attributed to air pollutants is loss of foliage. Different degrees of foliage loss define different decline classes. The damage cycle describes 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 pine stands. Our results show clearly that the decline process is more rapid for more sensitive sites and with increasing depositions. In our sensitivity analyses, no significant differences could be identified for different forest site classes. Significant differences were identified, however, for different age classes and species groups.

Growth effects are linked to the loss of foliage. We have estimated a set of growth effects expressed in relation to undisturbed growth according to yield tables for different damage classes. Our results for middle-aged (50-year-old) conifer stands show that growth effects occur only when defoliation exceeds 25 percent. Sensitivity analyses show no significant differences among site classes, but strong relations between age classes and growth effects. A literature review found consensus that the growth decline started several years before the damage was visible in the form of foliage loss.

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 these silvicultural measures are intensified thinning, shortened rotation periods, and changed species composition. A number of different research organizations have been engaged by the Forest Study to formulate explicit silvicultural responses to the decline. The silvicultural responses documented by the organizations are based on decline patterns caused mainly by depositions of sulfur. The main responses identified include more intensive thinnings, shortened rotation periods, delayed regeneration, and changed species composition.

It should be emphasized that our approach is a rather serious simplification in that it does not consider all of the existing natural variations, but it is pragmatic. The information presented above is based only on specific conditions in Continental Europe. It does not take into account altitude, land exposure, and ecological conditions (other than used sensitivity classes).

To incorporate decline effects in our forest simulators, the description scheme or matrix of the forest was expanded by two variables: decline class and sensitivity class. In addition, the transition rates were made changeable over time. Changed silvicultural regimens also were incorporated into the models.

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

(1) We have calculated decline effects based mainly on sulfur and on nitrogen emissions and effects, without consideration for the effects of other pollutants.
(2) We assume no emissions of sulfur and nitrogen after the year 2000.

On the other hand, we have been able to implement analytically only those kinds of silvicultural and management interventions that are already structured into our modeling framework, that is, changed thinning regimes, rotations and delayed regeneration. 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 and explored. Considering our basic assumptions about air pollution, we feel that our results, on balance, are conservative.

5. Scenario Assumptions

We implemented seven scenarios in our analysis of potential wood-supply futures, using different assumptions about pollution-induced decline, silviculture, and forest-land area. The base year for the simulations is 1985. All of them have a time horizon of 100 years (up to year 2085).

5.1 Basic scenarios without forest decline

Three basic scenarios assume no forest decline:

Handbook Basic 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. Results show the degree to which forest policies incorporating ideal silviculture have been implemented.

ETTS-IV Basic Scenario. Total wood supply taken from the forests is set at the high estimates in the fourth European Timber Trend Study

(UN, 1986). We used this scenario to explore the forest-dynamics effects of implementing the harvest levels of ETTS-IV (official country estimates) up to year the 2020. The harvest level of 2020 is also used for the remainder of the simulation period up to the year 2085.

Forest-Study Basic Scenario. Consistently high levels of both growing stock and harvest levels are the objective over the total simulation period.

5.2 Decline scenarios

Three scenarios incorporating pollution-induced forest decline were designed to complement the basic scenarios. The same principles were followed as for the no-decline scenarios. These scenarios are called, respectively, the **Handbook Decline Scenario**, the **ETTS-IV Decline Scenario**, and the **Forest-Study Decline Scenario**. The models and the management programs were adjusted according to the decline assumptions discussed above.

5.3 Forest-land expansion scenario

These six scenarios do not account for any change of the forest land base in Europe over time. Because ETTS-IV projections do include forest-land expansions, we devised a seventh scenario, our **Forest Land Expansion Scenario**, to take into account land expansion up to year 2020. This scenario is based on the Forest Study Basic Scenario, incorporating no effects of forest decline.

It is important to recognize that we are projecting potential biological wood supplies in the scenarios and not the market supply. In reality, there are factors that can restrict actual harvests, such as roundwood prices, behavior of forest owners, and restrictions for non-wood benefits. These factors have not been considered.

6. Results of Analyses of Wood-Supply Potentials

As expected intuitively, our results show that the "handbook" scenarios potentially give the highest total harvest (*Table 3*). In most regions, there are no problems in reaching the harvest levels suggested by ETTS-IV. The decline effects are strong in the Eastern, Central and EEC-9 Regions. By comparing the 100-year average harvests from the Forest Study Basic Scenario with actual removals in 1987, it can be seen that there is a potential to increase long-term sustainable harvests by about 110 million cubic meters per year (m^3/yr).

In all our scenarios, growing stocks increase strongly in most regions over time (*Table 4*). This indicates that the potential harvest levels presented in *Table 3* are rather conservative and cautious and understate likely potential actual harvests.

A special comment should be made about the Handbook Basic Scenario. When results for it are aggregated for all of Europe and all species (*Figure 1*), we find a strong harvest pulse during the first five-year period of the simulation. This indicates that there is an imbalance between existing forest structures and those that would exist under ideal silviculture. Thus there is a strong need for improved or more-intensive forest management throughout Europe in reaching ideal forest policies. We emphasize that the results of the Handbook Basic Scenario are not practically attainable, but are illustrative of the urgency for stricter implementation of declared policies that espouse ideal silviculture.

Timber-assessment results from the Forest Study Basic Scenario suggest that the Nordic and EEC-9 Regions have the most potential to strengthen their role as wood suppliers, followed closely by the Eastern Region. As shown in *Table 5*, under basic conditions, the highest growth rates are expected in the Regions EEC-9, Central, and Eastern.

A special comparison between prognoses in ETTS-IV (UN, 1986) and the Forest-Land Expansion Scenario was carried out. We used our Forest-Land Expansion Scenario in this comparison because ETTS-IV includes expansion of the forest land base. (Note that the total forest-land expansions in our scenario amount to only about 75 percent of the expansions in the upper estimates of ETTS-IV.) We also used the upper estimates 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 also above actual 1987 fellings. Around year 2020, however, the Forest Land Expansion Scenario shows harvest levels very close to those of ETTS-IV.

The unexpected concordance between potential harvests projected in the Forest Land Expansion Scenario and the actual harvests projected in ETTS-IV can be explained by growing-stock developments. From the early 1980s to year 2020, growing stock for all Europe increases slightly – by 7 cubic meters per hectare (m^3/ha) – in ETTS-IV while the corresponding figure in the Forest Land Expansion Scenario is 27 m^3/ha. Thus, while the harvest

Table 3. Aggregated results for the seven scenarios concerning potential harvest.

	Basic handbook	Basic ETTS-IV	Basic forest study	Decline handbook	Decline ETTS-IV	Decline forest study	Expansion of forest land and no decline	Removals in 1987 according to FAO[4]
Average for the simulations under 100 years								
Potential harvest in million m^3 o.b./year for all species								
Nordic[1]	153.4	150.8	155.3	155.2	149.9	144.2	158.3	120.7
EEC-9	159.3	129.5	150.1	146.4	122.7	126.2	169.1	109.3
Central	26.6	25.8	24.8	25.4	25.8	18.9	25.2	22.3
Southern[2]	–	–	78.4			71.0[3]	83.6	72.1
Eastern	130.7	108.4	126.0	123.2	104.6	91.7	127.4	99.5
Europe	–	–	534.5			452.1	563.7	423.9

Table 4. Aggregated results for the seven scenarios concerning the development of growing stock.

	Basic handbook	Basic ETTS-IV	Basic forest study	Decline handbook	Decline ETTS-IV	Decline forest study	Expansion of forest land and no decline
Average for the simulations under 100 years							
Potential harvest in million m^3 o.b./year for all species							
Nordic[1]	93–154	93–147	93–147	93–125	93–124	93–139	93–141
EEC-9	152–184	152–222	152–185	152–161	152–170	152–190	152–182
Central	298–342	298–315	298–350	298–215	298–179	298–369	298–345
Southern[2]	–	–	82–127			82–124[3]	82–119
Eastern	169–202	169–239	169–206	169–148	169–147	169–200	169–206
Average Europe	–	–	122–166			122–164	122–164

[1]The same division as presented in *Table 2*. [2]It was not possible to calculate Basic Handbook and Basic ETTS-IV scenarios for the Southern region and corresponding for total Europe due to a lack of good data. [3]Decline effects for Spain are not included due to existing data. [4]Total removals.

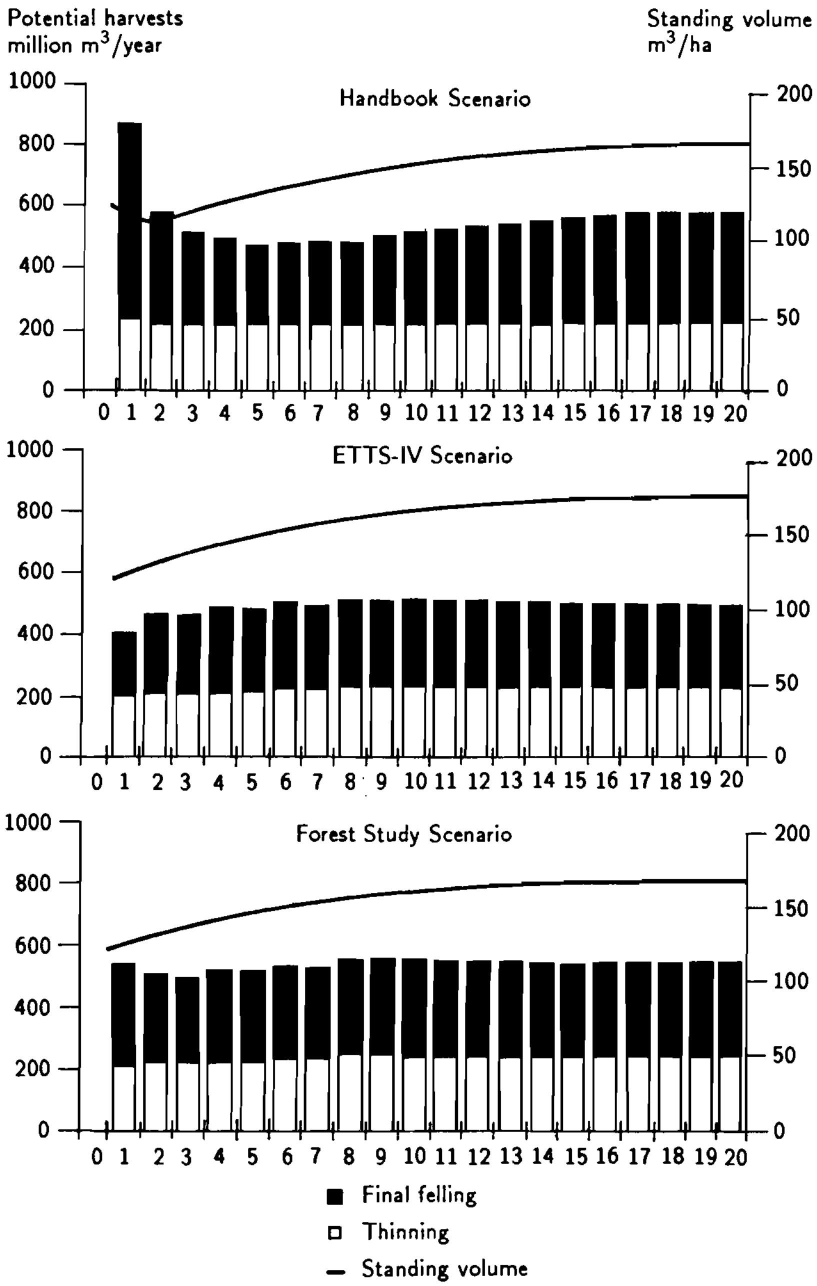

Figure 1. Projections for total potential harvest and growing stock in Europe under the basic scenarios.

Table 5. Increment rates projected under the Forest-Study scenarios. Data are annual increments in m^3/ha averaged over 100 years. Percentages of Basic-Scenario increments are in brackets.

	Forest-Study Scenario		
Region	Basic	Decline	Forest-land expansion
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	2.9	2.6 (90)	2.8 (97)
Eastern	5.1	3.8 (75)	5.0 (98)
Europe	4.2	3.6 (85)	4.2 (100)

levels of the two studies are quite similar around 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 m^3/yr. The total average harvest per year for the studied period would have been 593 million m^3 in comparison with 497 million m^3 for ETTS-IV.

Although the Forest Study objective is to assess potential harvest levels, the results presented in *Table 6* imply that our simulations are rather cautious. The inventory and growing stock of the forests are consolidated and harvest patterns are not extreme. This is in line with behavior in the European forest sector during the last few decades. We might also interpret these results as suggesting that harvest levels illustrated in the Forest Study scenarios could be pursued even in the presence of restrictions and increased demands on non-wood benefits from the European forests.

Figure 2 provides another indication that the Forest-Study Basic Scenario and the Forest-Land Expansion Scenario are rather cautious is that earlier estimates of future fellings have been revised upwards on several occasions in recent decades (UN, 1986). We note that the Forest-Study Basic Scenario yields results close to the high-assumption harvest levels of ETTS-IV. We also note that the 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 used the ETTS-IV regionalization of Europe so that our results could be directly compared with those of ETTS-IV. This regionalization includes

Table 6. A comparison between the results from the Forest Study and the ETTS-IV. Expressed in million m^3. FS = Forest Study. Fell. = Fellings.

	Nordic	EEC-9	Central	Southern	Eastern	Europe
Fell. ETTS-IV Base Period	123.8	98.2	20.0	66.7	93.1	401.8
Removals, FAO, 1987	120.7	109.3	22.3	72.0	99.5	423.8
Fell. FS, 1985	130.3	133.2	23.2	70.2	116.2	473.1
Fell. ETTS-IV, 2020	167.6	149.0	26.1	113.4	113.1	569.2
Fell. FS, 2020	162.7	174.1	25.5	82.6	131.6	576.8
Av. annual fell. ETTS-IV for the period 1980–2020	147.7	148.3	24.2	75.9	124.1	520
Increase of growing stock between 1980–2020 ETTS-IV, (m^3/ha)	8	11	13	8	23	7
Add. potential harvests mill. m^3/year in comparison with the Forest Study scenario	32	8	1	27	7	73

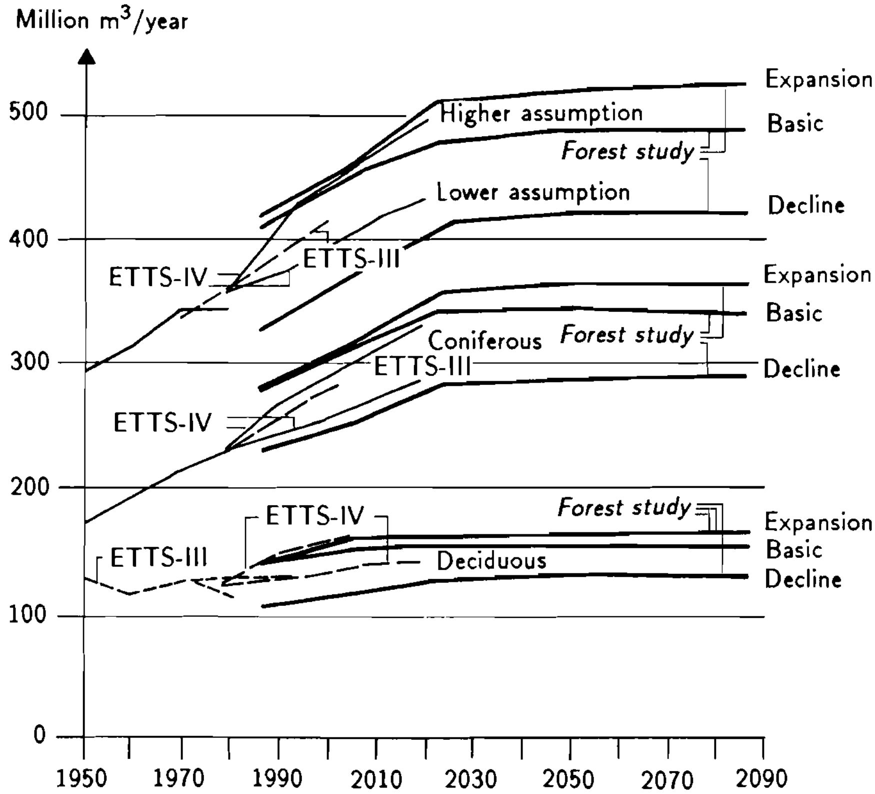

Figure 2. Comparison of results from ETTS-III, ETTS-IV and the Forest Study. Expressed in million m^3/year.

the EEC-9 grouping, which formally was expanded recently to twelve countries with the additions of Spain, Portugal, and Greece. Results from country aggregations for EEC-12 show that potential biological wood supplies projected by the Forest Study Basic Scenario are about 20 million m^3/yr higher up to year 2020 than the high ETTS-IV estimates.

The regions most affected by forest decline attributed to air pollutants are the Eastern and Central Regions, followed by EEC-9 (*Table 7*). The loss of potential harvest caused by air pollutants expected to be emitted in Europe up to 2000–2005 is estimated to be about 16 percent of the total under conditions of no air pollution effects. This is a loss of about 85 million m^3/yr averaged over 100 years. If we calculate expected decline effects as a proportion of actual 1987 harvests, the decline effects are even higher.

Table 7. Potential harvest losses caused by air pollutants. Data are percentages. Scenario data used to calculate the percentages are 100-year averages. "Basic" is from the Forest-Study Basic Scenario, "Decline" is from the Forest-Study Decline Scenario, and 1987 are actual removals from FAO statistics.

Region	$\frac{\text{(Basic - Decline)}}{\text{Basic}} \times 100$	$\frac{\text{(Basic - Decline)}}{1987} \times 100$
Nordic	7	9
EEC	16	22
Central	23	26
Southern[a]	13	14
Eastern	27	34
Europe	16	20

[a]No decline effects have been calculated for Spain.

The anticipated expansion of forest land in Europe (assuming no pollution-induced decline) will generate a strong increase in the total timber-harvest potential in Europe of some 25 million m^3/yr, averaged over 100 years, in comparison with harvest potentials projected using a constant forest land base and no decline. Since about 70 percent of the increase will take place in Region EEC-9, this region has the possibility of becoming a leading wood supplier in Europe. If this scenario begins to unfold, structural changes in the European forest-products industry will occur.

6.1 Demand/supply balances for industrial roundwood

Based on 1987 actual harvest data and 1985 demand data (both derived from Food and Agriculture Organization sources), it appears that Europe was in a surplus supply/demand situation in the late 1980s (*Table 8*). The surplus of wood supply over demand amounted to some 55 million m^3/yr. The picture changes significantly for the years 2000 and 2010. Even in the case of no future decline in European forests, the continent may face an annual roundwood deficit of some 40 million m^3 by 2010. If we account for decline as we have in our Forest-Study Decline Scenario, that deficit amounts to about 130 million m^3/yr. Increased wood-harvest potentials through expansions of forest land can only provide about 8 million m^3 to mitigate these annual deficits in 2010.

The region with the most serious potential deficits is EEC-9, largely because roundwood demand is expected to grow so strongly in this region.

Table 8. Outlook for regional wood demand/supply balances in Europe. Data are expressed in millions of m^3 roundwood equivalents.

Region	Balances at year		
Variable	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

Table 8. Continued.

Region	Balances at year		
Variable	mid-1980s	2000	2010
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 Forest-Study Basic 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.

The strongest effects of pollution-induced forest decline in making potential deficits worse are in the EEC-9, Eastern, and Southern Regions.

6.2 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 wood supply, potential wood supply, and industrial wood-processing capacities. On the one hand, overcapacity in the industry should be avoided because it indicates inefficiencies of industrial investments. When roundwood imports are not available, significant overcapacities cannot be kept active for very long, and mill closures would disrupt local economies. On the other hand, undercapacity signifies either that roundwood is being exported, thus contributing little in terms of high-value-added domestic manufacturing and the attendant economic benefits, or that potential biological harvests are not being realized because of inadequate domestic roundwood markets.

Most countries welcome the economic benefits that come from vigorous industrial, manufacturing, and commercial activity. They probably would encourage expansion of the forest-products industry if markets for consumer products were expected to be buoyant and if depressed roundwood markets were the major constraint against realizing wood-harvest potentials. Major factors to be considered 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.
- Outlook for availability of other inputs, such as capital, labor, and energy at reasonable costs.
- 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 not suffer from serious imbalances between actual wood supply and processing capacity.

We have examined the current and potential balances/imbalances between wood supply and industrial capacity in the regions of Europe (*Table 9*). 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 lack of processing facilities may not be a strong constraint (or in some places no constraint at all) on increasing wood harvests toward the higher potential levels our simulations indicate to be possible. Unfavorable profit margins due to low roundwood prices (for example, because of the EEC "Inner Market" due in 1992) and forest-owner attitudes favoring the non-wood forest benefits may be more important factors in keeping actual roundwood harvests below biological potentials.

Industrial undercapacity does become a constraint, however, to full achievement of the biological wood-supply potentials we have calculated in our simulation analyses. If it becomes possible to remove other constraints against realizing biological harvest potentials, our simulation assuming no forest decline suggests that all regions except Central will face industrial undercapacities. These undercapacities would be strongest in the EEC-9 and Eastern Regions. If forest land expansions are implemented to the extent we have assumed in our 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.

As shown in *Table 9*, at the end of the 1980s most countries had industrial overcapacities compared with actual levels of timber harvests. Exceptions include Denmark, Ireland, and the UK. Under the Forest-Study Basic Scenario, this general situation would change and most countries would be short of industrial capacity compared with the potential wood supply. This situation would be most severe in Norway, Denmark, Federal Republic of Germany (excluding the former German Democratic Republic), Ireland, Italy, UK, Bulgaria, Romania, Switzerland, Turkey, and Yugoslavia. With the Forest-Study Basic 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, Federal Republic of Germany (excluding the former German Democratic Republic), Ireland, Italy, and UK. A comparison of current capacities with potential wood supplies under forest-decline conditions, however, 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 our Forest-Study Decline Scenario. Again, the comparison assumes that all other constraints against achievement of biological harvest potentials can be lifted. If they can, forest decline has different effects on adjustments to industrial capacity that are required in each region to be able to process the wood supply. 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 all 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 results from our inability to account for effects of forest decline in Spain, due to insufficient data.

Table 9. 1987–88 industrial capacities and comparisons with 1987 actual harvests and potential harvests under the Forest-Study scenarios. Data for the scenarios are 100-year averages. Expressed in roundwood equivalents.

			Forest-Study Scenarios		
Country/ Region	1987–88 Industrial Capacity (IC) (mill. m^3)	1987 Removals (mill. m^3) (% of IC)	Basic (mill. m^3) (% of IC)	Decline (mill. m^3) (% of IC)	Forest-land expansion (mill. m^3) (% of IC)
Finland	55.5	47.5	59.1	54.6	59.1
		86	106	98	106
Norway	15.3	11.8	20.6	19.8	20.6
		77	135	129	135
Sweden	77.0	61.4	75.6	69.8	78.6
		79	98	91	102
NORDIC	147.8	120.7	155.3	144.2	158.3
		82	105	98	107
Belg & Lux	6.8	3.9	4.0	3.3	4.7
		57	59	49	69
Denmark	1.8	2.4	3.3	2.9	4.7
		133	183	161	261
France	49.0	47.4	56.7	53.2	61.8
		97	116	109	126
FRG	38.2	37.1	49.4	37.5	52.3
		97	129	98	137
Ireland	1.3	1.5	1.9	1.7	4.7
		115	146	131	362
Italy	16.3	9.6	20.3	17.2	22.2
		59	125	106	136
Netherlands	1.6	1.4	0.9	0.7	1.1
		88	56	44	69
UK	5.8	5.9	13.4	9.7	17.6
		102	231	167	303
EEC-9	120.8	109.3	150.1	126.2	169.1
		90	124	104	140
Austria	24.7	16.9	17.1	13.7	17.6
		68	69	55	71
Switzerland	5.7	5.4	7.5	5.1	7.7
		95	132	89	135
CENTRAL	30.4	22.3	24.7	18.9	25.2
		73	81	62	83

Table 9. Continued.

Country/ Region	1987–88 Industrial Capacity (IC) (mill. m³)	1987 Removals (mill. m³) (% of IC)	Forest-Study Scenarios: Basic (mill. m³) (% of IC)	Decline (mill. m³) (% of IC)	Forest-land expansion (mill. m³) (% of IC)
Greece	4.6	3.4	2.8	2.7	2.8
		74	61	59	61
Portugal	12.6	11.5	7.4	5.9	10.3
		91	59	47	82
Spain	25.4	21.9	17.8	17.8	20.0
		86	70	70	79
Turkey	20.1	17.8	27.0	24.2	27.0
		89	134	120	134
Yugoslavia	19.2	17.4	23.2	20.4	23.6
		91	121	106	123
SOUTHERN	81.9	72.1	78.2	71.0	83.6
		88	95	87	102
Bulgaria	6.0	5.1	8.6	6.4	9.2
		85	143	107	153
CSSR	21.1	20.7	23.7	14.2	23.7
		98	112	67	112
GDR	13.9	12.5	14.6	9.7	14.6
		90	105	70	105
Hungary	7.7	7.1	8.5	5.5	9.5
		92	110	71	123
Poland	30.7	27.3	30.5	19.4	30.9
		89	99	63	102
Romania	29.8	26.9	40.2	36.4	40.2
		90	135	122	135
EASTERN	109.2	99.6	126.1	91.6	128.1
		91	116	83	117
EUROPE	490.1	423.8	534.1	451.8	564.5
		87	109	92	115

6.3 Non-timber forest values

Due to serious paucities of appropriate data and functional relationships for building forecasting models, we have been unable to prepare Europe-wide 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 both 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 highlight two distinct sets of considerations with respect to non-wood forest values: the potential role of these values in restricting actual wood harvests from attaining biological potentials and the potential role of air pollutants in reducing these values.

6.4 Role in restricting potential wood harvests

Typical European forest-management practices that focus on timber production usually involve mono-specific, even-aged stands, mainly coniferous, that normally are not allowed to persist long into the mature phase before being clear-cut and regenerated. 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 over-mature 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 even mainly non-timber benefits. When forest stands are primarily for recreation and protection purposes, they see more appropriate silviculture as including mixed species and uneven ages, often with significant proportions of over-mature 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. Classical timber production, however, probably does not 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 land base under timber-oriented management.

We sense a strong wave in Europe at the present time toward multiple-use forests with reduced 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. Even if wood supplies remain stable or increase, prices may go up due to implementation of more environmentally sensitive silviculture.

Clearly, governments will try to achieve a reasonable balance among plentiful, healthy, attractive forests; a thriving forest-products sector contributing to national economic development; and 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 keep up stand vitality through judicious implementation of timber harvests but also to improve stand vitality and attractiveness through changed age-class structure and species composition.

Policies to enhance the viability of the forest-products sector may need to focus also on forest-land expansions and on public-education programs outlining the importance of timber harvests 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. We can anticipate increased controversies over forest-land use and forest-management practices in Europe in the coming decade.

6.5 Air pollutants and non-timber forest values

We already have demonstrated the likely serious effects of continued pollution-induced forest decline on potential biological wood supplies. Forest decline will negatively affect all non-timber benefits as well. Forests in decline due to air pollution will be much less valuable than healthy forests for such common non-timber benefits as recreation, soil and water protection, wildlife habitat, microclimate amelioration, and carbon sequestration. What scant literature there is on effects of air pollution on non-timber forest values (e.g., Metz, 1988; Stoklasa and Duinker, 1988) suggests that the economic 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 point to two lines of policy development. These impacts lend additional weight to the call for much more vigorous schedules and programs for air-pollution control. In addition, they underline the importance of implementing changes in silviculture that will maximize forest-stand vitality and resistance to air-pollution stress.

7. Policy Implications of Continued Forest Decline in Europe

Air pollution is without question a key contributor to much of the forest decline witnessed in the 1980s in Europe. Therefore, policy-makers must focus strongly on air-pollution control if forest decline is to be reduced. Major pollutants that cause forest declines are sulfur dioxide, nitrogen oxides, ammonia, and ozone, but other pollutants, such as organic compounds, also are suspected of contributing significantly.

Sulfur dioxide is emitted into the European atmosphere mainly by coal- and oil-burning power plants and smelters. Nitrogen oxides enter 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 been rising steadily during this century except where specific recent initiatives are beginning to control sulfur dioxide. Even optimistic scenarios for future patterns of air-pollutant emissions in Europe, as indicated in *Table 10*, give little cause for optimism about the air-pollutant stress on forests indicated in *Table 2*. So-called "lag effects" of air pollutants on forest ecosystems may last for several decades, so that even if pollutant emissions are adequately controlled soon, forests will not respond fully to the clean atmosphere immediately. Results of our timber-assessment scenarios that include pollutant effects on potential wood supplies are rather conservative in that we assumed a clean atmosphere from the year 2005. Since this is an impossible scenario, real effects are likely to be larger than we have projected.

Scientific evidence linking atmospheric pollutant concentrations and depositions with forest decline is limited. 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 proclamations of specific air-pollution effects on forests across broad regions and over long periods of future time rather speculative. Such speculations are useful, however, to describe the dimensions and seriousness of the problem and to identify critical research needs.

If air pollutants are really having the effects on forests that we suspect, the whole of European society loses in a significant way. The forest-products industry loses wood quality and, over the long term, wood quantity

Table 10. Emissions of sulphur and nitrogen in Europe. Data were provided by the IIASA Project on Transboundary Air Pollution.

	Sulfur dioxide				Nitrogen dioxide			
		2000				2000		
Region	1980 kt	kt	% of Europe total	Change %	1980 kt	kt	% of Europe total	Change %
Nordic	1205	675	1.9	–44.0	751	526	3.4	-30.0
EEC-9	17048	10020	28.8	–41.2	10139	7916	51.2	-21.9
Central	481	170	0.5	-64.7	356	250	1.6	-30.0
Southern	6172	9873	28.3	+60.0	2018	2936	19.0	+45.5
Eastern	16332	14092	40.5	–13.7	3631	3841	24.8	+5.8
Europe	41238	34830	100.0	–15.5	16895	15469	100.0	-8.4

[a]Quantitative estimates are only available 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.

as well. Declining forest stands lose their ability to provide wildlife habitats, recreational opportunities, and water and soil protection. Clearly, all European peoples and visitors to the continent lose important values due to air-pollution effects on forests.

Based on our simulation work, we estimate that the sulfur and nitrogen emission scenarios shown in *Table 10* will cause the following losses in potential wood supply (in terms of million m^3/yr averaged over a 100-year future): Nordic, 11.0; EEC-9, 23.9; Central, 5.8; Southern, 10.2; and Eastern, 34.3. For all Europe (excluding the Soviet Union), lost potential wood supply due to air-pollution effects could average some 85 million m^3/yr.

7.1 Opportunities in air-pollution control

There are two major ways to mitigate the potential effects of air-pollutant emissions on forests: controlling pollution and raising the stress resistance of forests. Our results show that current policies for reducing emissions of sulfur and nitrogen oxides will make relatively small reductions in the areas of forest at risk from these pollutants. Indeed, pollution-control policies for sulfur in the Southern Region will likely increase forest areas at risk.

Blanket application of fixed-proportion reductions of air-pollutant emissions across Europe clearly ignores certain facts: Some forest ecosystems are more sensitive than others; countries are emitting very different amounts, whether absolute or standardized to *per capita*, per unit land area, or per unit GNP; and pollutants usually are not deposited in the locale of their emission. Under the ECE Convention on Long-Range Transboundary Air Pollution, policies should be devised for pollution controls strongly 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 policies for air-pollution control. Because of the international nature of the problem, however, international organizations such as the European Community and the ECE have a responsibility to bring national governments together to undertake international impact assessments and develop strong pollution-control policies acceptable to all parties.

Despite potential problems in implementing new pollution controls in old industrial plants, the technology for pollution control, especially for sulfur, is known and available. The key resource required to install and operate pollution controls is money. A key constraint, of course, is the availability of funds in the countries where most controls ought to be installed. Significant difficulties can be expected in international negotiations, first in determining which countries ought to take the blame for pollutant depositions exceeding critical loads, and second in determining who should shoulder the financial burden of controlling that pollution.

7.2 Opportunities in silviculture

Silvicultural practices in European forests have largely deviated from the declared policies of most countries. Three basic silvicultural elements are critical in determining the level of vitality of forest stands:

- Timing and intensity of thinnings, controlling the density of trees in forest stands.
- Age at final felling, controlling the degree to which stands become overmature.
- Matching regenerated species with site potentials, which could enhance the vigor with which certain species can grow on specific kinds of sites.

In the Forest Study, we concentrated our analytical efforts on thinnings and final fellings as tools to reduce the risk to forest stands from air-pollution stress. Because these tools together account for all timber extraction, changes in their implementation automatically imply changes in harvest levels.

Like all biota, trees can exhibit signs of stress or decline when they are in strong competition with other trees for basic resources of light, nutrients, and water, and when they are physiologically old. Thinning forest stands can control tree density so that inter-tree competition does not induce tree decline, and final stand felling (or final tree felling in the case of uneven ages) 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 ages to prevent old-age decline are not being implemented in many European forests.

Intermediate indicators in the cause-effect path from silvicultural practices to forest-stand condition are stand density and age. Impact indicators, as in the case of pollution-induced decline, include canopy defoliation and discoloration, and stand increment and volume.

We have used the indicator of annual forest harvest volume to discover to what degree "handbook" silviculture 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. Our analysis was implemented as follows: Any simulation of the future development of forest resources begins with a description of their current condition. The current condition of forest resources has evolved, of course, under particular implementations of silviculture. In the simulation, if one attempts to implement handbook silviculture immediately on a forest where actual silvicultural practice has not followed the handbook, harvest levels will change immediately. For example, if actual deviations from handbook silviculture include inadequate frequencies and intensities of thinnings and excessively long rotation periods, implementation of handbook silviculture in a simulation will cause an immediate rise in harvest level. The results of these analyses are summarized below.

Appropriate silvicultural practices have been researched and developed intensively in Europe for more than a century. For a variety of reasons, however, handbook silviculture has not been faithfully implemented in most countries. Kuusela's (1988) observations along these lines confirm our analyses, which showed that all European regions except the Southern displayed very large immediate harvest pulses when we implemented handbook silviculture in our simulations. This kind of analysis was not possible for the Southern Region, due to the poor quality of the basic forest-inventory data. We conclude that the problem of silviculturally induced stress in European forests is a widespread and serious problem. Kuusela (1988) foresaw little change in implementation of actual silvicultural practices throughout Europe, suggesting that silviculturally induced stress will not be reduced in the next decades.

Because so many European forests now have age-class structures and growing stocks that have evolved under decades of less-than-ideal silviculture, it would be 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. The objective should be as rapid a full implementation as possible within the bounds of acceptable increases in wood harvest.

All members of the forest sector group have a role to play in bringing about higher resilience of European forests to stress through application of appropriate silviculture.

- Research institutions have the responsibility of reaffirming what the good practices are and adjusting them as required, considering the relatively new stress of air pollution.
- Landowners, including private interests and governments, have the responsibility of becoming aware of the consequences of not implementing resilience-building silvicultural practices and of finding means to implement these practices.
- The forest-products industry has the responsibility of being receptive to the increased wood supply that would result from strong implementation of proper silviculture.
- Governments have the responsibility of assisting industry in expanding to absorb the increased wood supplies.

Our analyses show these roles should not be temporary if countries wish to increase long-term production of forest products.

A strong move to full implementation of handbook silviculture in European countries would require increased 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.

- Governments that have policies calling for good silvicultural practice to be followed must begin to implement those policies; this may even mean legislation governing silvicultural practices.

- The public and private landowners need to learn that old and dense forest stands, while attractive for recreation, have low resistance to air-pollution stress, and that judicious cutting is the most powerful tool to restore stress resistance.
- The shortage of skilled labor for forest work needs to be overcome with training, image improvement, and higher wages.
- 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.

7.3 Opportunities in expanding forest lands

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 such international organizations as the European Community about redirecting agricultural subsidization from food production to tree production. European planners are discussing vigorous programs for converting land from food crops to forest stands. Considering also the increased attention recently to reforestation of degraded and unused land, there is a strong potential for increases in the amount of forest land in Europe.

It is not 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, 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. To get an idea of the biological potential of forest-land expansion programs to 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 only being able to capture the potential biological wood supplies.

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

With strong help from our network of collaborators throughout Europe, we have generated estimates of forest-land expansion possibilities to the year 2020, for which the primary management goal is expected to be timber

Table 11. Scenario for forest-land expansions in Europe, and potential contribution to long-term wood supply.

	Land-expansion scenario		Total potential harvest levels in year 2020		
Region	Annual increase, 1985–2020 ('000 ha)	Total forest landbase expansion (% increase)	Forest Study Basic Scenario[a] (mill m^3)	Forest-Land Expansion Scenario[a] (mill m^3)	Harvest increase (%)
Nordic	14	1.1	158.3	162.7	2.8
EEC-9	151	18.1	157.1	174.1	10.8
Central	19	17.0	25.1	25.5	1.6
Southern	103	10.9	77.5	82.6	6.6
Eastern	37	5.1	129.9	131.9	1.5
Europe	324	8.1	547.9	576.8	5.3

[a]Neither the Forest-Study Basic Scenario nor the Forest-Land Expansion Scenario incorporate any account of forest decline.

supply (*Table 11*). As a total for all Europe, our expansion estimates are roughly 75 percent of those upper estimates contained in the prognoses in ETTS-IV. According to our sources, forest-land expansions will be strong in the EEC-9 and Southern Regions and rather modest in the Nordic, Central, and Eastern Regions.

Results of our simulations suggest that, if the potential biological wood supply can actually be taken from the expanded forest-lands, total potential harvests increase marginally in the Nordic, Central, and Eastern Regions, rather modestly in the Southern Region, and strongly in the EEC-9 (*Table 11*). The increases occur even in the short term (by the year 2020). Although the newly established stands will not be available for harvest until some time later, their existence allows increased harvests to take place sooner in available stands.

Two important uncertainties bear on the results of our analyses of forest-land expansions. The first is simply whether the land-expansion scenarios we simulated will ever come to pass. We have found strong controversy within the European forest sector as to whether these proposed programs can be implemented. Many arguments suggest that the programs are much too optimistic. In the context of ETTS-IV, however, our estimates of forest-land expansions seem reasonable.

The second major uncertainty concerns the degree to which wood will be harvested at the rate we have assumed to be the biological potential under proper silvicultural practices. As noted earlier, landowners may want to retain growing stocks on the land expansions for their amenity values. In asking for advice from our collaborators in each country, we specifically asked them 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 expansions of forest land to wood supply in Europe.

European nations also may need to make sure that owners have sufficient incentives to apply proper silvicultural practices and to harvest and market their wood. Each country needs to examine the future course of domestic forest-products demand and capacities as well as 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, planting stock, and stand tending. In return, governments may wish to enter into long-term contracts with private landowners to secure wood harvests at some future time.

When forests are large enough that there is harvest activity within them each year, management expenses can be considered as costs to be charged against revenues from timber sales. Farm woodlots and other small forests receive rather infrequent harvests, however, 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 may need considerable subsidization before they will consider changing land use from food crops to tree crops. In reality, huge amount of money may be required to implement the land-conversion scenarios we used.

Several constraints have the potential to impede use of future expansions of the forest land base. 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. Amenity values of tree stands will become more and more important, and landowners (as well as the public in general) may become less and less inclined to treat new woodlots as sources of timber; they may see them rather as venues for recreation and ways of implementing land stewardship and slowing the build-up of carbon in the atmosphere. Even if landowners want to establish new timber-oriented woodlots, and governments want to encourage this, the funds required may be difficult to secure.

8. 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.

Basic Forest Inventory

A fundamental prerequisite of quantitative forest-policy analysis is a sound forest inventory. Such an inventory should not merely serve as a snapshot of current forest composition and structure, but also as 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 (Sweden, Poland, United Kingdom) are already taking excellent inventories as a basis for policy analyses. Others have yet to design and implement strong inventory programs (for example, Greece, Turkey).

Monitoring of Forest Condition

Fortunately, most countries in Europe are already conforming to the basic requirements of the 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, defoliation and foliage discoloration, suffer from two key problems:

- They are both subjective estimates, and thus susceptible to observer biases.
- They are not useful as early warning indicators of pollution-induced decline because they cannot identify the factors that affect them.

There is a need for development and implementation of more objective and discriminating variables for continent-wide monitoring programs for forest decline.

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.

Several laboratories in Europe already 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 to be drawn from in policy analyses is rich indeed and represents a wide range of pollutants, stand types and conditions, and hypotheses of effect. Perhaps a coordinated network or consortium of research institutions working on this theme ought to be established, with regular communications and an annual symposium.

Regional-Scale Scenario Analysis of Potential Wood Supplies

While it is a basic forest-management principle that long-term future forest performance is predicated strongly on near-term actions, our study further emphasizes the need to make quantitative, internally consistent, long-term projections of forest response to management and air pollution in order to discover what policies are reasonable to pursue now. It is not enough 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, 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. Our conclusion is that each country should be studying forest-sector futures with the aid of quantitative simulation tools for building alternative, possible 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 equivalent analyses for ozone and other pollutants.

Determination of Economic Wood Supply

An important caveat about the results of our analyses is that we have calculated potential biological wood supplies for all forests where industrial timber harvest is permitted. We have calculated what the forests *can* produce under conditions where what can be produced is actually harvested. Such analyses make the basic assumption that future potential harvests may be higher when one increases the current harvest, depending on current forest structure and current harvest rates. In other cases, of course, there may be current over-harvesting so that future potentials can only be raised if current harvest levels are reduced.

A host of factors interact to prevent actual harvest levels in each country or region from reaching biological harvest potentials, including, for example, 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 potential biological harvests should be supplemented with analyses incorporating realistic assumptions about harvest restrictions. More accurate projections of actual wood supply would be generated, under an assumption that restrictions on reaching the biological harvest potential cannot, should not, or will not be lifted. These projections certainly would be of interest. On the other hand, countries may be quite interested in discovering the relative importance of each kind of restriction, with an eye to developing policies to lift specific restrictions and capture a greater share of the biological harvest potential.

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 for use in analyzing basic forest-policy goals relating to maintenance or increases of these indicators. Because of an overwhelming lack of data and information, we have been unable to build quantitative scenarios of potential responses of non-wood forest benefits to continued pollution-induced forest decline. Moreover, we also have been unable to compare relative forest benefits for wood and non-wood values 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 at the present time be analyzed quantitatively and comprehensively for incisive national policy formulation. 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 most important work of gathering the data and undertaking the cause-effect research required to analyze future possibilities and the attendant actions needed to reach these objectives.

Climate Change

Our work has dealt with just 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 our work reported here, need to be undertaken soon. After the first stage of such analyses is complete, it will be important to look at simultaneous threats to European forests from both air pollutants and climatic changes. Analytical systems of the kind we have implemented here should be expanded for use in exploring potential effects of climate changes on European forests.

9. Conclusions

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

Immediate reductions of air pollutants in Europe are required. Even full success in controlling the major damaging air pollutants, however, 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 required, too. Thus, the European forest sector needs to implement silvicultural practices that help mitigate the damaging effects of air pollutants. Considering the pressures on many of the world's forests today, and anticipating such additional pressures as climate change, Europe has a responsibility to humanity to conserve her forests and keep them vital.

With respect to forest resources, Europeans are facing a complex policy dilemma:

- Pollutant emissions are unlikely to be controlled as rapidly and comprehensively as desirable.
- Several of the major polluting countries in Europe face very uncertain political and economic futures, at least over the near-to-medium term.
- A host of constraints will act to prevent easy improvement of the vitality of forest resources.
- Many policy people have a pessimistic outlook about the possibility of expanding the forest land base.
- Strong demands for both non-wood benefits and forest products can be expected over the coming decades.
- Lower prices can be foreseen for roundwood on international markets, due mainly to fewer trade barriers, and this development may result in lower incentives for European landowners to harvest roundwood, intensify management, and afforest land.

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

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