Working Paper

SILVICULTURAL REGIMES IN THE CAUSE AND EFFECT RELATIONSHIPS OF THE FOREST-DAMAGE SITUATION IN CENTRAL EUROPE

Kullervo Kuusela

April 1987

WP-37-31

PUBLICATION NUMBER 41 of the project:
Ecologically Sustainable Development of the Biosphere

International Institute for Applied Systems Analysis
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FOREWORD

IIASA's Project on Ecologically Sustainable Development of the Biosphere seeks to clarify the policy implications of 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 (a list of the Project's publications appears at the end of this document).

This paper, by Professor Kuusela of the Finnish Forest Research Institute, examines the relationship of silvicultural regimes to the current and future effects of airborne pollutants on European forests. Since silvicultural treatments represent one set within a broad array of interventions that might alleviate such effects, they must be explicitly taken into account in any realistic analysis of alternative scenarios of future forest decline and appropriate policy responses. This indeed is the aim of the Forest Sector Case Study within the Biosphere Project, with emphasis in the first phase of the study on issues of major relevance to industrial and government policy-makers in Europe. In addition to an analysis of future wood supply in Europe under different assumptions about the rate and extent of forest decline, the study will produce a number of papers, such as this one, to address various topics related to forest decline and the European forest sector in general.

R.E. Munn
Leader
Environment Program

PREFACE

As a Finnish correspondent and contributor in the last European Timber Trend study, I have had a chance to follow the rising role of the new forest damages in the discussion about European forest resources and their future. It has been impossible to avoid a strange feeling caused by the number of competing hypotheses and doomsday prophesies concerning the functioning of forest ecosystems under the effect of air-borne pollutants.

Vague intentions to put the problem of "forest damages" against the frame of current silvicultural regimes and traditional knowledge of stand ecology were spurred to action by discussions with Prof. Sten Nilsson in the spring of 1986. I sincerely expect that this paper, although somewhat unconventional, may highlight points of contact not sufficiently recognized so far between the health condition of forests and silvicultural regimes.

Kullervo Kuusela
Helsinki, December 1986

ABSTRACT

"New forest damages", often attributed to air-borne pollutants, are a complex, multi-cause process in which current silvicultural regimes have a decisive role. The treatment of stands has changed considerably in the time during which agrarian societies have developed into industrializing and post-industrialized welfare ones, and the commodity and timber production functions of the forest have changed to protective and social functions. On the side of forest management, economic success has become a secondary criterion next to protection and social values. As a consequence, tree stands have become denser and older. Under the glooming threat of pollution, the preservation principle, with an aim to preserve stands at full density and postpone the regeneration felling as far as possible, is becoming more and more popular. In over-dense and -mature stands, increasing numbers of trees lose their vitality and die under the stress of insects, diseases, and pollutants.

Forest managers cannot directly decrease the load of pollutants. But they can keep their forests young and give the trees enough growing space to be as resistant as possible to pollutants and other causes of death.

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SILVICULTURAL REGIMES IN THE CAUSE AND EFFECT RELATIONSHIPS OF THE FOREST-DAMAGE SITUATION IN CENTRAL EUROPE

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INTRODUCTION

Silvicultural regime refers to the combination of tree species, site quality, stand establishment, thinning, and rotation sub-regimes in growing timber and keeping up multi-functional forests. The current discussion about the so-called "new forest diseases and damages" in Central Europe is characterized by an *a priori* opinion that air-borne pollutants from industrial production and combustion-engine traffic (in the form of direct fumes, acid rain including sulphur and nitrogen, etc.) are the primary cause of these diseases. There are, however, many competing hypotheses of how acid-rain components affect forests and what is the true ecological explanation of forest damages.

Another *a priori* assumption seems to be that the silvicultural regimes applied have no damage-increasing effect in spite of the obvious fact that the regimes differ greatly from each other and also from the specified ones. In addition to this, the current tree-species composition, density and age structure of the Central European forests differ markedly from the earlier forest conditions. For example, many of the tree stands established by the re- and afforestation projects in the 19th century have reached their maturity. A great part of these coniferous stands grow outside the conditions where the coniferous species are biologically stronger than the deciduous broadleaved species. The age of the mature stands is in large areas much older than the original planned rotation, the stand density is very high, and so on. Consequently, an analysis of the current silvicultural regimes may give information valuable from the point of view of successful management in the situation of forest damages.

There are three principal types of tree stands in Central Europe which should be separated from each other:

(a) deciduous, broadleaved stands;
(b) short-rotation production plantations; and
(c) long-rotation coniferous stands.

The first two types comprise: the residual coppice forests; beech, oak and other broadleaved forests; and poplar, eucalyptus, pine, etc. (tree stands with a rotation of 10-20 years and no longer than about 40 years). Although there are "new forest damages" also in these stands, the problem essentially comprises the long-rotation coniferous forests, which are the subject matter of this paper.

FOREST DAMAGE ATTRIBUTED TO AIR-BORNE POLLUTANTS

A great number of papers and articles published in the 1980's present a huge amount of facts, fancies and competing (often contradictory) hypotheses of the phenomenon of "new forest damages". A review of them all here is not possible, and is unnecessary in this connection. A representative picture can be found in the latest European Timber Trend and Prospects study (United Nations, 1986; Vol. I, pp. 102-110).

Since the 19th century it has been known that air-borne pollutants, especially industrial fumes, damage vegetation. In the late 1970's and early 1980's, the "new forest damages" attributed to air-borne pollutants and acid rain became the number-one subject matter with respect to Central European forests. Newspapers and periodicals have been full of doomsday prophesies about dying forests.

In most national forest surveys, the shares of the trees in defoliation and damage classes are presented by areas of damaged forests (e.g., Table 1). However, such data are not directly comparable because of the different methods used in the surveys. Nevertheless, great variation in the extent of damage can be observed (Table 1). For example, the amount of damaged area as a percentage of the total exploitable-forest area is 54% in the Federal Republic of Germany (FRG), and 1% in France. Denmark and Britain have not reported any damages.

Table 1. Extent of forest damage attributed to air pollutants in selected European countries (source: United Nations, 1986; vol. I).

Country	Damage Class				Proportion of Total Exploitable Closed Forest
	Light	Moderate	Dying or Dead	Total	
	1000 ha				%
Ten Countries[1]	4203	1692	232	6127	16
FRG	2424	1163	111	3698	54
Austria	240	80	10	330	10
Switzerland	295	76	13	384	48
Czechoslovakia	514	123	53	691	17
Poland	419	199	36	654	8
France	86	11	3	100	1

[1]The countries include those listed in the table plus Belgium, Hungary, Luxembourg, and the Netherlands.

Even if the most sensational and demagogic prophesies about the dying forests are set aside, several aspects of the treatment and presentation of the damage data can be criticized.

Although the multiple causes of the damages are very well known, the observed defoliation is attributed almost exclusively to air-borne pollutants. The direct effect of fumes, and the forests damaged by them, are treated together with the phenomenon of acid rain over large areas. The fume damages are considered to give advance knowledge of the damages which will also happen sooner or later outside the proportionally limited areas damaged by the fumes. The forest area of the ten countries mentioned in Table 1 is 39 million ha. Hardly more than 100 000 ha, or 0.2%, is damaged directly by fumes.

The most criticizable aspect of such surveys is the method to extrapolate the single-tree observations to hectares of forest damaged. In every forest however healthy, there are always single trees or small groups of trees which are losing their vitality and dying. This is especially the case with dense stands and old stands. Thus, the current area estimates of the damaged forest are highly misleading.

Finally, according to an a priori assumption, there can be nothing in current silviculture and forest management which may contribute to an increase in forest damage. Stands, regardless of their species-site relationships, density and age, should be healthy if there were no air-borne pollutants. One may have a feeling that the trees and stands are believed to be never dying, eternal in the absence of acid rain. The traditional knowledge of stand ecology and of stand development from the seedling stage to the mature and over-mature stages has been partially or totally forgotten.

SILVICULTURAL REGIMES AND CORRESPONDING GROWING-STOCK CONDITIONS

Criteria for Selecting Stand Treatments

Criteria of stand treatment and management rise from the functions of the forests and the types of economic activity (Windhorst, 1978). In early societies, the life of human beings was based on food gathering, hunting, nomadic pasturing and shifting cultivation. In that time the role of the forests was quite different than in the current, post-industrial welfare societies where commodity production is carried out by machine power and automatic guiding and control systems.

In agrarian and industrializing Europe, forest management was dominated by the commodity function. Growing populations needed more and more timber and other commodities as well as more land for fields and pastures. All this led to overexploitation of the timber resources and a decrease of forest land. With increasing knowledge and experience, the protective function of the forests against erosion and avalanches became more and more recognized. Large afforestation projects were commenced in the 19th century in order to rebuild the timber resources and protection forests.

In the post-industrial welfare societies, the social function, the notion of forests as an integral part of the landscape and of the living, working and recreation environment, and the cultural function including nature conservation and the symbolic and aesthetic values of the forest, dominate. This changing role of the forests has been possible because effective production methods decreased land needs for agriculture and pasturing, and advanced economies have become wealthy enough to satisfy their need of forest products by imports.

In conditions where the timber function dominates, the criteria for stand treatment are technical and economic. Production goals defined by technical specifications such as the greatest mean yield of usable timber or of high-quality heavy timber are formulated in a way that the resulting management regimes are considered to be the most economic ones. Technical criteria can be based on economic analysis or they can be intuitively grasped relations between the technical and economic criteria. The technical and physical standards are often used to satisfy particular silvicultural practices or bio-romantic ideas preferred by managers who do not question the cost of their preferences.

There are several economic standards which have been used in specifying thinning and rotation regimes. The most important of them are described below (Kuusela, 1968).

Net Annual Income

Net annual income (forest rent) can be applied in a single stand or in a regulated (normal) forest. The net income of a stand is the surplus of the gross income from thinnings and regeneration felling over the costs of the stand establishment, thinning and felling costs, and the costs of administration during the rotation. Divided by the number of years in the rotation, it gives the net annual income. The regime giving the greatest net income per hectare and year is characterized by a very high stand density and long rotation age. In using net income as the management criterion, the time element, i.e., the time lag between the costs and income, and the interest of the capital or the possible alternative use of the capital tied up in the growing stock, do not come into consideration.

In a forest composed of many stands, the net annual income is the surplus of the annual gross income from the sales of timber over annual expenses. In a regulated forest (consisting of equal areas of stands in the different age classes) it equals the mean net annual income of a unit stand. The net annual income is an applicable measure of success in theoretical considerations and in cases where the forest is approximately fully regulated. In a forest of uneven age-class structure, it is an inaccurate criterion of success because the area of thinnings and final fellings, and consequently the gross income of a given year or a period of years, may be exceptionally high or low.

Under conditions where the net annual income is the criterion of success, there may be an unnoticed tendency for some costs (for example, stand establishment costs) to increase. Compared with the income from the final felling, the establishment cost is small, and a small increase in it is seemingly negligible. However, every small extra cost in stand establishment accumulates during a period of years into a heavy burden on the profitability of tree-growing. It is not a mere chance that the net annual income used as the main criterion of success is often combined with a low profitability of forest management.

Net Discounted Revenue

Net discounted revenue of a project is the difference between the discounted revenues and discounted expenditures using a predetermined rate of discount in the calculation. In the case of growing a stand, the net discounted revenue at the time of stand establishment is called the soil expectation value (land rent). It measures the profit discounted to the beginning of the single project of stand establishment, thinnings and the regeneration felling assuming a predetermined cost, expressed in the discount rate, to the capital invested in the project. The cost of the capital may be said to measure the benefits lost because of the time lag between the investment and revenue. The discount rate measures the opportunity cost of the capital invested in the project. Because of the long period of time between stand establishment and final felling, the discount rate is expressed in the real value of money.

If the net discounted revenue as a criterion of success is applied in the production process of a single stand, the growing of the stand is continued until the marginal rate of return set by the discount percentage is reached and the net discounted revenue is zero. Thus, a forest where each growing- stock treatment is controlled by the net discounted revenue and where each treatment giving a net discounted revenue less than zero is abandoned, is a going concern functioning on the marginal rate of return expressed by the discount rate. The average overall rate of return from the forest where the growing-stock treatments are controlled by the net discounted revenue is greater than the discount rate because all projects and treatments having a smaller earning power than the discount rate are abandoned.

Another measure of investment earning-power is the internal rate of return on a single project. It measures the interest earned on the total sum of money invested, while the net discounted revenue estimates the profit assuming a predetermined cost of the capital.

Marginal Rate of Return

Marginal rate of return is an economic criterion applicable in managing the existing growing stock as an accumulated capital convertible into money under the conditions of an opportunity cost of the capital. The net income from a regulated forest can be increased to its highest amount by increasing the rotation, the mean volume of the growing stock, and the volume of the fellings.

In the marginal analysis of input and output relationships, the increase of the net income is compared to the required increase of the growing stock volume. This relationship, expressed in percentage, is the marginal rate of return. Maximization of net income occurs when the marginal increase of the growing stock no longer increases the returns. At this point the marginal rate of return is zero, which is acceptable if there are no possibilities for alternative investments outside the forest. At this point the opportunity cost of the capital is zero. If there are possibilities for alternative investments, the increase of the growing stock volume is stopped at the point where the marginal rate of return equals the opportunity cost of the capital.

The marginal rate of return is zero in a regulated growing stock having the rotation set according to the maximum net annual income. For example, at a marginal rate of return of 3%, the rotation of a regulated forest approximately equals the rotation of the maximum net discounted revenue by discounting at the rate of 3% in the case of a single stand. The dominating function of the forest correlates with the economic criterion in such a way that when the timber production dominates, the net discounted revenue (or land rent) guides the stand treatments. In the 19th century in Central Europe, the land rent theory dominated. Combined with a discount rent which obviously was too high with respect to the earning power of tree growth, it led to short rotations and small growing-stock volume which decreased the timber yield much below the biological potential.

Side by side with the change from the commodity function to the protective and social functions, the net discounted revenue as an economic criterion changed to the net annual increment, rotations became longer, and the growing stock volume greater. The costs of forestry increased and undermined the profitability of growing timber. Rationalization and mechanization of forest operations were neglected (e.g., Eidg. Departement des Innern., 1975). Low profitability and zero interest on the capital tied into the heavy and old timber stock became acceptable under the scapegoat of multiple benefits.

On the other hand, in those current management systems which have been developed in connection with large afforestation projects, the net discounted revenue is the guiding criterion of success. In Britain the purchase of land and its afforestation has been considered acceptable if it earns a marginal rate of return of at least 3.5%.

Growing-stock Conditions

Growing-stock conditions are composed of stand establishment, thinning regime and rotation. The type of establishment (i.e., planting, seeding or natural seeding), site preparation and improvement, and tending of the seedling stand are the elements of stand establishment. The thinning regime consists of stand age at the first thinning, and type, cycle, intensity and weight of the thinning. Rotation is the age of the stand at the time of the regeneration felling. The type of thinning describes the qualitative nature of the treatment (e.g., high or low thinning). The cycle is the number of years between successive thinnings. The intensity is the average annual volume per unit area removed over a period of one or more thinning cycles. The weight is the volume per unit area removed in a particular thinning.

Stand Establishment

A characteristic feature of Central European forestry is the establishment of tree stands sufficiently dense to utilize site productivity fully and to improve the quality of stems by self-pruning. The number of planted spruce and pine seedlings has been 5 000-7 000/ha and 15 000-20 000/ha respectively. This great seedling density originates from the time of cheap labour; it is more a tradition than a course of procedure guided by economic analyses. Rising planting costs have led to efforts to decrease the number of plants per hectare. On the other hand, the threat of pollutants and the recreational value of the forest have called for the establishment of coniferous stands with a mixture of deciduous broadleaved tree species, and this further increases establishment costs.

Ground preparation and weeding of young stands are intensive, and fertilizers are used on sites of poor quality. Regeneration by natural seeding is largely accepted on poor sites and in protection forests as well as being a part of bio-romantic silviculture. There are management systems where natural seeding obtained by the shelter-wood or seed-tree methods is a current procedure.

In stands reaching the stage of first thinning, the number of the stems per hectare is great and the diameter increment is retarded compared with a smaller number of trees. In contrast, in Britain the aim to eliminate all unnecessary costs limits the number of seedlings per hectare (about 2 000-2 300/ha) to the minimum for a fully stocked stand. Ground preparation and weeding are intensive, and fertilization of planted peat sites is a current practice. It has been found profitable to guarantee the rapid development of the planted seedlings.

Natural regeneration is comparatively rare and almost nonexistent on peat sites under the humid conditions. Stands from natural seeding of the native Scots pine are not considered acceptable because the net discounted revenue of these stands is smaller than the economic goal.

Thinning

In Central European forestry, the objective of thinning is to harvest those trees which would succomb to mortality and to improve the quality of the standing stock. Thinnings start early in young dense stands, their intensity is comparatively low, and the thinning cycle is prescribed to be 5 to 10 years. The type of thinning is to remove trees from below.

The density of the standing stock is kept as high as necessary for maximum volume production. Consequently, the thinning yield in most management tables is 35-40% of the total volume yield during the rotation. According to the cutting statistics (see Kuusela, 1968), it varied from 25% to 40% in the 1960's (comp. Bundesministerium für Land- und Forstwirtschaft, 1983; p. 97). Low profitability of thinnings, especially in mountainous terrain, and the shortage of labour have led to a postponement of thinnings. Consequently, the stand density and mean volume per hectare have increased to a greater extent than specified by the management tables.

In British forestry (Forestry Commission, 1971), the alternative courses of thinning have been analyzed on the basis of net discounted revenue using a discount rate of 3.5%. The discounted revenue has been found (a) to increase with increasing weight of thinning and with decreasing ratio of average volume of thinned trees to average volume of standing trees before thinning, and (b) to decrease with a 10-year delay in thinning (from a stand age of 25 years to 35 years).

It is more profitable to thin early than to delay the first thinning, with great rather than small weight, and from below rather than from above.

On the best sites, and in cases of fast-growing species, thinning is prescribed to start 17-25 years after stand establishment, and on poor sites with slow-growing species at 25-40 years. The normal thinning yield per year from fully stocked stands is 70% of the maximum mean yield. This means that at least 45% of the total volume production is removed in the form of thinnings, and because the rotations in British forestry are shorter than in Central European forestry, the British thinning intensity is markedly higher.

The prescribed thinning cycle is 5 years. In fast-growing stands it can be 3-4 years, and in slow-growing as well as in later ages 5-10 years. The rules can be adjusted according to harvesting and road conditions in order to guarantee economic extraction.

Compared to Central European conditions, in British forestry the stand density is lower and therefore the current volume production may be smaller than the full volume production. The thinning regimes described above are not fully followed in Britain. First thinning has been delayed in areas outside the net of the logging roads. Another reason may have been the shortage of labour. In topographic and site conditions where the risk of wind damage is great, a regime without thinnings is adopted.

Rotation

Some time ago the usual prescribed rotation in Central Europe for coniferous tree stands was 80-100 years. In some countries it has become longer, probably because there have been delays in regeneration fellings. In the FRG in the 1960's, the optimum rotation was considered to be 110-120 years in public and large private forests under continuous management. The actual rotation was often 60-70 years in small private and farm forests.

Let us examine the age-class structure of Bavarian forests in some detail (Table 2). The length of the rotation has increased much since the 1960's, and the share of seedling stands has decreased. A 5% share of the 10-year age class corresponds to an average rotation of 200 years. The current average rotation in Bavaria is about 130 years. In the Central European mountains it can be 140-150 years. There, prescribed rotations are often not followed and the growing stocks have become older and older. Because of delayed thinnings and extended rotations, the fellings have been at least 20% smaller than the net increment of the growing stock volume.

In Britain the specified rotations based on the net-discounted-revenue criterion vary from 50 to 75 years depending on the tree species and site quality.

The bulk of the current coniferous stands are younger than 60 years. The future will show if the specified rotations are followed or if they start to become longer and longer when the time of the basic investments is far enough in the past.

Current Coniferous Forests and the Original Growing Conditions of their Tree Species

Most of the coniferous tree stands in the Central European plains are planted or regenerated by natural seeding from the stands which were planted in the time of the large afforestation projects. They grow in the zone of temperate deciduous summer forests where species such as oaks and beech once dominated.

Table 2. Age-class structure of Bavarian forests (figures are percentages of total area; sources: Bayerisches Staatsministerium für Ernähung, Landwirtschaft und Forsten, 1975; and Kennel, 1983).

Year	Age Class (years)							
	10	30	50	70	90	110	130+	All
All Forests								
about 1960	26	23	20	13	9	9	9	100
1970/71	18	17	19	18	13	8	7	100
1983	5	13	18	26	19	9	10	100
Spruce Forests								
1970/71	19	18	21	19	12	6	5	100
1983	7	14	18	27	20	6	8	100

In this zone the conifers are biologically weaker than the deciduous broadleaved trees. Conifers can compete successfully with the latter in the ecotone of mixed coniferous and non-coniferous forests against the boreal coniferous zone in the northern outskirts of Central Europe. They are biologically dominating in the coniferous mountain forests.

Estimates of the original and current tree-species composition in Germany are given in Table 3. A great part of the coniferous stands grow on sites where non-coniferous trees are biologically more competitive. Seeds of the planted stands may not in all cases be from conditions equal to those conditions where the current stands grow, a factor that should be kept in mind when considering the possible causes of forest damages. In many cases, tree species growing outside their natural conditions have turned out to be sensitive to insect and disease damage.

Density and Age Limits of Healthy Stands

The natural development of tree stands without human interference is characterized by a very great number of trees in the seedling stage, rapid decrease of the tree number in young and middle-age stands, and the final collapse of over-mature stands due to damages caused by insects and diseases. The age of deterioration and collapse varies by tree species and site types. In South Finland the deterioration of spruce stands begins at the age of about 110 years and tree death is frequent at 130-140 years of age. If a stand grows outside the natural zone of its tree species, the deterioration often begins earlier than under natural growing conditions.

Table 3. Changes in the tree-species composition of German forests (figures are percentages; source: Weck and Wiedebecke, 1961).

Forest Type	Proportion of Total Forest	
	Original	Current
Non-coniferous		
Oaks	20	10
Beech	38	14
Other	8	5
Total	66	29
Coniferous		
Pine	20	44
Spruce	7	25
Fir	7	2
Total	34	71

In thinning regimes there is a density called the self-thinning boundary. At and above this boundary, some of the trees lose their vitality and die because of mutual competition in a limited growing area. In "good" silviculture, the stand is thinned before reaching this boundary (see Figure 1).

In the life cycle of every stand, there comes an age when the stand is overmature and it begins to deteriorate and collapse due to insect and disease damages. Whatever economic criterion is used to specify the rotation, in a rational silviculture (and also in sound management of environmental values), the stand will be regenerated before the deterioration starts.

These laws of stand ecology are illustrated in Figure 1. The lines describe the development of the prescribed stand volume per hectare up to the regeneration felling at the age of 80 years. If stand density and mean volume are allowed to increase over the self-thinning boundary, some of the trees die. If the stand is allowed to over-mature, more trees begin to die. The combination of high density and old age is the most mortality-prone condition. Periods of drought often accelerate the deterioration process. Trees that lose their vitality because of high density and old age become more and more sensitive to all kinds of diseases as well as to pollutants.

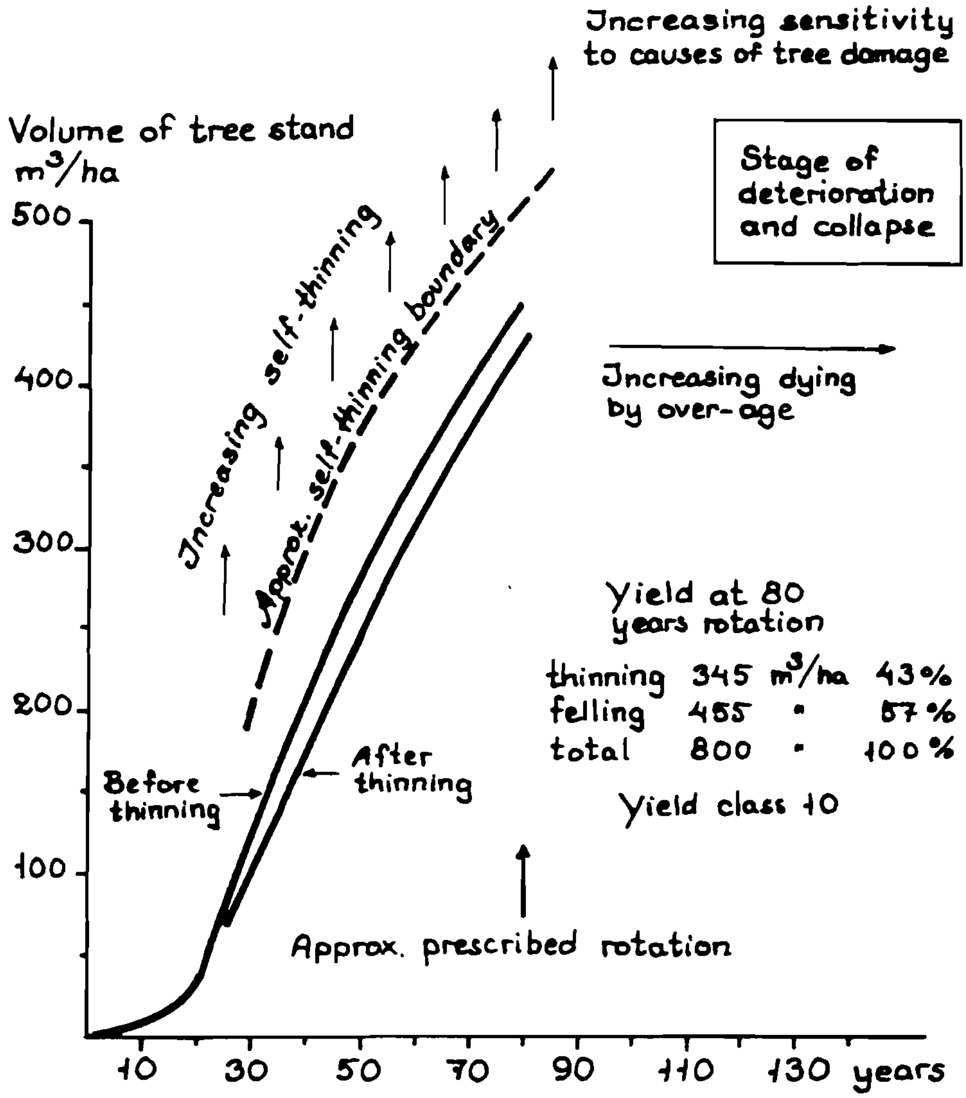

Figure 1. Stages of spruce-stand development (source: Forestry Commission, 1971).

Results of the 1983 Bavarian damage survey concerning spruce stands are illustrated in Figure 2 (Kennel, 1983). Average stand density in the 70-year age class is very high. Even if the sample plots do not include the less dense strips at the stand boundary, the mean basal area of 48 m^2/ha for this age class is above the self-thinning boundary.

The percentage of defoliated trees increases with increasing age from 13% to 80% at the age of 110 years. The drop in the damage percentage for the age class 130+ years is probably caused by heavy thinning which decreases the stand density and opens the canopy for natural seeding in parts of the stands. The share of dead trees is greatest in the oldest stands which are definitely older than a reasonable rotation age. An obvious conclusion is that defoliation increases with increasing stand density and age.

DISCUSSION AND CONCLUSIONS

There is evidence to suggest that the air-borne pollutants falling on large forest areas are not the only and possibly not even the most important cause for the "new forest damages" symptomized by defoliation and discoloration of leaves. Gradual weakening and dying of trees is a complex, multi-cause process in which the current silvicultural regimes and distortions of them have a decisive role.

This does not mean that the air-borne pollutants are harmless to the trees and forest. The load of pollutants is heavy enough to cause deeply penetrating changes in the forest ecosystem. Pollutants are one of the multiple causes of forest damage and the situation may become more serious in the future. Contradictory, exaggerating and irrational presentation of the damage observations and, at least in their time schedule, erroneous doomsday prophesies have made the situation chaotic with respect to rational analyses.

The first prerequisite to understand the situation better is to separate the direct-fume effects from the effects of pollutants carried by winds over large forest areas. The direct-fume damages have been used misleadingly to foretell the death of trees in other areas as well.

Comparability of the damage observations should be increased. In particular, the defoliation and discoloration estimates should be carried out on a much more unbiased basis than so far. Extrapolating the areas of the damaged forests from single-tree observations should be abandoned as unscientific and highly misleading. Area estimates should be based on stand observations. Damage observations should be supplemented with information of all the site and stand characteristics that are routinely measured and recorded in complete inventories of forest resources. This is the only way to get enough data to find out the cause and effect relationships in the damage phenomenon.

In addition to the common stand characteristics, special attention should be paid to such factors as chemical and physical soil structures, water conditions, drought periods, groundwater conditions disturbed by construction of buildings and roads, and effects on trees caused by construction, logging machines, and heavy traffic. The health condition of the trees in stands should be analysed by multi-factor models within the frames of tree, stand and forest ecology, and with special reference to the origin of the seeds of the current stands.

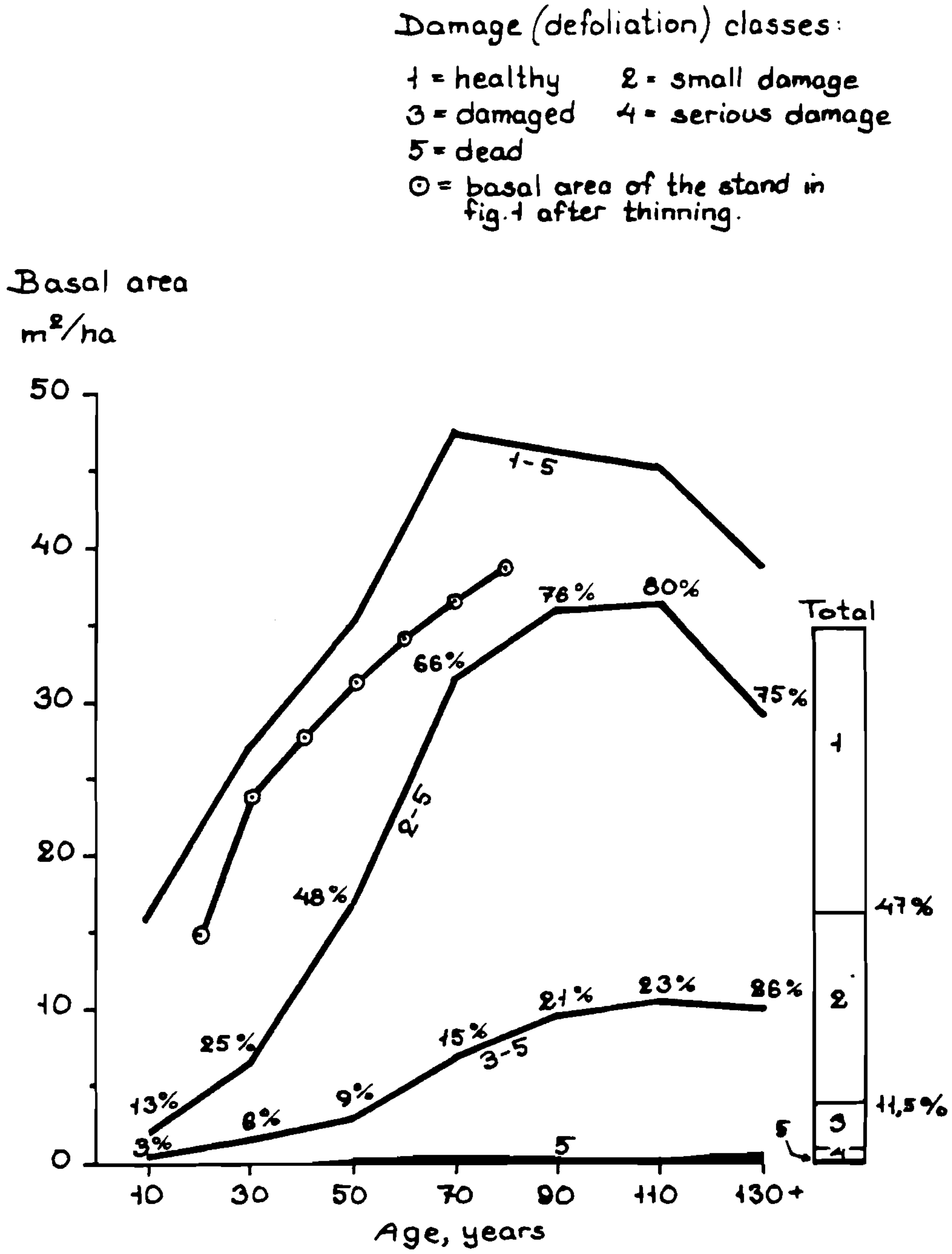

Figure 2. Damage estimates for Bavarian spruce stands in 1983 (source: Kennel, 1983).

There is evidence to conclude that (a) the current silvicultural regimes, (b) increasing density, mean volume and stand age, and (c) fellings permanently about 20% smaller than the growing-stock increment, are also sources of increasing tree damages. There is much more damage in the dense and over-mature forests in Central Europe than in the forests managed under British silvicultural regimes.

The development of agrarian societies into industrializing and post-industrialized welfare ones has changed the commodity and timber functions of forests to a multiple function in which the protective and social functions dominate over the timber function. Side by side with this development, the economic criterion of stand treatments has changed from the net discounted revenue (forest land rent), with the aim to cover the predetermined cost of the capital tied into the long-term investments and into the growing stock, to the net annual income (forest rent) without any interest on the capital, and finally to the stage of management where economic success is a secondary criterion next to protection and social values.

At the moment under the glooming threat, the preservation attitude is becoming more and more popular. It is characterized by the silvicultural and management aim to preserve stands at full density and seemingly full health by picking away the damaged trees before they die and postponing the regeneration felling as far as possible to the future. This aim is valuable in itself regardless of the costs involved and the decreasing profitability.

At the same time, the costs caused by anachronistic stand establishment and thinning regimes are overlooked. Rationalization of forest operations has been neglected. Forest industries have also lost their competitive power. Many mills have become out-of-date and their capacity is too small to consume the potential timber supply. Paradoxically, even many countries which cover half or more of their need for forest products by imports have become timber exporters. This forest situation and its connections to the other parts of the forest sector are illustrated in Figure 3 (comp. Nilsson, 1986).

However stubborn the preservation attitude is, the consequences of (a) fellings permanently smaller than the growing-stock increment, (b) increasing density and age of stands, and (c) the accumulation of mature and overmature timber stock, can not be prevented. Fellings will be increased sooner or later in a way which changes the quality and composition of the timber-assortment mix. If silvicultural regimes are changed in order to increase the profitability of forestry, or if forest damages force an increase in fellings, the supply and demand situation in the European timber markets will be found in dramatic turmoil. This would create great changes through the whole forest sector. Only a reliable advance knowledge, with alternative projections and analyses of the growing-stock development, can guarantee a future staying in man's full control.

At the moment, a tentative scheme for a more rational attitude towards management of the forests could be as follows. Although the pollutant load may decrease gradually, it continues by amounts which cause penetrating effects to forest ecosystems. Those responsible for forestry can not change this situation directly. But they can and must do all in their power to keep tree stands as healthy and resistant to the pollutants as possible. In stands with increasing density and age, as well as under

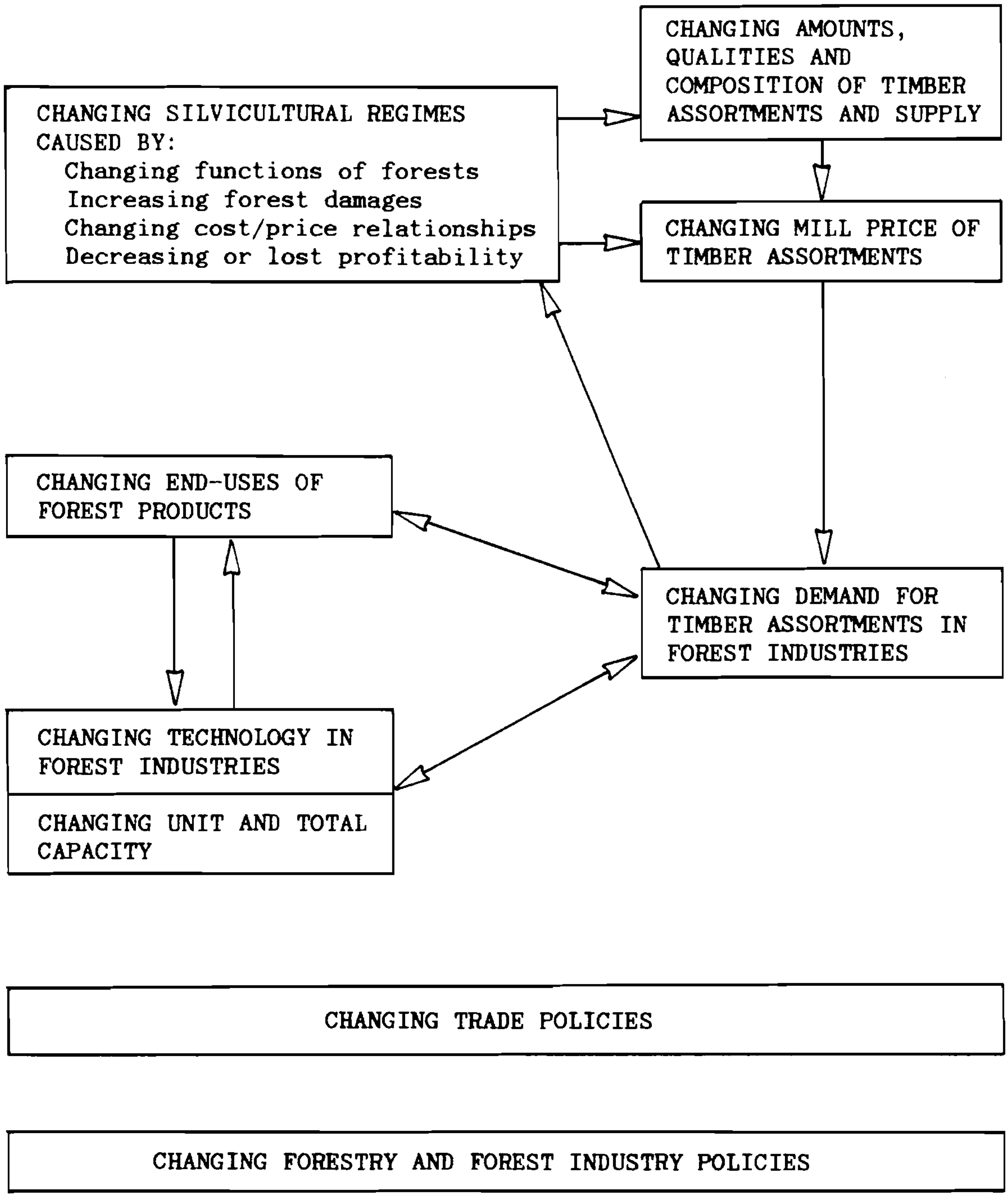

Figure 3. Forestry in a changing environment.

conditions without pollutants, some of the trees lose their vitality and die at the mercy of insects and other pests. Whole stands start to collapse after certain ages.

Results of the damage inventories include evidence to suggest that if British thinning and rotation regimes were applied in Central European coniferous forestry, the share of defoliated trees would be much smaller than it is now. On the basis of this assumption, a preventive measure in the conditions described in Figure 2 would be to decrease gradually the density and rotation age of the stands and to reject the current practice of picking away dying trees and postponing regeneration. The latter can postpone but not prevent the final collapse of over-mature stands.

Increasing thinning and regeneration will increase removals. Command of the situation requires more knowledge, planning and management. There are basically two choices: launch a new management now, or leave the reigns of management to the forest damages of tomorrow.

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The following publications appear with their serial numbers from the compilation "Publications of IIASA's Project on Ecologically Sustainable Development of the Biosphere". Serial number and date of final publication do not always coincide because papers are assigned a serial when first circulated as preprints. Copies of as yet unpublished documents are available from the Project.

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