REGIONAL RESOURCE MANAGEMENT

VOLUME I

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Editor

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FOREWORD

In an innovative attempt to bring together specialists in dendrochronology*, forestry and regional planning, the International Institute for Applied Systems Analysis (IIASA), together with the Scientific and Coordination Centre for Ecology and Environment Protection of the Bulgarian Academy of Sciences, hosted a Workshop on *REGIONAL RESOURCE MANAGEMENT* which was held in Albena, Bulgaria (September 30 – 4 October, 1985).

The Workshop was a great success and its aims were fulfilled: for the first time, leading dendrochronologists met with regional planners, foresters and specialists in acid rain to address questions related to long-range climatic background fluctuations as apparent from dendrochronologies, to long-range transport of pollution and acid rain, and to resource management policies and sustainability of regional systems. Some forty participants from 15 eastern and western countries participated in a stimulating week of discussions; following the recommendations made at the Workshop, it was decided to publish the papers presented by the participants and, in addition, to write a short, concise volume in the IIASA Summary Report Series. The latter (forthcoming), should reach an informed, but not expert, audience in environmental science as well as policy makers, and those who are not specialists in the different fields.

In a continuing effort in this innovative field of science, a further meeting will be held in Kraków, Poland (June 2-6, 1986). The Task Force Meeting *METHODOLOGY OF DENDROCHRONOLOGY: East/West Approaches* will again be hosted by IIASA, together with the Systems Research Institute of the Polish Academy of Sciences as well as the Agricultural Academy in Kraków. The ultimate goal of the Task Force Meeting will be to establish the current state-of-the-art of dendrochronology methodology, especially common aspects and differences in East/West approaches and to draft an international review on the rationalization of dendrochronological sampling and analysis of different methodologies.

Robert E. Munn
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*Dendrochronology: the method of dating events and variations in the environment by a comparative study of tree rings.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to all authors and participants of this Workshop who devoted their effort and time to this volume and to continuing research in this field of science. I would also like to thank our gracious hosts in Bulgaria for the kind hospitality extended to us during our visit in Albena and for making this meeting a very successful and fruitful experience.

Academician Leonardas Kairiukstis
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Preface

This paper discusses the approach to sustainability of the biosphere subsystems. The problems to be solved and the systems in which they interact are analyzed on the local, regional (national), zonal and global levels. In order to mitigate the confrontation between the socio-economic development and the environment, an integrative methodological approach has been suggested. This approach is based on systems analysis of rational use and reproduction of natural resources in combination with a purposeful formation of an optimal environment. The example of the Lithuanian SSR has been used for this purpose.

INTRODUCTION

Acceleration of scientific and technological progress and of industrial, metropolitan and agricultural development leads to man's confrontation with nature. The influence of man changes the equilibrium of nature processes which leads to unpredictable consequences. Generally, these are negative, such as desertification, water and atmospheric pollution, increase in soil acidity or salinity, destruction of forests and severe exhaustion of natural resources, impacts on human health and genetic mutations in plants and animals. This primarily occurs at the local and regional levels, sometimes leads to unpredictable negative consequences for the separate regions, and may also lead to negative consequences for the entire biosphere.

The increasing scale and significance of man's role as an agent of global change was forcefully articulated between the two World Wars by a remarkable group of scholars (Clark and Holling, 1985). These included the French theologian and paleontologist, Pierre Teilhard de Chardin, the Austrian-born American biophysicist, Alfred J. Lotka, and above all, the Russian mineralogist, Vladimir Ivanovich Vernadsky. Vernadsky (1926) first formulated the concept of the biosphere as the only terrestrial envelope in which life can exist. In Vernadsky's opinion the most significant aspect of man's development was not his technology per se but rather the sense of global knowledge and communication engendered by that technology. He portrayed this "noosphere" or realm of thought as a new geological phenomenon on our planet. Vernadsky's main concept was strongly developed by Soviet Academician Vladimir Nikolajevich Suckachev (1964) as a complete science of biogeocenology or the science of ecosystems.

Man's role as an agent of global change is associated with the emergence of an increasingly interdependent world economic system (Richards, 1985). Following the second World War, expanding industrial and agricultural development increasingly intensified the global economic interdependence among nations. It also began to introduce issues of ecological and geophysical interdependence between countries. This has led to some significant achievements in monitoring, in defining the issues in scientific and technical terms, in raising public awareness, and in institutional and policy action, on the national and international level. At the same time, research on the biosphere is characterized by an increasing scale and complexity of problems. Examples are the SCOPE program on the major biogeochemical cycles, the ICSU exploration of an international geosphere-biosphere program, NASA's work on global habitability, the WMO's World Climate Programme, UNESCO's Man and the Biosphere Programme, and UNEP's report on the World Environment 1972-82. Furthermore, there is IUCN's World Conservation Strategy, the OECD's work on economic and ecological interdependence, and the WRI's Symposium on The Global Possible.

At the International Institute for Applied Systems Analysis (IIASA) there are many subjects under investigation, such as Acid Rain, Climate Impacts, Design of Resource and Environmental Policies, Population Aging and Changing Lifestyles which are deeply concerned with the sustainability of regional development and development of the biosphere as a whole*. Most of this investigation is characterized by a considerable uncertainty in initial empirical information, a large number of input variables which are collected in different ways (official statistics, experts' estimates, indirect observation, etc.) and have different structures (qualitative, quantitative) and most of which can hardly be forecast. Nevertheless, the preliminary analysis of the investigations on the biosphere shows that:

- the cumulative impact of industrial, agricultural, and social development on the environment has approached a level where it is dangerous for particular regions and can be dangerous for the biosphere as a whole;
- better integrative understanding by international organizations, governments, and the scientific community is now urgently required to plan effective interventions that will bring the above situation under control;
- the demand for help in creating such integrative understanding is high but it is not being met by present isolated research activities around the world;

It is therefore very important in the biosphere studies at IIASA to integrate subjects already being investigated and to focus new investigation on an interconnected, manageable number of key issues which cover the processes that affect life on our planet and the role of life itself in the evolution of our present environment.

The standard agenda of investigations, as it concerns the sustainability of development, includes at least three interrelated groups of issues: natural resources, environmental pollution and human settlement issues.

Key natural resources issues include:

1. Depletion of forests, particularly tropical forests;
2. Loss of genetic resources;
3. Loss of cropland, soil erosion, and desertification;
4. Depletion and degradation of groundwater resources;
5. Energy, including fuelwood.

*In early 1985 within the Environmental Policies Program at IIASA a special "Ecologically Sustainable Development of the Biosphere" project was created.

Key environmental pollution issues include:

1. CO_2, O_3, trace gases, etc. and climatic change;
2. Air pollution, including acid rain;
3. Water pollution, including coastal and marine waters;
4. Soil pollution;
5. Hazardous wastes.

Key human settlements issues include:

1. Land use and tenure;
2. Shelter;
3. Water supply, sanitation, and recreation;
4. Social, education, and other services;
5. Management of very rapid urban growth.

THE HIERARCHY OF PROBLEMS TO BE SOLVED AND THE SCALE OF SYSTEMS IN WHICH THEY INTERACT

The problems to be solved can be divided into groups of environmental development concerns, as suggested by Clark and Holling (1985). Nevertheless, each group of problems interacts on a different space and time scale, and is involved in different systems. Therefore, I suggest that the problems that concern each generation should be analyzed within the systems in which they interact, as follows:

- The first group comprises small-scale problems concerning *local environmental systems on the landscape level.* Such problems are: local air or water pollution, soil erosion by water or wind, sustainability of agricultural crops, forest or fish die-off due to pollution, etc. These problems mostly affect the social well being of people and involve only certain branches of the economy and some management bodies. They have proved to be largely controllable. Moreover, they can be analyzed easily with the use of quantitative models. However, local control (e.g., construction of a very tall chimney, cultivation of field protective forest belts, etc.) sometimes contributes to a regional problem.
- The second group includes the larger-scale problems of *economic-environmental systems on the regional or national level.* The problems are: regional resources utilization, industrial and agricultural development, assessment of the impact of human activities on the environment, environmentally balanced sustainable regional development strategies. These deeply concern the socio-economic development and living conditions of human populations—ethnic groups in certain regions or nations. Despite the complexity, methods for solving these problems can be identified on the basis of systems analysis by using complete and incomplete models and choosing appropriate regional development strategies. Frequently, however, the conflict between short-term economic benefits and long-term ecological damage is difficult to resolve.
- The third group includes large-scale problems of *macro-systems on the transregional, zonal or continental level.* The problems are: long-distance transportation of air pollutants, acid rain, long-distance water transfer (between basins), large international rivers, depletion of tropical forests, loss of genetic resources, desertification, shifts of agricultural and forest

productivity onto marginal areas due to climatic changes, depletion of living marine resources, etc. These problems have shown themselves to be more difficult to solve partly because the costs of reversing the trends in some cases are prohibitive. Moreover, they span so many political spheres that the authority and understanding required for concerted action are often lacking.

- The fourth group consists of even larger-scale problems directly concerned with the ***development of the biosphere on a global scale.*** Such problems are: climatic background fluctuations due to sun-earth relations, biogeochemical cycles and evolution leading to a dynamic exchange of chemical constituents among the oceans, the atmosphere and terrestrial biosphere, biogeochemical cycles of soils, global economic-industrial growth, energy consumption and emissions into the atmosphere of significant amounts of active constituents, CO_2, O_3, trace gases, etc., anthropogenic changes in the atmosphere, their climatic and economic consequences, pollution levels in the oceans and their ecological consequences, anthropogenically induced global biospheric change and transition to the noosphere. If these extremely complex problems can be managed at all, it is only with a commitment of resources, and a consistency of purpose that transcend normal cycles and boundaries of scientific research and political action. Nevertheless, there is no other alternative but to try to formulate the approach and find tools (a system of models) with which it would be possible to describe the basic properties of the dynamics of the biosphere which could serve as a point of departure in the efforts made to understand evolutionary trends and biogeocenotic processes in the world and to react to them either by adaptation or confrontation.

APPROACH TO THE SUSTAINABILITY OF THE BIOSPHERE

When seeking the sustainability of the biosphere, the problems discussed above, from our point of view and in terms of the current possibilities for IIASA, can be solved on four levels – global, zonal (continental), regional and local.

An Analysis of Issues on a Global Level

An analysis of the problems that arise and change course on the global scale can be made outside IIASA in highly specialized institutions in both Eastern and Western countries. The characteristics of the issues of global change can include:

- climatic background fluctuations due to sun-earth relations;
- analysis of changes occurring in different geophysical media and their impact on biosphere sustainability;
- analysis of anthropogenic changes in the atmosphere and their ecological consequences;
- analysis of pollution levels in the oceans and their ecological consequences;
- analysis of possible anthropogenic changes in climate and their impacts on the sustainable development of the biosphere; and
- modeling the naturally and anthropogenically induced changes in the biosphere in seeking to find ways for transitions to the noonsphere.

Our understanding of global changes can be integrated on the basis of the above-mentioned analysis and simulation of general laws governing the biosphere (Moiseev et al, 1984). The revealed aggregate impact of global changes will be taken as an input for proposals of regional and local action to redevelop the biosphere.

Analysis of Issues on the Zonal or Continental Level

Some issues which characterize environmental changes on the zonal or continental level are already being studied at IIASA (e.g., Acid Rain, Climate Impacts) and appropriate models and software are being prepared (Alcamo et al, 1984) (Parry, Carter, 1984). Other problems must be solved using a collaborative network of organizations. The environmental changes on the zonal and continental level which have an impact on the biosphere as well as on regional and local systems, can be characterized as follows:

- analysis of long-distance transportation of air pollutants and acid rain;
- analysis of water transfers from one basin to another; international rivers;
- analysis of depletion of tropical forests and desertification with attendant climatic changes;
- analysis of depletion of living marine resources.

The revealed negative impact of the factors mentioned above must be transformed to systems of a lower level in order that counteractive policies may be worked out to deal with them.

Analysis of Issues on the Regional Level

The research on Ecologically Sustainable/Unsustainable Regional Development concentrates on the alternatives of regional resource utilization, industrial and agricultural development, as well as the development of other economic branches, and the assessment of the impact of human activities on the environment. The main goals of the research are the development of concepts, tools, methods, and software for regional economic and environmental development analysis and selection of better management strategies while taking into consideration the sustainability of the regional system in long-range dynamics. Such a strategy has to be worked out on a multidisciplinary basis and must involve the experience and joint efforts of economists, biologists, ecologists, mathematicians, statisticians, hydrologists, and specialists in agriculture, forestry, demography, and health. In other words, the problems to be solved belong to the sphere of applied systems analysis.

To achieve the goals mentioned above, the activities should include the preparation of concepts and the core of the model system, including supporting models to describe the links between industrial and agricultural development, utilization of natural resources, changes in the environment, the influence of these changes on recipients, including man, and the adverse influences on the socioeconomic development of society. There are some integrated regional models which have already been developed (Brouwer, Hettling, Hordijk, 1983). The cycle is modeled as follows: economy changes the environment (air and water pollution, soil erosion, destruction of forest ecosystems, etc.), the changed environment influences natural resources, production means and people, and through this by the reversible link it influences the economy. The model system (Figure 1) consists of the following blocks: information data bank, economy, categorization of territories into influenced zones, ecological evaluation models, determination of changes in recipients' state, economic evaluation of damage, and environmental quality regulation.

The territory of the region, chosen in the form of case studies, is divided into squares. For every square, the data regarding its geographic position, structure of the farm lands, environment and economic activity are determined. The information is stored in a regional (national) data bank from whence the primary information for modelling is drawn.

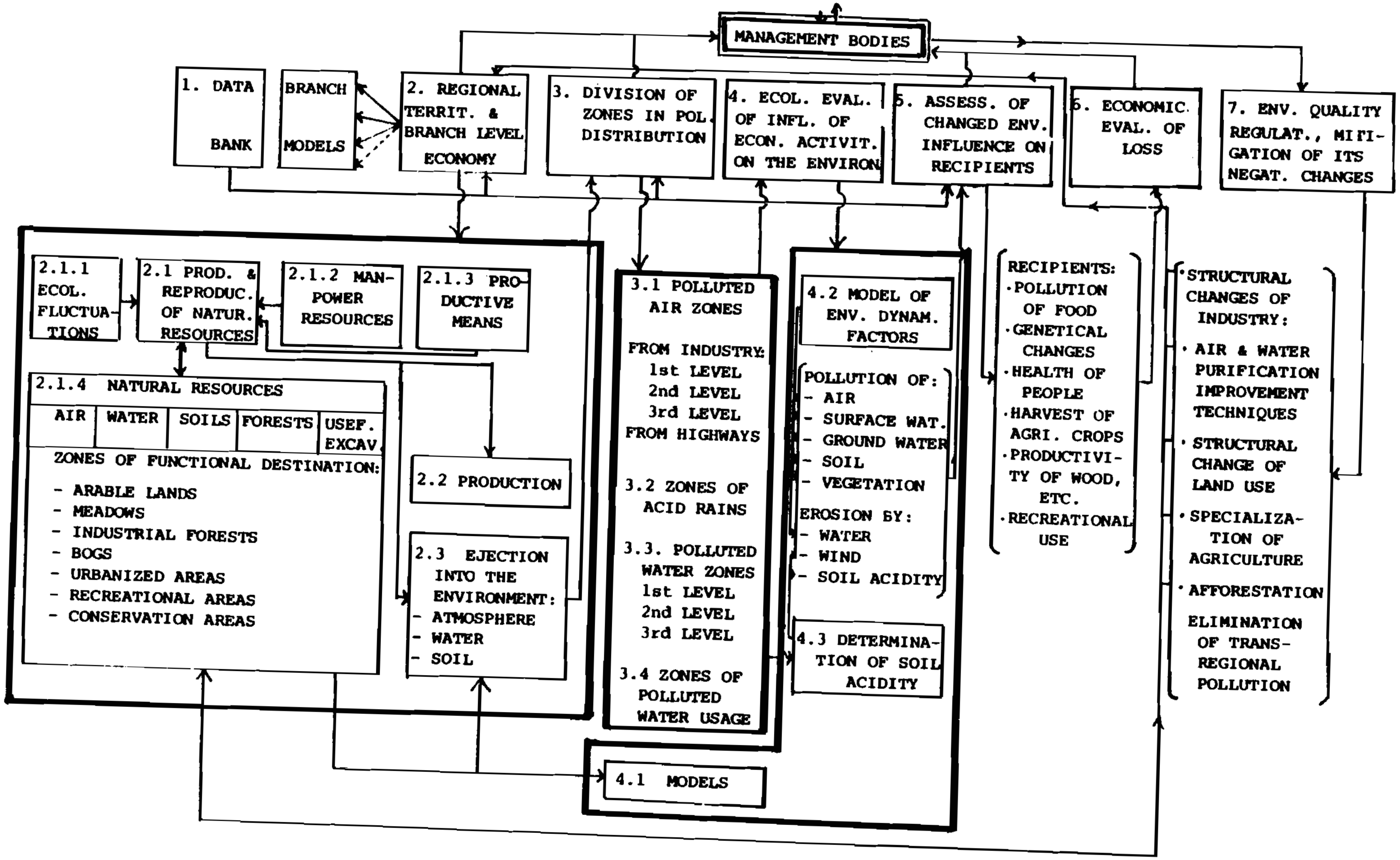

Figure 2: The scheme of a system models for the analysis of regional-economic-environmental systems.

The main items of the economic block are:

- to balance the production and utilization between branches;
- to determine the indices of economic activity for the region as a whole and separately for the main land users;
- to characterize the activity of natural resources reproduction;
- to determine the influence of economic activity on the environment; and,
- to balance the utilization of natural resources.

The following kinds of influence on the environment are included in the economic block:

- emissions of toxic substances into the atmosphere including those from industrial activities and motorized vehicles;
- water pollution; and
- soil pollution.

In the block of categorization of territories into influenced districts, the following zones are distinguished:

- air pollution by industrial emissions and motorized vehicles;
- water pollution; and
- utilization of polluted water.

The block of ecological evaluation of the influence of economic activity on the environment is determined to characterize the level of air, water, soil and vegetation pollution and the level of soil erosion. It is worked out on the basis of the following models: model for evaluation of chemical runoff and soil erosion in agricultural farmland (Knisel et al, 1980) which is affected by various management systems (CREAMS); model of environmental factor dynamics (Krutko et al, 1982); model of acid rain (Alcamo et al, 1984) and soil acidity (AR).

In the block of recipients their state is determined under the influence of environmental changes. The main kinds of recipients are as follows: quality of food stuffs, genetic changes in animals, state of health for humans, crop capacity, productivity of natural resources (forests, water basins), condition of recreational resources, and main productivity funds.

On the basis of the changes of recipients, the economic evaluation of damage is made, which is caused by environmental pollution and which in turn affects the national economy. By the reversible link this damage influences the economy and negatively affects its future development.

The block of environmental quality regulation deals with the simulation of means to improve environmental quality. The main means are as follows: changes in the structure of the industry; changes in the structure of land utilization, air and water purification; and introduction of technologies with less waste materials. Besides, the negative influence on some recipients can be decreased by means of physical planning and functional redistribution of the regional territory, for example, by relocating food crops, recreational areas, settlements, etc., away from strongly polluted zones (Kairiukstis, 1982).

The kind of input-output model mentioned above leads to great simplifications and often fails to reproduce non-linear interactions. Nevertheless, the model system provides the management bodies (planning) of the zone or the region with the conditional optimal scenario of natural resources utilization and environment formation of a region, and also with various alternatives. This scenario forwards the decisions taken to the management bodies (ministries, departments or complexes). By means of their economic systems the latter influence the natural resources and environment on the specific territory. The annual or five-year results of such activity together with the volume of industrial production are received through information channels and comprised in the models system. This makes it possible to correct the annual and five-year scenarios of natural resources utilization and environment formation.

Analysis of Issues on the Local Level

The activities on Ecologically Sustainable/Unsustainable Regional Development are supported by detailed local studies on the landscape level. As mentioned above, regional economic-environmental models evaluate the ecological consequences of economic development and facilitate a determination of landscape redistribution according to function; (e.g., exploitable forests, agricultural, recreational, water-soil protected zones, urbanized territories, etc.). For the main branches experiencing the most dangerous environmental impacts from the other economic branches of the region, the following tasks are to be solved:

- agricultural problems regarding sustainability, pollution impact, and agricultural practices that threaten other objectives in land use: What are their causes, which counteractive policies are possible, how can their effectiveness be continuously monitored?
- forest die-off due to pollutants: What are its causes, which counteractive policies are available, how can their effectiveness be continuously monitored?
- water management problems regarding sustainability of use, and pollution impacts that threaten other objectives in land use: What are their causes, which counteractive policies are possible, how can their effectiveness be continuously monitored?
- recreational areas and genetic resources, in terms of sustainability of use, pollution impacts: Which counteractive policies are possible, how can their effectiveness be continuously monitored?
- urbanized territories, in terms of pollution impacts that threaten human health and other objectives in land use: What are their causes, which counteractive policies are possible, how can their effectiveness be continuously monitored?

For the analysis of the above-mentioned separate branches of the regional economy adequate models should be used. They should include a simplified regional interbranch economic development model and a more detailed territorial model. For example, in the detailed model of the forest sector, as a branch of the economy the forest resources are analyzed with demand; when there is a shortage of forests to cover demand measures must be taken to meet this demand. When there is no opportunity to satisfy the requirements, the structure of production in the interbranch model is altered. The following submodels are used in the forest sector model:

1. the submodel of forest biocenose (for the analysis of the sustainability of the forest system and the forest front of influence upon the environment);
2. the submodel for analyzing the specialized sectors of forest growth: industrial, agroprotective, recreational etc. (Kairiukstis, 1981).
3. the submodel for analyzing the renewal of forest resources;
4. the submodel for analyzing forest utilization (Deltuvas, 1982);
5. the submodel for the analysis of demand for forest products; and,
6. the wood processing submodel.

In addition, forest die-off is currently being analyzed at IIASA with the help of a model (POLLAPSE) on pollution and forest collapse (Grossmann, 1984).

For the above-mentioned specific branches of the regional economy, the anticipated results (when these problems are solved) will be as follows:

- an indication as to which counteractive policies for agricultural crops, forest die-off, water quality, recreational areas, and urbanized territories are best in a specific area, as far as concerns sustainability of the separate branches and sustainability of regional development;
- information on which counteractive policies are effective and which will lead to financial loss;
- a new tool for much better management of agricultural and forest land use, water basins, recreational areas, urbanized territories, other resources, etc.
- help to direct and synthesize research on the above-mentioned problems concerning the sustainability of local and regional systems development;
- assistance in establishing a data bank and an environmental monitoring system on the regional level.

GENERAL APPROACH TO THE METHODOLOGY

The complexity of the above-mentioned problems and systems in which they commonly interact constitutes the subject of investigation on sustainable/unsustainable regional development as well as sustainable/unsustainable development of the biosphere as a whole.

The systems comprising the global biosphere differ greatly in space, time and complexity. They are open, and essentially interact with the ecological and socioeconomic environment. The hierarchical nature of systems is very complicated, with cooperation and conflicts between different subsystems. Possibilities to control the subjects under investigation, on large-scale systems in particular, are very limited. The higher the level of the hierarchy, the fewer the possibilities to experiment with the subsystem. Therefore, it is necessary to use an integrative approach to elaborate a strategy of systems management (control) in a united, hierarchical structure during the process of receiving and collecting data.

The systems under consideration have many facets, each of which can most adequately be addressed with a different set of tools. That is the reason why a "multifaceted" hierarchical approach can be used. At IIASA this approach has been suggested and widely used by W.D. Grossmann (1984) for small-scale local systems analysis, in contrast to large-scale models which were strongly criticized previously (Lee, 1973). We developed the former approach for the analysis of problems and systems related to the sustainability of the biosphere. Complementarily, the main scheme was extended to four levels of problems and factors to be analyzed, methods to be adopted, as well as systems to be covered. Using this approach, we intend to investigate interrelated local, regional, zonal and global systems, according to the strength of the impact felt on each other. The zonal system among them is the turning point. It is expressed in a maximum of outside environmental cross-action and a minimum of management cross-action (Figure 2). For most of the problems discussed above this approach permitted the use of dynamic models in combination with a geographical information system and the generation of a time series of highly precise geographic maps.

Nevertheless, in many cases (particularly in analyzing complex regional socio-economic and environmental systems) it is not realistic to use formal methods and mathematical models. Such models are usually based on the assumption that

INCREASE OF MANAGEMENT CROSSACTION

THE HIERARCHY OF BIOSPHERE SYSTEMS: PROBLEMS TO BE SOLVED AND METHODS TO BE USED

PROBLEMS	THE HIERARCHY OF SYSTEMS	CHARACTERISTICS AND DOMINANT FACTORS	METHODS
Understand geosphere–biosphere interactions, environmental fluctuations and biogeochemical cycles. Reveal the factors that seriously constrain sustainability and habitability of all lower systems.	GLOBAL	Absence of permanent structure. Lack of data. Fluctuations of the universe.	Theoretical hypotheses importance of empirical data.
Preserve sustainability. Decide structure of all lower systems. Decrease risks. Explore, recognize and exploit opportunities. Prepare system so that it can cope better with "whatever may happen".	ZONAL	Uncertainties in structure and data. High influence of the outside environment. Climatic. No decision systems.	R&D. Evolution, succession. Biocybernetic approach. Principle of viability and resilience. Importance of subjectivity. Scenarios.
Within the defined structure: Preserve the structure, keep the system going. Problem solving such that interdependencies and feedback reactions are taken into account.	REGIONAL (National)	Uncertainty in data and to a lesser degree in structure. Considerable influence of the outside environment. Sustainability of human population. Few decision systems. Many interdependencies.	Strategic management. Holistic approaches. Importance of experience. Considerations must include reactions. Aggregated dynamic models. Preserving of balance.
Prepare counter policies which are best in a specific area. Solve the many routine jobs quickly and precisely. Help sustainability of all higher systems.	LOCAL	Preciseness in data and structure. Low influence of the outside environment. Social well being. Many not interacting decision systems.	Optimization both heuristic and exact. Adaptive control. Real time process control.

INCREASE OF OUTSIDE ENVIRONMENTAL CROSSACTION

Figure 3: The hierarchy of biosphere systems: problems to be solved and methods to be used.

the models describe these systems exactly and sufficiently. However, it is not always possible to build mathematical models with the required properties and the user must invest much effort in verifying the practical applicability of the solutions obtained by standard schemes. For these cases more practical environmental impact assessments and socio-economic methods, developed by R.E. Munn (1979) as well as incomplete models, can be used (Umnov, 1985).

Using both approaches, an analysis of the main constituents of the global biosphere and verification of the theoretical hypothesis about possible changes will illustrate what the most serious constraints are for the future sustainable development of lower scale, i.e., zonal, regional and local systems. On the other hand, analysis of local and highly aggregated regional systems will reveal the factors which have negative or positive impacts on the sustainability of the systems of a higher level.

Let us consider an approach to environmentally balanced regional development using the example of the Lithuanian SSR.

THE APPROACH TO SUSTAINABLE REGIONAL DEVELOPMENT IN THE LITHUANIAN SSR

The Lithuanian SSR is one of 15 republics of the Soviet Union with 3.6 million inhabitants living in an area of 6.5 million hectares, i.e., the average population density is 55 km^2. In the last few decades industry as well as agriculture has been highly developed. The average yearly crop production of cereals for the last five years was between 2.5 - 3.0 tons/ha., for meat 0.13 tons/ha., and dairy products 3.6 tons/animal.

The Lithuanian Republic is a highly cultivated part of the USSR. Land reclamation by closed drainage was carried out on 60% of the area of collective farms. Extensive road networks were established. Two large (approx. 400-500,000 inhabitants) and 12 small towns (about 100,000 inhabitants) were developed.

In Lithuania, traditionally developed complex silviculture is practiced (the average area of forest preserve is 3,000 ha., forest husbandry - 30,000 ha., with one highly educated specialist each per 1,000 ha.). The forests constitute 1.8 million ha. (27.6%) of the total land surface. This means that approximately 75% of the demand for wood is met. There is a well organized nature conservation service in Lithuania. In addition, Lithuania is well-known for sport hunting and tourism.

Despite great efforts by the State for nature conservation, natural resource utilization and technogenic use of the land have a negative impact on the environment.

Negative Consequences of Human Activities During Technogenic Reconstruction of the Landscape.

Industrial growth, increased motorization, land reclamation, and intense agricultural activities have destroyed the natural landscape. Extensive land use has caused deterioration of the soil and water. Investigations show that land reclamation and cultivation, as well as the intensive use of pesticides sharply diminish the variety of soil fauna (Atlavinyte, 1978 and Eitmanaviciute, 1982). Hydrophilic species of worms disappear, and other species have diminished fivefold. The variety of ornithofauna also suffers greatly. Insectivorous birds (e.g, thrushes and finches) have been greatly decimated because they use small field bushes for reproduction rather than forests. The disappearance of forests and bushes inside arable lands reveals the negative consequence of surface water runoff. The arable lands in the Aukstaiciu and Zemaiciu uplands especially suffer from erosion. Using the CREAMS model (which was adapted at IIASA), model calculations of runoff, amount of water evaporation and deep percolation were carried out for the hilly Utena region with regard to soil types, variety of forms of landscape. Model calculations show that in 1972-1980 runoff and deep percolation correspond to about one-third or 204 mm precipitation per annum. This determines soil erosion processes which in conformity with the degree of steepness, mechanical particles specification and crops grown there can form 100 tons/ha. of drifts in the nine-year period (Kairiukstis and Golubev, 1982). The aforementioned erosion processes do not happen on slopes with belts of forest cover.

The increase of the plain field area causes wind erosion and depletion of soil fertility. It is a special characteristic of the light soils. For example, in Lithuania, such areas cover about 190,000 ha. The investigations carried out (Pauliukevicius, 1982) show that the annual runoff washes away from every ha. of arable land 50-250 kg of chemicals dissolved in the water. Every year the Nemunas river carries away about 0.5 million tons of drifts into the Kursiu Marios Lagoon. It is partially for this reason, as well as due to a scarcity of sewage treatment plants in large towns and industrial centres, that water pollution has not been sufficiently reduced.

West winds being predominant, the industrial pollutants from Western and Middle Europe, England and Scandinavia are transported to Lithuania. Acid rain, oxidized deposits, harmful gases, and carcinogenic substances reach the Lithuanian territory in 1-2 days. They cause acidification of soils, water pollution and deterioration of the forest ecosystems. Against the background of the whole atmospheric pollution, the zones of high local pollution around industrial centres like Jonava, Mazeikiai and Keadainiai prove to be dangerous to the forest vegetation, which in its turn is the index of the conditions for human existence. Under the impact of emission processes, litter, soil and water reservoirs accumulate large quantities of dust, fluorine, nitrates, ammonia, chlorite sulphates, phosphates, potassium and other harmful compounds (Vaicys, 1982). Within a radius of 3-5 km from the source of pollution, as shown in the data of the Lithuanian Institute of Forestry, coniferous forests wither. In the places more remote from the pollution sources under the influence of emissions, changes of morphological, physiological, chemical and species composition of vegetation take place. In these areas, the increment of coniferous forests is 30-50% and deciduousness 20-30% less in comparison with non- affected areas. The white fungus disease which affects needles, leaves, branches and trunks is widely prevalent. Cancer of larch and pine-tree sprouts is especially dangerous.

Increased environmental pollution increases mutagenesis. It has become a characteristic of modern civilization. Among some four million pollutants circulating in the biosphere, in the Baltic region alone we found about 300 pollutants bearing mutagenic effects. They expose the genetic stability of species to great danger. Geneticians of the Vilnius State University (Lekevicius, 1980) determined that in the 3-8 km radius of the Mazeikiai oil-refining plant the frequency of point mutations in field vole (Microtus arvalis) increases 10 times. The same phenomena are observed on non-irrigated meadows with a high usage of mineral fertilizers. It is notable that the field vole is an example of chemical pollutants on animal species and possible impacts on man. In many countries there is now sufficient data to prove that human beings who come in close contact with chemicals such as mercury, and with plastics such as polyvinylchloride and who live in a polluted environment, suffer from chromosomal aberrations causing retarded or handicapped offspring.

At the same time, the environment transformation process was and still is an inevitable precondition and consequence of the further development of society. It gives an opportunity to create productive agriculture, to develop industry and transportation networks, to create a good economic basis for higher material, cultural and social population welfare.

The problem faced is how to deal with these conflicts, and in particular:

- How to avoid situations in which certain economic branches and planning organizations disregard local environmental conditions and only solve problems of their own interest?
- How to avoid the creation of bordering territories with contradictory functional purposes, which increase the self-decay of economical branches, prevents the stable economic development of the whole region and has an adverse affect on the environment?
- How to coordinate the interests of the separate economic branches and concerted development of the whole region?

The traditional environment protection agencies are unable to deal with these shortcomings. It is necessary to rationalize natural resources utilization of the region, taking into account redeveloping measures for the sustainability of regional development and the creation of better environmental conditions. While undertaking regional physical planning of the territory, one must not only consider the needs of each branch of the economy, but also the long-term perspectives of socio-economic and environmental development of regional human populations. In other words, sound environmental principles, maintaining the balance between ecological systems and the socioeconomic development in a chain of natural resources utilization and reproduction to ensure long-term economic development.

In order to realize the above, we urgently need a reliable set of tools for economic-environmental situation analysis and scientific experts system for top-level decisionmakers. Only in this case do possibilities really appear to select and implement Sustainable Regional Environmentally Balanced Development Strategies (SREBDS) for each region.

Environment Formation as a Part of Natural Resources Utilization and Socio-Economic Development of the Region.

In the last few years, the universal process of man's intrusion into nature and the spontaneous destruction of ecological systems in Lithuania was met by the rational use and reproduction of natural resources, in combination with the purposeful formation of an optimal environment. To support such an alternative, better interaction between scientific experts and decisionmakers was achieved (Kairiukstis, 1985). The efforts of scientists at the Academy of Sciences, branch institutes and higher schools were united under the program, "Man and the Biosphere". The General Model System (GMS) was created, which made it possible to optimize the development and specialization of the main resource utilizing branches of the national economy on a territorial basis (Kairiukstis, 1982).

Keeping to the tasks of sustainable development of the national economy, efforts have been already made for natural medium optimization (quantity of main landscapes determining its state), to determine the purposeful destination of the landscapes. An evaluation of separate territories was carried out. For example, the Department of Geography of the Academy of Sciences revealed the anthropoclimatic resources of Lithuania (Figure 3).

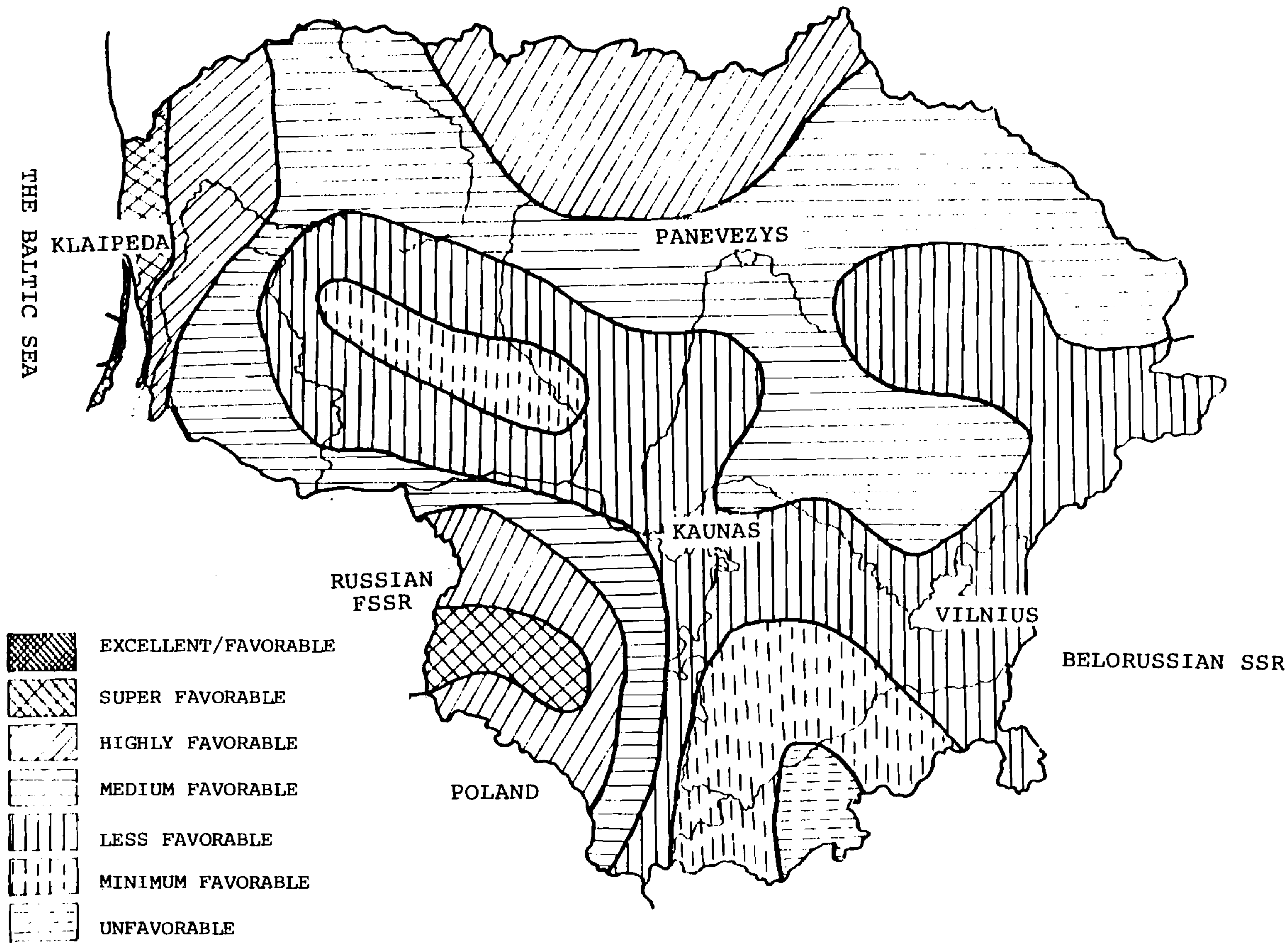

Figure 3: Territories of the Lithuanian SSR according to anthropogenic favorability.

Source: Department of Geography of the Academy of Sciences of the Lithuanian SSR.

It appeared that regions favorable from the point of view of the anthropoclimate such as the continental sea-shore of the Kursiu Marios lagoon, west and middle Suvalkija, the central part of North Lithuania have hardly been used for the development of recreation and health resorts. The Institutes of Construction and Architecture of the Lithuanian SSR together with the Vilnius State University prepared a distribution scheme of recreational regions (Figure 4). While undertaking such an optimization one has to take into account the local anthropoclimatic peculiarities, air and water pollution, so that the objects destined for recreation are notable for the healthy climate.

The joint efforts of scientific research institutes and scientists of higher schools distinguished those zones being protected for special purposes. They concentrate the natural fund of flora and fauna, landscape variety as well as historical and ethnographical objects. These zones include reserves of grassy and forest vegetation genofund and of separate animal species. Only the concentration of these territories and the legalization of their status can protect them from ever growing industrial penetration and from negative consequences of agriculture and industry. Moreover, part of the protected territories should at least satisfy the utilitary needs of recreation (berry plantations, fields of intensive recreational sport hunting, etc.).

The Department of Geography of the Academy of Sciences of the Lithuanian SSR evaluated the degree of erosion and denudation in Lithuania (Figure 5). Together with the Lithuanian Research Institute of Forestry and the Institute of Botany, those regions were determined which are lacking in forests (Figure 6). Means for afforestation were prepared to protect arable lands and waters (Kairiukstis et al., 1980). The investigations of the Institute of Physics of the Academy of Sciences of the Lithuanian SSR have made it possible to discuss in broad terms the background atmospheric pollution, fall-out of sulphur, fluorine, nitrogen and other compounds, to make model calculations and to reveal the influence of large industrial objects and towns on the neighboring regions. Data are stored on the intensive use of fertilizers and pesticides and their influence on ecosystems links in separate regions. All this is the basis for the monitoring and also the prognosis of inevitable change of forests and arable lands. This also serves as a basis to obtain a sustainable environmentally balanced regional development.

The state of the natural ecosystems depends on climatic background situations which have an impact on all ecosystems. Dendrochronological investigations carried out in the Lithuanian Research Institute of Forestry and in the Institute of Botany reveal the long-term rhythm of the forests' growth. Approximately every 11 and 22 years the maximum and minimum in the growth of trees repeats itself. The long-term (about 50 years) fluctuations of favorable and unfavorable ecological conditions are determined (Figure 7). For example, favourable conditions in 1904, 1915, 1925, 1945, 1957 and 1968, in areas with high humidity the growth of trees was 20-30% above average. Vice versa, in 1908, 1930, 1952, 1963 and 1978 the growth of trees was 20-30% below average. The fluctuations mentioned are in good correlation with crop capacity of agricultural lands. For example, the yield of cereals in that year is higher in which the marsh vegetation increment increases. It is thus possible to forecast forest growth and the growth of other vegetation for at least the next decade. Fluctuations of climatic conditions also bear an influence on the general economic situation in the region. This phenomena can perhaps be explained through the "fluctuation factor of entrepreneurship" developed by W. Krelle (1983). It must be taken into account while modelling the ecological situation and socio-economic development.

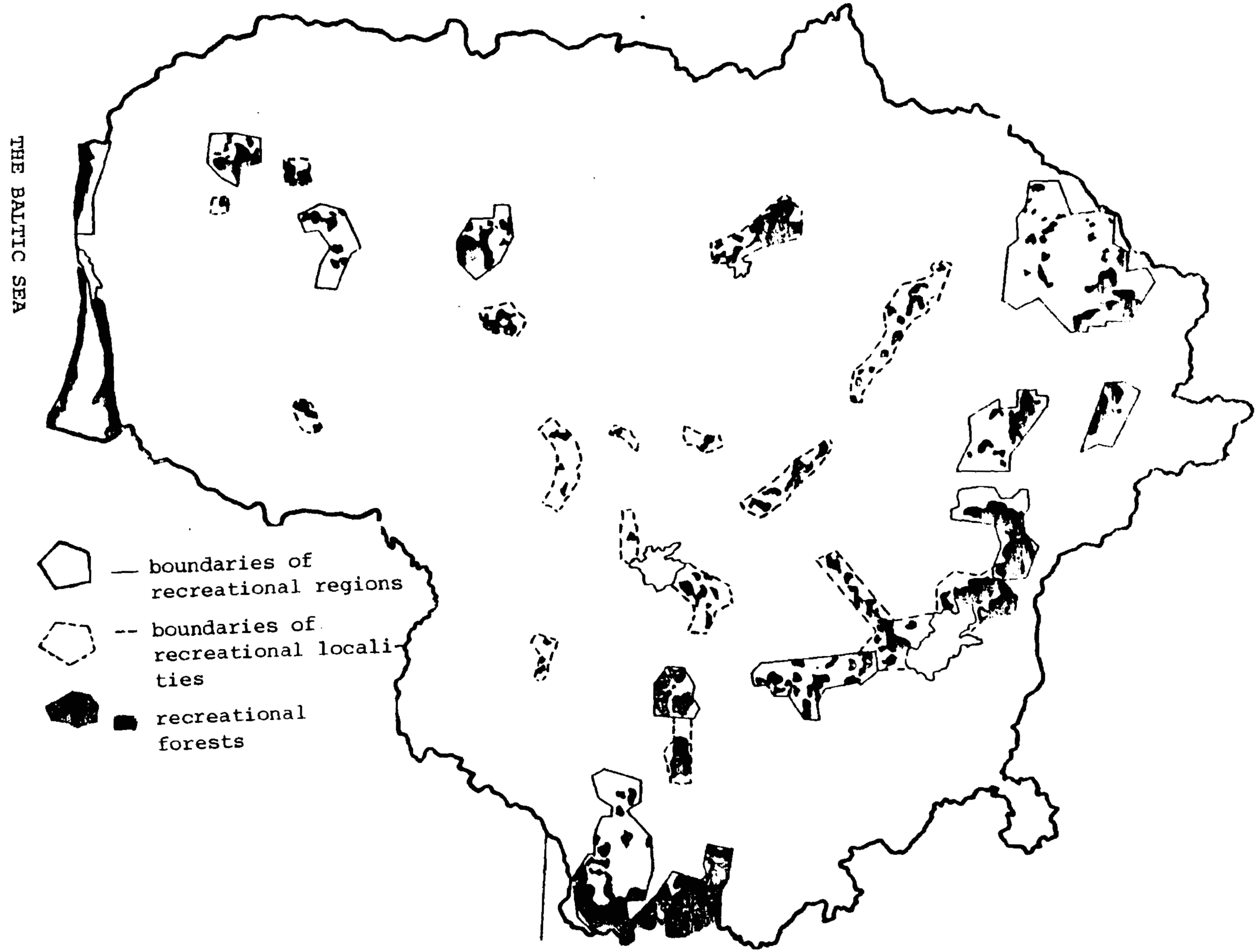

Figure 4: Recreational resources of the Lithuanian SSR.

Source: Scientific Research Institute of Building and Agriculture and the Vilnius State University, Lithuanian SSR.

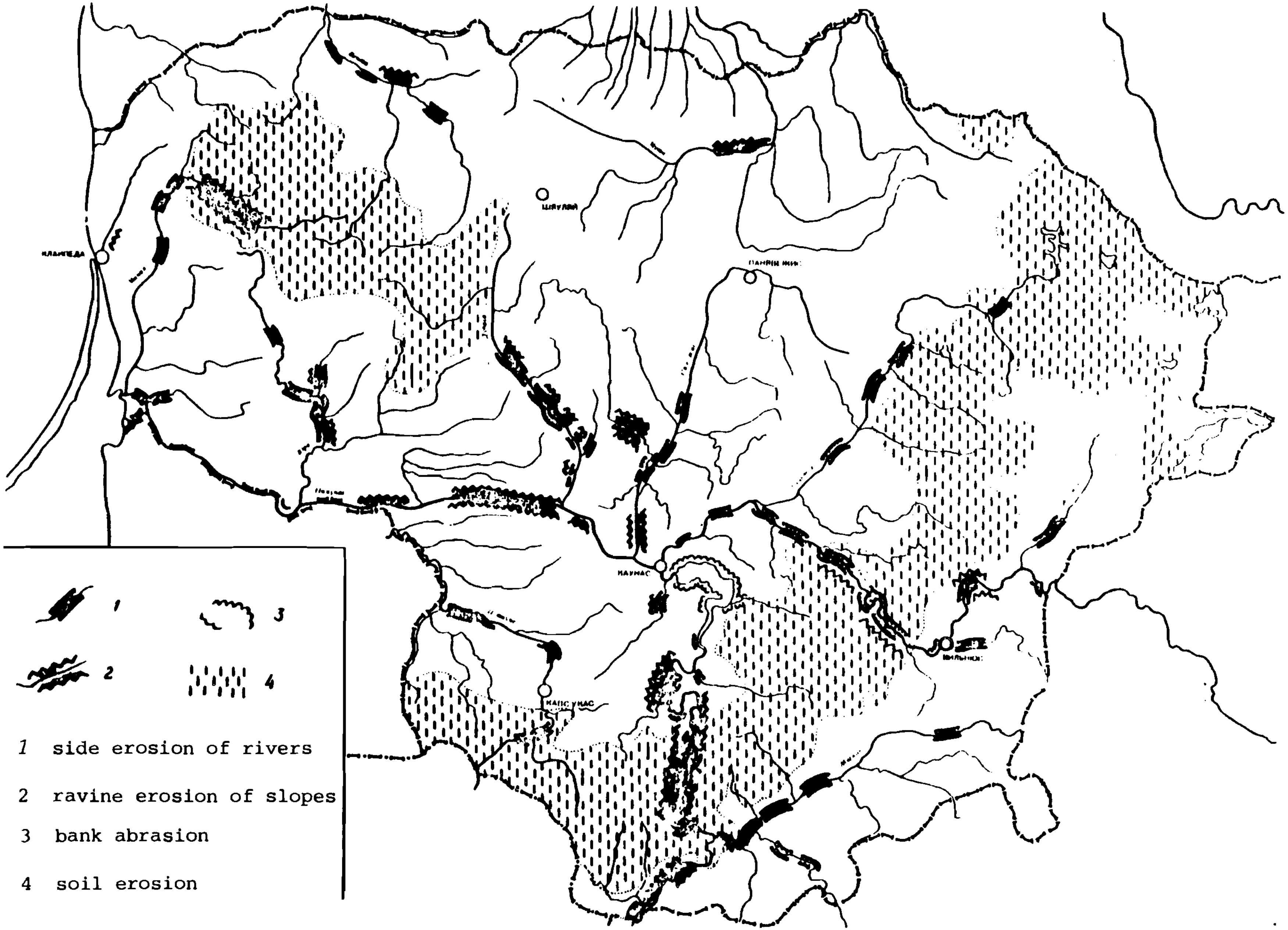

Figure 5: **The distribution of erosion and denudation processes on the territory of the Lithuanian SSR.**

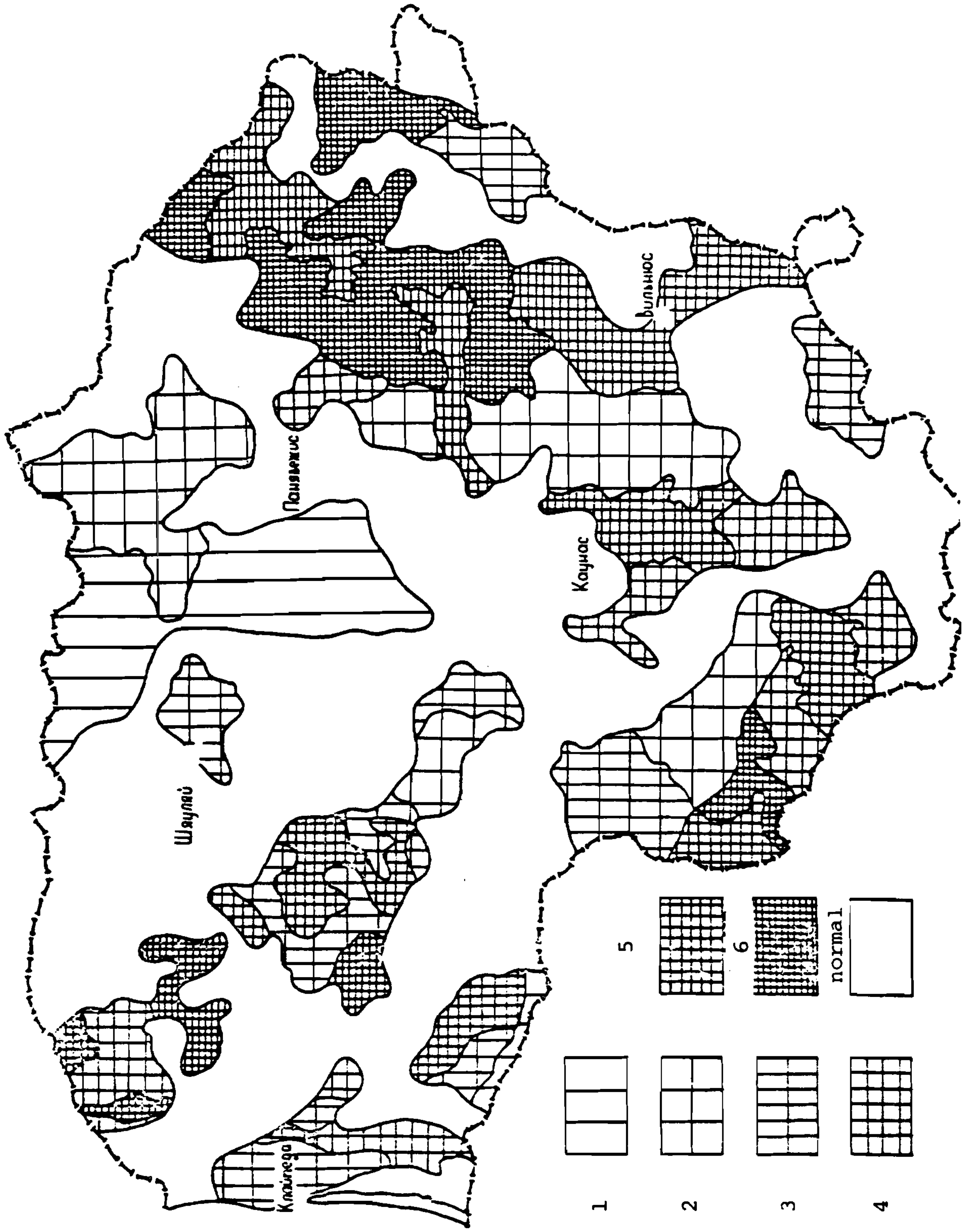

Figure 6: Regions of the Lithuanian SSR insufficiently forested from an ecological point of view. (It is necessary to increase wood covered areas by 1-3% in area 1, 3-5% in area 2, 5-8% in area 3, 8-10% in area 4, 10-15% in area 5 and over 15% in area 6.)

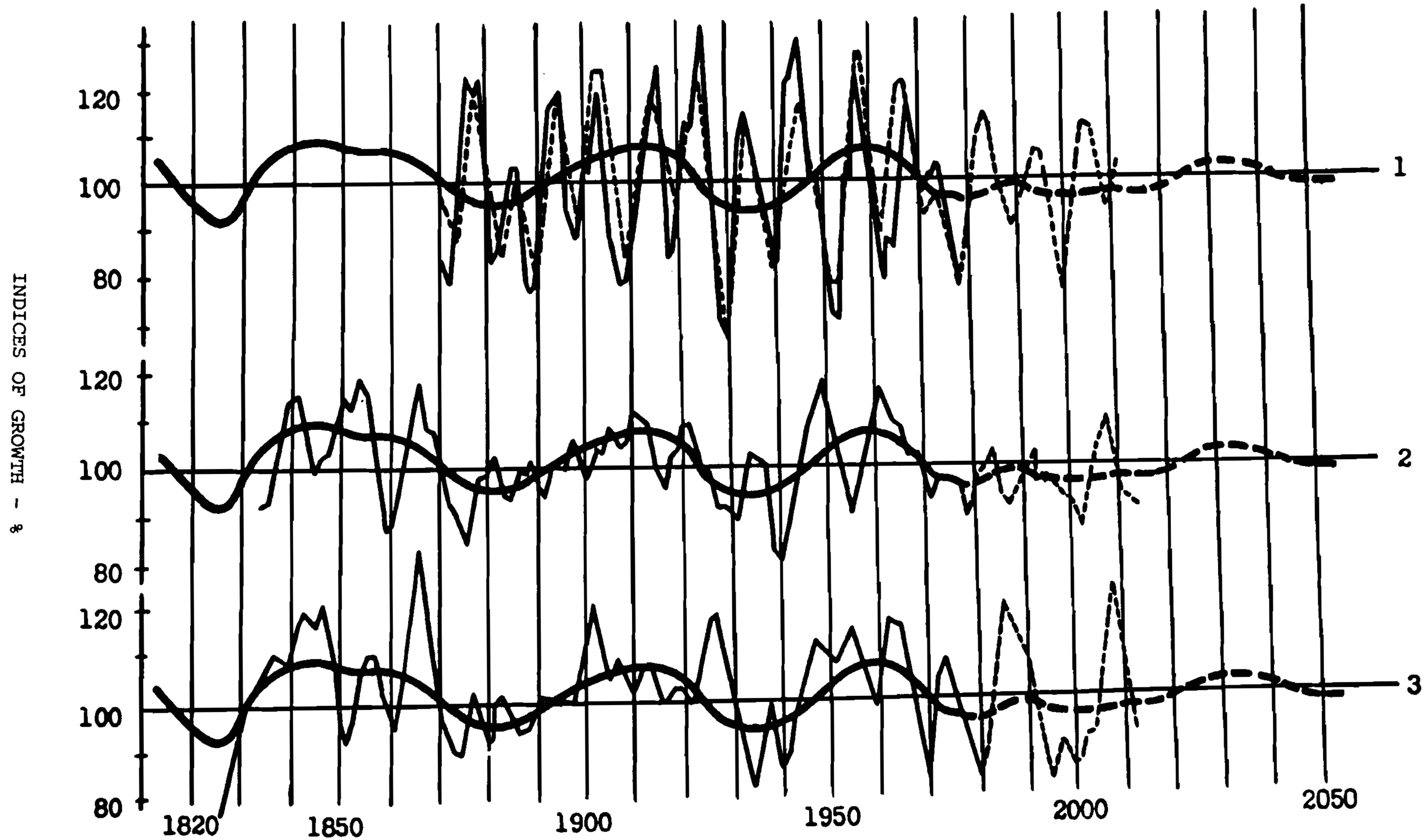

Figure 7: Climatic background fluctuations in the Lithuanian SSR;
___ factual data; -- forecast by model.
1 = Average for moisture soils; 2 = Average for dry soils, South Lithuania;
3 = Average for dry soils on the Baltic Sea.

The successful use of the ecological situation, forecast for the coming decade, and its adjustment to man's economic activity, make it possible to enlarge the ecosystems suitability and to grow more stable yields. For example, in Lithuania, during the drier and warm period, more productive crops should be sown as in the regions to the south (Ukraine, Byelorussia), giving preference to irrigation and moisture accumulation. On the other hand, for the period of cold and wet weather forecast for the end of this decade, one should be provided with sowing grain produced in the same district or in neighboring northern and western regions, widen the grassy fields and repair and maintain the drainage equipment. An analysis of the cereal yield during the last decades shows that a strategy of adaptive agriculture such as that outlined above might prove valuable.

The accumulated data based on the investigations of various branches of science (Gvishiani, 1977) as well as on data banks using the above mentioned approaches (see section on Analysis of Issues on the Regional Level) enabled the creation of the General Model System (GMS) of the optimal use of natural resources and environment formation based on socio-economic regional development scenarios (Kairiukstis, 1982).

Economic models (Buracas, Rajackas, 1982) simulating the development of the main branches of the national economy influencing the environment (agriculture, forestry, water management) and also of the industrial complexes (chemical, energy, etc.) through the Models of Interbranch Reproduction of Public Products and Land Use (Rutkauskas, 1978) give an opportunity to forecast and optimize the (regional) resources utilization.

The ecological consequences caused by the industrial processes in the course of public product reproduction are evaluated in the typified geographical landscapes. Besides, the model of environment factor dynamics suggested by the All Union Scientific Research Institute of Systems Analysis (Krutko, Pegov et al., 1982) and the CREAMS (Knisel, 1980) are also used. The adapted models are based on the suggestion that separate branches of the national economy, depending upon the management systems and technologies dominating in them, bear a different influence on the separate landscapes (farm lands, waters, urbanized territories, etc.). This influence is revealed in the changes of hydrological, erosive and chemical processes and parameters in soil, water and atmosphere. By simulating possible changes of farm lands and technologies, the desirable and undesirable tendencies of the economic influence on the environment are revealed. Those tendencies are evaluated according to the dynamic concept of the environment.

Analogously, the model adopted evaluates the ecological influence of the atmosphere on flora, fauna and man. In accordance with the functional destination of landscapes according to separate pollution sources (chemical plants, power stations, transportation networks, etc.), the necessary technological changes are made.

The results of economic development integrally determine the welfare of the population. The ecological consequences of economic development are determined and evaluated for each landscape with functional destination. These consequences determine productivity and genetic stability conditions of vegetation and animals, including man.

The decisionmaking (planning) bodies of the Republic select the optimal scenarios of natural resources utilization and regional environment formation. They analyze the alternatives and pass their decisions on to leading bodies—ministries, departments and industrial-agricultural complexes. The departments and complexes, carrying out the orders of the leading bodies through their economic systems influence the natural resources and environment on the specific territory. The annual and five-year results of this influence in the areas monitored, together with the amount of Gross National Product through the information channels (statistical) are returned to the GMS of the State Planning Committee. The information, bearing in mind the dendroclimatic prognoses of natural change of ecological conditions with the help of the mentioned models, makes it possible to correct the previously established annual and five-year scenarios for the optimal use of natural resources and environment formation.

For example, a preliminary optimization of farm lands shows that in the Lithuanian SSR the agrarian territories should occupy no more than 55-57% of the territory including about 17% of meadows stable to erosion. Forest areas should be widened up to about 31-33% of the country's territory. In regions with a small percentage of forests, as well as near highways and industrial complexes, it is advisable to grow antierosion protective forests. To keep a stable moisture regime, boggy areas and inner water reservoirs must occupy about 5-6%. The remaining territory (about 7%) will be inevitably urbanized. Conservation areas of various kinds, national and natural parks, recreational territories and territories under sanitary protection according to specificity, should occupy the most wooded areas, places of sandy dunes and with the greater number of lakes. Because these places in some cases are adjacent to farming and industrial-urban territories, the necessity for interstitial or buffer territories are needed. A special management of these territories is then determined. Therefore, the farming or forestry activity on specific territories are determined not only by the soil and climatic peculiarities, but also by the functional landscape destination. For example, forestry, in accordance with the dominating landscape destination specializes in:

1. Industrial wood growth - exploitable forests subsector;
2. Soil and water protection - agroprotectional forests subsector;
3. Recreation and rehabilitation needs - recreational forests subsector;
4. Conservation of flora, fauna and genofund - conservation forests subsector;
5. For scientific and hunting fauna needs - recreational hunting forests subsector.

For all these forestry subsectors, modules and programs are prepared for specialized economy management (Kairiukstis et al., 1983).

Optimizing landscape farm land will also show its specificity. Highly specialized industrial agriculture is retained in the main agricultural regions. In recreational and conservational areas, agriculture must be specialized to grow the so-called "bioproduction", unpolluted by chemicals.

On the other hand, in suburbs or lands adjacent to industrial centers as well as in other areas strongly polluted by industrial waste materials and transportation networking, state farms should not grow food (vegetables, cereals, etc.) but "technical" cultures necessary for industry, as well as flowers. As these territories are presently, and will be even more polluted in the future, their production, especially of vegetables and fruits, will be less suitable for food.

The division of the territory into zones according to their functional destination and economic regime will affect industries and the development of some towns. As we know, previously the growth of towns was determined by demographic structure, the availability of fresh water sources and other natural resources. Data on the state of atmospheric pollution, soil and water, also on the anthropoclimatic resources, prove that it is not advisable to evenly develop all the regions or a small state. It would complicate the struggle against industrial pollution, and would make the use of purification equipment and industrial waste materials more costly. In general, with the uniform development of industrial urbanization, the natural medium of pollution of the region is greater. All the more so as the even distribution of large towns and industrial plants in the region or state make it impossible to preserve non-polluted conservational and recreational territories which are distinguished by the most suitable conditions for health recreation.

In conclusion, it should be stressed that in the future, when the nature protection scheme of the Republic has been completed, the territory distribution has been carried out according to its functional destination, the economic activity in nature has been specified, a reasonable combination of branch and territory management fulfilled, only then will it be possible to escape the detrimental consequences in nature caused by branch management. It will promote a more rational use of natural resources, a stable development of agriculture, specialized water and forest husbandry with less expense in funds and labour force, to achieve a higher production; it will also help to lessen food cultivation pollution by industrial waste materials, to widen the urbanized areas and at the same time to retain clean recreational zones to ensure genofund and conservation zones for many years. Mitigation of the negative impact of human activities on the environment at a regional level will help to achieve a more sustainable development of systems of a higher level, including the biosphere as a whole.

CONCLUSIONS

The cumulative impact of industrial, agricultural and social development on the environment has approached a level where it is dangerous for particular regions and can be dangerous to the biosphere as a whole. At the same time, the environmental transformation process is still an inevitable precondition and consequence of the development of the material, cultural and social welfare of mankind.

In the process of general penetration of man into nature and the spontaneous destruction of ecological systems an alternative is made--the rational use of natural resources and reproduction united with an optimal and purposeful environmental formation. To realize this task, system approaches to large-scale global, zonal, regional and local problems to be solved were developed. Using the multi-faceted approach to resources and environment management, the situation in Lithuania was analyzed (regional level). Enlisting the rich heritage of scientific research and in collaboration with IIASA, the General Models System (GMS) was prepared on an interbranch basis. GMS should be of great use for the management and regional development planning agencies of the Republic. It consists of three blocks of models: economic models, models for the ecological evaluation of a medium, and models for the evaluation of social consequences of economic development and ecological changes. The cycle is modeled as follows: economy changes the environment (air and water pollution, destruction of natural ecosystems, etc.); the altered environment influences the biota including man, and through this by inverse link it influences the economic and social development of society (micropopulation).

According to the GMS the territory distribution optimization of the Republic conforming with the main landscapes was carried out beforehand, the specificity of the main landscapes' functional destination was revealed, the buffer zones between the landscapes of contradictory destination was pointed out, and tasks for the specificity of economical management (agricultural, forestry, etc.) were defined.

The use of the above-mentioned systems approach and the multi-faceted analysis of the rational use of natural resources and environment formation, when completed, will help to avoid detrimental actions in nature, to achieve the sustainability of regional systems and mitigate biospheric collisions.

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2. ABOUT THE METHODOLOGY OF COMPLEX ECOLOGICAL TERRITORIAL MANAGEMENT

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With the development of the scientific and technological revolution man is exerting still more and more pressure on the ecological components and the biosphere as a whole. As a result of this pressure, one can find, nowadays, the so-called "hot ecological sites", presented in different degrees of influence. Irreversible ecological processes were carried out in these "hot ecological sites" which have resulted in the destruction of plants and animals due to the total pollution of waters, soils and the air. These facts also create ecological conditions that are undesirable for human life.

Nowadays, we are witnessing the negative ecological "boom" on the ecosystem and biosphere level. As a result of the new situation, measures to be taken to manage and protect the ecological balance are of great importance. Undoubtedly, it will only be possible to solve the ecological problem on the basis of a complex ecological project. The existing practice of territorial management for urbanistic purposes cannot be theoretically and methodologically made use of to create new ecological projects. The latter just mention briefly the protection of ecosystems' components and the biosphere. On the other hand, the activities mapped out in the projects have no direct interconnections. This imposes a new evaluation to be made of the theoretical, methodological and practical solutions of the existing territorial management as well as a new type of complex territorial management must be perceived.

The complex solution of ecological territorial problems is an extremely complicated process as a multi-factor systematic analysis to be applied in investigation and design work. So far, this has been successful in some specialized fields such as forestry and urbanistic systems. However, a comprehensive approach has not yet been completely solved. This matter should be treated theoretically and methodologically and the right methodology for the purpose should be chosen to be applied in practice.

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On the territory of the town of Vratza and its surroundings (which include agricultural and forestry lands, populated areas, industry, automobile transport, etc.), the Scientific and Coordination Centre for Ecology and Environment Protection is attempting to work out a new method for complex ecological territorial management and an ecological and territorial project. In developing this method, we have been guided by the objectives and assignments of the ecological project.

In order to complete the project, the methodology goes through two stages: 1) the investigation stage, and 2) the designing stage. During the first stage, an examination of the terrain and ecosystems having various functional purposes are explored. When studying the ecosystems, a totality of a ecotop (abiotic medium) and a biocenose (living organisms) is assumed. First, one must distinguish between different types of ecosystems and then each ecosystem should be studied individually, starting from the basic rock investigation both with respect to the detailed differentiation in geological and geomorphological characteristics and to its natural metalogenics (metal content).

It is known that a great number of heavy meals from industrial wastes and transport are toxic. Very often, territories with high natural metal containing background, if not studied properly, lead to inaccuracies during the research process. Moreover, all heavy metals found in investigation of plants and animals on a given territory can be improperly referred to pollution. Thus, soils should be studied in detail with respect to their genetic type, degree of erosion and geochemistry. It is also imperative to find out the degree of soil pollution in forestry, agricultural, industrial and automobile transport. In terms of the degree of solution, soils should be classified according to their fitness for use as agricultural, forestry and other lands.

The state of the surface and sub-soil waters and lakes should be studied in detail and the ecosystems contained in them should be established. It is necessary to find out their heavy metal contamination, the chlororgenic acid and other combines and their pollution resulting from the main activities such as agriculture, industry and automobile transport. A classification of the waters in terms of their utilization should be made on this basis. The degree of pollution of sub-soil waters should be made according to the pollution of surface waters.

Air is one of the faster means for spreading of toxic elements. Investigations should be made on the degree of air pollution, on the kinds of pollutants and the sources of pollution.

Qualitative and quantitative research should be made also on the vegetation. The diversity of species, the biomass productivity and the availability of toxic elements in vegetation according to the environmental pollution should be established. Based on this, an estimation of the fitness of use of the plant species and the rare and endangered plants should be made.

This research should prove the actual and potential productivity both of the natural and artificial forest and agricultural ecosystems. The secondary productivity, i.e., the animal world, should be studied as a component of the ecosystem. It is necessary to study the living organisms qualitatively and quantitatively; their productivity is assessed and the animals which have become rare and endangered from extinction are established.

The agricultural ecosystems, are previously mentioned, are in all cases of anthropogenic character. They should be studied in detail, both in terms of abiotic and biotic components and in terms of their structure and functions.

Animal-breeding farms which are included in agricultural territories are not only places for secondary productivity but are also pollutants of a big scale. It is necessary to establish the coefficient of utility in using the energy in the primary – secondary productivity link in the trophic chain. Then, the most efficient ecological and economic indices for energy use should be sought.

The technogenic ecosystems (various industries) are heavy sources of pollution. Their infrastructure, the pollution they cause of the environment and that imitated by them in a qualitative and quantitative respect should be studied. Finally, efficient ecological and economic methods should be found to restore these ecosystems to a normal ecological condition (not to pollute the environment).

Transportation, especially that of automobiles, is also one of the major sources of pollution. The pollutants and the ecological trophic chains included in them should be investigated qualitatively and quantitatively. It should be taken into consideration that transport appears to be a large consumer of ground territory which otherwise could be used for primary productivity.

The urban ecosystems are one of the most complicated systems. All their ecological parameters regarding pollution, and acoustic energy should be studied and respective measures to create urbanistic ecosystems of the eco-polis type should be found. All these investigations form the basis for study of ecological territorial and management projects consisting of two parts:

1. Making a statement (i.e., it is a product of the research work and reflects the status of all ecological parameters).

2. Making a design (containing all activities for complex ecological restoration of territories).

These activities are classified in terms of priority which afterwards enables a decision to be taken in order to establish the normal ecological condition of the territories destroyed. The activities should be of a comprehensive nature and a separate plan for the different categories of lands in the functional respect should be made.

It has become clear from what has been stated that complex territorial management is a most complicated process which requires great knowledge. It can be done only on the basis of the methods for systematic analysis and ecological approach.

3. FACTORS BEARING AN IMPACT ON REGIONAL RESOURCES MANAGEMENT

3.1 LONG-RANGE ENVIRONMENTAL BACKGROUND FLUCTUATIONS AS THESE APPEAR FROM DENDROINDICATIONS: HISTORICAL AND PRESENT FLUCTUATIONS

3.1.1 TEMPERATURE FLUCTUATIONS IN WESTERN EUROPE DURING THE LAST 1000 YEARS AS DERIVED FROM TREE RINGS AND OTHER PROXY INDICATORS

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ABSTRACT

This paper starts with a brief overview on the temperature fluctuations in Western Europe during the last 1000 years. Then the dendroclimatological concept to extract climatic information from tree rings is demonstrated and applied in two case studies. For verification the temperature estimates are compared with direct measurements as well as with indirect evidence. This evaluation proves the potency of dendroclimatology for the reconstruction of environmental changes back into the past.

INTRODUCTION

Until 50 years ago it was commonly agreed that the climate of the past 2000 years was practically invariable. But today it is generally acknowledged that the climate never was constant. Through intensive research efforts the knowledge on climate history has been furthered into two directions, first, the time axis has been extended considerably into the past, second, the temporal resolution of the climatic records has been much refined. All these attempts have escalated as one has become increasingly aware of the impact of climatic change on human society. In order to be able to consider what could happen in the future, and to define the potential range of climatic variation and the frequency of climatic extremes, still more knowledge of what has occurred in the past is necessary (Kelly 1979). The reconstruction of the climate of the pre-instrumental era depends on so-called proxy indicators of climate, e.g. distribution limits of animals and plants, pollen profiles, lake levels, chemical substances in ocean sediments or ice cores, and also tree growth; in addition documentary climatic observations of floods or droughts and indirect evidence of climatic extremes like grain prices or tithes are useful records.

In the following section the last 1000 years of climate are briefly summarized according to Schönwiese (1979). To begin with, in Figure 1 the temperature fluctuations of the last 10.000 years are illustrated. But due to the rough time scale the so-called "Little Ice Age" shrinks to a single valley, and the so-called "Medieval Optimum" is represented only by a single peak in the curve. But there is already more knowledge about this time span (see the following table):

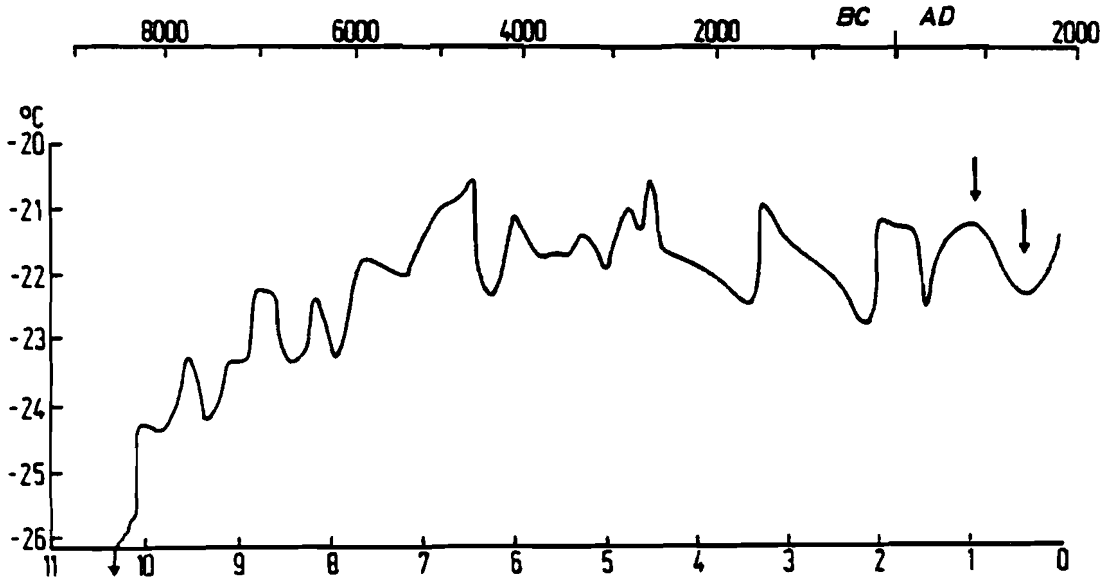

Figure 1. Temperature fluctuations in Europe over the last 10.000 years according to Schönwiese (1979); the Medieval Optimum and the Little Ice Age are indicated by arrows.

time	description of the climate
1950	"modern optimum": warm epoch
1850–1550 (1850, 1750, 1650, 1550)	"little ice age": cold epoch temperature by 1°C less than at present dry
1450–1350 (1450, 1350)	"climatic change": cooling rich in precipitation heavy storms
1250–950 (1250, 1150, 1050, 950)	"medieval optimum": warm epoch, temperature by 1-1.5°C higher than at present precipitation first poor, later rich

From 950 to 1200 the Medieval Climatic Optimum occurred probably with two culminations around 900/1000 and 1150/1300. The annual average of temperature was by 1 to 1.5°C higher than today, and also the precipitation was high, both resulting in a warm and moist climate. After this beneficial epoch the climatic conditions turned worse, which means the temperature decreased and as it is known for the North Sea coast the frequency of storms and floods increased. Well known are the floods of 1250/51, 1287, 1304 and 1362. Between 1313 and 1317 cool summers prevailed and harvest failures are reported. From around 1550 a long-lasting climatic deterioration started, the Little Ice Age, which lasted until around 1850, whereby the temperature was by 1°C lower than today. Then temperature increased again, above all between 1890 and 1900 and between 1940 and 1950, resulting in an overall increase by 0.8°C from 1850 to 1950. After a short interruption of this trend a new increase of temperature can be experienced from 1970 onwards.

Can these climatic changes, derived from both direct measurements as well as indirect evidence, be confirmed and refined using dendroclimatology?

DENDROCLIMATOLOGY

During the last two decades dendroclimatology as the science by which to extract climatic information stored in tree rings was essentially furthered by Fritts (1976) and his group in Tucson (USA). In Western Europe where basically the same concept is applied there is nevertheless no systematic application of dendroclimatology as yet. There are some common efforts of the groups in Belfast, Liverpool and Norwich in the UK (Briffa et al. 1983); there are studies performed in Birmensdorf in Switzerland

(Schweingruber et al. 1979), Marseille in France (Serre 1978), Krakow in Poland (Bednarz 1984), as well as common studies of the groups in Hamburg in the FRG and Lund in Sweden (Aniol, Eckstein 1984); but this list is certainly not complete.

A brief introduction into the basic dendroclimatological concept is given below, and the subsequent two case studies will illustrate the kind of information that can be obtained from tree rings.

Fritts (1976) showed how the climate of a given year t effects the ring width in a tree (Fig. 2), but not only for that same year t, but through effects on buds, sugar, hormones, and the growth of needles and roots also in subsequent years so that the response extends over several years. As each year t influences year t+1, t itself is influenced by the preceding year t-1. This complex relationship makes the extraction of climatic information from tree rings rather complicated.

For the reconstruction of climate the series of ring widths of many trees must be averaged to dampen individual variations of growth and thus to gain a mean series showing the common response of a group of trees to the prevailing climatic influences (Fig. 3).

The basic strategy of dendroclimatology is to find a statistical relationship between a biological set of data such as ring widths and a set of climatic variables such as temperature and precipitation. This can successfully be done only for a period, for which the values of the climatic variables have been measured. A part of this period is used to build up a model for the climate-growth relationship (calibration period). If a good agreement between measured and estimated climatic values can be achieved, one can use the model to compute estimates for the

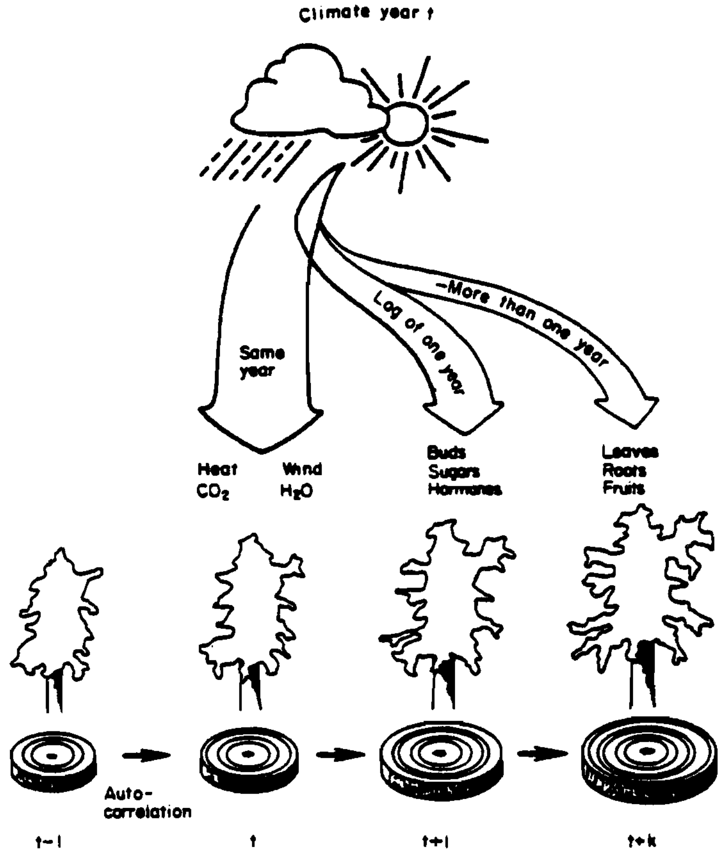

Fig. 2 Effects of the climate of a given year t on the ring widths in the year t and in subsequent years according to Fritts (1976).

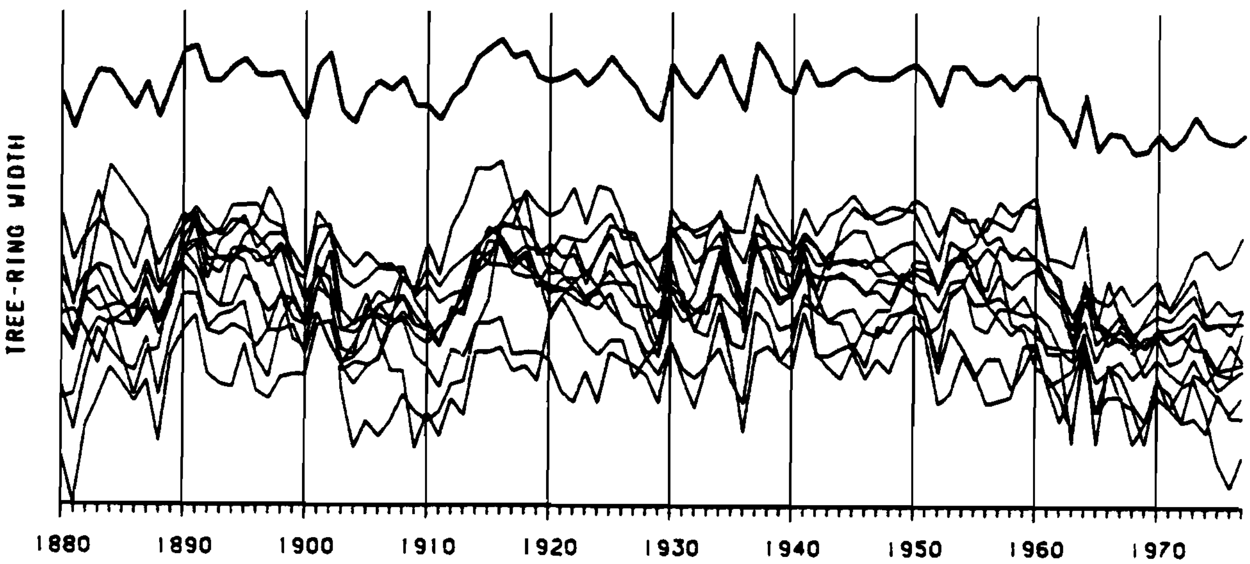

Fig. 3 Ten cross-dated tree-ring series of pines from Northern Sweden and the resulting mean curve (thick line) (Aniol, Eckstein 1984).

climatic variables in a second period for which measurements of the climatic variables are still available. If in this verification period the approximation fits equally well, one can use the model to estimate values for the climatic variables in a third period for which no climatic measurements are available. This period is the reconstruction period.

DENDROCLIMATOLOGICAL CASE STUDIES

In the first case study the tree-ring widths of larch, spruce, and stone pine from Tyrol (Austria) were used (Eckstein, Aniol 1981). The collection of the wood samples and the composition of the three tree-ring chronologies were made by Siebenlist-Kerner (1984). The chronologies contain tree-ring series from living trees as well as from building timber from farm houses, barns and store houses found at heights of 1200 to 2100 m a.s.l., going back at least as far as 1471. The necessary climatic data were supplied by a weather station about 10 km from the tree sites. The records for the average monthly temperature start in 1851 and the records for the sum of the monthly precipitation go back as far as 1891 A.D.

The effects of the variation in mean temperature and total precipitation on tree growth for each month from previous July to current August on the variation in ring width during the period from 1891 to 1968 are shown in Figure 4. A value above zero indicates a direct relationship and a value below zero an inverse relationship; the vertical lines delineate the 0.95 confidence level for each effect. The ring widths of the years t-1, t-2, t-3 are also taken into account.

The response diagrams of the three species show that

- the temperature is of dominant importance for the growth of all three tree species, usually showing a positive effect,
- this positive influence of temperature is obvious for the

previous autumn (October and November) and the current summer (May to August),

- the precipitation is of minor importance and does not show any common response pattern for all three species, and
- the ring widths of the year t-1 and t-2 have a positive effect on the ring width in the year t.

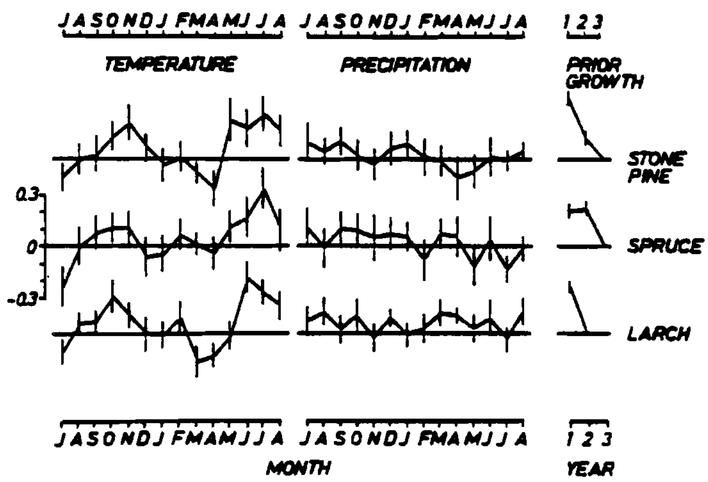

Fig. 4: Response functions for stone pine, larch and spruce in Tyrol (Austria) (Eckstein, Aniol 1981).

These statistical results are supported by biological evidence. A number of scientists have pointed out the importance of summer temperature for the growth of trees in high altitudes because a warm summer is favourable to high net photosynthesis (e.g. Tranquillini 1976). The carry-over effect of the prevailing living conditions in one year to the growth in one or more following years, proven statistically, has also been found in empirical biological studies. This means that the effects of an unusually cool or warm summer on growth are smoothed over several years, presumably by the retention of the needles and by the development of the cuticle which is to prevent desiccation damage in the subsequent winter.

It is evident that in the ring width a large amount of information on summer temperature is stored. Consequently one could try to extract this information for the recon struction of summer temperature records as far as tree-ring series are available. The result is shown in Figure 5. In addition to the reconstructed annual values of summer temperature the low frequency fluctuations have also been calculated and plotted; below average values are plotted in black.

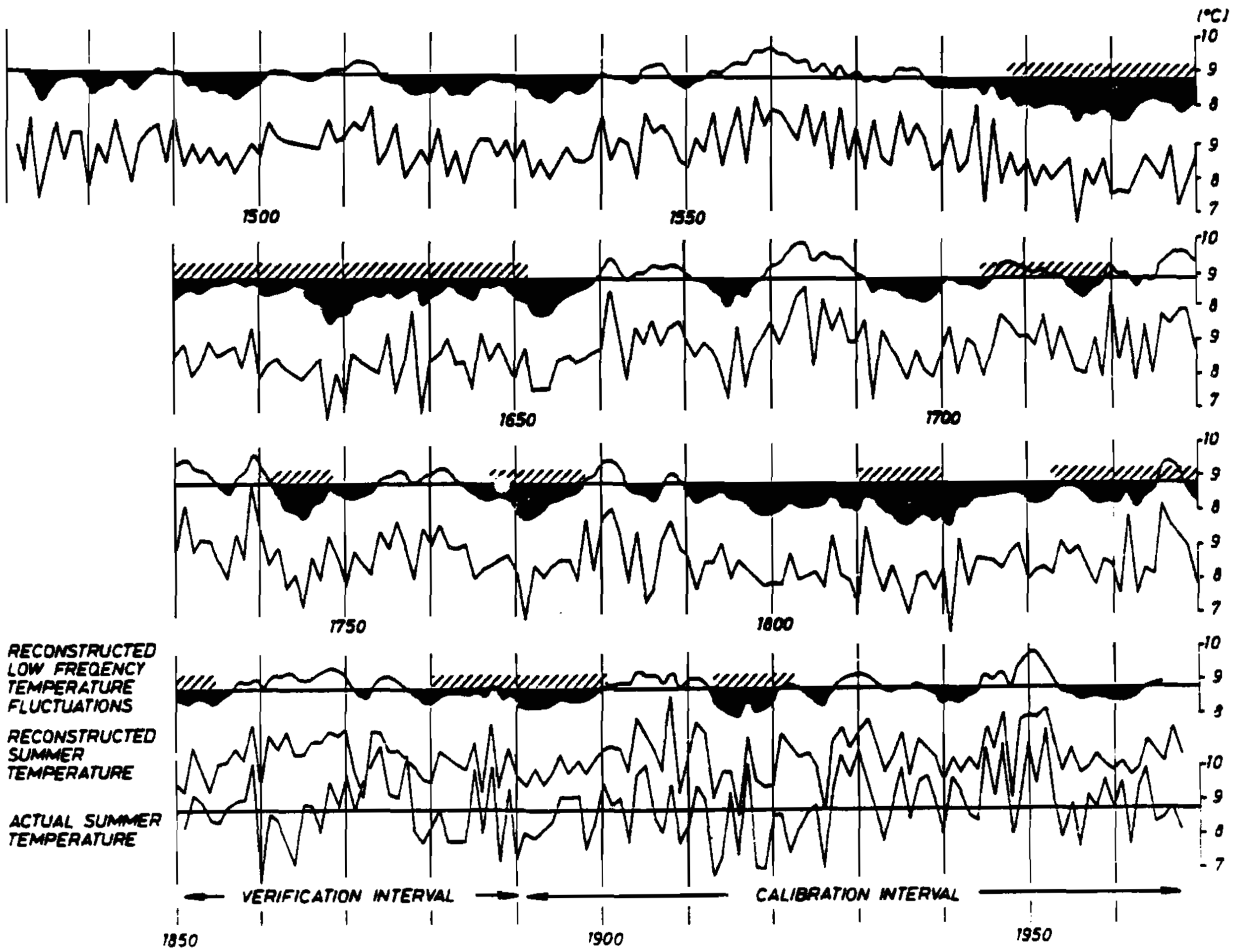

Fig. 5 Reconstructed summer temperatures and their low frequency fluctuations from 1968 to 1471 for Tyrol (Austria) (Eckstein, Aniol 1981).

In the second case study (Aniol, Eckstein 1984) the tree rings of pine from four sites in northermost Sweden at the northern timberline around 400 m a.s.l. are used (Bartholin, Karlén 1983). Since this area is almost untouched by man it is especially suitable for such analyses. Mountain birch is the main tree species, whereas pines are infrequent and show a relic type of distribution.

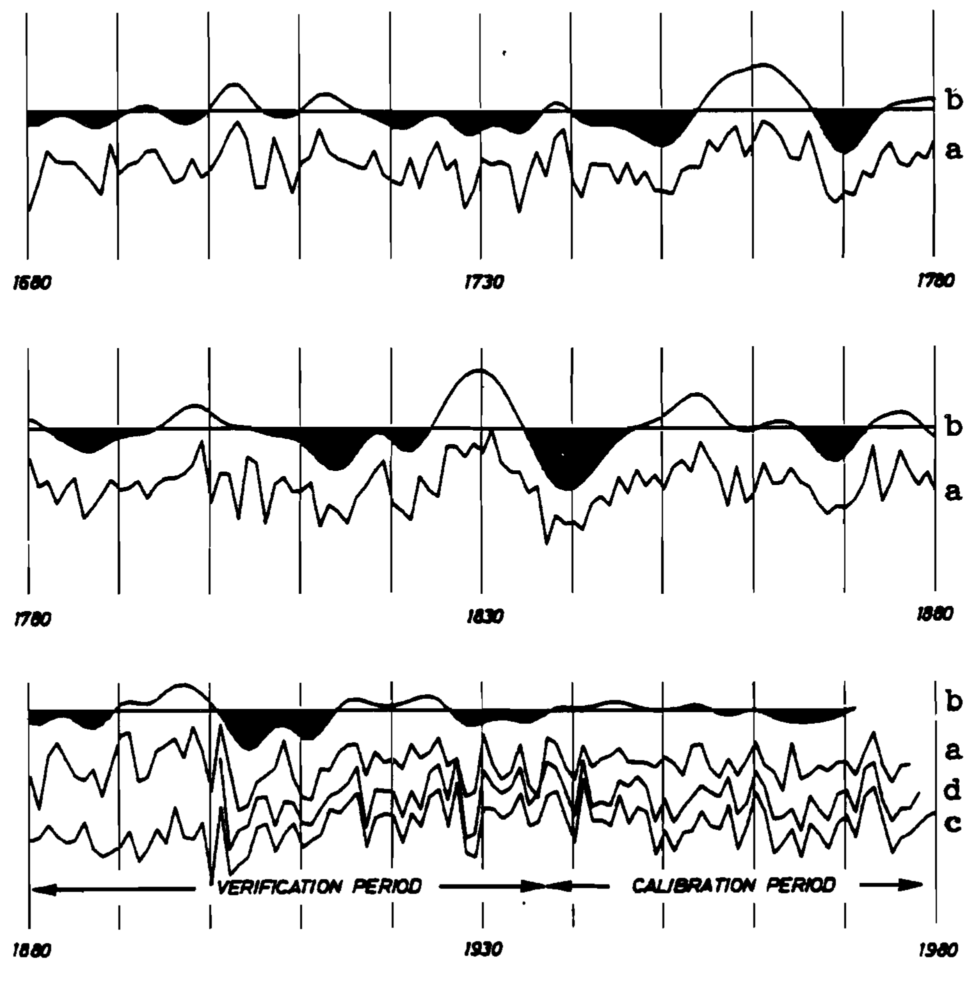

Fig. 6 Reconstructed July temperatures and the low frequency from 1980 to 1680 (a and b); c mean temperatures of July in Karesuando 1980-1880, d mean temperatures of July in Kiruna 1978-1901 (Aniol, Eckstein 1984).

The growth of 60 trees was correlated with the weather records of the station in Kiruna 50 km southeast from the tree sites. Monthly data of temperature and precipitation were available for the period 1901 to 1979. The calculation of how the trees respond to these climatic conditions is based on 43 periods of 14 months each from previous July to current August from 1938 to 1980.

At all four sites the temperature is of dominant importance for the tree growth. If one considers temperature in detail, July temperature has by far the greatest influence. Consequently one could try to reconstruct the July temperatures. The reconstructed annual values of July temperature and the low frequency fluctuations are shown in Figure 6; below average values are coloured black.

DISCUSSION

If we try to compare the estimates of low frequency temperature fluctuations of both regions, Scandinavia and the Alps, we find it confirmed that they do not occur contemporarily. But there is no simple or constant phase difference between north and south either. Therefore the regions will be considered separately.

The Alpine site will be considered first. The reconstructed summer temperatures give a good representation of the actual temperatures in the verification period. But how reliable are the reconstructed temperature fluctuations for the time before 1850? We checked the periods of below-average summer temperatures against the more or less known intervals of glacial advances and retreats (Patzelt, pers. comm.).

There are historically known glacial advances in the Alps as indicated by hatching in Figure 5 from 1913 to 1925, from 1880 to 1903, from 1810 to 1855, and from 1768 to 1780. In the time before 1770 there was an advance beginning presumably about 1705 and reaching its culmination about 1720, and possibly another one in about 1743. Around 1600 a long period of maximum length of the glaciers is reported. Recently, an advance of the Great Aletsch Glacier in Switzerland could be accurately fixed in time to have occurred from 1588 to 1653 (Holzhauser 1984). The period from the late 16th century through the middle of the 19th century is characterized by long-lasting periods of below-average temperatures. But even within those periods there were single summers occasionally warmer than average summers. In the decade from 1680 to 1690 the Grindelwald Glacier was minimal. The period from 1855 to 1880 is also reported as an extreme glacial retreat throughout the Alps.

But apart from the confirmation of the estimated low frequency fluctuations extreme single years can also be confirmed by indirect evidence, for example from documents on the dates when the tithes were paid in grain in Switzerland (Pfister 1979). These dates were chosen according to the stage of maturity of the crop, and maturity was essentially a function of temperature in May and June. Series of cold early summers were derived for 1688-1702, 1740-51, 1766-71 and 1812-17. Cold and moist summers were experienced in 1627/28, 1673, 1675, 1740, 1770, 1785, and above all in 1816 ("the year without a summer"). In 1821 and 1822 the largest difference between two subsequent summers was reconstructed from harvest records which corresponds to a temperature difference of 4^{o}C. All in all, the dendroclimatologically estimated summer temperatures for the Alpine region are rather realistic and earn some confidence.

More difficult is the verification of the reconstructed temperatures in North Sweden. First of all, the reconstructed values were compared both with the actually measured data of the station of Kiruna back to 1901 and of Karesuando near the Finnish border 120 km east from the tree sites. From the latter station climatic data are available up to 1880. During this period there is a good similarity between measured and reconstructed temperature. Until 1800 the fluctuations could be verified by an independent dendroclimatological study using birch trees from Finland. All above-average and below-average summer temperatures at both areas coincide with each other.

If the striking deviations from average temperature beyond 1800 can also be verified by glaciological, historical or other evidence, we will continue to estimate the July temperature back to A.D. 436. This is at present the total length of the pine chronology of Northern Sweden (Bartholin, Karlén 1983).

CONCLUSIONS

A great deal of tree-ring analyses have been carried out in Europe in the last 20 years, but this work is mostly unsuitable for climate studies. Almost all the existing chronologies have been constructed for dating purposes. Thus the criteria for the inclusion of samples into a chronology were purely those of convenience in producing a useful dating tool.

The living trees in Europe are not of great age. All the long chronologies depend on the use of timbers from architectural and archaeological structures. The origin of these timbers is often uncertain and there may be no modern analogue of the forest from which the timber were cut (Eckstein, Pilcher 1982). Although the chronology may be presented as a continuum running up to the present day, it is not sure that the earlier portions represent trees growing on similar sites to the modern portion. But since Europe has the best climate data base in the world, dendroclimatology should try to overcome the limitations mentioned by common and interdisciplinary efforts.

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3.1.2 NATURAL FLUCTUATIONS OF CLIMATE IN THE EASTERN REGIONS OF THE USSR BASED ON TREE-RING SERIES

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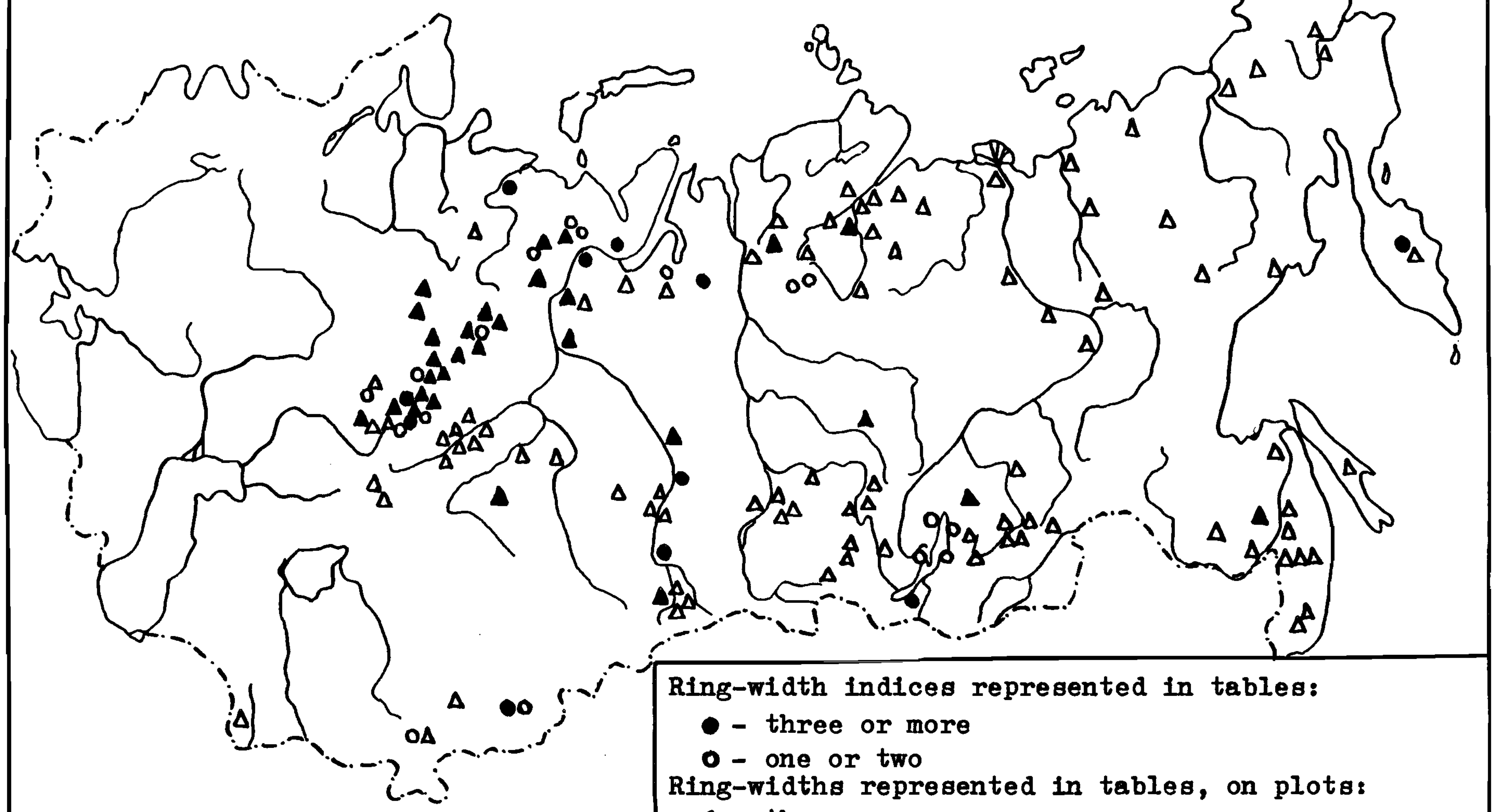
Tree-ring chronologies

Spacious territories of the USSR (the Urals, Siberia, Far East, Middle Asia) are comparatively poorly studied from the dendrochronological point of view. More or less systematic investigations began from 1960's. Tree-ring analysis was mainly used for reconstructing climatic and hydrological conditions, for studying forest ecosystems dynamics, environmental and tree-ring cycles, for dating catastrophic phenomena.

In most cases living coniferous trees were used in constructing tree-ring series. Archaeological and subfossil wood were used rarely. At present about 350 tree-ring chronologies are available from the eastern regions of the USSR, as well as tables of ring-width and its indices and plots. Fig.1 shows distribution of the tree-ring chronologies obtained for the eastern regions of the USSR. The most investigated areas are the Urals, Southern and Northern Siberia, the least investigated ones are Central Sibiria, Far East and Middle Asia. The most

Fig.1. The distribution of the obtained tree-ring chronologies in the eastern regions of the USSR



Ring-width indices represented in tables:
- ● - three or more
- o - one or two

Ring-widths represented in tables, on plots:
- ▲ - three or more
- △ - one or two

abundant are chronologies of Pinus sylvestris L. (about 150), Picea obovata Ledeb. and P. schrenkiana Fisch et Mey (about 90), of some species of Larix genus (about 80), Pinus sibirica Du Tour and P. koraiensis Sieb. et Zucc. (about 35). However, only 72 series have been recently published as tables of ring-width indices. The most long-term are the chronologies of Juniperus turkestanica Kom. (1224 years, Middle Asia, K.D.Mukhamedshin,1978; 808 years, Middle Asia, N.V.Lovelius, 1979) and of Larix sibirica Ledeb. (1010 years, the Polar Urals, S.G.Shiyatov,1981; 867 years, West-Siberian forest-tundra, S.G.Shiyatov,1975; 677 years, Altai, M.F.Adamenko, 1978). At present 12 chronologies over 500 years are available.

Sparsely distributed chronologies do not allow for analysis as tree-ring variability and climate over the whole territory. Therefore we have restricted ourselves to the series of coniferous species growing in high mountains and subarctic regions, containing the most reliable climatic information in ring-width indices.

Materials and methods

Analysis of tree-ring variability in the eastern regions of the USSR has shown that Larix genus are best suited for dendroclimatic reconstructions. Ring-width indices of Larix contain more reliable climatic information than those of Pinus, Picea and Abies. This may be caused by biological and ecological peculiarities of the larch, such as light-loving, poorer canopy density, deciduous, ability for better usage of thermal conditions of the vegetation season in biomass

Table 1

Characteristic of dendrochronological series used in this paper

NN series	Regions	Altitude	Species	Number of trees	Length of series	Mean sensitivity	Authors
1	2	3	4	5	6	7	8
1	Polar Urals, Rai-Iz massif	150-300	Larix sibirica	10	1648-1964	0.36	Shiyatov, in the press
2	- " -	150-380	- " -	71	960-1969	-	- " -
3	Subpolar Urals, Neroika Mt.	550-700	- " -	14	1673-1970	0.43	- " -
4	- " -	- " -	- " -	52	1673-1970	0.38	- " -
5	Northern Urals, Konzakowski Kamen Mt.	800-950	- " -	23	1598-1969	0.29	- " -
6	- " -	- " -	- " -	70	1590-1969	0.33	- " -
7	Southern Urals, Iremel massif	1000-1100	- " -	11	1770-1972	0.31	Shiyatov, 1978
8	Jamal peninsula, Chadyta-Jaha river	15-30	- " -	14	1656-1982	0.39	Shiyatov, not published
9	West-Sibirian forest-tundra, Lower Taz river	- " -	- " -	22	1624-1969	0.34	Shiyatov, 1984a
10	- " -	- " -	Pinus sibirica	27	1273-1969	0.18	Shiyatov, 1973
11	- " -	- " -	Picea obovata	136	1245-1969	0.24	Shiyatov, 1972
12	- " -	- " -	Larix sibirica	156	1103-1969	0.25	Shiyatov, 1977
13	- " -	- " -	- " -	30	1103-1969	0.27	Shiyatov, 1975

1	2	3	4	5	6	7	8
14	Eastern Taimyr, Lower Khatanga river	10-15	Larix gmelini	20	1514-1977	0.51	Shiyatov,1979
15	Putorana Plataeu, Tembengi Lake	Upper timberline	- " -	15	1866-1969	0.28	Galaziy,1981
16	Khamar-Daban mountain range, Langatui river	1710	Pinus sibirica	20	1858-1959	0.10	Galaziy,1981
17	Zailiyskiy Alatau, Talgar river	2800	Picea schrenkiana	20	1782-1978	0.14	Boršceva,1981a
18	Kungey Alatau, Satty site	2100-2400	- " -	16	1590-1978	0.15	Boršceva,1981b
19	Kamchatka, Tolbachik volcano	1300-1400	Larix kurilensis	11	1793-1980	0.23	Balčiunas and Krikšciuniene, 1984

increment. Therefore in our report the tree-ring series of Larix sibirica Ledeb., L. gmelini Pilger and L. kurilensis Mayr growing at the upper and polar boundaries of forest vegetation were basically used. Brief characteristics of these series are given in Table 1.

Along the two profiles - the Urals (meridional) and the Subarctic (latitudinal) ones the majority of standardized chronologies were obtained. The Urals high mountain profile is 1300 km long, including the Polar, Subpolar, Northern and Southern Urals. 30 mean and 8 generalized chronologies from 198 to 1010 years have been derived from the upper forest boundary along this profile (Shiyatov,1981). 32 mean and 8 generalized chronologies from 140 to 867 years have been derived from the Subarctic profile stretching for 2100 km (from the Lower Pechora river in the west to the Lower Khatanga river in the east) (Shiyatov,1972,1973,1975,1981,1984a,1984b).

Ring-width indices for these series were calculated by the curves of maximum and minimum possible increment (Shiyatov, 1972). This enables us to reveal both the short-term (intrasecular) and the long-term (secular and oversecular) fluctuations of ring-width indices. Inhomogeneity of the mean chronologies was eliminated in case of unsufficient and different number of the model trees (Shiyatov,1980).

Cycle components in the chronologies were revealed by different methods: by mooving average smoothing, by estimating autocorrelation function and its integral, by spectral analysis with linear filtration.

Repeated efforts to point out cycle components in the tree-ring chronologies and to use them in extrapolation (forecast) were unsuccesful in many cases. The reasons may be the irregularity of fluctuations in time (cyclic parameters vary and separate cycles may disappear within certain time periods), interference of cycles, poor knowledge of the nature of fluctuations, uncertain definition of the term "cycle" (Abrosov, Mazepa,1984).

Recently we have tried to use spectral presentation of stationary successions and linear filtration in estimating cycle parametres (Mazepa,1985). Spectral densities were analyzed without assumption of the parametric model producing these processes. It was assumed however, that the series, we were dealing with, were realizations of the stationary random successions. Several machine experiments were made to confirm this assumption. The following conclusions were drawn:

1. The universally known statistical methods of estimating spectral density (Blackman-Tukey method, maximum entropy method) give rather well descriptions of frequency structures of tree-ring chronologies based on the trees growing under extreme abiotic conditions. The spectra of ring-width indices for individual trees growing in different ecological conditions of one climatic region are similar. They do not significantly alter within the period 300-500 years.

2. The spectral analysis shows the existence of important narrow frequency bands with fluctuation amplitudes higher, than those of the neighbouring ones. Their widths are about 0.02-0.05 cycle/year. In case if these frequency bands are important for the majority of the tree-ring chronologies in the investigated area, they may be used as the characteristics in studies of wood increment dynamics.

Based on these conclusins we suggest the following concept of the term "cycle". By cycle we mean a component of the ring-width chronologies, which corresponds to a certain important narrow frequency band.

This concept is methodically convenient. Purposefool narrow band-pass filtration with prescribed transfer function becomes possible. Being found the important frequency bands can be analysed by choosing a corresponding filter. A linear symmetric filter with coefficients of the expansion into a truncated Fourier series by cosine of the П-shaped function was used. Successive outgoing series 9 are given in Fig.2. The spectrum for this series are shown in Fig.6.

As is known from the theory of stationary random processes, that narrow band-pass filtration of the realization of such processes being applied to outgoing series may be rather accurately approximated by a sinusoid. It is evident that the outgoing series will not be exactly periodic: two series sections separated by some extended time period are well approximated by sinusoid sections of the same frequency, but may differ in amplitude and phase.

The results of our machine experiments have shown that frequency structure of tree-ring chronologies changes rather slowly. Therefore, only important bands were used in the filtration. Outgoing series are shown by a thick line in Fig.2. They were approximated by sinusoids and the whole chronology was represented as a sum of selected sinusoids. Good approximation of the outgoing series by sinusoids was a base for extrapolation of chronology for several decades forward.

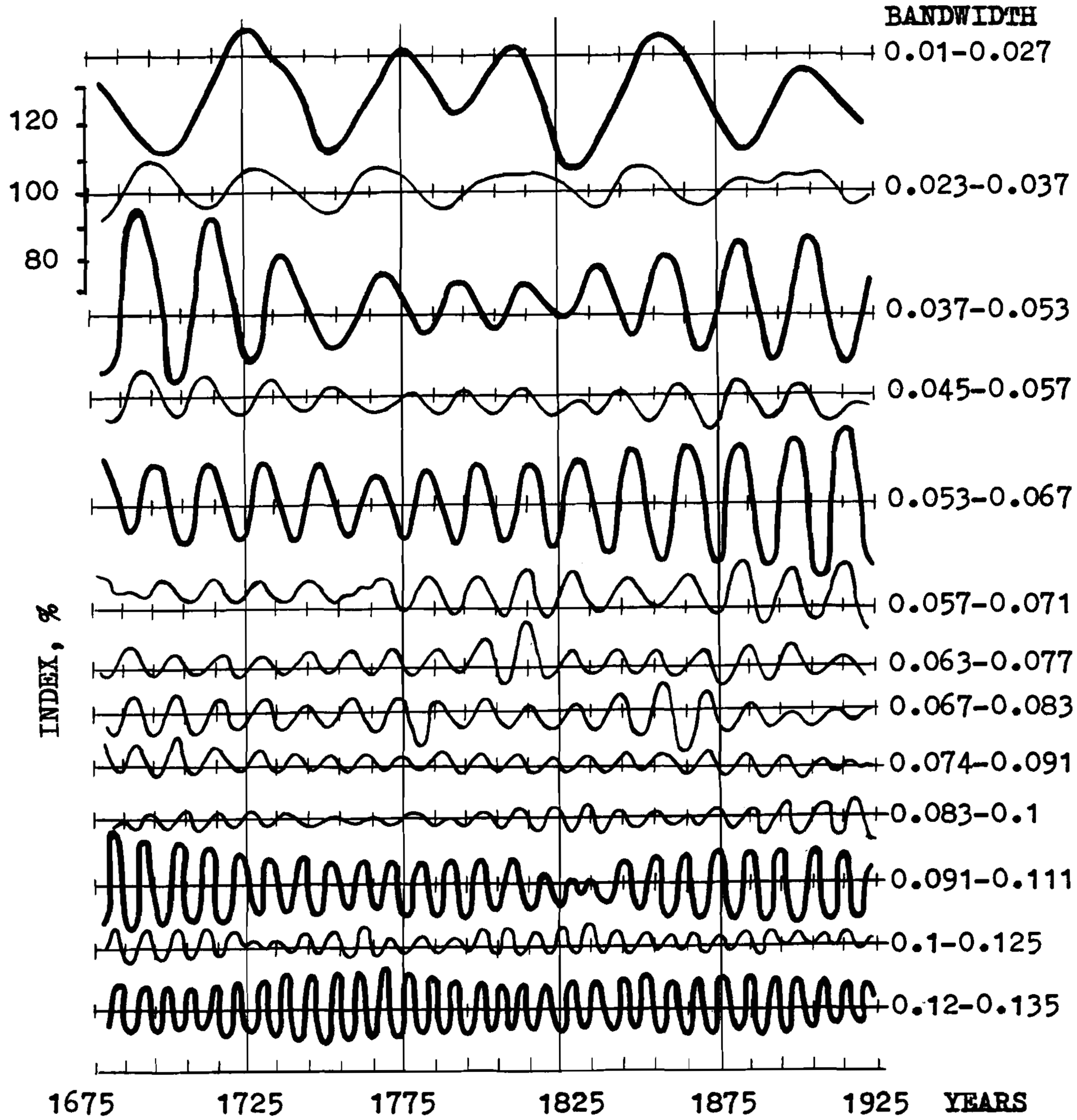


Fig.2. Successive outgoing series 9 in the band pass filtration. The thick line corresponds to impotant friquency bands, the thin line - to the intermediate ones. To the right: bandwidth (cycle/year).

Sensitivity of the tree-ring chronologies, similarity and correlation among them

The analysis of the annual ring-width indices variability has shown significant decline of the mean sensitivity from the North to the South. The chronologies of the Subarctic profile have the highest sensitivity coefficient (0.3-0.5), while those of boreal zone are only 0.2-0.3. The chronologies from the Subtropical zone are still less sensitive (Table 1). This is due to lesser climate variability in the direction from the North sea coast to the South, at the upper boundary of the forest stands in particular. The most sensitive are the chronologies of the larch, the chronologies for dark-needled forests are the least sensitive.

The coefficient of the synchronization among the chronologies obtained from the same climatic region can be high. This is especially typical for the Subarctical areas. For example, in the Polar Urals it changes from 70 to 95%, while in the Southern Urals the value is 53-88%. In the northern regions the synchronization among the series is preserved at a distance of 500-600 km. Synchronous fluctuations in the ring-width indices are obtained in the vast area covering the West-Sibirian forest-tundra, Polar, Subpolar and Northern Urals. Synchronization among the chronologies for the Polar and Southern Urals, for the Urals and Taimyr peninsula is lacking. Correlation coefficient changes similarly.

Thus the climatic limiting factors are showing up most vividly in the Subarctic regiöns. The most reliable climatic reconstructions are possible there. This suggestion is proved by the fact, that the chronologies of the same tree species growing in the different habitat types (from dry to swampy) have high similarity and synchronization values.

Reconstruction of the summer thermal conditions

Air temperatures of the summer months, June and July especially, are the main growth limiting factors at the upper and polar boundaries of the forests. The correlation coefficients between the thermal regime and ring-width indices are 0.6-0.8 in the northern regions and 0.4-0.5 in the southern ones (Polozova, Shiyatov,1975,1979; Mazepa,1982). Thus the reconstructions of the summer air temperature for the northern Urals provinces and the Lower Taz river were made by the regression equations (Fig.3). During the latest 250-1000 years the significant thermal fluctuations were observed. The mean summer temperatures at the upper forest boundary during the separate 5-year periods ranged from 8.7 to 11.0° in the Polar Urals, from 8.9 to 10.1° in the Subpolar Urals, from 9.1 to 10.5° in the Northern Urals. For some years the range of the variability of the summer temperatures was much higher. Attention is drown to the marked temperature rise in the X-XIV centuries, called the Little Climatic Optimum. The upper forest boundary in the Polar Urals was 80-120 m higher at that time than at present (Shiyatov,1979). In the XV-XIX centuries the climate was colder and wetter (the Little Ice Age), since the 20's of the XX century it became warmer. Against the background of these long-term climatic changes shorter fluctuations are traced. XIII, XVI, XVIII and XX centuries were the warmest, XV, XVII and XIX centuries were the coldest ones.

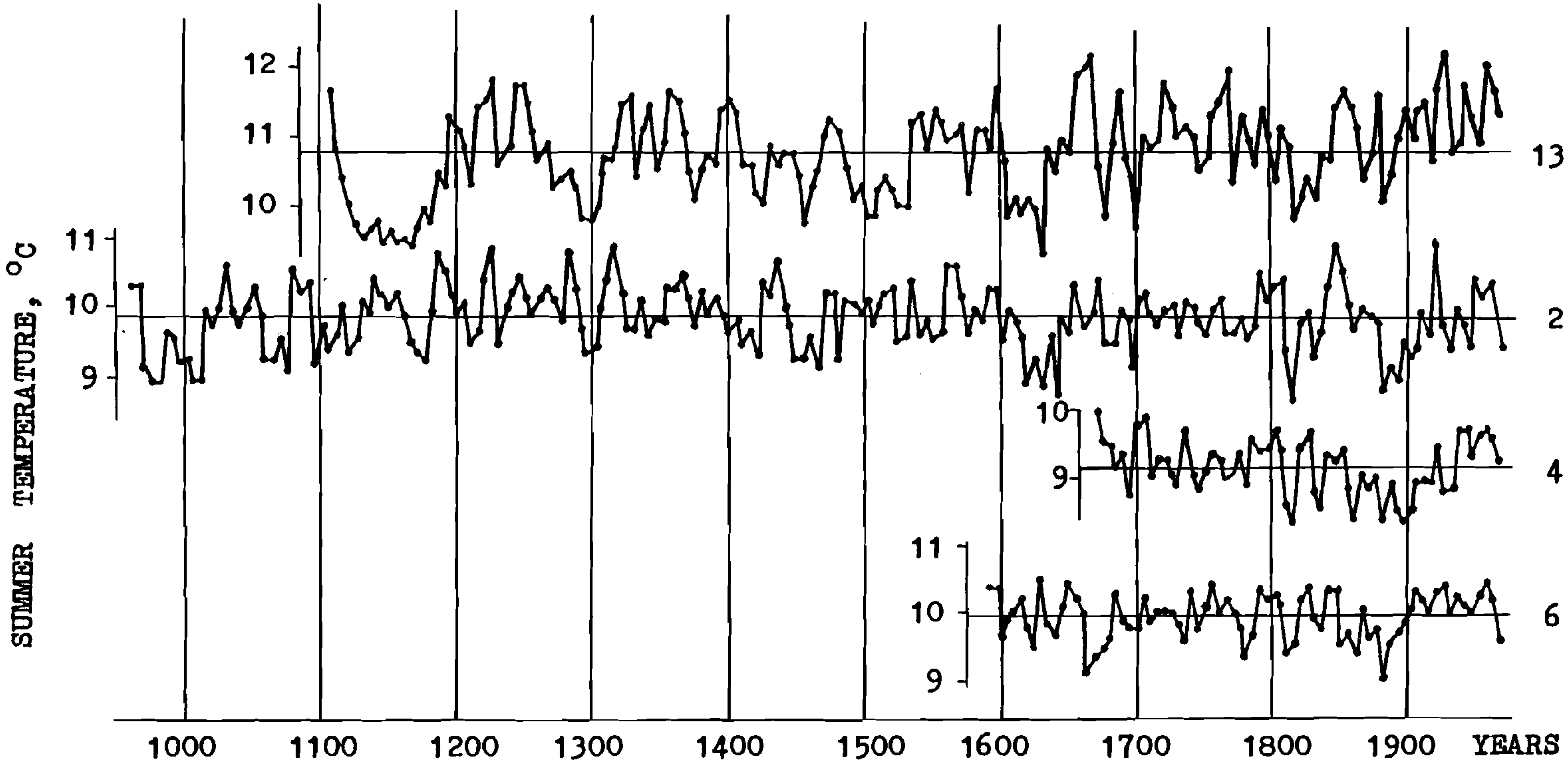


Fig.3. Reconstructed summer temperatures for the Lower Taz river (13), the Polar Urals (2), the Subpolar Urals (4), the Northern Urals (6).

Cycles in the tree-width indices variation

Interest in the cyclic tree-ring fluctuations is associated with the possibility to use them in the forecasts. Up to now the short-term cycles were more or less throughly studied, the investigation of the long-term cycles have just begun. The cycles are usually subdivided into intrasecular (from 2 to 60 years), secular (from 60 to 120 years) and oversecular (over 120 years).

Oversecular cycles. The cycles of this duration are the most dificult to be pointed out in the tree-ring chronologies. The reasons are: the comparatively short life span of trees (no more than 300-500 years usually) and elimination of the largest cycles in converting absolute ring-width values to relative ones. Such cycles have been revealed only in the longest chronologies, obtained for the Urals and West-Sibirian forest-tundra (Fig.4). The double secular cycle of 160-180 years is shown up in the series 2 (the Polar Urals) and in the series 13 (the Lower Taz river). 200-300 years cycles were revealed only in some series. However their parameters were consedered to be unsufficient , becouse they were repeated only once or twice in the series.

Secular cycles. The length of the most obtained chronologies is enough to reveal the secular cycles. Fig.4 shows 55-60 years cycle in the series 2, 10, 11 and 12. It is seen from this figure that the secular cycle is synchronous in different tree species (Pinus sibirica, Larix sibirica and Picea obovata) and as the distance of 600 km from one another. 55-60 years cycle was revealed almost in all series of the Urals high mountains and the Subarctic profile. Many series of the

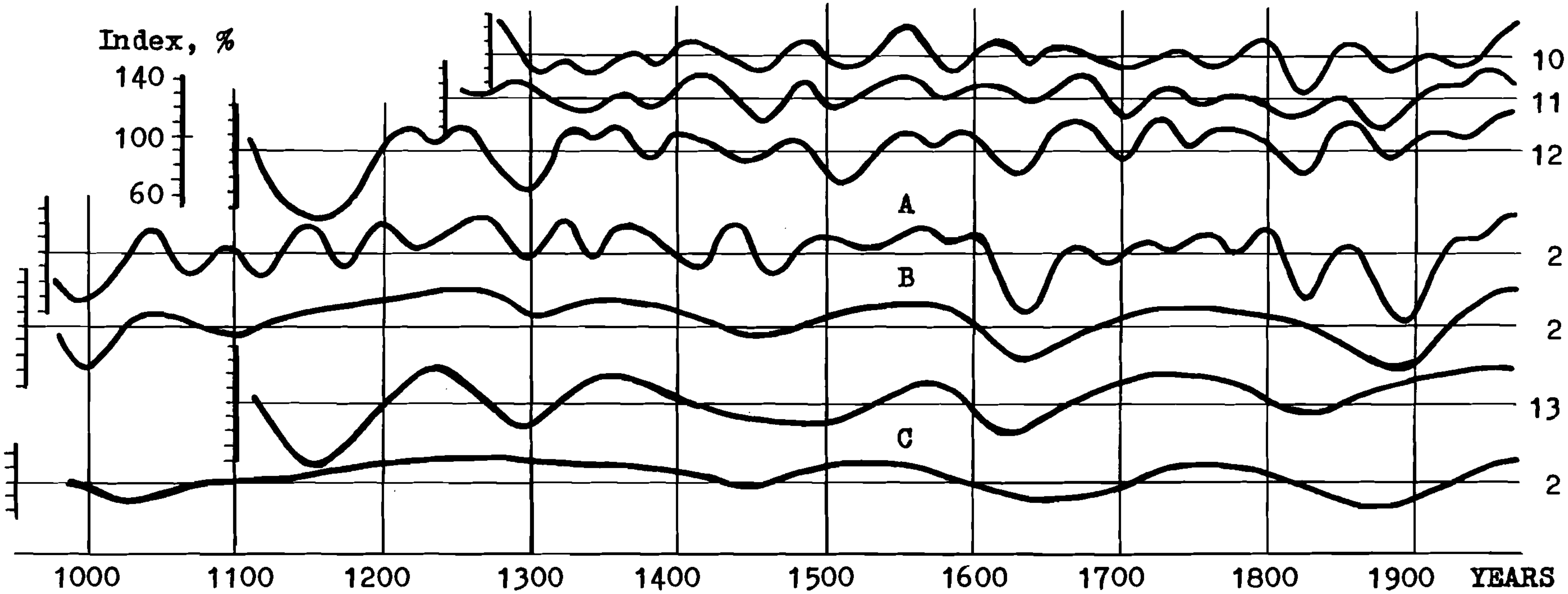


Fig.4. The secular and oversecular cycles of tree-ring indices for Larix sibirica (2,12,13), Picea obovata (11), Pinus sibirica (10) in the Polar Urals and the Lower Taz river. The curves A,B and C obtained by mooving average smoothing of 30-, 50- and 110 years respectively.

northern regions have the cycle of 110-120 years long. 80-90 years cycle was observed only in some series. High synchronization of the secular cycles was noted for different tree species, growing under varios habitat types of the Subarctic, this synchronization is preserved in distant areas. Amplitude of these cycles declines from the North to the South. The chronologies of larch show up the greatest synchronization possible in secular cycles. The least synchronization is observed in series of Sibirian fir and Sibirian cedar.

Intrasecular cycles. The most detailed analysis of the intrasecular cycles was made in the Urals high mountains profile. We managed to follow the changes in the tree-ring cycles in different species and different habitats. The spectra for different chronologies of Sibirian larch are given in Fig.5.

The analysis of the cycle components shows that a number of cycles in different Urals provinces is dissimilar. The number of cycles increases from the Polar to the Southern Urals. The majority of the cycles is common to all provinces, 70-90% of all series investigated, have common cycles. The following cycles are wide spread and common to the Urals highlands: 21-24, 16-18, 10.0-11.5, 5.3-6.0, 3.9-4.4, 3.3-3.7, 2.8-3.1, 2.1-2.2 years. Some cycles are revealed mainly or specifically within one or two Urals provinces. For example, the cycles of 7.5-8.4 and 4.6-5.0 years are typical for the Southern Urals, the cycles of 41-45 and 36-39 years are characteristic of the Subpolar and Northern Urals, 12-14 years cycle is peculiar to the Northern and Southern Urals.

There are cycles manifesting themselves predominantly in the chronologies of particular tree species. Thus, the chro-

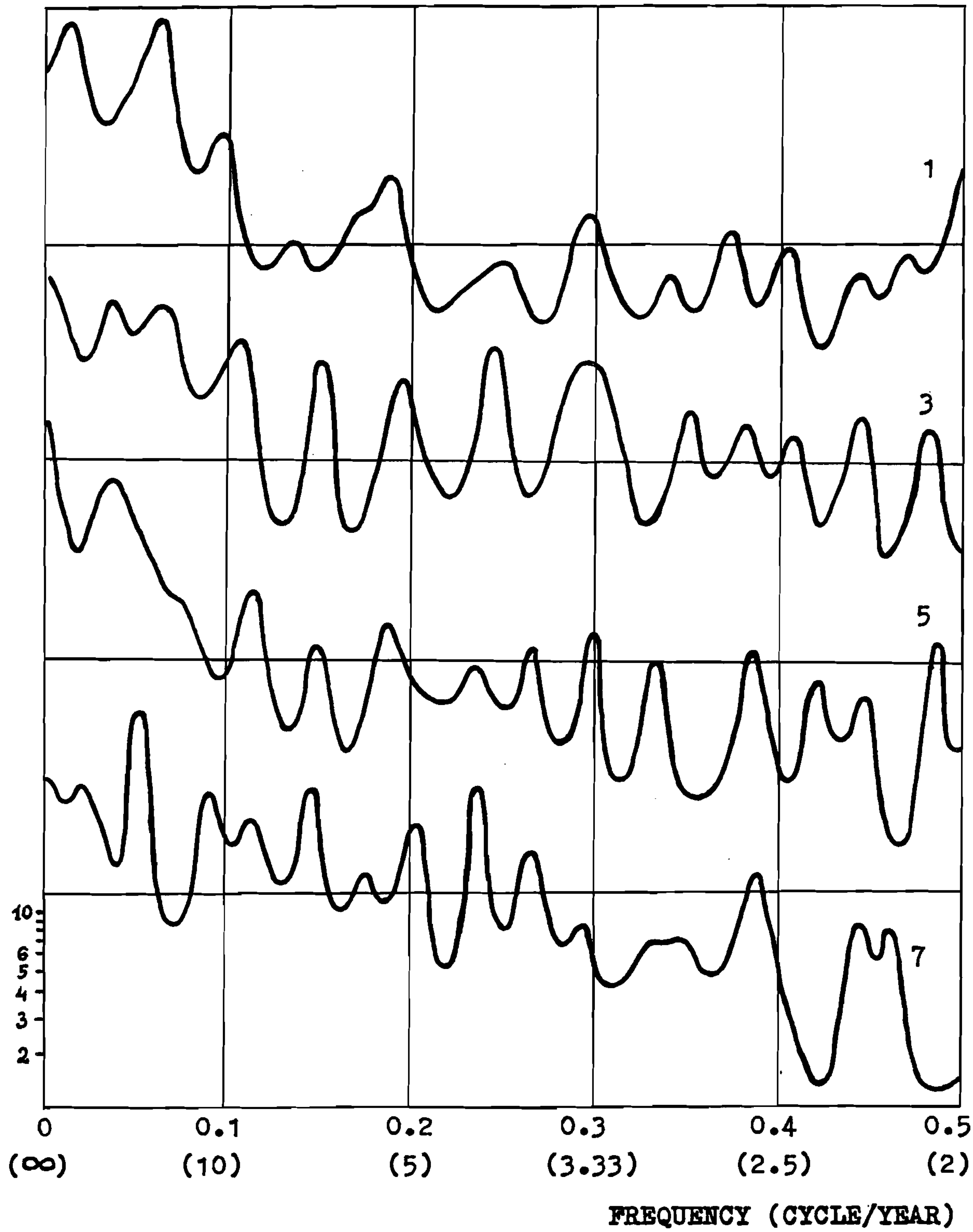


Fig.5. Spectra for the chronologies 1, 3, 5 and 7.

The Urals profile.

nologies of the common pine have the 32-34 years cycle, those of the Sibirian fir exibit the 41-45 and 12-14 years cycles, those of the Sibirian larch reveal the 16-18 years cycle. The environment does not practically influence the number of the cycle components in the chronologies, derived from the Polar, Subpolar and Northern Urals, but they do effects in the Southern Urals high mountains, where the role of the limiting climatic factors is diminished.

The cross-spectral analysis of the chronologies for the Urals profile has shown that there is a close correlation among the series of the Sibirian larch. This evidences its greater sensitivity to environmental fluctuations, especially for the climatic variations, as compared with the Sibirian fir and common pine. The chronologies of the Sibirian fir were observed to have lagged of some cycles compared with the chronologies of the Sibirian larch.

The highest correlations among the chronologies and cycles were received for the Polar Urals and West-Sibirian forest-tundra. They gradually decline toward the South.

According to the number and correlation among the cycles, as well as the synchronization among the chronologies the Urals highlands can be subdivided into two areas: the northern region, covering the Polar, Subpolar and Northern Urals, and the southern region including the Southern Urals only.

The cyclic components in the tree-ring chronologies for Sibiria, Middle Asia and Far East are revealed in the separate chronologies. The spectra for these chronologies are given in Fig.6 and 7.

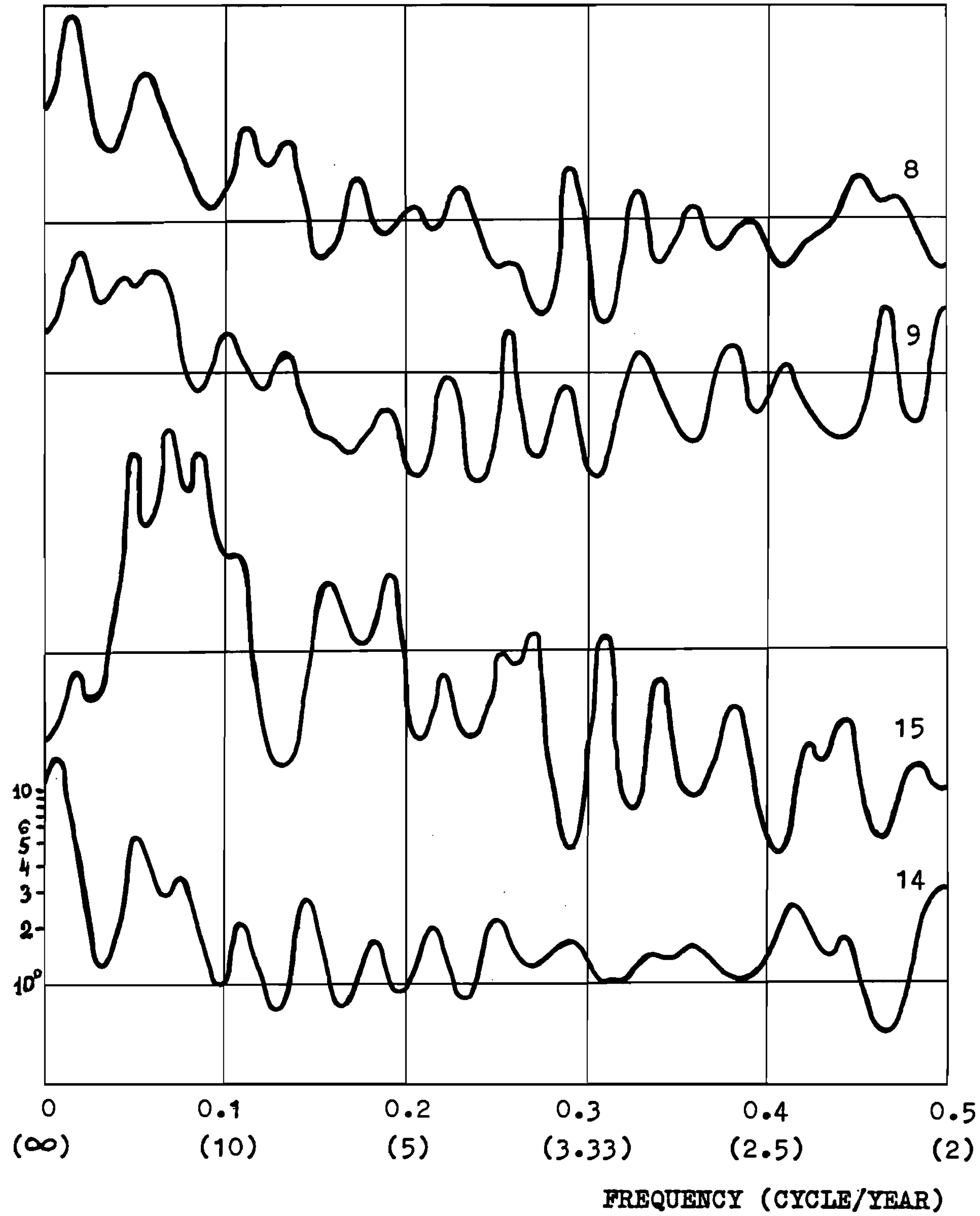


Fig.6. Spectra for the chronologies 8, 9, 15 and 14.
The Subarctic profile.

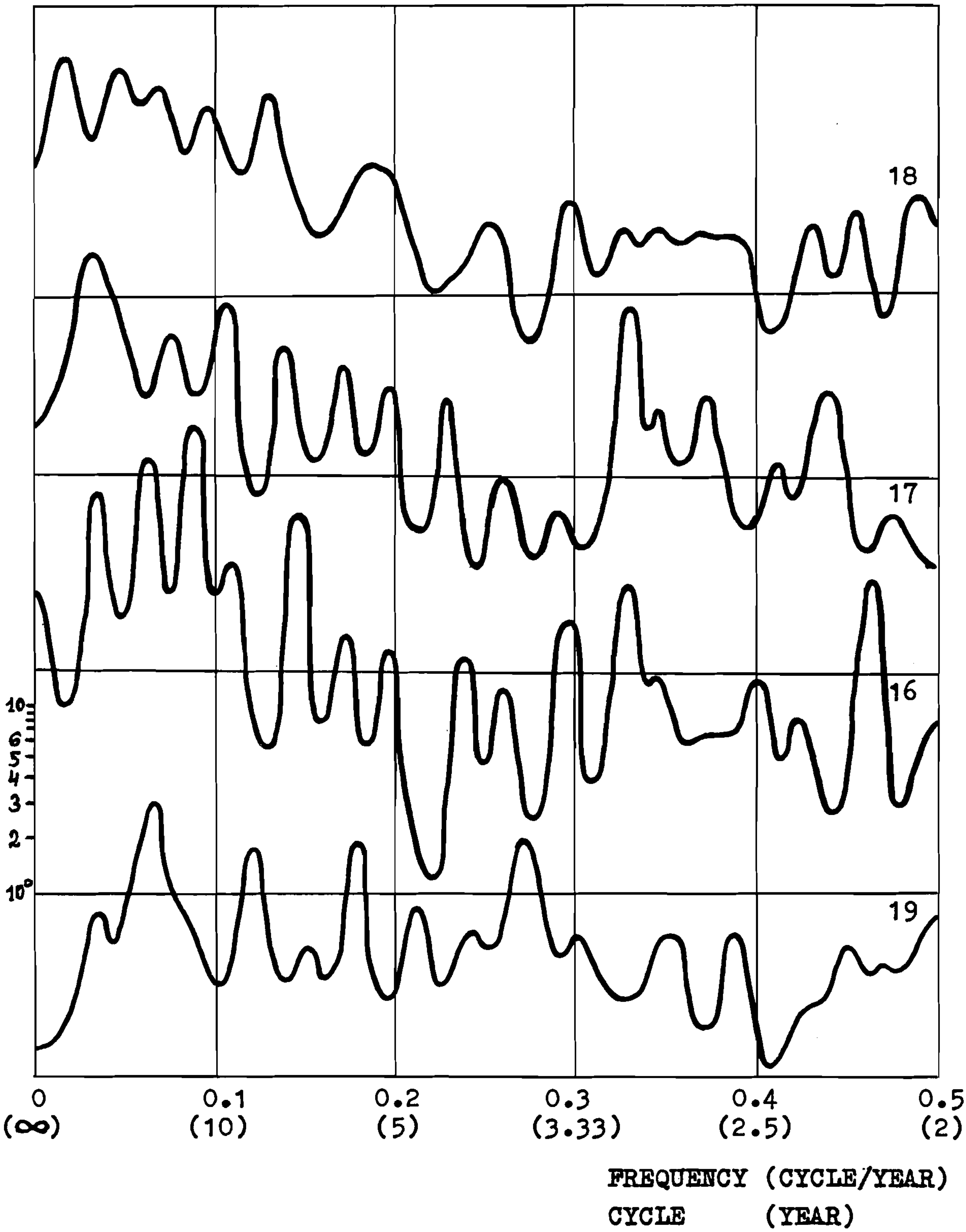


Fig.7. Spectra for the chronologies 18 (Kungey Alatau), 17 (Zailiyskiy Alatau), 16 (Khamar-Daban) and 19 (Kamchatka).

Approximation of the tree-ring chronologies by the sum of sinusoids and the forecast

The calculations have shown that a mean-root-square error for the sinusoidal approximation of an individual cycle ranges from 3 to 10 units, most frequently the error is 5 or 6. The final chronologies sections and their approximations by a sum of sinusoids are plotted in Fig.8-11. The correlation coefficient and mean-root square errors show approximation quality. To our point of view the similarity between the original and the approximated series is satisfactory. Assuming the comparatively stable increment dynamics, we produce quantative forecast for 30-50 years. However, we realize that the polyharmonic model is not quate appropriate for describing the relative wood increment process owing to its stable periods.

Connected with long-term plans of natural resources usage and preservation, forecasting is essential. The analysis of cycles helps to forecast climate caused increment dynamics of the trees growing in extremal abiotic conditions. Besides such analysis helps to estimate global anthropogenic impacts on vegetation cover , judjing by the sharp disturbancies in the frequency structure dendrochronological series. However, it should be noted, that the analysed chronologies are based on the model trees living in undisturbed areas. Therefore the observed changes are caused by natural climatic fluctuations of the wood increment dynamics.

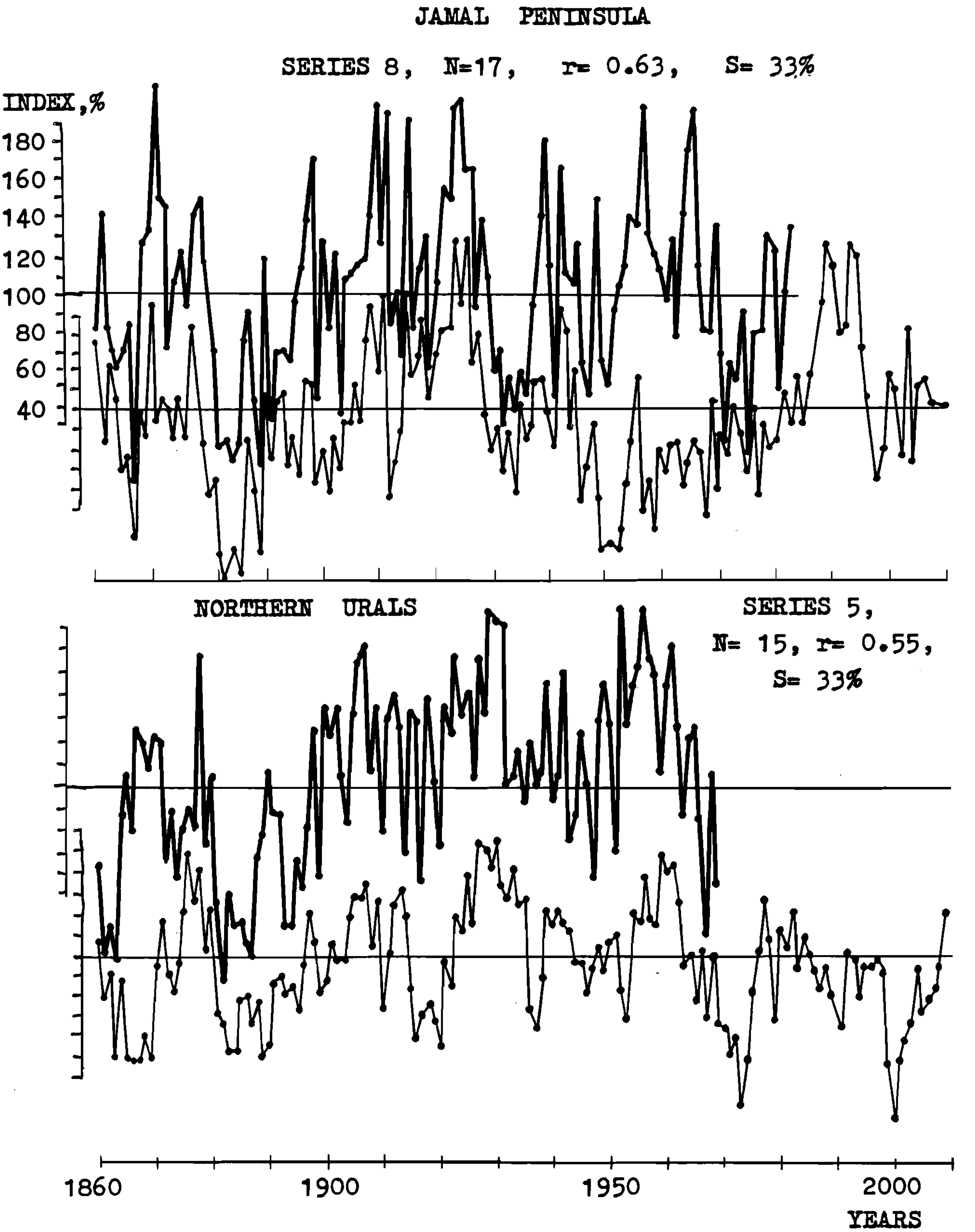


Fig.8. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

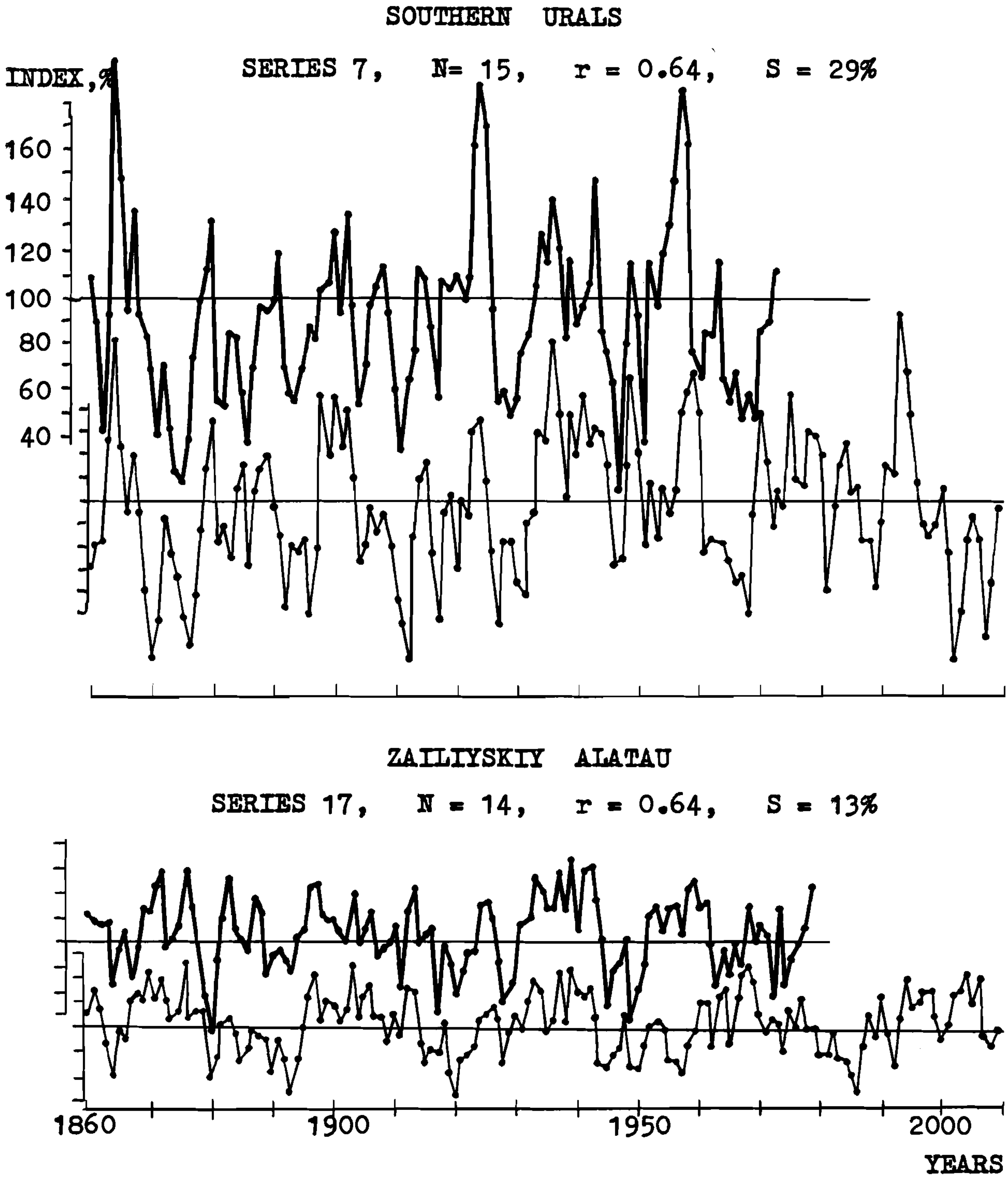


Fig.9. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

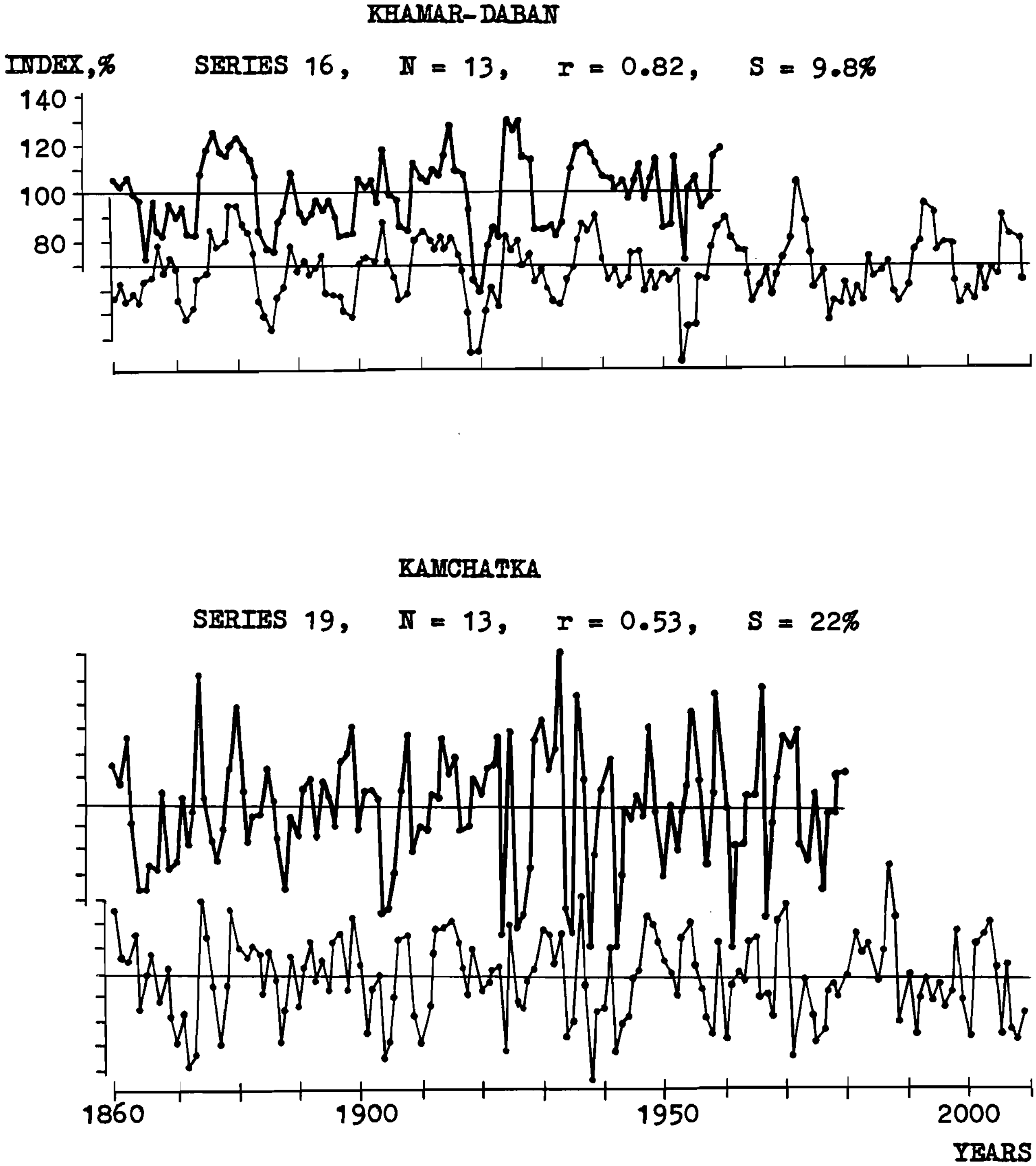


Fig.10. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

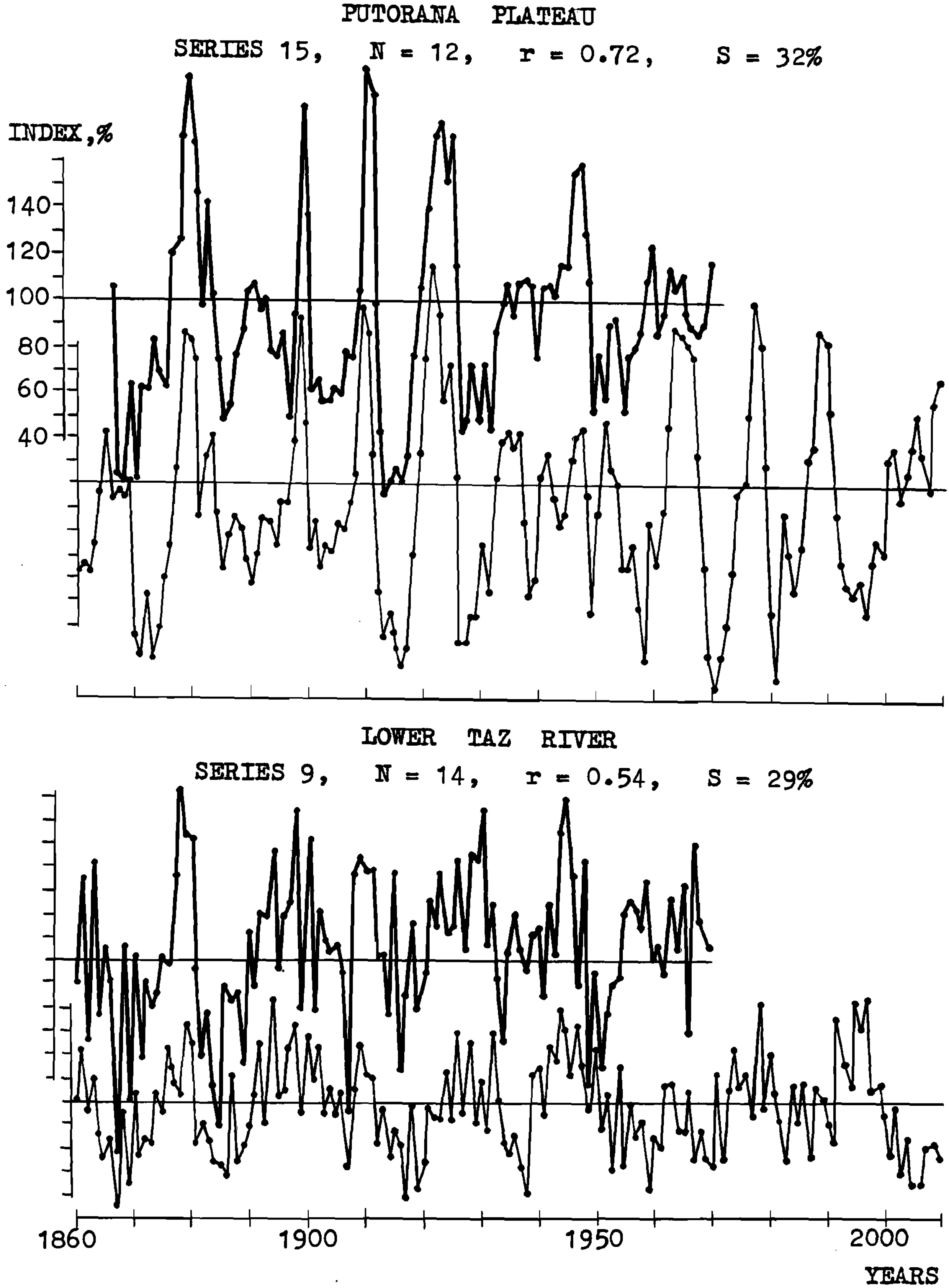


Fig.11. Tree-ring chronologies (thick line), their approximations and extrapolations (thin line). N - number of sinusoids in the approximation, r - correlation coefficient, S - mean-root-square error.

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3.1.3 CLIMATIC FLUCTUATIONS IN NORDEN AS DERIVED FROM TREE RINGS AND OTHER PROXY DATA

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ABSTRACT

The Late-Quaternary climatic development in Scandinavia and adjacent areas is examined. The reliability of proxy data is discussed. The different proxies show that many climatic fluctuations have occurred at different time intervals. The climatic development also shows several regional differences. There was a general rise in temperature from Late-glacial to mid-Holocene times, but during the past 5000 years a cooling trend can be observed. Within the main lines of development there are many climatic oscillations of varying amplitude and duration. The Medieval Warm Period, which reached its peak around 1100-1200 AD, was one of these fluctuations, and the best known of them is the 'Little Ice Age' of the past centuries. That period was cool on average but especially characteristic of that time were many repeated cool and warm phases, lasting sometimes several decades and making the climatic development vary variable. A new dendrochronological master curve from eastern Finland is published in this paper, providing some information of climatic variations during that time period. The 'Little Ice Age' came to an end, when temperatures began to rise considerably in the last century. A further considerable warming is possible in the coming decades as a result of the anthropogenic increase in atmospheric CO_2.

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INTRODUCTION

Global climatic system is extremely complex with numerous connections and response mechanisms which are still largely unknown today. Both global and regional climates change and fluctuate and these variations are known to have occurred at different time intervals. To understand the behaviour of modern climate, we need, among other things, information about what has happened in the past.

Recently there has been a remarkable expansion in data collection in different parts of the world, and the knowledge of past climates is increasing rapidly. Another approach is to construct mathematical models to help us to understand the mechanisms of former climatic changes and in this way to try to explain the responses of the system in each situation.

Palaeoclimatic studies naturally focus, for the most part, on Quaternary development because climatic variations are the principal feature of that period. Another field of growing interest today is historical climatology, which studies the connections between historical and climatic events. Despite the rapid advance in these studies, many fundamental questions still remain open.

The results of some remarkable palaeoclimatic studies are summarized in Fig. 1. Curve I in that figure shows the oscillations in the time-scale of hundreds of thousands of years. Curve II depicts temperature variations during the last ice age and the beginning of our present warm interglacial time. The variations in temperature between

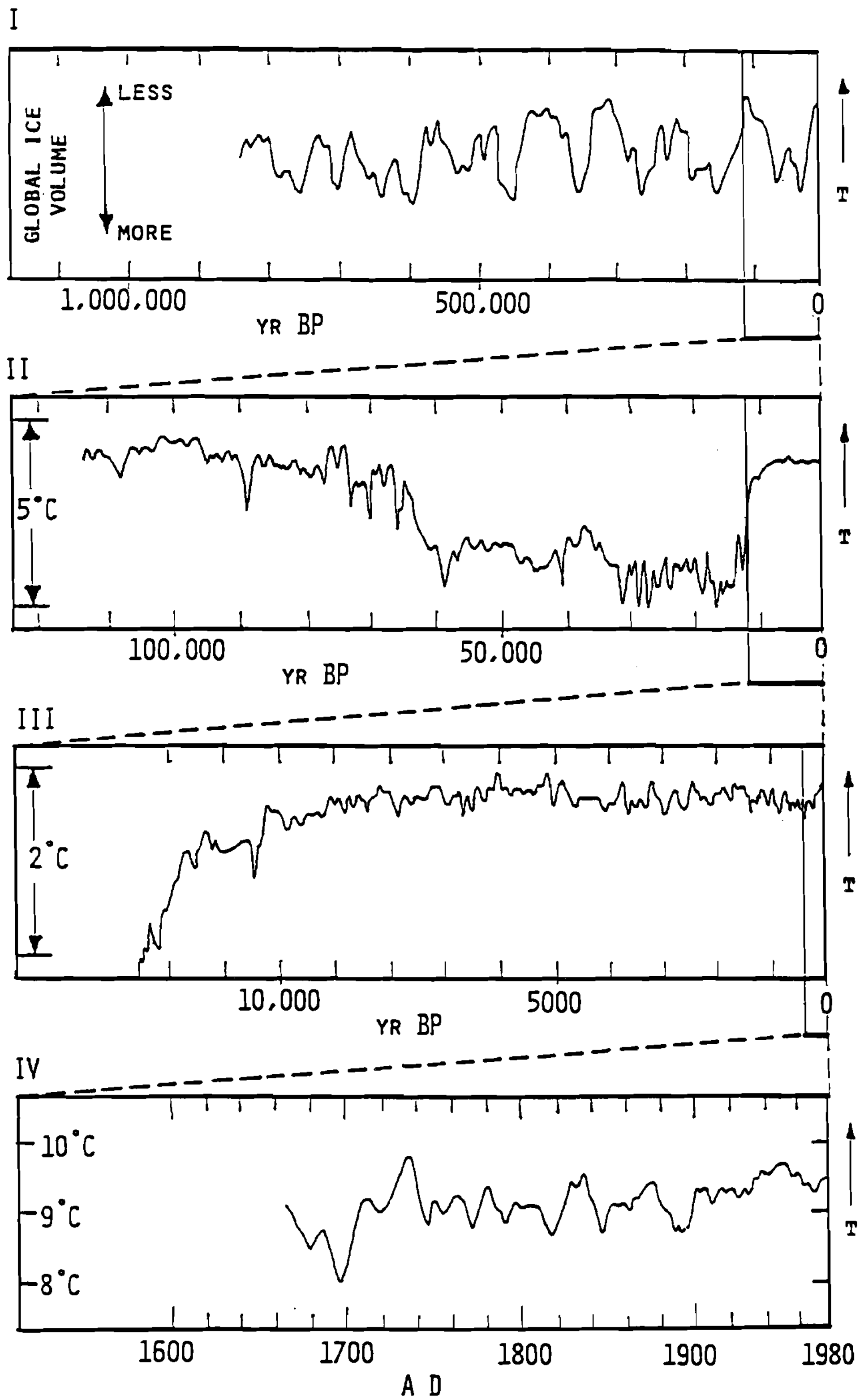

Figure 1. Curves showing climatic fluctuations at different time intervals. Curves I and II are based on oxygen isotope ($^{18}O/^{16}O$) variations in deepsea cores (Shackleton and Opdyke, 1973). Curve III is compiled from oxygen isotope variations measured in a Greeland ice core (Dansgaard et al., 1971). Curve IV depicts temperature variations in Central England over the past 300 years, as shown by the instrumental record (Mason, 1976). The picture is drawn after Salzman (1985) slightly modified.

glacial and interglacial periods at the global scale have been of the order of several degrees centigrade, but in some areas the amplitude of change has certainly been clearly more than that shown by curve II. The two upper curves are based on oxygen isotope variations in deep-sea cores.

Curve III represents temperature changes during the past 12,000 years. This curve is deduced from oxygen isotope variations in a Greenland ice core. The first part of the curve shows the closing phases of the last ice age. There is an average rising trend in temperature but there are also many fluctuations, the most distinct of which is the cooling phase between 11,000 and 10,000 BP. The subsequent warming led to the end of the glacial period and to the beginning of the present interglacial, the Holocene. That Pleistocene/Holocene boundary is placed at 10,000 (radiocarbon) years before present. The warming continued in the early part of Holocene. Numerous small fluctuations can be seen in the main trend, which shows a slight cooling after the Holocene climatic optimum from 8000 to 5000 BP.

The lower curve shows fluctuations in yearly temperature from the late 17th century to the present, based on temperature records measured in Central England. The changes are notable even for this short time-span. Such short-term oscillations are often impossible to distinguish in long records extending into the more distant past, because not all changes leave marks in the fossilizing material.

In Fig. 1 variations in temperature can be seen, but that is only one element of climate. Precipation, or more generally the seasonal wetness, has an enormous impact on the ecosystems as well as on human life. The occurrence of strong winds, storminess, can also be a very decisive climatic factor in some areas.

In Norden (i.e. the Nordic countries, Finland, Sweden, Norway and Denmark) the climate is humic and very probably has also been of that kind during the entire postglacial period. Changes in wetness are known to have occurred. These changes were already reported by A. Blytt and R. Sernander in their classic theory of Late-Quaternary climatic changes. In Norden, however, changes in temperature have been far more significant to ecological development than changes in precipitation. Therefore the emphasis in this paper is on temperature variations.

PROXY DATA USED IN CLIMATIC CONSTRUCTIONS

Proxy data are variables which can be interpreted in terms of climate. The climatic proxies are always somewhat inaccurate, but attempts are being made to get more and more detailed information using different materials. Proxies can be natural or historical. Historical proxies are written sources depicting in one way or another the climatic conditions of former times. They can be descriptive weather registers, weather diaries, annals, chronicles, state and local documents, farm and estate management reports, records of local plant growth and harvest times, river flood and lake level records, reports of freezing times, accounts of military campaigns, travel and ships' logs etc. (Lamb 1982, Landsberg 1985). The commonly used natural proxies include: tree-rings, varved sediments, pollen analysis, identification of different plant remains, insect faunas, marine microfauna , deposits and landforms showing lake level fluctuations, marks of glacier advances and retreats, and stable isotopes ($^{18}O/^{16}O$ ratio) from deep sea cores, cave deposits, lake deposits and ice sheet cores (Lamb 1982, Hecht 1985). The results of palaeomagnetic measurements from sediments can also been interpreted in climatic terms (Oldfield and Robinson 1985).

The accuracy of proxy data can be improved, if modern analogs of the material can be found, and climatic proxies can be changed, to temperature variations for example, through so called transfer functions. These are statistically defined equations which connect the preserved record to the present-day biotic elements. In spite of the sophisticated mathematical methods used in these interpretations, some inaccuracy evitably remains (Bryson 1985, Webb 1985). Tree-rings have the advantage that they can be associated with calendar or sidereal years and such accurately dated ring series can be extended to cover centuries and millenia.

Some historical proxies available for palaeoclimatic studies in Norden will be discussed briefly later. The most important natural proxy data used in that area are: pollen analysis, plant remains preserved in peat bogs and lake sediments, and glacier fluctuations on the mountains. There are also some studies on former insect faunas, stable isotope and palaeomagnetic measurements from lake sediments as well as tree-ring studies. The age daterminations are mostly by means of the radiocarbon method. Our picture of the Late-Quaternary development in Norden is based on these materials.

LATE-GLACIAL TO EARLY HOLOCENE CLIMATIC FLUCTUATIONS

In Fig. 2 there are two curves which serve at the same time as an example of Late-Weichselian (late glacial, 13,000 to 10,000 BP) climatic changes and as a demonstration of the problems sometimes connected with the use of proxy data. The solid curve is drawn according to the results of palaeobotanical studies in southern Scandinavia, mainly after Iversen 1954, 1973, and the broken line is based on beetle faunas studied in Central England (Coope 1977). Recent studies in southern Sweden show that the palaeoentomological evidence for Late-Weichselian climatic fluctuations in that area is very much similar to the fluctuations found in Central England for the same time period (Berglund et al. 1984). Thus the main trend of the respective curve in Fig. 2 is valid for southern Sweden, too. The difference between the two curves is explained by the difference in the time lags by which vegetation and insects react to climatic changes. The insects are more sensitive indicators in that they can move more rapidly than plants to new areas, if conditions become favourable. So, the temperature curve shown by the beetle fauna is more accurate than that shown by the palaeobotanical evidence, here first of all by pollen analysis. In late glacial times the time lag in the vegetational response to climatic change can be from 300 to 1000 years. That means

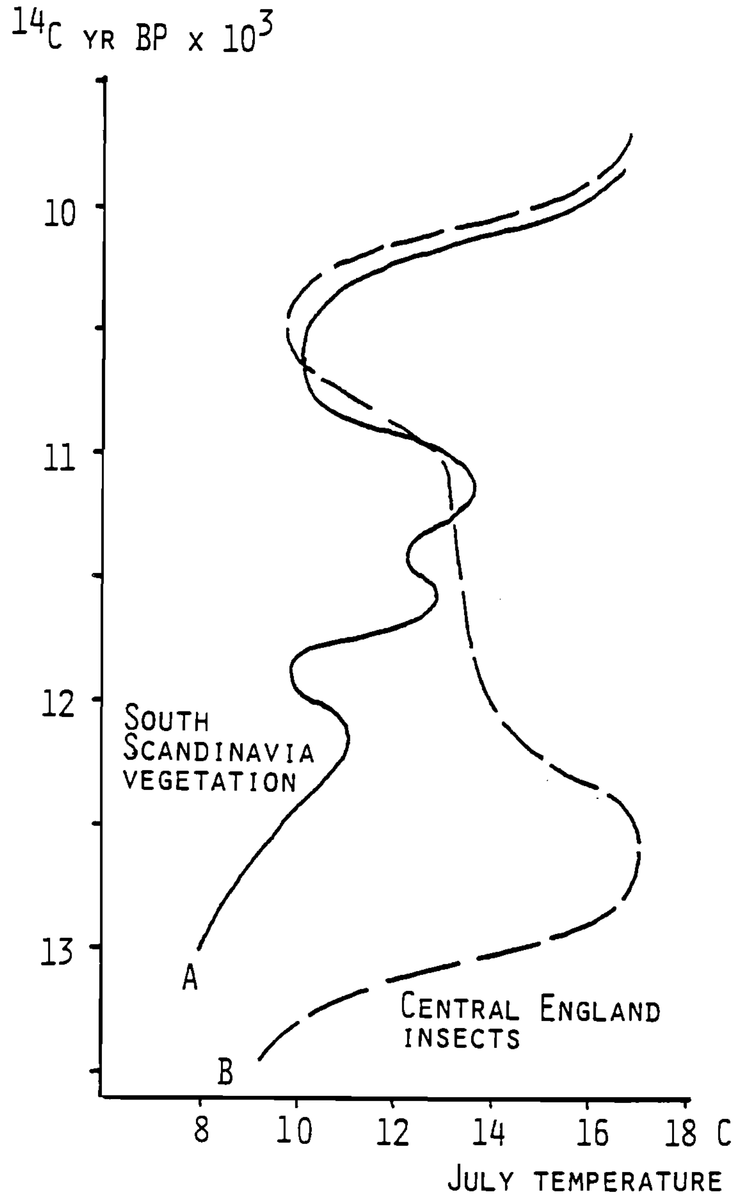

Figure 2. Reconstructions of the average July temperatures for the time 13,000 to 10,000 BP. Curve A is drawn according to palaobotanical evidence and curve B is based on subfossil beetle faunas. After Berglund et al., 1984, slightly modified.

that for a long time the vegetation was not in balance with the summer temperature (Berglund et al. 1984).

It can be concluded from the above that pollen studies from Holocene deposits also fail to reveal short-term temperature variations. However, during the Holocene, the vegetation in Norden was generally in a more stable state than in Late-glacial time when forests were still immigrating to newly deglaciated regions.

It is believed that the global climate began to warm rapidly shortly before 10,000 BP leading to interglacial conditions at that time. Recently, Björck and Digerfelt (1984) have dated the most important turning point to warmer climates to 10,500 BP (cf. also Figs. 1 and 2). The results indicate that there may have been regional differences in the climatic shifts, although small errors or inaccuracies in dating can also give that impression. Be that as it may, climatic changes certainly do not take place exactly at the same time in different regions and the amplitude of change can vary, too.

In southern Finland, fossil ice wedges have been found which were formed during the Late-Weichselian cold Younger Dryas phase between 11,000 and 10,000 BP. Such ice wedges can be formed in the ground only if there are permafrost conditions, the average yearly temperatures being something like $-6^{\circ}C$ or below. On the other hand, the vegetational evidence from southern Finland indicates that during the Holocene climatic optimum, some 6000-5000 years BP, the average summer temperatures and probably also the yearly temperatures were about two degrees centigrade higher than the present-day ones. Nowadays the yearly mean temperatures in southern Finland are around +3 - +5°C. According to this evidence, the temperature rise in southern Finland during the time period concerned has been 11 to 13 degrees centigrade (Donner 1974). That change in temperature is greater than is generally estimated for the same time period in Europe and elsewhere (cf. curve III in Fig. 1). Here again the large amplitude can be considered as being only a regionally restricted feature in the development.

The inaccuracy of the available proxies, the time-transgressive nature of the changes and many regional differences raise many serious problems in the study of Late-glacial and early Holocene climatic development.

ATTEMPTS TO RECONSTRUCT THE HOLOCENE CLIMATIC PATTERN

The ample evidence from numerous pollen analyses shows that during the climatic optimum between 8000 and 5000 BP the distribution of thermophilous deciduous trees (elm, oak, lime, hazel etc.) in Norden was wider than it is today and those species were also more common components of the forest than they are at present (e.g. Faegri and Iversen 1975, Mangerud et al. 1974, Donner et al. 1978).

Isolated finds of some macrosubfossils bear, in accordance with the pollen floras, evidence for mid-Holocene warm conditions. Seeds of waternut (Trapa natans) have been found in peat bogs in central and western Finland, while the northernmost growing sites of that plant are today in Latvia (Valovirta 1960). That kind of find does not, however, tell anything about possible temperature fluctuations during those warmer times.

The climatically determined vegetational boundaries, such as the tree-line, are naturally very sensitive to any kind of change. Accordingly, changes in the pine limit in the northern parts of Finland, Sweden and Norway as well as on the Scandinavian mountains give indications of climatic development. Scots pine (Pinus sylvestris) forms the limit of proper forest in those regions; the areas covered by mountain birch beyond and above the limits of pine are only some kind of woodland or scrub. Changes in the pine limit can be studied by means of absolute pollen analysis and by dating subfossil pines which are preserved in peat bogs, at the bottom of lakes and in wet depressions in the ground.

There are many relatively recent studies on the Holocene changes of the pine limit in Fennoscandia. Some contrary results have been presented, but a somewhat consistent picture of the development can be drawn today. Karlén (1976) proposed that the pine limit on the fell slopes in northern Sweden has fluctuated up and down several times during the past millenia. Later Kullman (1980) suggested, however, that no essential changes in the pine limit on the Swedish fells had occurred between 8000 and 4500 BP. This view was supported by the material collected by him from the mountains of central Sweden. Similarly, the evidence from northern Finland indicates that no large short-term oscillations took place in the pine limit during the Holocene (cf. Fig. 3). Pollen analysis, together with radiocarbon dated finds of subfossil pines shows that pine spread to Finnish Lapland between 8500 and 7000 BP and immediately after immigration occupied large areas beyond its present limit, the time of maximum distribution being between 7000 and 4000 BP. The retreat in the pine limit began between 5000 and 4000 BP indicating the beginning of the deteriorating trend in climatic development (Hyvärinen 1975, 1976, Eronen 1979, 1981, Eronen and Hyvärinen 1982, Eronen and Huttunen in press).

Differences can be found in the changes in the pine limit in different parts of Fennoscandia. Lundqvist (1969) put forward evidence that pine had already reached areas above its present limit in central Sweden prior to 8000 BP, growing at that time at higher elevations than at any later time during the Holocene. Hafsten (1981 a and b) has suggested that the history of the pine limit on the mountains of southern Norway was very similar to that of central Sweden. Thus the pine limit as a climatic indicator does not show parallel trends in the northern and southern parts of Fennoscandia. There have probably been some differences in regional climatic development. Moreover, the pine limit is not determined solely by macroclimate. Such factors as microclimatic conditions, soil type and development and general topography can locally limit or favour the growth and regeneration of pine.

The evidence for former glacier fluctuations can also be used as a climatic indicator, although the relationship between

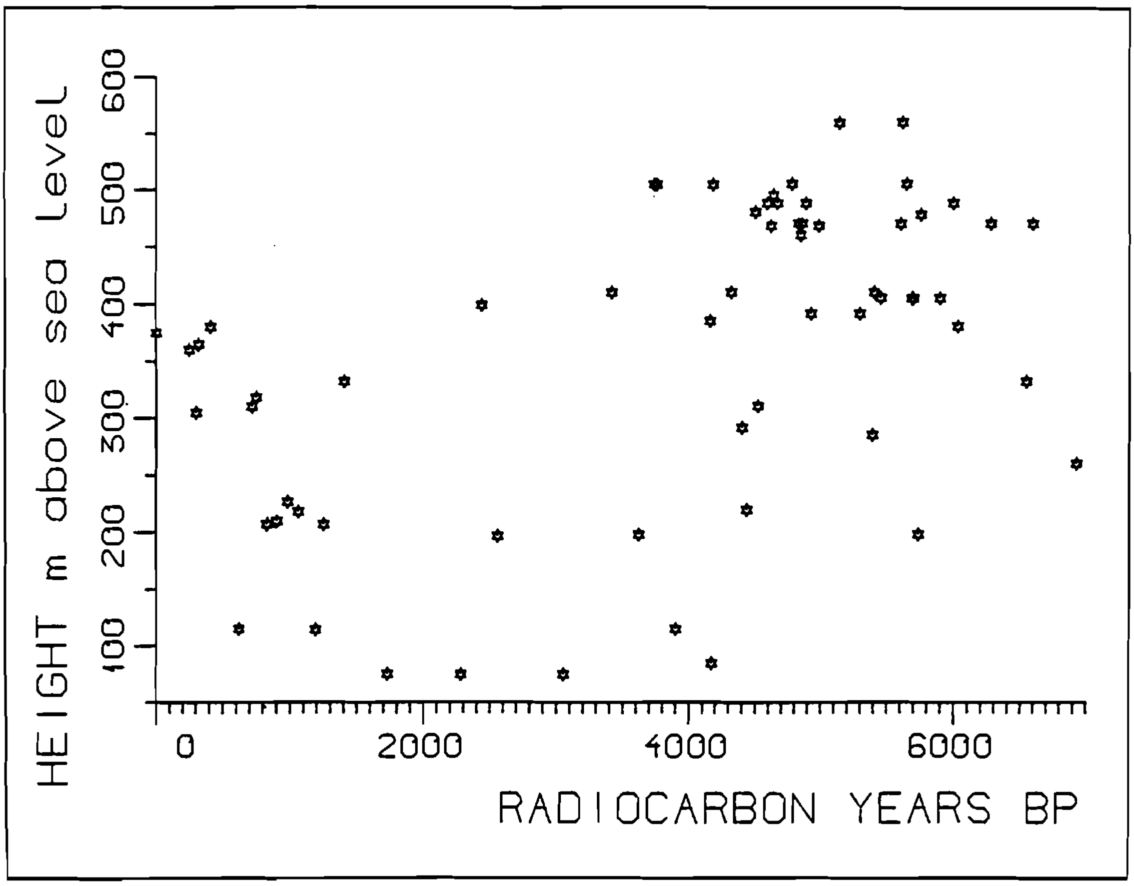

Figure 3. Diagram showing radiocarbon dated subfossil pine from Finnish Lapland. The heights of the sampling sites above sea level are on the vertical axis. The horizontal axis shows the ages of the samples in years BP. Centuries-long fluctuations back and forth in the pine limit cannot be detected from this material. The dates are discussed in more detail in Eronen and Huttunen (in press).

glaciers and climate is complex. Denton and Karlén (1973, and Karlén 1976) have suggested that there have been several more or less synhcronous glacier fluctuations on the Scandinavian mountains and elsewhere during the Holocene and those advances and retreats of the glacier tongues are thought to reflect global climatic variations. Such a Neoglacial chronology rests largely on the radiocarbon dating of palaeosols from beneath ice-pushed morainic ridges.

There are, however, many problems in dating such buried soil horizons and thus the concept of many Holocene glacier expansions is subject to criticism (Caseldine and Matthews 1985). Probably there are also differences in the Holocene glacier oscillations between northern and southern Fennoscandia (Karlén 1984). All in all, the Fennoscandian chronology of Holocene climatic fluctuations is still largely an open question.

CLIMATIC VARIATIONS DURING THE PAST TWO MILLENIA

The climatic fluctuations of the last 2000 years in the northern Hemisphere are discussed in detail by Williams and Wigley (1983), who selected the proxies indicating summer temperature variations for closer scrutiny. The study confirms that climatic fluctuations have not been parallel and contemporaneous in different parts of the world. On the other hand, the proxy data used do show the same kinds of trends in restricted areas, demonstrating that those climatic indicators are reliable within certain limits. The material from Norden used in that study comprises radiocarbon and lichenometric dates on glacial deposits in the mountain areas, radiocarbon dates of subfossil pines from beyond the present limits of pine and tree-ring width indices (a master curve for northern Finland starting 1181 AD, data from Sirén, 1961).

According to Williams and Wigley (1983), the early part of the first millenium AD is difficult to characterize. There is, however, some information on climatic fluctuations in southern Norway during that time since Hafsten (1981 b) has collected palaeobotanical evidence which indicates that summer temperatures in southern Norway around 400 AD and some time after that were 1-2 ^{o}C higher than at present, but that a considerable lowering in temperatures took place around 600-800 AD.

There is evidence for glacier expansion in northern Scandinavia around 800-900 AD which is indicative of a cool phase at that time (Karlén 1984). A remarkable warming was felt again during the last century of the first millenium AD.

The well-known Medieval Warm Period occurred between 900 and 1300 AD reaching its culmination around 1100-1200 AD. The average temperatures during that period in Fennoscandia were higher than at present. The fluctuation was probably comparable to that in England where the mean temperatures at their highest were about one degree centigrade higher than at present (Lamb 1982). Signs of climatic deterioration appeared in 1200-1300 AD and that cooling resulted in the so called Little Ice Age climatic episode of the past centuries.

THE 'LITTLE ICE AGE' IN NORDEN

The lowering in temperature from the Medieval warm peak to the coolest periods of the 'Little Ice Age' was probably of the order of two degrees centigrade throughout Europe. However, the development was everything else but a straightforward cooling of climate. There were also relatively warm phases during the 'Little Ice Age'. The main feature of that climatic episode is the variability and instability of the climate. Because of the many oscillations, the length of the 'Little Ice Age' is difficult to define. In any case the cooling trend commenced in the 13th century, and that climatically unfavourable phase was finally over late in the 19th century (Lamb 1982). Some people have applied the term 'Little Ice Age' to the time interval 1550 to 1800 AD. Landsberg (1985) has justifiably criticized the use of that term because it is scientifically misleading to talk about an 'ice age' when that period was only characterized by a very variable climate, even though on average a ralatively cool one. Following Landsberg's views (1985), it would be preferable to designate cool decades as katathermal and warm decades as anathermal periods. Nevertheless, the term 'Little Ice Age' is today so wide-spread that it is probaly very difficult to reject it completely.

The climatic fluctuations of the 'Little Ice Age' are known most accurately in western Europe where there are numerous written reports of the climatic chracteristics of that time. In addition to these historical proxy data, the longest instrumental records of temperature extend to the latter part of the 'Little Ice Age'. The Central England temperature record, constructed by Gordon Manley from actual measurements, is continuous from 1659 AD onwards (Manley 1974, Lamb 1985).

The cold decades of the 'Little Ice Age' affected ecological development and human life in many ways. In Scandinavia, the most dramatic consequences of the cooling were experienced at farms located near mountain glaciers. In southern Norway the advancing glacier tongues buried pastures and even destroyed farm houses. A wide-spread glacier expansion began in that area towards the end of the 17th century and many glaciers reached their maximum extent around 1750 AD (Matthews 1977, Matthews and Shakesby 1984, Grove 1985). This particular glacier advance was probably also the largest of the Neoglacial oscillations. It is suggested by Karlén (1984) that 'Little Ice Age' glacier growth in southern Norway was, for a large part, due to increased precipitation. There is evidence for a considerable increase in wetness in England during that period (Lamb 1982) and it is probable that a largely similar change took also place in southern Norway at the same time. High winter precipitation values could have resulted in increased accumulation of snow on the mountains and in that way to the advance of glacier tongues.

According to Karlén (1984), no mid-18th century glacier expansion similar to that in southern Norway occurs in northern Scandinavia. Karlén has suggested that in northern Scandinavia the glacier fluctuations are primarily dependent on changes in temperature and less dependent on changes in wetness. Therefore the pattern of glacier advance and retreat on the northern mountains of Scandinavia does not follow the mode found in southern Norway. That would explain some of the contradictions incorporated in studies of glacier oscillations in Scandinavia.

Integrated dendrochronological and glacier fluctuation studies in northern Sweden indicate that glacier fluctuations are in fact in agreement with summer temperature variations. There is now a dendrochronological master curve derived from pine material for that region extending from the present to 436 AD. It has been demonstrated that the variations in tree-ring width are associated with variations in July temperature and that glacier oscillations loosely follow the changes in the tree-ring curves (Bartholin and Karlén 1983, Bartholin 1984, Aniol and Eckstein 1984).

The trends and fluctuations in the tree-ring curves presented in the above studies are partially similar to the changes in the pine growth record published earlier by Matthews (1977), which is based on data collected from the tree-line zone of the mountains of central southern Norway. However, there are also many remarkable differences which can be explained at least for a large part by the non coincidence of climatic fluctuations. Matthews (1977) found ten climatic oscillations during the past 250 years showing changes in summer temperature with amplitudes of 1-3 ^{o}C. These changes were also indicative of glacier advances and retreats in the same region.

In addition to the proxies which are believed to indicate former summer temperatures there are also proxy data which are unambigously indicative of winter temperatures. Historical sources giving the times of freezing of lakes and rivers and melting of the ice cover belong to that latter group. Such data from Norden cannot be reviewed extensively here but the importance of some exceptionally cold winters can be elucidated by an example. In February 1658, during a war between Sweden and Denmark, the Swedish king, Charles X Gustavus led his army over the frozen Danish Straits. That daring crossing of ice during the unusually cold winter gave the victory of the war to the Swedes and Denmark lost all that land which today is southernmost Sweden. The are also other descriptions of military sea-ice crossings during the 'Little Ice Age', which, especially if they took place in the southern half of the Baltic Sea, reflect the severity of the winters (Lindgren and Neuman 1982).

The 'Little Ice Age' came to an end in the 19th century, and especially in the latter half of it, when temperatures began to rise noticeably in Europe and elsewhere. That rise is documented by numerous instrumental records at different weather stations. In Helsinki the rise in yearly mean temperatures was about 1.5 ^{o}C from the early 19th century to the 1940's (Heino 1978). The reason for the rise is unclear. It is commonly suggested that the variation is due to 'climatic noise', which is scientifically an unsatisfactory explanation. Some research workers have proposed that the warming, which is best documented in the northern Hemisphere, results from the rise in atmospheric carbon dioxide. During the time period in question man cleared huge areas of forests and grasslands to cultivated fields. Large amount of carbon stored in soils and forests was released into the atmosphere in the course of that activity. At the same time, the use of fossil fuels was increasing. These factors together caused a considerable growth in atmospheric CO_2 (Wilson 1981, Broecker and Peng 1982). However, in the 1950's the rise in temperatures turned to a slight lowering and 'climatic noise' is the only available explanation for that change. There are signs of a new rise in the 1980's (Gribbin 1984).

TREE-RING DATA FROM EASTERN FINLAND AS CLIMATIC INDICATORS FOR THE PAST 500 YEARS

A recently compiled dendrochronological master curve based on pine material from eastern Finland, is presented in Fig. 5. The data are collected, for the most part, from living trees but also include material from logs used as booms in timber floating and the beams from old houses. The dendroclimatological analysis of the material is not yet finished. Weather records are available for Helsinki from 1829 and for Lieksa from 1909 (see Figs. 4, 5 and 6). Tentative calculations show some correlation between the tree-ring curve and the early summer temperatures at these weather stations.

The relationship between pine (and spruce) tree-ring indices and climatic factors is discussed in a recent paper by Henttonen (1984). Statistical analyses showed that, in northern Finland, variations in the radial growth of pine were

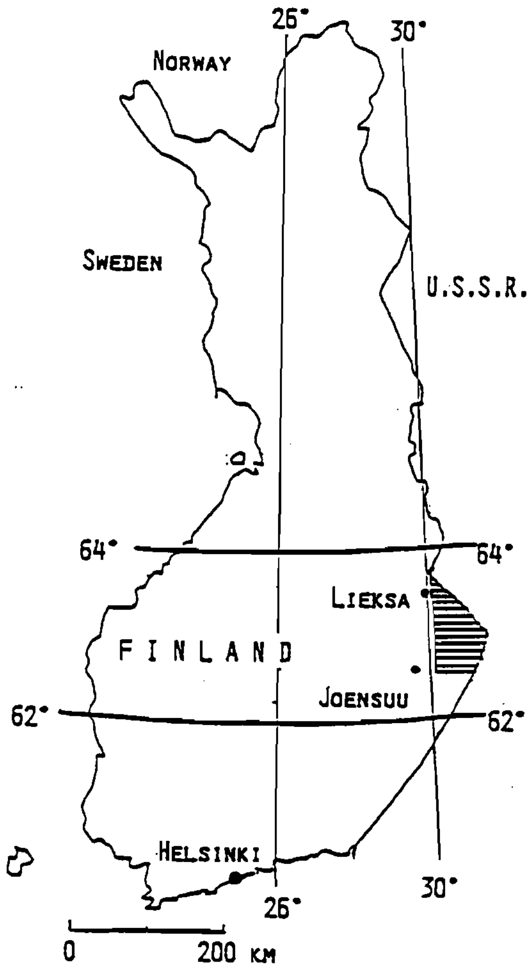

Figure 4. Location map showing the area of dendrochronological studies in eastern Finland.

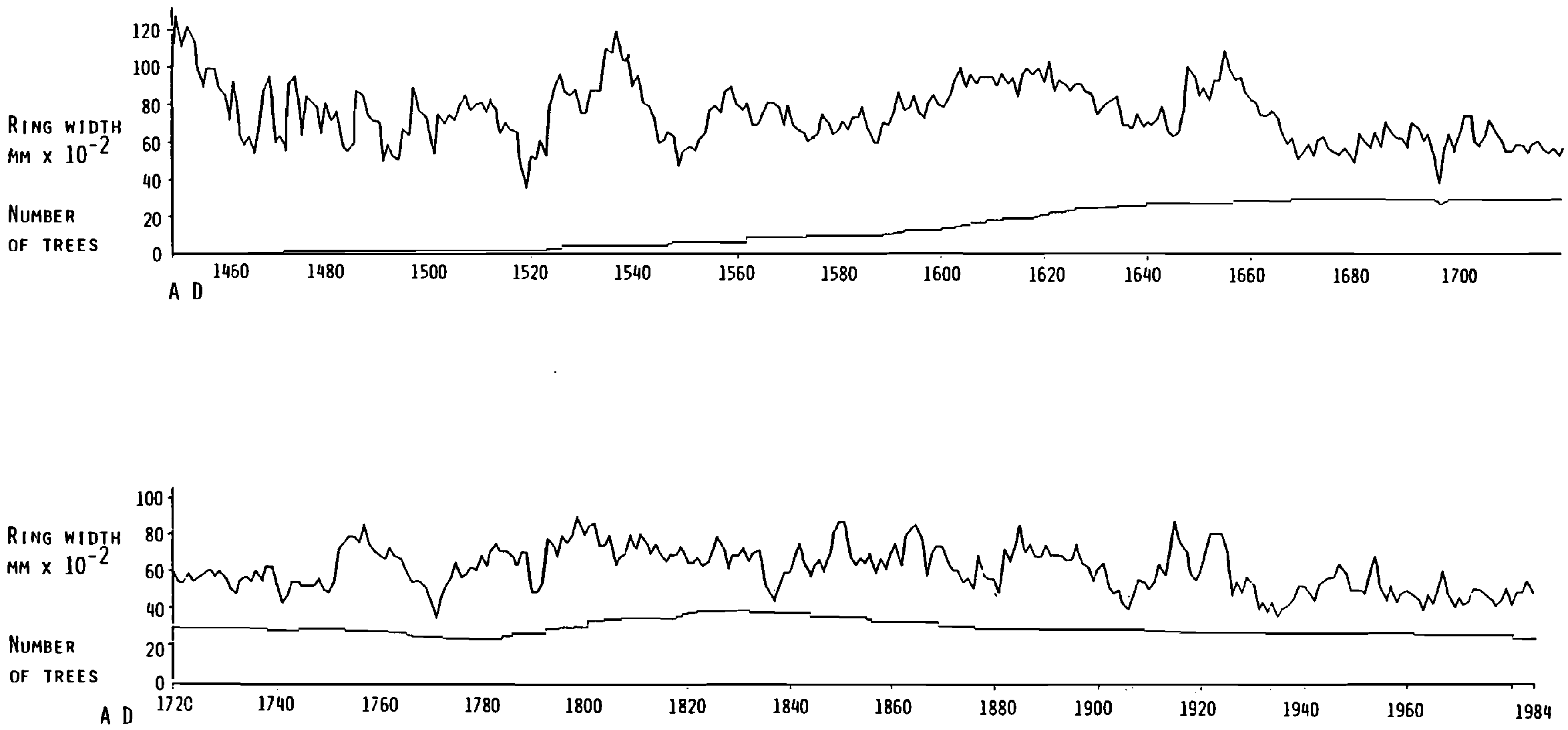

Figure 5. Dendrochronological master curve for eastern Finland. The curve is based on pine material and extends from the present time to 1450 A.D. The number of trees used in the curve construction are shown in the figure.

regulated mainly by summer temperatures, which has also been clearly documented in earlier studies (Hustich 1948, Hustich and Elfving 1944, Sirén 1961), while in southern Finland the pine tree-ring curves correlated very weakly with the summer temperatures but the effect of summer precipitation was found to be more significant. The material used in the study by Henttonen is rather heterogeneous. There are a lot of relatively young trees included in the data and there were stands treated by thinning and fertilization. Nevertheless, it shows that there might still be one complicating factor in the use of proxy data, namely that the same kind of data do not always reflect exactly the same climatic variables in different regions.

It is premature to discuss the changes of the curve in Fig. 5 in detail, because the statistical treatment of the material is not yet complete. In a visual preliminary examination many coinciding points were found between the ringwidth variations and the instrumental and historical record of past climate. The centuries-long main trend of the 'Little Ice Age' oscillation cannot be detected from this curve, but one can expect that a lot more climatic information can be obtained with the advance of data collection and further analyses.

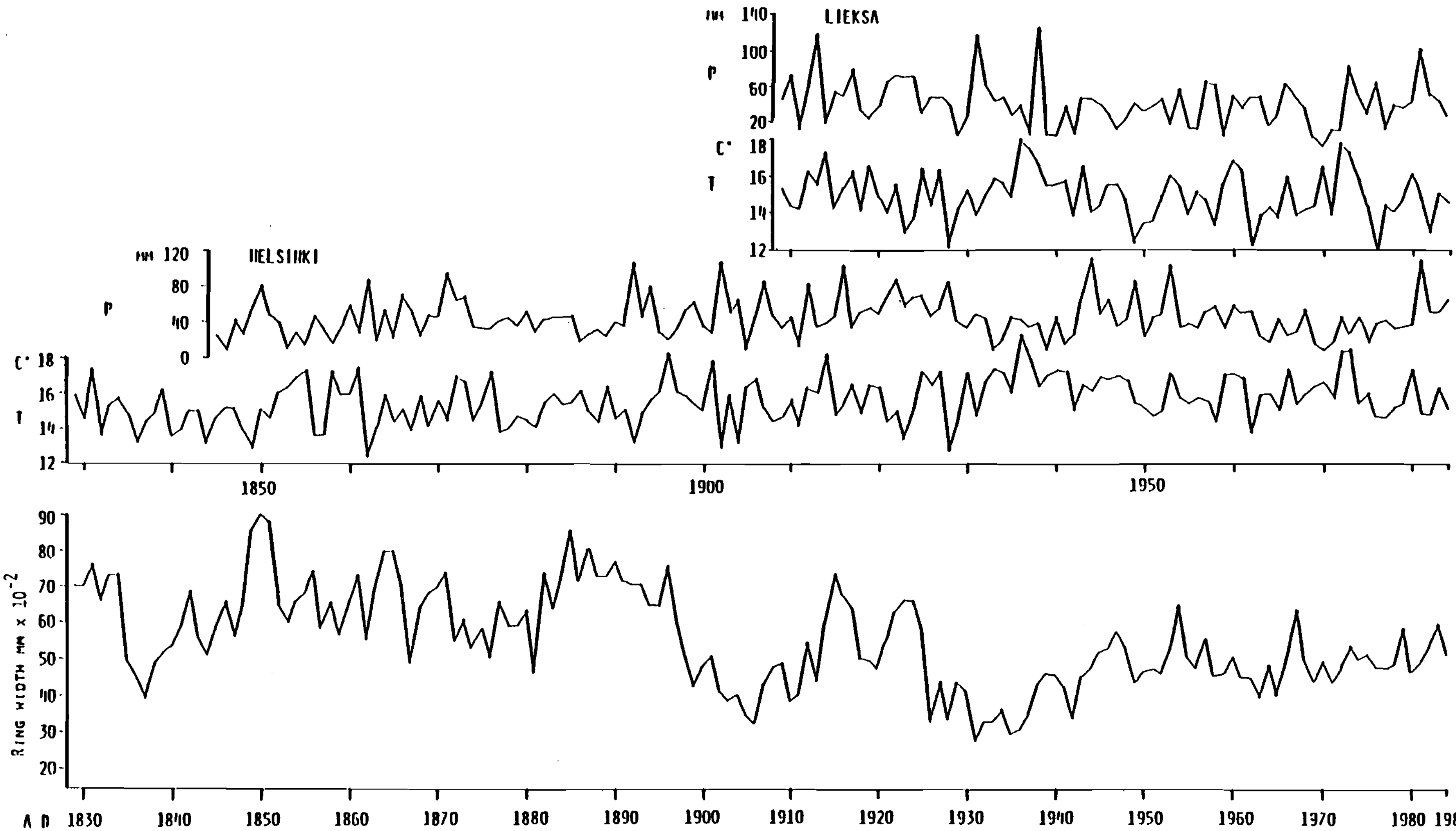

Figure 6. The lower curve is the latter part of the tree-ring curve in Figure 5. Temperature (T) and precipitation (P) values from Helsinki and Lieska (cf. Fig. 4) are plotted in the diagram. The temperature curves show mean June-July temperatures and the precipitation is calculated from the values from May and June. In this construction the weight is on the June precipitation in ratio 1:3.

POSSIBLE FUTURE TRENDS

Mankind's activities will, in all probability, warm the earth in the coming decades. The CO_2 content of the atmosphere is rising and almost all calculations show that the development going on at present will raise global temperatures so that in the 21th century the earth will perhaps be 3 ± 1.5 °C warmer than today. In high latitudes the rise in temperature would be several degrees centigrade (Gilliland and Schneider 1984).

A climatic change is nothing new in the earth's history, as is seen from the above discussion. Palaeoclimatic studies can give some indication of what kind of enveronmental changes will take place when the warming comes into effect. However, the predicted warming is by no means a return to the conditions of the Holocene climatic optimum, for example. Circumstances today are quite unlike those prevailing thousands of years ago. Some differences can briefly be examined here.

When temperatures were rising in early Holocene times, the sea level in the world's oceans was also rising, because continental ice-sheets were melting. The global rise in sea level came to an end around 6000 to 5000 BP and since then only small variations have occurred (Clark and Lingle 1979). There would be a new rise in sea level connected with the future warming, in which case the large ice sheets would shrink to an even smaller size than they were during the climatic optimum and this change would probably affect global atmospheric circulation.

In Norden, postglacial relative sea-level changes are governed by land uplift. After the melting of the North European continental ice-sheet there was a strong isostatic rebound of the earth's crust, which thoroughly changed the geography of Scandinavia and especially the forms of the relatively flat areas around the northern half of the Baltic Sea. The relative sea level today, in the northern Baltic area, is more than 200 metres lower than it was in early Holocene times. Former shorelines of the Baltic can be found hundreds of kilometres inland from the present shores. That development has resulted in a considerable reduction in the water volume of the Baltic Sea, which certainly has had an impact to the regional climatic development (Eronen 1983). The general history of landscape development, soil forming processes, including extensive paludification, natural and man-made changes in the vegetaation are all additional factors making the circumstances markedly different from those of prehistoric times.

One point which must not be forgotten in this connection is the climatic effect of the variations in the earth's orbit. It has been shown that major climatic changes are caused by these astronomical variations (Imbrie et al. 1984). Although the important astronomical cycles are longer than the entire Holocene, they, nevertheless, govern certain trends of development in this time interval, too. Some 9000 years ago the perihelion (the point in the orbit, when the earth is at its closest to the sun) was in July. In the middle of the

Holocene climatic optimum the perihelion was in September. At present the perihelion is in the midwinter of the northern Hemisphere. The tilt of the earth's rotation axis (in relation to the ecliptic) in the mid-Holocene was about half a degree greater than today. These factors affect the seasonal weather. In early to mid-Holocene times the northern summer and autumn were generally warmer than they are today and in any case there was more solar insolation during these seasons in the northern Hemisphere than in the present-day situation. The climate of the coming centuries will not be like that of the climatic optimum, because the perihelion will not be in the autumn (Bryson 1985).

It has been predicted, on the basis of computer models, that there will be remarkable changes in regional precipitation patterns and in seasonal wetness, when the CO_2 induced warming comes into effect (Flohn 1981, Hansen et al. 1981, Manabe et al. 1984). It is impossible to say, what kind of changes in natural conditions that development would bring about in different parts of Fennoscandia. A rise in mean temperatures could give some benefit to the countries or areas lying in the zone of cool climate, but the net effect of the change at the global and regional scales could also be negative.

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3.1.4 METHODOLOGICAL ASPECTS OF DENDROCHRONOLOGICAL PROGNOSTICS

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Lithuanian SSR – USSR

Tree-rings are an important source of information about past growth conditions of biogeocenosis. Most species of trees in extreme and relatively favorable environmental conditions form clearly marked yearly layers, the width and structural features of which enable us to study growth conditions of trees dating back to hundreds of years. Additional information about variations of environmental conditions is obtained by cross-dating the wood of ancient buildings, archaeological excavations, and naturally preserved remains of trees.

In many ecological situations, tree-ring series nicely correlate with meteorological and climatic events. They are good indicators of anthropogenic activity. The width of tree-rings can also serve as a direct indicator of a phenomenon taking place inside the biocenosis.

The latest studies have shown that tree-rings carry a vast amount of information by structure of yearly tree-rings (early, late wood) by the wood elements (width, cell thickness), wood density, isotopic composition of chemical elements, etc.

Since the 1950s, intensive studies on tree-ring research were initiated in the Soviet Union focusing mainly on forestry and archeology, and more than fifty high-level researchers can be mentioned who have used dendrochronological and dendro-climatological methods. A great number of regions of the Soviet Union have been dendrochronologically explored, the territory of which makes up one sixth of the country. As a result, some hundreds of dendroscales have been obtained which can be used for various fields of science as well as used in practice. It should be mentioned that satisfactory results have been obtained from studies undertaken lately in the Baltic regions, the mountainous Ukraine, Karelia, some parts of the northern Caucasus and the central zone of the European part of the USSR. The Causasus, the Urals, some regions of northern Siberia as well as some regions of mountain chains of Middle Asia have been extensively studied. However, many remote regions have not been studied as yet. Three volumes on dendro-scales of the Soviet Union have been published to date; a fourth is under preparation.

Many scientists in the Soviet Union and elsewhere are engaged in modeling climatic processes. Dendrochronology draws on information from long-term series of tree-ring variations which have a pseudocyclic character, and can also be processed by means of various mathematical methods. In many cases, dendrochronological information correlates well with many processes which are of a natural and anthropological nature. That is why such important indices of natural environment as precipitation, level of lakes and rivers, air temperature, winds, droughts, humidity, forest fires, spreading of entomophyto vermin, influence of industrial smoke and gas, and many other influences and consequences reflect in the width and structure of yearly tree-rings. Methods of mathematical modeling and forecasting of tree productivity are being worked out in the Institute of Plant and Animal Ecology (Sverdlovsk). Some supplementary research has been undertaken in the Lithuanian Research Institute of Forestry.

In the Dendro-climatolo-chronological Laboratory of the Institute of Botany (Lithuanian Academy of Sciences) some base (or registration) years were used to which radial tree growth can be "attached", in order to forecast environmental conditions of forest growth. Solar activity number of sunspot (according to Wolf) for hydrological years was chosen as the base year. It was shown that in certain regions of the USSR there is a clear correlation between the amplitude of solar activity in the 22-year cycles and radial tree growth during the same period. In different phases of the solar activity (at maximum marked "a" and "b", and minimum marked "c" and "d" as well as in time periods of increasing and decreasing solar activity "ac", "cb", "bd" and "da"), forest growth in different regions of the country and under different growth conditions is very different.

Our research is based on the assumption that at certain phases of the solar activity in different regions and conditions of growth we can expect, with certain probability, extreme radial tree growth (optimum and minimum) for the given periods of time. At the same time, we foresee an improvement or worsening of ecological conditions for that period. The methods conceived involved general phenomena which took place at certain phases of the solar activity. In the late years (1983-1984) we attached yearly data of tree-rings and their indices to the base year of the solar activity essentially coming nearer to the method of overlapping epochs.

Methods of Investigation

Hydrological years (September–December of the previous year and January–August of the present year) of the highest and lowest solar activity are registration years for "attachment" of the dendrochronological data. The central year of the three years with maximum indices is taken in order to determine the maximum solar activity, and the central year of the three least values of the Wolf's number. Trustworthy data of the Wolf's number are found since 1749, which at present form twenty-one 11-year and eleven 22-year cycles. Solar activity series in the registration system were checked according to Showe's system. Table 1 shows the base (registration) years of the solar activity according to the first and second maxima of the solar activity $\bar{a}$, $\bar{b}$ and the minima - the first, $\underline{c}$ and second, $\underline{d}$.

Ecological forecasting is based upon the definite prognoses of 11-year and 22-year cycles of the solar activity. In particular, the determination of the maxima and minima of the solar activity is of very great importance. It is known that the prognosis of the solar activity is guided by mathematical modeling of regularities of variability of Wolf's numbers and they differ from each other for different characteristics of the rhythmics of the solar activity. We tried to use the method of overlapping epochs while making up generalized series of the solar activity for the hydrological year (Table 1) in order to reveal the distinctive features in time of the 22-year cycles as well as of 44-year and 88-year cycles.

As a result, the average data of the solar activity theoretically and practically allows one to calculate the average variability as a certain standard for methodical work; we can thus date forward (prognosis) and backward (retrospect).

Retrospective dating can be easily checked with the help of the data available; a prognosis can also easily be made by constantly observing the increment by monitoring. With the available registration system it is easy to make

Table 1. Basic (registration) years of the solar activity.

Cycle no.	Phases of the solar activity $\bar{a}$	$\underline{c}$	$\bar{b}$	$\underline{d}$
0			1751	1755
1	1761	1765		
2			1770	1775
3	1779	1784		
4			1788	1798
5	1804	1811		
6			1817	1823
7	1829	1834		
8			1837	1843
9	1849	1856		
10			1860	1867
11	1871	1878		
12			1884	1889
13	1894	1900		
14			1907	1913
15	1918	1923		
16			1928	1933
17	1937	1944		
18			1948	1954
19	1958	1964		
20			1969	1976
21	1980	(1987)		
22			(1991)	(1997)

tables of the distribution of the dendro-climatological date regarding the basic (registration) of the past solar activity (Table 2) and foresee the variability of tree increment (growth) in the future (Table 3). If there are enough long series of natural phenomena (e.g., air temperature, precipitation, complex climatic indices, earthquakes, etc.), the method of the overlapping epochs can also be used to process this information.

The distribution of dendrochronological data according to the years in relation to basic years of the solar activity is shown in Table 2, the order of distribution and calibration of average indices in relation to the basic years of the solar activity is shown in Table 3–3a. The basic years of the solar activity built as a method to study the peculiarities of variability of the radial increment of woods during the centuries is shown in Table 4. For dendrochronological analyses, dendroscales from various regions of the world were used (see Table 5).

Results of the Study

It was shown that using the basic years of the solar activity is one of the few methods which have proven worthwhile in the study of predicting regularities of tree increments in different regions of the world. The width of tree-rings and yearly indices calculated can be easily "attached" to the maximum and minimum of the 22–year cycles of the solar activity since 1745 till the present. This numerical and graphic method enables one to expose the different increments of trees in different phases of the solar activity.

It is known that the increment of trees depends mainly on soil conditions, hydrothermal conditions of climate and ecological features of trees in that region. We therefore consider that series of yearly tree rings, processed by the basic years method in most cases reflect well the changes in the productivity of trees and, at the same time, certain fluctuations in the climatic changes.

The novelty in our method lies in the fact that the basic year used consists of not only 11–year, but 22–year, 44–year and 88–year cycles. Hence, we obtain a complex, but decipherable picture of the variability in living nature with relatively periodically recurrent regularities of astrophysical phenomena.

The data of the solar activity processed by the method of basic years can serve as a preliminary mode of long-term prediction of solar activity values in 22-, 44- and 88-year cycles. The data of tree growth, arranged according to separate maximum and minimum of the solar activity, as a rule overlap with a similarity in value data.

Table 2. Deviation of years from the basic (registration) years of the solar activity (0).

Group of cycles	Cycle	Distribution of calendar year in relation to the first maximum of the solar activity (phases ā)													
1	1	1755	56	57	58	59	60	1761	62	63	64	65	66	67	68
2	3	1773	74	75	76	77	78	1779	80	81	82	83	84	85	86
1a	5	1798	99	00	01	02	03	1804	05	06	07	08	09	10	11
2a	7	1823	24	25	26	27	28	1829	30	31	32	33	34	35	36
1	9	1843	44	45	46	47	48	1849	50	51	52	53	54	55	56
2	11	1865	66	67	68	69	70	1871	72	73	74	75	76	77	78
1a	13	1888	89	90	91	92	93	1894	95	96	97	98	99	00	01
2a	15	1912	13	14	15	16	17	1918	19	20	21	22	23	24	25
1	17	1931	32	33	34	35	36	1937	38	39	40	41	42	43	44
2	19	1952	53	54	55	56	57	1958	59	60	61	62	63	64	65
1a	21	1974	75	76	77	78	79	1980	81	82	83	84	85	86	87

Group of cycles	Cycle	Distribution of calendar year in relation to the first minimum of the solar activity (phases c)													
1	1	1759	60	61	62	63	64	65	1766	67	68	69	70	71	1772
2	3	1777	78	79	80	81	82	83	1784	85	86	87	88	89	1790
1a	5	1804	05	06	07	08	09	10	1811	12	13	14	15	16	1817
2a	7	1827	28	29	30	31	32	33	1834	35	36	37	38	39	1840
1a	9	1849	50	51	52	53	54	55	1856	57	58	59	60	61	1862
2	11	1871	72	73	74	75	76	77	1878	79	80	81	82	83	1884
1a	13	1894	95	96	97	98	99	00	1901	02	03	04	05	06	1907
2a	15	1916	17	18	19	20	21	22	1923	24	25	26	27	28	1929
1	17	1937	38	39	40	41	42	43	1944	45	46	47	48	49	1950
2	19	1957	58	59	60	61	62	63	1964	65	66	67	68	69	1970
		−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6
					ā		--		c		—		b̄		

Table 2. (Continued) Deviation of years from the basic (registration) years of the solar activity (0)

Group of cycles	Cycle	Distribution of calendar year in relation to the second maximum of the solar activity (phases $\bar{b}$)													
2a	0	1745	46	47	48	49	50	1751	52	53	54	55	56	57	1758
1	2	1764	65	66	67	68	69	1770	71	72	73	74	75	76	1777
2	4	1782	83	84	85	86	87	1788	89	90	91	92	93	94	1795
1a	6	1811	12	13	14	15	16	1817	18	19	20	21	22	23	1824
2a	8	1831	32	33	34	35	36	1837	38	39	40	41	42	43	1844
1	10	1854	55	56	57	58	59	1860	61	62	63	64	65	66	1867
2	12	1878	79	80	81	82	83	1884	85	86	87	88	89	90	1891
1a	14	1901	02	03	04	05	06	1907	08	09	10	11	12	13	1914
2a	16	1922	23	24	25	26	27	1928	29	30	31	32	33	34	1935
1	18	1942	43	44	45	46	47	1948	49	50	51	52	53	54	1955
2	20	1963	64	65	66	67	68	1969	70	71	72	73	74	75	1976

Group of cycles	Cycle	Distribution of calendar year in relation to the second minimum of the solar activity (phases $\underline{d}$)													
2a	0	1748	49	50	51	52	53	54	1755	56	57	58	59	60	1761
1	2	1768	69	70	71	72	73	74	1775	76	77	78	79	80	1781
2	4	1791	92	93	94	95	96	97	1798	99	00	01	02	03	1804
1a	6	1816	17	18	19	20	21	22	1823	24	25	26	27	28	1829
2a	8	1836	37	38	39	40	41	42	1843	44	45	46	47	48	1849
1	10	1860	61	62	63	64	65	66	1867	68	69	70	71	72	1873
2	12	1882	83	84	85	86	87	88	1889	90	91	92	93	94	1895
1a	14	1906	07	08	09	10	11	12	1913	14	15	16	17	18	1919
2a	16	1926	27	28	29	30	31	32	1933	34	35	36	37	38	1939
1a	18	1947	48	49	50	51	52	53	1954	55	56	57	58	59	1960
2	20	1969	70	71	72	73	74	75	1976	77	78	79	80	81	1982
		−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6
					$\bar{b}$		—		$\underline{d}$		—		$\bar{a}$		

Table 3. Distribution of yearly indices of pine (Pinus silvestris) in Neringa, Western Lithuania (soil site: Pinetum Oxalidoso–myrtilosum); C_2 to the basic years of the first maximum of the solar activity a.

Group of cycles	Cycles	Value of yearly indices a											
1	1	108	103	84	128	108	127	103	97	124	107	89	80
2	3	118	98	104	117	138	45	36	62	76	85	116	119
1	5	88	111	130	141	34.5	29	49	67	90	70	67	77
2	7	127	90	76	106	120	85	71	116	113	89	90	77
1	9	49	116	117	96	81	100	110	64	37	62	122	160
2	11	155	104	74	53	77	112	133	108	90	116	128	118
1	13	102	111	98	88	126	181	102	85	115	71	34	48
2	15	28	82	121	160	132	114	125	91	91	90	84	109
1	17	97	83	78	93	104	137	123	132	64	142	117	94
2	19	102	80	92	86	107	94	140	76	59	54	83	114
I gr.	Σ	444	524	507	546	453.5	574	487	445	430	452	429	459
II gr.	Σ	530	454	467	522	574	450	505	453	429	434	501	537
M	Σ	974	978	974	1068	1027.5	1024	992	898	859	886	930	996
I gr.	M	89	105	101	109	91	115	97	89	86	90	86	92
II gr.	M	106	91	93	104	115	90	101	91	86	87	100	107
M	average	97	98	97	107	103	102	99	90	86	89	93	100
		−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6

Table 3a. Distribution of yearly indices of yellow pine (Pinus ponderosa) in the Western territory of the USA; longitude 112°18' and latitude 37°32' in relation to the basic years (the first maximum of the solar activity $\bar{a}$). The basic years are determined according to Showe's data for 1449–1749.

Source: *Collected Dendroscales 1*, Published by the Laboratory of Tree Ring Research, University of Arizona, Tucson, AZ, USA.

							$\bar{a}$							
Grp of cycl	Cycl	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+6	+7
1	-31	79	83	68	78	72	93	82	104	101	114	95	88	62
2	-29	113	80	103	111	102	102	72	67	96	96	62	70	106
1	-27	101	101	139	122	109	82	72	99	61	55	80	122	128
2	-25	131	69	65	79	85	71	95	91	109	80	104	95	105
1	-23	118	84	95	74	90	68	112	110	36	78	88	87	85
2	-21	110	95	90	64	66	81	93	103	100	85	71	67	83
1	-19	107	65	81	102	84	71	92	52	75	99	106	115	130
2	-17	97	121	95	112	114	84	94	107	101	103	98	93	74
1	-15	84	95	70	52	38	87	101	82	101	69	78	68	89
2	-13	137	134	128	145	140	185	147	148	99	130	153	148	163
1	-11	93	101	102	67	45	100	87	107	109	75	81	101	120
2	-9	110	102	117	83	97	51	82	97	121	120	100	122	124
1	-7	106	132	108	81	115	97	81	103	114	93	106	71	66
2	-5	112	98	96	97	86	91	71	90	94	116	106	55	71
1	-3	88	107	101	131	100	69	108	111	113	123	111	112	61
2	-1	90	92	88	79	112	116	115	134	119	83	120	112	105
1	1	122	83	85	86	109	116	139	142	138	141	126	127	109
I		898	851	849	793	762	783	874	902	848	847	871	891	850
II		900	791	782	770	802	781	769	837	839	813	814	762	831
III		1798	1642	1631	1563	1564	1643	1643	1739	1687	1660	1685	1653	1681
I	M	99	94	94	88	85	87	97	100	94	94	97	99	94
II	M	112	99	98	96	100	98	96	105	105	102	102	95	104
III	M	106	96	96	92	92	92	97	102	99	98	99	97	99

Table 4. Variability of solar activity according to the phases of the 88-year cycle.

I				II				Ia				IIb			
$\bar{a}$	$\underline{c}$	$\bar{b}$	$\underline{d}$	$\bar{a}$	$\underline{c}$	$\bar{b}$	$\underline{d}$	$\bar{a}$	$\underline{c}$	$\bar{b}$	$\underline{d}$	$\bar{a}$	$\underline{c}$	$\bar{b}$	$\underline{d}$
1449	1457	1461	1468	1742	1476	1480	1488	1492	1498	1505	1512	1519	1525	1528	1535
1539	1543	1548	1553	1538	1567	1572	1578	1581	1587	1591	1599	1604	1611	1615	1619
1626	1634	1639	1645	1649	1655	1660	1666	1675	1679	1683	1689	1693	1698	1705	1712
1718	1723	1727	1734	1738	1745	1751	1755	1761	1766	1770	1775	1778	1784	1788	1798
1804	1811	1817	1823	1829	1834	1837	1843	1849	1856	1860	1867	1871	1878	1884	1889
1894	1901	1907	1913	1918	1923	1928	1933	1937	1944	1948	1954	1958	1964	1969	1976
1980															

$\bar{a}$ – the first maximum of the solar activity

$\underline{c}$ - the first minimum of the solar activity

$\bar{b}$ – the second maximum of the solar activity

$\underline{d}$ – the second minimum of the solar activity

Table 5. Dendroscales used for the dendrochronological study.

Region	Latitude	Longitude	Altitude	Tree species
1. Carpathians, Lithuanian SSR, Murmansk				
Lithuanian SSR*	56°27'–53°54' North	20°56'–26°51' East	5–150 m	Pinus silvestris, Picea excelsa, Quercus robur, Alnus glutinosa
Baltic: Latvia, Estonian SSR	56°00'–59°40' North	21°00–28°00' East	10–150 m	Pinus silvestris
Novogrod	58°00'–59°00' North	30°00'–34°00' East	30–250 m	Picea orientalis
Middle & East Karelia	62°00'–66°30' North	30°00'–34°00' East	50–1000 m	Pinus silvestris
Western Caucasus	43°00' North	42°00' East	1550–2000m	Picea orientalis
Middle Asia Zail Alatau	43°30' North	76°00'–77°00' East	1400–2800 m	Picea sreniana
Lake Baikal	51°00'–56°00' North	104°00' East	1400–2800m	Larix dahurica, Pinus cembra
Kamchatka	55°00'–56°00' North	160°00'–162°00' East	500–1200 m	Larix kajanderi, Pinus pumila
Bashkir ASSR	54°00' North	58°00' East	1000–1500m	Pinus silvestris
Komi ASSR	67°00' North	52°00'–54°00'	50–200m	Larix sibirica, Picea sibirica
2. The Mongolian People's Republic				
	48°00'–50°00' North	100°00'–112°00' East	500–1500 m	Pinus silvestris, Laris sibirica
3. North America (western part of the continent)				
		50°45'–30°10' North– 120°30' West	610–2135 m	Pinus ponderosa
	50°45'–34°10'	120°43'	613–3111 m	Pinus flexilis, Pseudotsuga mensiensii, Pinus edulis, Pinus longeava, Pinus artistat, Pinus Jeffrey
	44°19'–35°35' N	83°26'–71°23' W	183–458 m	Picea rubens
	41°44'–34°37' N	93°45'–74°15' W	150–503 m	Pinus echinata
	42°00'–34°34' N	94°15'–83°50' W	183–458 m	Quercus alba

*The research was conducted using conditions of various soil richness and soil humidity (dry, fresh, damp and swampy) in Central, Western, Northern and Eastern Lithuania).

4. Southern Hemisphere:

Region	Latitude	Altitude	Species
Argentina:	42°57' S–71°26' W	820 m	Austrocedrus Chilensis
Chile	37°21' S–71°36' W	850-1000 m	Austrocedrus Chilensis
South Africa:	34°24' S–19°13' W	360 m	Cap. Widdringtonija cedarbergensis
Australia:	43°22' S-143°16' E	450m	Tasmania Phylocladus alternifolijus

For the study using the above-mentioned method, the most suitable species proved to be: pine (Pinus silvestris), fir (Picea exelsa), oak (Quercus robur), fir in Komi ASSR, trees in the Lake Baikal region, Kamchatka; pine (Pinus silvestris) and Siberian larch in Mongolia; pine (Pinus ponderosa) in Western Canada and the USA; oak (Quercus alba) and similar species in the eastern part of the USA; Austrocedrus chilensis in Chile and Argentina; eastern fir in West Caucasus, Schrenk's fir in Tien Shan, and pine in North Karelia.

An opinion has been formed that the solar activity's lesser effects on tree growth are felt in extreme environmental conditions as for example in large mountain canyons, near the northern limits of forests and under some optimal growing conditions, e.g. in Lithuania in soil site oxalidosum.

According to the preliminary investigation, we consider that it is worthwhile to look for fluctuations of increment dependent on solar activity using trustworthy dendroscales, in which after 5 overlapping epochs, the average fluctuations of increment remain no less that 25–30 percent and in which it is possible to single out no less than 2–3 periods of time where tendencies in changeability of tree growth evidently coincide by 60–80/100 percent.

The study of the radial increment reaction of trees in certain regions of the USSR and in other countries make it possible for us to ascertain that regularities in changeability of tree increment within certain time periods (which can be characterized by certain phases of the solar activity) evidently differ. These periods differ in great recurrence of extremities. For example, in Lithuanian SSR in marsh–ridden conditions, phases $\bar{a}$, $\bar{a}$ $\underline{c}$, $\underline{c}$ distinguish themselves by rather deep minimum, phases $\bar{b}$, $\bar{b}$ $\underline{d}$ by great maximum. A relatively small increase is seen in phase $\underline{d}$. Even in normally drained, fresh conditions, the increase is small in phases $\bar{a}$ $\underline{c}$. The minimum in growth is manifested not only in pineries of the Lithuanian SSR, but also in spruce-groves, oak-woods, and in alder-groves. It is manifested in pineries of Latvian SSR, in Valdai, Belorussia, in Tataria and in the Carpathians. A small increase is also found in some western regions of the USA (Pinus ponderosa, Pseudotsuga). In phase $\bar{a}$ $\underline{c}$ a small increase is noted in Argentina and Chile. Thus it is possible to confirm that in some periods of time (simultaneously) negative ecological conditions manifest themselves in vast territories.

In conclusion, we can state that the basic registration method of the solar activity is one of the concrete methods which allows one to foresee the present and future climatic background according to the regularities of the past. In future, the dendroclimatological laboratory will study the global changeability of tree rings as well as regional peculiarities of the dynamics of tree increment and its eco-geographical regularities.

3.1.5 TREE-RINGS AS INTEGRATORS FOR NORMAL AND ANTHROPOGENIC ENVIRONMENTAL CHANGES

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ABSTRACT

Growth ring sequences from the area of the Alps provide excellent material for climatological and ecological research. Radiodensitometry, the identification of pointer years, and the pinpointing of abrupt changes in growth all permit the determination of year-by-year and long-term events.

Summer temperatures may best be reconstructed from the maximum densities of trees near mountain and northern timberlines. Given sufficient moisture, it is the temperature which limits latewood development in these regions. A sampling network for Europe has allowed the determination of areas of agreement between chronologies and, from year to year, of areas with higher or lower latewood density. The pattern of summer temperatures during the Holocene has been determined from a density chronology from conifers found in geological deposits and ancient buildings. Abrupt growth reductions in modern trees indicate an extensive threat to the environment.

TREE-RINGS AS INTEGRATORS FOR NORMAL AND ANTHROPOGENIC ENVIRONMENTAL CHANGES

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INTRODUCTION

The materials and methods available in dendrochronological research allow the exact dating of changes in the width and density of tree rings. Such changes are caused by the influence of climate, local events such as insect attack, changes in site conditions, or air pollution, and may last from one vegetation period to many years. Such events can be identified in the growth ring pattern. On the basis of these facts, research has been carried out in the Alps on various questions:

- How much climatological information can be obtained from growth ring sequences from different sites?
- What climatic changes occurred during the Holocene period?
- What changes in the environment have been caused by pollution?

1. The material available

Material from the Alps provides a great deal of information, since there is great variation between sites, and the differences are reflected in the tree ring patterns. The amount of information on climate and site conditions, however, varies from site to site.

Modern trees. In the extensive high altitude coniferous forests of the Alps, 300-year-old trees occur quite frequently despite utilisation, although trees over 500 years old are rarely found. At lower elevations the forests have been intensively utilised, so that there is little old material suitable for dendrochronological research remaining. For research on pollution effects, however, trees aged only 50-100 years may be suitable.

Historical material is plentiful in all zones, especially in wooden buildings in the mountains. Many buildings both in town and country are constructed of wood. Little dendrochronological research has been carried out so far on buildings of conifer wood in the mountains, although such material contains much climatological information.

Archeological material. Hardly any region of the world is as rich in well-preserved archeological wood as the Alps. Hundreds of bogs and lakeshore settlements provide countless tree trunks suitable for dendrochronological interpretation. Oak stems are particularly suitable for dating, although they provide only limited dendroclimatological information. Most of the dendrochronological laboratories working on material from the Alps utilise such material.

Geological material. Dateable oak stems can be found in the deposits of large rivers. The climatological information directly available from their growth ring sequences is, however, sparse. Dating of hundreds of stems allows the age of the tree and the date of its death to be related to geological processes and sometimes to climatic fluctuations.

2. Methods

All of the dendrochronological techniques developed so far are suitable for decoding environmental effects.

2.1 Radiodensitometry

This method differs from conventional dendrochronology in that it uses density profiles of growth rings from which a number of parameters for dendrochronological interpretation can be obtained. It was first developed by Hubert Polge and has since been described several times, e.g., Polge 1966, Parker and Hennoch 1971, Schweingruber 1983. It is particularly suitable for dendrochronological studies on conifers growing in cold-moist zones, e.g., the subalpine zone of the northern hemisphere.

2.2 Measurement of ring width

This constitutes the core of all dendrochronological studies. Ring width sequences provide information on the climate, particularly those from semi-arid areas such as the southwestern United States, the steppes of Eurasia, or the pine forests of the central Alps.

2.3 Dating by means of pointer years

The skeleton plot method was first elaborated by A.E.Douglass at the beginning of the century. Its main basis is the pinpointing of very narrow rings within fairly long sequences. Very narrow or very broad rings are not only good markers for dating but also indicate the occurrence of extreme environmental influences in particular years. This method has rarely been applied in dendroecological research, although it is excellent for such work.

2.4 Dating of long-term events

When a tree is physiologically favoured or impaired, it indicates the fact by producing a series of broader or narrower growth rings (Fig. 1). The onset, duration, and end of such periods of reduction or recovery can be recorded for every tree. This method is particularly suitable for the determination of damage due to pollution. Since there are few records of emissions and their effects on trees, only growth ring sequences can provide reliable information on the condition of the tree (Fig. 2a, 2b).

Modern statistical processes allow the compilation of large amounts of data and the determination of general trends apparent in growth ring sequences in terms of both time and space. Any form of statistical interpretation, however, can only achieve its goal if it is based on suitable material. The most effective 'statistics' is the selection of study material in the field.

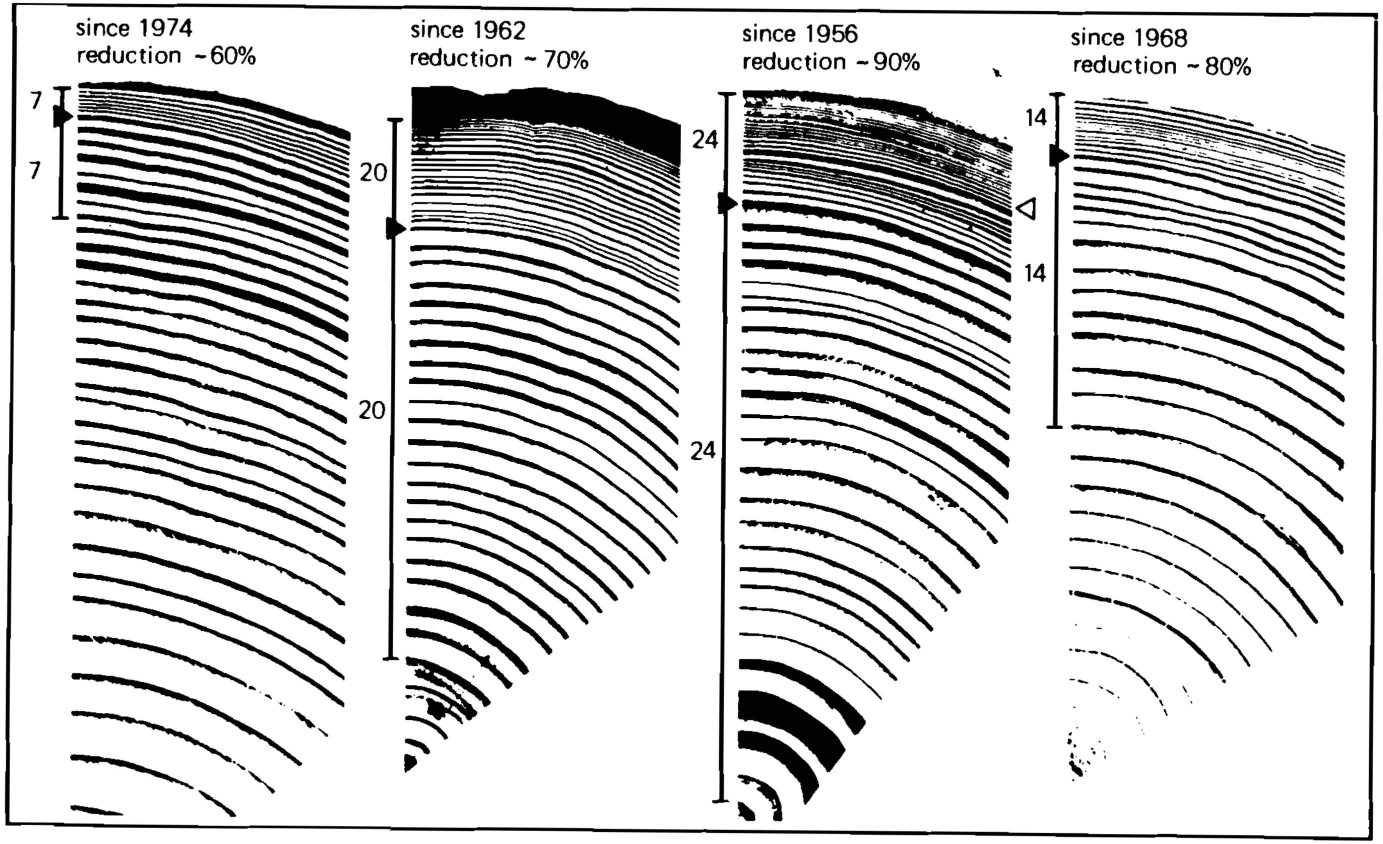

Figure 1. Growth ring sequences for fir (*Abies alba*) showing abrupt growth reductions. The number of narrow rings formed after the abrupt change is compared with an equal number of normal rings before the change (figures on the left). Direct prints from polished stem discs. After Schweingruber, et al., 1983.

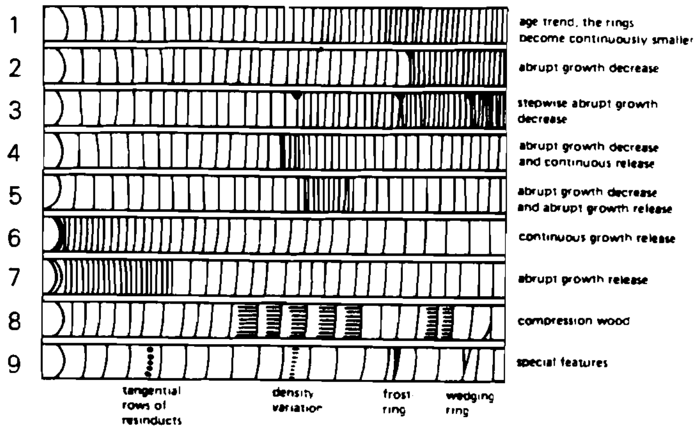

Figure 2a. Schematic representation of growth ring sequences showing long-term changes in growth. Even without measurement, all the abrupt changes, e.g., No. 2-5 and 7 can be immediately recognised. These changes can be dated by means of ring counts and pointer years.

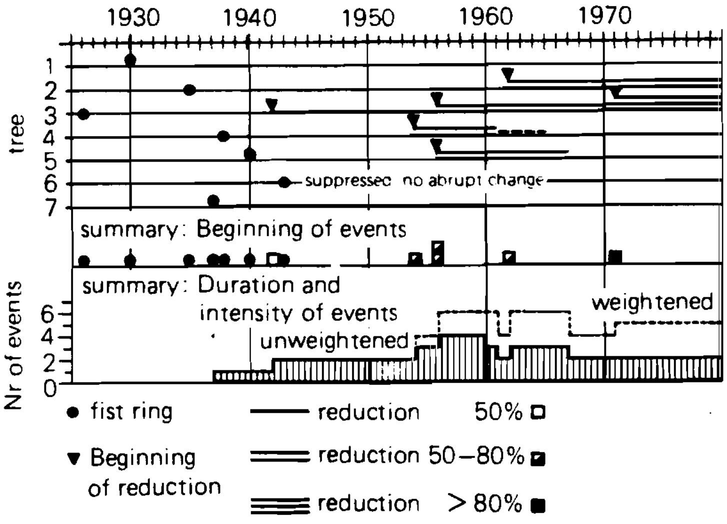

Figure 2b. Schematic representations of the core samples shown in Figure 2a. The events are summarized in event summation diagrams and summation diagrams showing the duration of the reduction phases.

3. Results, illustrated by examples from the Alps

3.1 Dendro-ecology. The relationship between growth rings and site in mountain areas.

Kienast 1985 analysed growth ring sequences from conifers growing along gradients of elevation and moisture in various climatic regions (Switzerland, temperate; Cyprus, mediterranean; Colorado, cold steppe). He established that ring formation is far more strongly influenced by conditions at the growth site than by the general climate. An example: in cold-moist years (1912 in the Alps), the maximum density is high on dry sites at low elevation but low on moist sites at high elevation within the same region. In warm-dry summers (1911 in the Alps), on the other hand, maximum density is low on shallow sites at low elevation but high on moist sites near timberline. Only at the upper timberline of the boreal zone, determined by cold, does cell-wall development in the latewood seem to be limited in every year by the mean summer temperature (July-September). At arid timberlines, minimum precipitation is practically the only limitation on cambial activity, i.e., ring width. Ring sequences from trees growing on mesophile sites reflect a number of ecological factors which vary from year to year.

3.2 Dendroclimatology. The European sampling network.

1976 saw the first steps in the construction of a European sampling network for conifers growing on cold-moist sites. Samples were selected from cool-moist sites as close to timberline as possible and analysed radiodensitometrically with the aim of maximising information on the effect of temperature on growth ring formation, particularly by determining the maximum density. These samples share the following features:

- the maximum density largely integrates the temperatures from July to September of the current year. Since the latewood cells have a live-span of two to three months, they are able to integrate climatic effects over this period.

- most conifer species, e.g., *Picea sp., Abies sp., Pinus sylvestris*, correspond in terms of the climatic information provided by their maximum densities. Less suitable are the five-needle pines such as *Pinus cembra* and *P. peuce*.
- differences in site conditions have only a subordinate influence on maximum density in trees at the subalpine and boreal timberlines.

Thanks to these features it has been possible to establish a uniform framework for a sampling network which is heterogeneous in terms of both species and site. this is demonstrated by the following features:

a) Areas of similarity (Fig. 3)

Comparison of chronologies by calculation of correlations and gleichläufigkeits values shows that the areas with statistically verified similarities are very large (Schweingruber 1985). For maximum density in northern Europe, for example, they extend for 2000 km, and for ring width for as much as 800 km. The areas of similarity for maximum density are considerably greater than those for ring width. Their extent decreases from the north to the south of Europe. In the south, the area covered by the sampling network is limited by summer drought; even on mountain timberline sites the trees are influenced by lack of precipitation in the summer.

b) Areas of year-by-year similarity in maximum density (Fig.4)

Mapping of maximum densities and deviations from the indexed mean value reveals that above or below average values occur over very large areas in each year. There are practically no exceptions within these areas. These growth maps show the great variability occurring from year to year; sometimes there is a

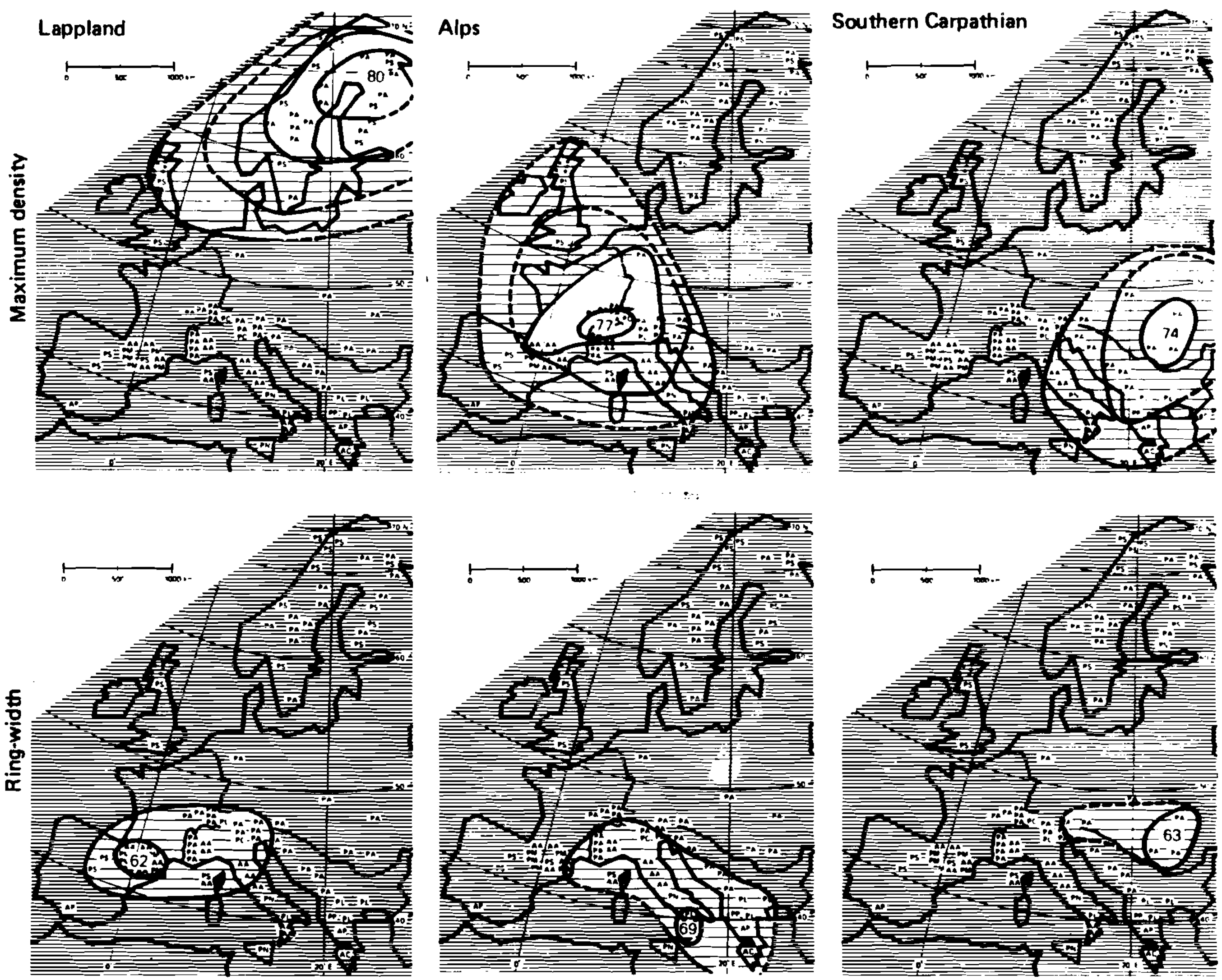

Figure 3. Areas for curves of maximum density and ring width with significant agreement between 1870 and 1976. Calculated on the basis of "gleichläufigkeit" values. After Schweingruber, 1985.

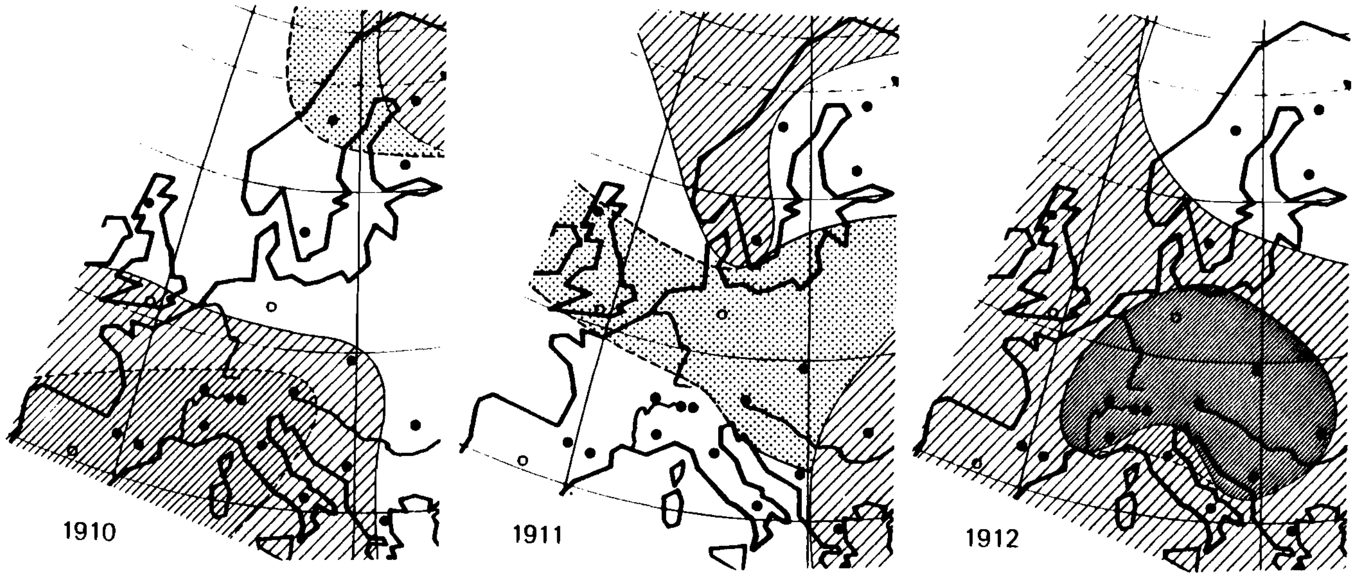

Figure 4. Areas of above and below average maximum density in the years 1910-1912, calculated on the basis of the indexed chronologies for the sites in Europe. The shape and size of the areas vary from year to year.

north-south division, sometimes an east-west one. Only seldom do small subareas occur within Europe.

3.3 Dendroclimatological research on chronologies from high altitute stems of the Holocene

Finds of old conifer stems, especially larch and spruce, in buildings and glacier deposits in the central Alps have permitted the construction of a long, radiodensitometrically elaborated chronology capable of climatological interpretation (Fig. 5), (Renner 1982, Bircher 1982, Röthlisberger 1976, Schweingruber et al 1984). The chronology is in places only sparsely covered, but it does indicate the following points:

- all fluctuations in maximum density occurring within the past 8000 years lie within the range of those occurring in our millenium;
- cold phases similar to the 'Little Ice Age' of 1570-1640 A.D. have occurred frequently. The longest cold phase lasted some 150 years (around 3300 BP), the longest warm phase lasted about 200 years (around 3100 BP);
- the transition from one phase to another may be slow, e.g., around 3700 or 3000 BP. Most transitions, however, took place within only a few years, e.g., around 3200 or 7700 BP;
- some of the periods of glacier maxima determined through pollen analysis and studies of glacier morphology are clearly reflected, although the time lags vary.

3.4 Forest damage research

Growth ring sequences from trees growing in the twentieth century manifest features indicative of pollution damage. This means that such sequences can only be climatically interpreted to a limited extent. In order to investigate this point, the condition of modern trees from several different parts of

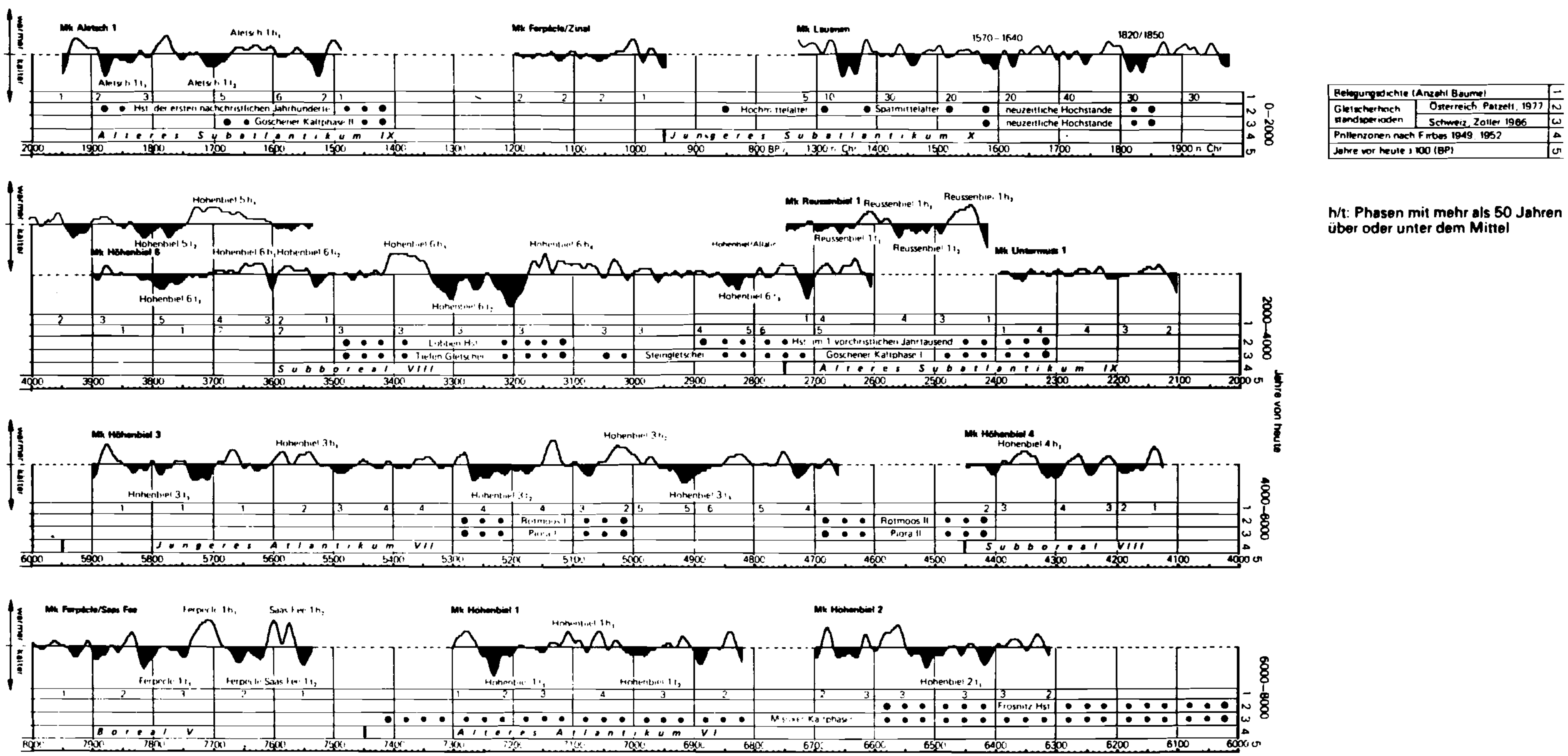

Figure 5. Fluctuations in maximum density of conifers from the subalpine zone in Switzerland between 8000BP and the present. After Renner, 1982.

Switzerland was determined through dendrochronological techniques, the main objective being to classify abrupt changes in growth as shown in Fig. 2a and 2b.

Several different studies investigated the relationships within single trees growing in a region with heavy industrial pollution and a densely populated but not greatly stressed area. The major findings were as follows:

- Within the individual tree, the onset of abrupt growth reduction spreads from the bottom to the top of the stem. Niederer 1985 investigated 41 fir trees (*abies alba)* from Bremgarten, Aargau, Swiss Mittelland, and found that abrupt, considerable growth reductions occurred as early as the 40s at 1 m above ground level, but only in the 70s at 20-25 m. This phenomenon is related to the aging of the cambium. Young cambial tissue (high up in the stem) seems to be less vulnerable to physiological impariment than the older cambium in the lower part of the stem (Fig. 6).

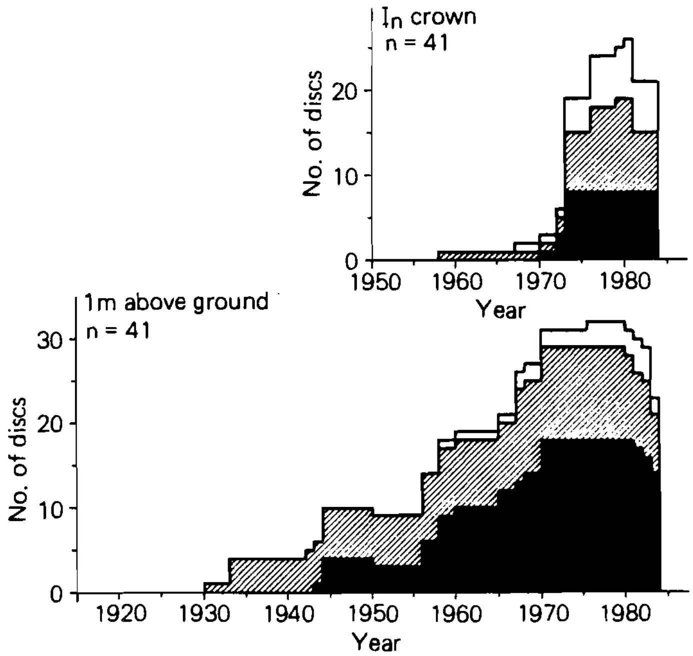

Figure 6. Summation diagram for the duration of growth reductions in firs from a stand in Bremgarten, Aargau. Switzerland. Reductions are reflected earlier and more strongly at the base of the stem than in the region of the crown. After Niederer, 1985.

- Different tree species behave differently in a given environment. Kontic et al. 1985, show that the onset, duration and intensity of abrupt growth reductions in conifers growing in the dry alpine valley of the Valais vary from species to species. The fluorine-containing waste gases of the aluminium plants there impaired the health of the pines as early as 1920, but did not affect the firs until 1964. The recovery which began in 1977 seems to be equally strong in all species. This may be related to the great reduction in fluoride emissions.

- The geographical distribution of damage varies greatly. For instance, Kontic et al. 1985, found that fir and spruce in the lower Valais generally exhibit more damage than those in the central and upper Valais. The winds in this area generally blow from the direction of the Lake of Geneva, but the aluminium plants are located in the central Valais; consequently, it is to be assumed that some additional stress factor originating in the lower Valais or around the Lake of Geneva is increasing the damage quota (Fig. 7).

Within a given area, however, the proportion of damage may differ greatly between sites, and the onset of abrupt growth reduction may vary. In the Valais, the proportion of damage decreases with increasing altitude, i.e. with increasing vicinity to the upper timberline (around 2100 m a.s.l.). This phenomenon is probably related to the frequent temperature inversions occurring in the Valais. The atmosphere above 1500 m is less polluted than lower down. In terms of the whole of Switzerland, the distribution of trees with reduced growth varies greatly. Highly intensive studies within different regions have revealed the following picture for fir *(Abies alba)* (Schweingruber et al. 1983):

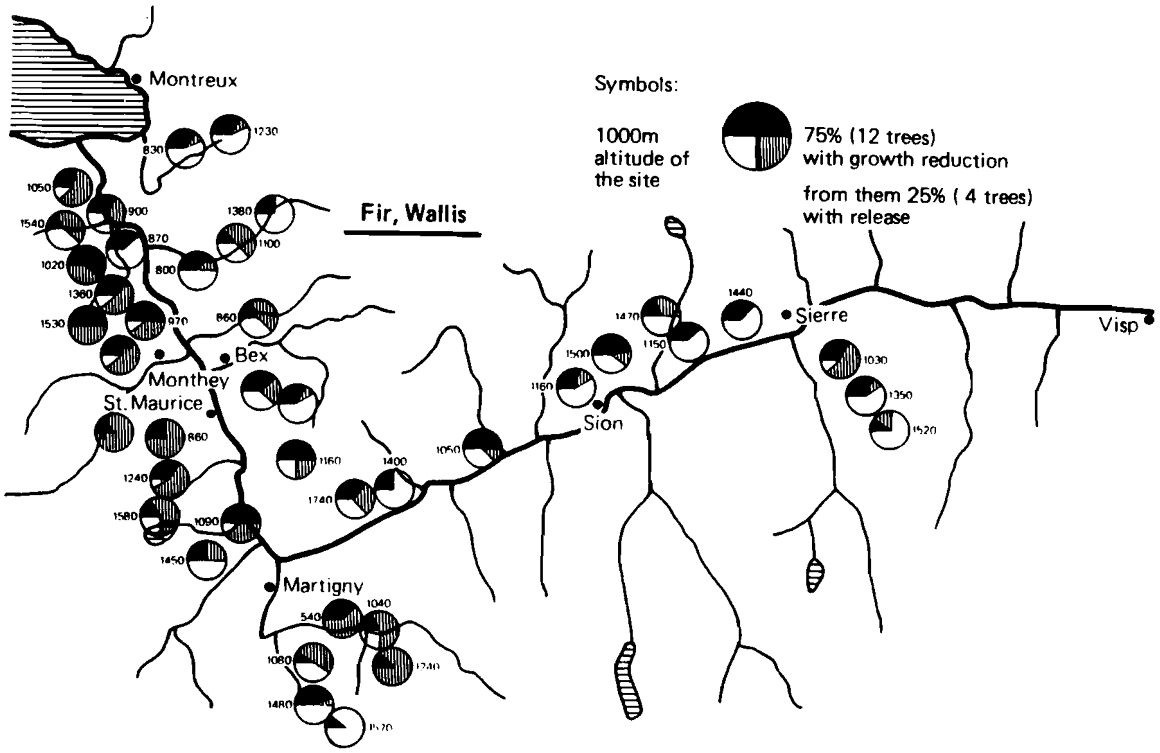

Figure 7. Percentage of firs with abrupt growth reduction and recovery in the Valais, Switzerland. After Schweingruber, et al., 1983.

Practically no reduction (R):	- a remote side valley in the Ticino, southern Switzerland
	- certain sites in the north-west Jura towards France
	- a remote valley in the Grisons (Andeer) (Hessel and Spang 1985).
R < 10%:	an area on the northern margin of the Alps (Emmental, Schwarzenburg area)
R ≃ 50%	Swiss Mittelland
R > 50%	Lower Valais

It seems clear that the quota of damage as determined from growth ring sequences is higher in densely settled, heavily industrialised areas than in remote zones. The highest rate of damage is displayed by deciduous trees in towns (Joos 1984).

- The chronological distribution of vigorous and reduced growth is at least regional in character. Keller 1985, working on spruce in the Solothurn area of the Jura, found that such changes in growth can often be explained in terms of climate. In many trees dry years initiate a phase of reduced growth which may last for several years. In the case of the canton of Solothurn it is particularly difficult, or even impossible, to detect the phenomenon currently known as forest decline. The effects of pollution seem to be obscuring the natural dynamic pattern of forest growth (Fig. 8). A. Spinnler 1985 has established a considerably higher proportion of damage in spruce in the past few years in the adjacent, heavily industrialised valley of the Fricktal.

In growth ring sequences from trees growing in towns, the effects of the climate are practically indetectable; they are obscured by the influence of tending, mechanical damage such as damage to the roots and soil compaction, and physiological injury through thawing salt (Joos 1985).

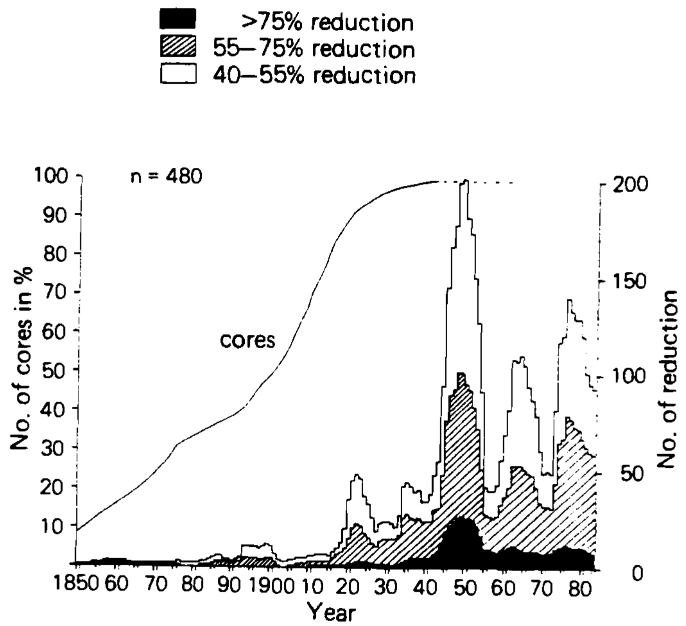

Figure 8. Summation diagram of growth reductions in fir in the canton of Solothurn, Switzerland. After Keller, 1985.

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3.1.6 DENDROSCALES OF NORTHERN IRELAND: Their Limitations for the Reconstruction of Past Environments

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Introduction

Dendrochronological research has been in progress at Belfast since 1968. The work has been almost exclusively related to studies on oak as this is the only species available in Ireland from all periods. The main objective of the research has been the construction of a single continuous oak chronology. The original objective was a chronology covering some six millennia. Recently the Belfast group has been able to report the successful completion of a continuous chronology back to 5289 BC in co-operation with colleagues in Hohenheim and Koln (Pilcher et al 1984). The stimulus fcr this chronology construction lay principally in the need for a more refined calibration of the radiocarbon timescale to elucidate problems associated both with the short term variations observed in the original Suess calibration (Suess 1970) and with its world-wide applicability. Results of high-precision radiocarbon measurements on precisely dated oak samples were presented at the International Radiocarbon Conferences at Seattle (Pearson and Baillie 1983, Pearson et al 1983). A continuous high-precision calibration of the whole of the last seven millennia was presented at Trondheim in 1985.

The construction of a long dendrochronology has involved detailed study of oak trees of all periods. Samples fall into four main categories; modern living material, timbers from historical buildings, timbers from archaeological contexts and naturally preserved sub-fossil or 'bog' oaks. Information of different kinds can be recovered from these different groups. The sub-fossil trees allow establishment of periods when peat bogs supported oak growth. They allow dating of bog horizons and can supply indications of changing water levels both in bogs and around lake margins. Archaeological and building timbers allow precise dating of past human activities and some inferences on timber use and availibility. All ancient timbers and the chronologies constructed from them hold some promise for the reconstruction of aspects of past climate or environment.

Most study has been directed towards modern oak trees as these represent good control material. Attempts to understand something of the nature of the signal which controls ring width, and the matching observed between ring patterns, has to be directed towards trees of known provenance. In Ireland and Britain the underlying consistency between ring patterns from widely differing sites has been tentatively explored (Baillie 1982, 1983). In addition long distance 'tele-connection' between chronologies constructed in Ireland, England and Germany has been used in confirming the correctness of both the Irish and German independent chronologies (Baillie et al 1983; Pilcher et al 1984). All of the chronolgy building and the limited interpretation so far attempted has been highly empirical in nature. Almost none of the success surrounding dendrochronology in Ireland and Britain was predicted. The strong underlying signal which allows consistent cross-dating between chronologies from widely separated areas was not only unexpected but remains largely unexplained.

The observation of a strong underlying uniformity gives rise to the assumption that tree-growth must be climatically controlled. As a result studies have been directed towards understanding the relationship between ring width and climatic factors. Results so far available show clearly that there is a climatic component though no single factor is decisive (Hughes et al 1978; Briffa et al 1984). All such work is aimed at the modelling of tree-ring widths with observational records in the hope of eventually extending the reconstruction of climatic or environmental data back into the pre-instrumental period. Other workers have suggested that differing factors such as insects may be important in controlling growth (Varley, 1978). However the very limited records of insect numbers, both in time and space, inevitably limit research in this area. The advantage of climatic reconstruction is that its results can be checked against documentary records.

Environmental and anthropogenic effects

Large numbers of timbers have been processed in the course of chronology building and dating exercises. It would of course be a bonus if some observed phenomenon could be related to a specific cause. Unfortunately there are relatively few anomalies in oak ring patterns. However it is worth mentioning some phenomena which have been observed and which may be of environmental or anthropogenic interest.

1) Sample availability

One macroscopic observation during chronology construction in Ireland has been the non-uniform survival of long-lived timbers (Baillie 1979, 1982). This phenomenon has also been observed elsewhere. Experience shows that the ring patterns of long-lived oaks fall into definite discrete periods (Baillie 1983). In Ireland large numbers of oak trees grew between 13 BC and 800 AD; between 900 AD and 1300 AD; between 1350 AD and 1700 AD and since 1700 AD. While the ring patterns of a few trees span the 'gap' in the 14th century AD, no trees have been found which grew continuously across the following periods: 1000 BC to 900 BC; 116 BC to 13 BC; 800 AD to 900 AD; 1650 AD to 1750 AD. With the exception of this latter period, these gaps in the tree-ring record in Ireland have been bridged with sections of chronolgy constructed in Britain. In England it has proved impossible to find timbers bridging the period 300 AD to 400 AD. There can be little doubt that these periods represent depletions brought about by environmental change or anthropogenic activity. Although the attribution to one cause or the other is not straightforward, reasonable arguments can be presented for human influence being the principal cause of the depletions in the AD period.

2) Narrow rings or groups of rings

If we look at modern site chronologies (normally containing the ring patterns of at least 10 trees) and at master chronologies constructed by combining such site chronologies, one of the most notable features are short periods where the growth rings are very narrow. Figure 1 shows three independent chronologies spanning the early 19th century. Highly synchronous narrow groups of rings occur around 1803, 1816-17 and between 1839-45. Unfortunately with the exception of 1816-17 it is difficult to attribute any definite cause.

1816-17

All oak trees growing in the north of Ireland show narrow rings in these two years. This same effect can be seen in Figure 1 not only in the original Belfast 30-tree master (Baillie 1973) but in an independent master constructed by meaning 18 site chronologies from Britain and Ireland. It is also seen in the independent chronology from Sherwood Forest. The summer of 1816 in Ireland was recorded as follows:

"In 1816 the spring was unusually late; the summer exceedingly wet and cloudy... The mean temperature of the spring, summer and autumn was 3.5 degrees below that of the preceeding year." (HMSO, 1856, 175) It seems likely that this bad weather was caused by the dust veil from the Tambora eruption in Sumatra in 1815 whose effects were noted worldwide. However, it is doubtful in the absence of the written records that 1816 would have been picked out as exceptional.

1839-45

This trough is evident in chronologies from Britain and Ireland. In the case of the 18-site master chronology it represents the narrowest tree-ring indices in the period from 1830 to the present. It is highly synchronous and was noted by Fletcher (1974) as a trough in three independent English chronologies from Berkshire and Sussex. Fletcher suggested that this trough might be due to defoliation by caterpillars though it is unclear how this could be tested. The widespread appearance of this narrow band with its definite minima in 1840 and 1844 coupled with its occurrence in both islands makes it an excellent case for study.

3) Small early vessels

This phenomenon, where the diameters of the spring vessels is reduced to one-half or less of their normal diameter, occurs in various configerations. They have been noted in art-historical panels in England by Fletcher (1975) though the source of these panels may well be in the eastern Baltic area (Baillie et al 1985). In theory SEVs, which on the basis of Russian work can be assigned to cold winters, would offer an excellent source of environmental information. If it could be demonstrated that the occurrence of an SEV was linked with a particular weather effect in the British Isles then these features could be of considerable importance. Unfortunately SEVs have not been widely observed in indigenous material. Preliminary analysis suggests that there are problems with definition - what is an SEV? - and severe problems with assessment of the significance of an occurrence. Figure 2 shows an extreme SEV which occurred in an oak from Cadzow in Central Scotland in the growth ring for 1861. It can be seen that the spring vessels are only 25% of normal size. Interestingly the effect has been so dramatic that the ray tissue is also affected. This alteration in the size of ray cells has been noted in association with SEVs from other sites but has not as far as I know been noted in the literature. There may well be grounds for defining SEVs with and without ray effects. The Cadzow SEV highlights the problems with interpretation of such phenomena. Jones (1959) cites a reference to oak being "the only indigenous deciduous tree to suffer notably from the severe weather of Christmas, 1860". This seems to be clear evidence for the link between SEVs and cold winters. Unfortunately only this one tree on the Cadzow site seems to have been affected. (One other problem with SEVs relates to checking specific years in every other tree to assess the level of occurrance). It is quite possible that at best an SEV observation may indicate no more than a single night of intense frost in a localised area. It may be very dangerous to assign cold winters to SEV years. In another preliminary survey of SEVs in Sherwood trees between 1650 and 1820 the coincidence with known cold winters was no better than random.

In general therefore there are no easy routes to environmental reconstruction from observed phenomena in dendrochronology. Each can be attributed to more than one possible cause. Gaps in chronologies could be due to climatic change or man's activity. Narrow rings could be due to climate or insect attack while SEVs could record frosts or mechanical damage.

Mean Ring Widths

Dendrochronological dating involves the matching of the high frequency information in the tree-ring patterns - the year to year changes. In

Ireland it has been common practise to index ring patterns i.e. to standardise individual ring patterns and remove long term growth trends. Indexing is a compromise between mean chronologies and ultra high-frequency chronologies of the type used by Hollstein (1980) where each ring is related to the width of its preedecessor. In Figure 1 short to medium term trends are clearly preserved in the index chronologies as well as the year to year detail. Such index chronologies have been used successfully in dating and in the preliminary climatic reconstructions referred to above. In one exercise, aimed at improving understanding of the tree-ring signal within the British Isles, 18 index site chronologies were combined into a single generalised oak chronology for the British Isles. Notably this general chronology appears to be capable of dating all new site chronologies which become available (Baillie 1983). It was decided for the purpose of this paper to re-make some of these site chronolgies in mean format. This information has not been available before and it is impossible to predict the growth profile in an individual oak chronology. It was hoped therefore that some environmental information might be gleaned from this exercise.

Mean ring width can be regarded as a proxy measure of wood production in particular where the same trees are being studied through time. So mean chronologies allow some inferences to be drawn on changes in wood production. Causes can then be sought for particular observations though as always there are serious limitations on interpretation. Having made mean chronologies for 8 oak sites in Ireland and 6 in England these were meaned in turn to form Ireland-8 and England-6 chronologies. In this way the average performance of a large number of trees could be assessed. Decadal means were then calculated and Figure 3 shows the decadal average ring widths for Ireland and England plotted on the same scale. Clearly the Irish trees have narrower rings than those from England but this may be due to most of the Irish sites being on slopes while the English trees came mostly from level sites. The age distribution of the trees is such that before 1850 new ring patterns are consistently being added into the overall chronologies. Since oaks often show vigorous growth in their early years caution is required in interpretations before 1850. However from 1850 no new tres are introduced and the performance of these growth curves must be due either to changes within the trees or changes in external factors affecting the trees. Before continuing it is necessary to look briefly at the question of baselines or standard growth curves.

This problem is exemplified by the radiocarbon calibration curve: since the early 19th century fossil carbon has been diluting the radiocarbon concentration in the atmosphere. Since the 1950s bomb carbon has dramatically altered that trend by causing massive radiocarbon enrichment. It is no longer possible to discover how the natural radiocarbon concentration in the atmosphere has varied during this period. In the same way anthropogenic factors may have affected tree growth. What would a tree-ring growth curve look like if the trees had grown under standard conditions? The construction of a standard growth curve, unrelated to anything except the natural aging of trees, may be a first step towards separating anthropogenic effects from natural fluctuations.

Unlike conifers, where ring width reduces exponentially with age, the growth curve of an oak is variable. The approach to identifying a generalised growth trend has to rely on the averaging of a large number of ring patterns which are not synchronized. Such a curve has been worked out by Delorme (1978) where the ring widths of some 100 trees were averaged. By placing each ring pattern at the same start year he established an average growth profile with increasing pith age. Unfortunately for the purposes of this current exercise increasing pith age is not relevant since modern trees started growth in different years and end essentially in the same year. For this reason a large number of trees were randomly selected and assigned the same end year. A 'mean outer-wood growth trend' was produced. The results suggest that overall Irish oak ring-width decreases by around 16% in the last 100 years of growth. This compares with a 38% decrease observed by Delorme for the first 100 years of German oaks. The difference appears logical.

We can now take the observed mean decadal ring widths of 8 modern Irish oak sites and compare this with our average decrease curve. The slope of the randomly derived growth curve is -0.02. This compares closely with -0.025 for the overall slope of the Ireland-8 curve from 1850 to the present.

When we look at the England-6 curve (Figure 3) we find a very different story. The curve is much steeper with a slope of -0.10 (for the period 1850 to 1945 there is a continuous slope of -0.14). This steeper decline is particularly marked when % decrease in ring width is considered. Between 1850 and 1945 the mean ring width for these six sites decreases by a full 50%. It can be seen in Figure 3 that the Irish and English curves cross in the 1940s. Given that the same trees are involved throughout it seems that English wood production has suffered disproportionately in the last century. The question is whether the cause is random variation, species difference, climate or pollution.

Are the observations real?

Figure 4 shows the mean decadal ring widths for the individual English sites. The main features seem to be wide rings in the mid-19th century and a consistent decline until the 1940s. All six sites show an improvement in the post-1940s with a further decline in the 1970s. The consistency suggests that we are looking at a real phenomenom and indeed reference to other independent chronologies from England show a broadly similar pattern e.g. the three chronologies constructed by Fletcher (1974). The consistency of the post-1940 profiles on all six English sites reinforces the differences with the Irish curve. In Ireland the decline into the 1920s is clear in all eight site chronologies. Seven out of eight show increased mean ring widths for the decade of the 1940s.

In order to see these variations in mean decadal growth curves in a wider context, data from other areas was investigated. Figure 5 shows three German growth curves. What is interesting in this case is the similarity in the detail of the curves. While the mean ring widths are different, all three show consistent trends in the 1820s, 30s, 40s, 70s, 80s, 90s and in the 1910s, 20s, 40s and 50s. Although two of the data sets do not run past 1960, there is a strong suggestion of the post-1940s improvement noted in the English curve. The English curve is indicated in Figure 5 for comparison. There is a reasonable degree of similarity with shared trends in the 1810s, 20s, 40s, 80s, 90s and in the 1900s, 20s, 40s and 50s. The most marked feature is again the reduction in English oak growth compared with the German curves. While each of them remains broadly consistent, the English oaks which are comparable in ring width with Huber's in the mid-19th century are more comparable with Hollstein's by the 1940s. So the reduction in ring width in English oaks is unparallelled in Ireland or Germany or in Denmark (not illustrated). The question has to be asked whether this decline is local in origin and specifically related to pollution?

Some correlations with climate

Earlier remarks about the negative response of oak to cold summers, coupled with results by Briffa et al (1984) which suggest that Central England Temperatures (CET) can be partially reconstructed from calibrated grids of tree-ring chronologies, raise the question as to whether any obvious similarity can be found between the decadal mean ring width curves and instrumental records. Figure 6 shows decadal means for CET(JJA) compared with the oak growth curve. The apparently good synchronization in the 19th century breaks down when the oaks fail to respond to the increased summer temperatures of the 1930s and 40s. However the Irish growth curve (Figure 7) does appear to show reasonable agreement with the CET curve particularly in the 1920s minimum and the 1940s maximum. This observation prompted comparison with each individual site curve. This resulted in the discovery of the remarkable correlation between the decadal mean growth curve for the oak site at Cappoquin in the south of Ireland and the CET decadal means, see Figure 8. It appears that this one site at least was capable of faithfully reflecting CET.

Limitations

The problem with all such correlations between variables is that correlation does not of necessity indicate causation . Tree-growth is complex and there is seldom a single factor controlling it. The observation that Cappoquin mean growth is strongly correlated with CET is interesting. It does not mean that all oaks site chronologies are so correlated. They are not, Cappoquin may be a clue that climate is at least the right place to look. This particular site nicely illustrates the problems facing the dendrochronologist who seeks to extend proxy records. Cappoquin is an isolated site chronology. There is no possibility of extending the length of its tree-ring record. If it had been 500 years long then its relationship with CET could have been tested further and just possibly a long reconstruction attempted. That is not possible. The other approach which is to build a 'Cappoquin area' chronology is unlikely to succeed because there is no guarantee that its response (using different trees from different sites) would be the same.

The observation of a major fall in English oak growth betwen 1850 and 1950 could be explained by climate or pollution or insects or differing responses, or a combination of these. Hopefully these preliminary investigations may prompt a more thorough study to be undertaken, designed to answer the questions raised. An initial hope was that tree-ring patterns in Ireland and Britain might, in combination with results from Germany and elsewhere, show gradients of increasing response to pollution. Taken at face value the behaviour of the English oaks suggests that they have suffered disproportionately compared with all of their neighbours.

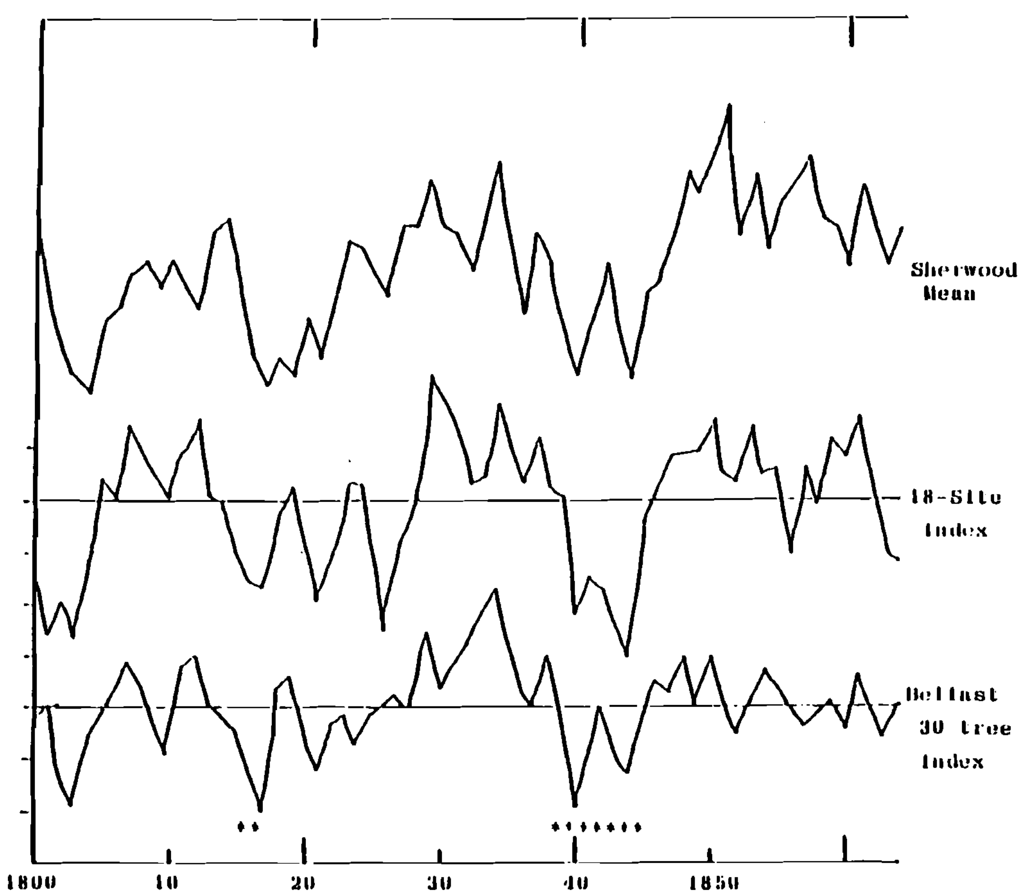

Figure 1. Ring patterns in three independent oak chronologies from the British Isles.

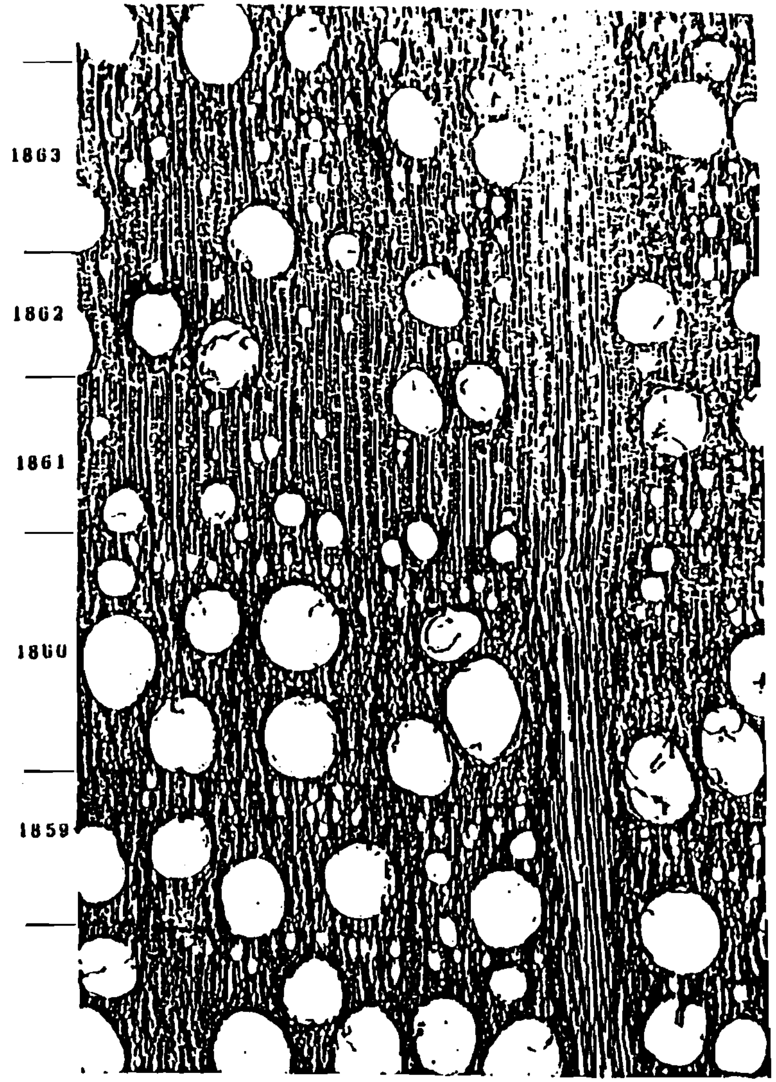

Figure 2. Small earlywood vessels for the year 1861 in an oak from Cadzow, Scotland.

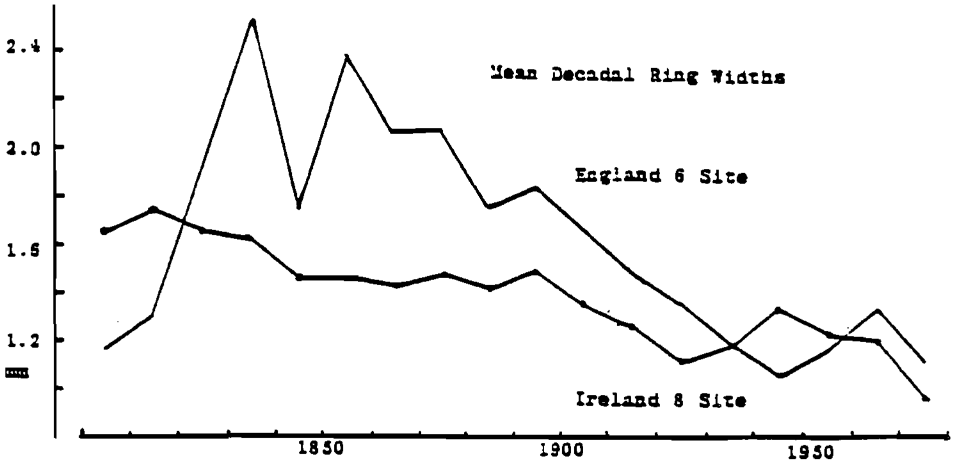

Figure 3. Mean decadal ring widths for six English and eight Irish oak site chronologies.

Location of the eight Irish and six English oak site chronologies.

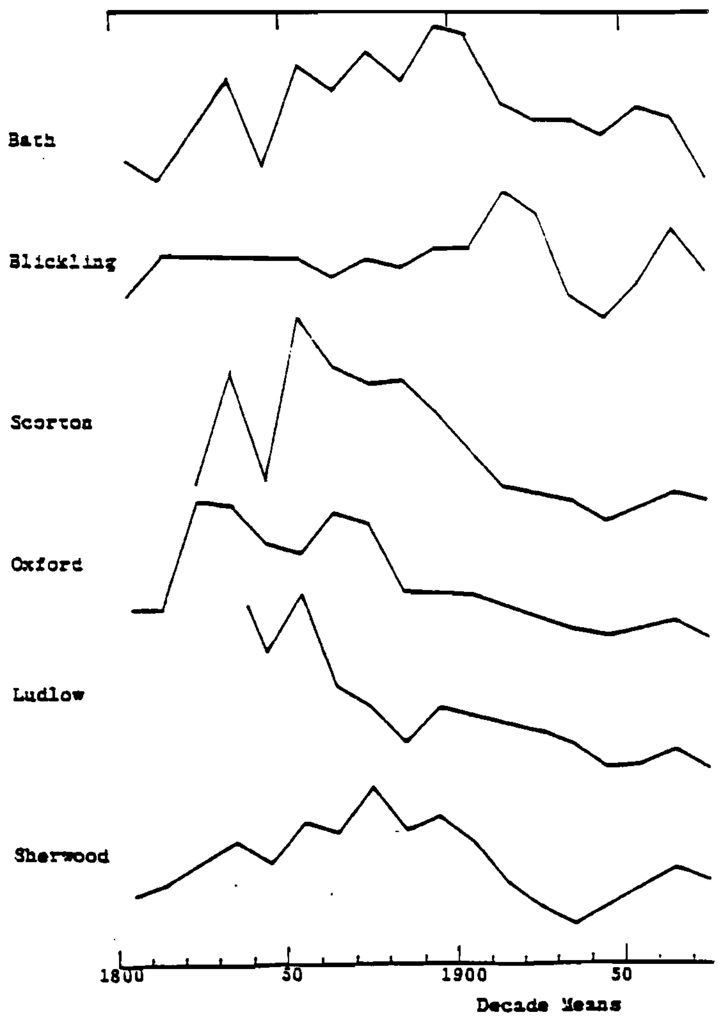

Figure 4. Growth profiles for six English oak site chronologies.

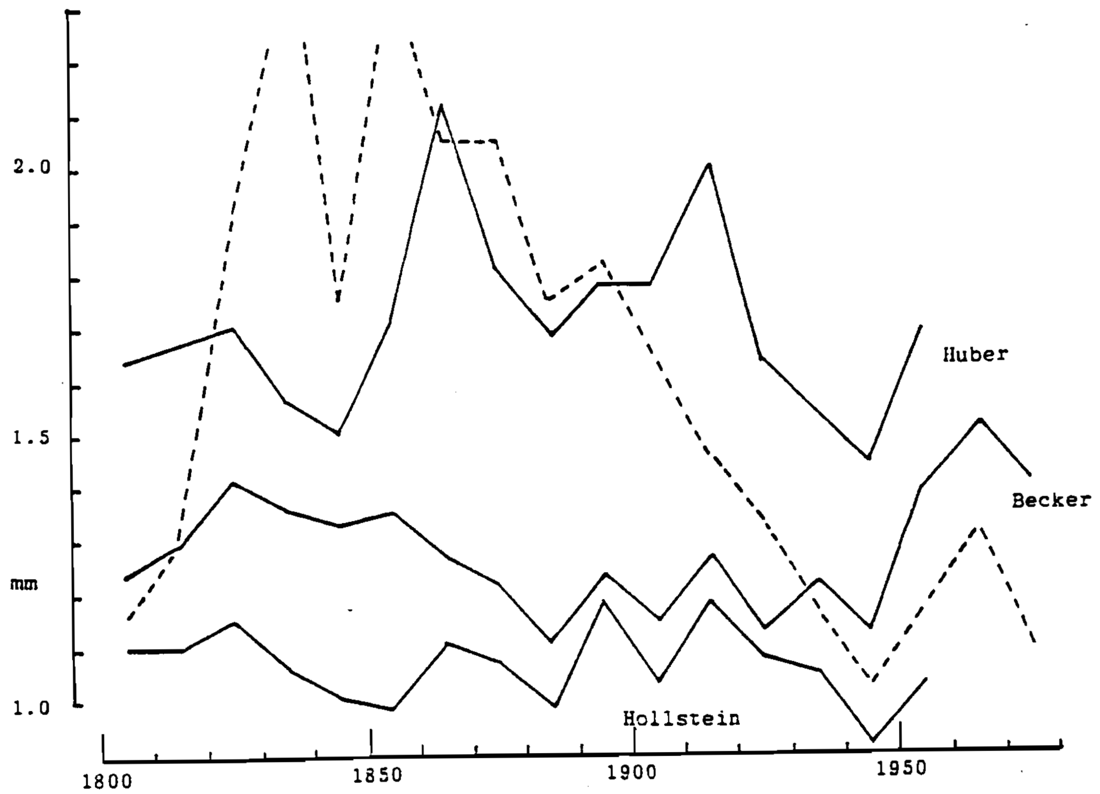

Figure 5. Mean decadal ring widths in three German oak chronologies. Dotted curve is the mean decadal ring width derived from six English site chronologies.

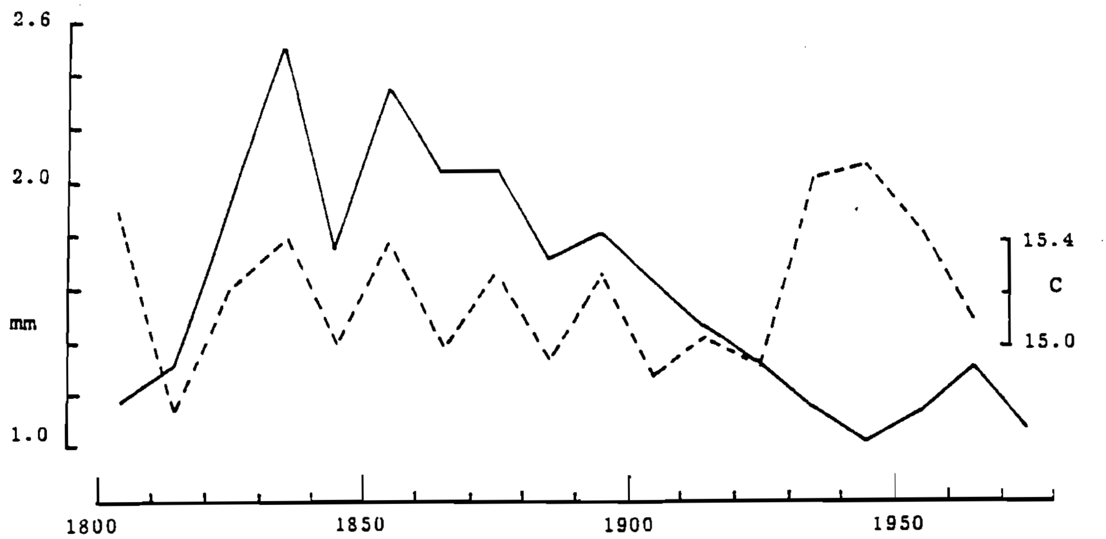

Figure 6. English mean decadal ring width (black line) compared with decadal means of Manley's Central England Temperatures for June+July+August.

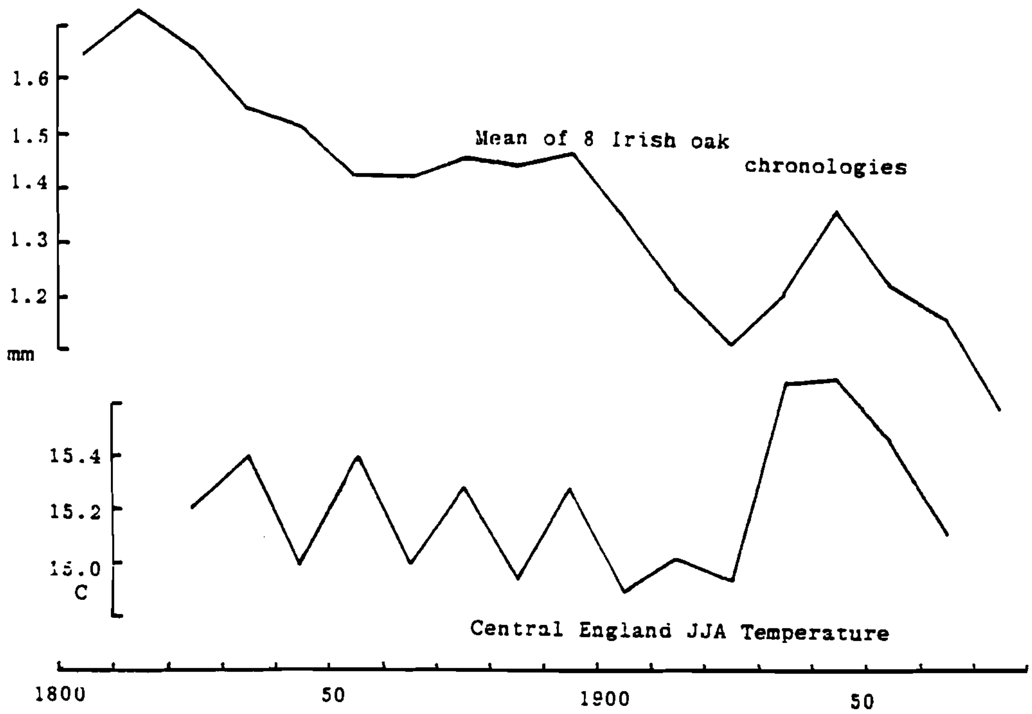

Figure 7. Mean decadal ring widths for eight Irish sites compared with decadal means of Manley's Central England Temperatures for June+July+August.

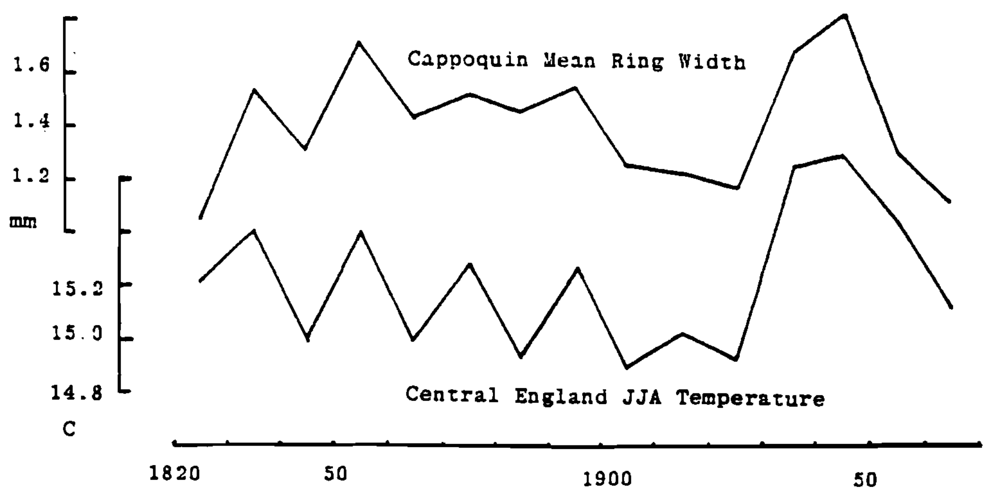

Figure 8. Mean decadal ring widths at Cappoquin, Ireland compared with decadal means of Manley's Central England Temperatures for June+July+August.

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3.1.7 NATURAL AND ANTHROPOGENIC FLUCTUATIONS OF CENTRAL EUROPEAN RIVER DYNAMICS BASED ON TREE-RING DATA, PRESENT TO 9000 BC

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The alluvia of our rivers are very sensitive regions for the development of natural forest communities.The fluvial environment is strongly related to the climate and the morphology of a certain region.Any change of the natural environment immediately leads to reactions of the fluvial dynamics.

During longer lasting periods of equilibrium between climate,vegetation cover and runoff the floodplains of the major rivers are characterized by a certain system of channels and meanders.The broadness of these floodplains,which have to drain even the largest occuring floodings,is a pronounced geomorphological structure of our valleys. Changes of the runoff within the catchment basin and the tributaries of major rivers initiate rapidly geomorphological processes like floodings with lateral erosion,redepositioning of sediments,shifting of river channels and accumulation of floodloam sediments.

Since the Late Glacial Interstadials forests have been developed along the Central European valley floors.Since that time,within the sediments of the rivers trees have been deposited and preserved up to present times.

These subfossil trees,the deposition of which evidently is related to past fluvial dynamics,are remarkable remnants for the study of past changes of the natural environment of the alluvia.Dendrochronological analyses,combined with radiometric datings,of the collection of more then 3000 subfossil trees from the Rhine - Main - Danube area have carried out a survey on the natural evolution of the forest vegetation along the valleys.The basic results are:

1. The earliest findings of alluvial forest sites are subfossil pines (Pinus sylvestris),dating from the Bölling and Alleröd Interstadials.

2. Within the deposits up to now not any pine have been dated from the Older ore Younger Dryas Periods.Probably the pine forest have been extincted during both Late Glacial Stadials.

3. Since the very beginning of the Holocene (earliest dated pine = 10150 BP) pine forests again spred over the valley plains of the Rhine and Danube Rivers.Radiocarbon dated individual trees and a first 774-years pine dendrochronology show a continuous record up to 8900 BP.

4. Preboreal pine remnants show severe natural damages.They occur as lateral woundings on the lower parts of the stems as well as vertical deep splits.Both features probably are related to remarkabely lowered winter temperatures,if they are caused by drifting ice blocks of floods of melting rivers and by frost-splittings of frozen stems.

5. Between 9200 and 8800 BP the Preboreal pine forests have rapidly been replaced by invading mixed oak forests.According to radiometric and dendrochronological datings,this replacement occured within one generation of trees only: The earliest oaks occur within the sediments at 9200 BP, whereas after 8800 BP not any pine have been found. This transition from Late Glacial conifer forests to the dense mixed oak forest community of the valleys indicates a last major climatic change at the transition from Preboreal to Boreal Times.

Since 7800 BC, the history of the rivers is recorded by three large dendrochronological oak series,which have been linked at Hohenheim. Two floating,radiocarbon calibrated series date from 7800 to 7200 BC, and 7200 to 4050 BC.The absolutely dated oak chronology dates from 4050 BC up to the present days oaks.

From the Early and Mid-Holocene part of the oak tree-ring record only gradually changes of tree-growth can be derived.Between 7800 BC and 2200 BC over a period of 5600 years the tree-ring pattern are very regularly grown and show high sensitivity,good crosscorrelation and low autocorrelation within their interannual variations.Together with fossil alluvial soils from the Main valley sediments one can derive, that the rivers since Boreal Times have been incised their channels and lowered their groundwater tables.Despite the regularly occuring floodings,the growth of the oak sites seems to be controlled by actual precipitation.The river courses reach from Atlantic Times on an equilibrium with a stable climate and a dense forest cover along the catchment basins.

Since Late Holocene Times,the fluvial processes seem to have changed reasonably.According to dendrochronological datings of houndreds of subfossil oaks,widespread tree-deposits have been developed along all of the valleys studied during three distinct phases:

1. Phase	: Bronce Age Times	Maximum 2100 - 1900 BC
2. Phase	: Roman Times	Maximum 1 - 200 AD
3. Phase	: Early Medieval Times	Maximum 550 - 800 AD

The investigation of the tree-ring records give clear hints for a remarkable change of the growth conditiones within Late Holocene valley sites.A statistical evident increase of ring-width,a decrease of mean sensitivity and crosscorrelation indicate much more favourable site conditiones.The temporal clustering of washed out trees during these shortly lasting phases must be caused by a reasonable increase in the occurence of valid floods.During Roman Times and Early Medieval Times there is substantited evidence,that the increased floodings have been caused by widespread forest clearances within the catchment regions of the rivers.In addition,deapreaching floodloam covers have been dated from both periods.They indicate an increase of the sediment load of the channels after increased soil erosion of the deforestated areas.

The following conclusions shall be derived from our study:

1. The remarkable increase in the fluvial dynamics since 2100 BC did not deteriorate the production rates of natural alluvial forests. In contrary, the reasonable increase of mean tree-ring width indicates, that the trees reacted to an improvement of the floodplain sites, which was related to the sedimentation of fertile, frehs floodloams. The adaption of valley oaks to the - since the beginning of their establishment within the valleys - regularly occuring floodings - prohibited any major damage of tree-growth even during catastrophic inundationes.

2. There is no evidence, that the occurence of the Late Holocene flooding phases has been caused by remarkable deteriorationes of climate. The flowering agriculture of Roman settlement in Southern Germany just during the time of maximum floodings of the rivers is the best example for this statement.

3. Widespread deforestationes during Roman and Early Medieval Times led to considerable reactions of the hydrological system. Excluding any major change of climate, the acceleration of the runoff from the slopes during periods of heavy rainfall can explain, why the floodplains, which have been adapted to drain the water flow even during catastrophic floods over thousands of years, at that time have been increasingly inundated. The rivers reacted to this change by lateral shiftings of the river channels, during which the floodplains finally reached the outermost parts of the valley floors. This broadening of the inundation fields has washed away most parts of the alluvial forest, the remnants of which have been found and dated within the gravel deposits.

4. The deforestation of the Romans ended at the beginning of the invasion of the Alamanns in S-Germany at the third century AD. The rapid decrease of findings of tree-deposits, dated between 250 to 500 AD, indicates low fluvial activity, which again raises since 500 AD to the Early Medieval Times maximum. Forest have spread over the abandoned agricultural regions as well as over the destroyed valley floors. As a result, by the dense forest cover the runoff from the slopes decreased, the river channels again could stabilize, and the river dynamics of the floodplains reached at the last time a natural equilibrium.

5. Since Medieval Times the increasing impact of men continuousely perturbates the natural hydrosystem. Increasing bedload by erosion, acceleration of the runoff from deforestated areas, downcutting of the river channels after damming the floodplains and finally the regulation of the rivers lead to the actual situation. Today a very limited number of somewhat undisturbed alluvial forest sites in Central Europe have been preserved, from which an impression can be derived of the ecosystem of the natural Holocene valleys and their forest vegetation.

3.1.8 RESEARCH ASPECTS OF TREES AND THE ENVIRONMENT

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ABSTRACT

This paper gives dendroscales derived in England for oak of slow growth in the 11th and 16th centuries used for the boards or planks of fine artefacts of art historical interest. It compares them with others of oak and pine for central and western Europe and discusses the agreement/disagreement in terms of ecological conditions and climatic fluctuations, also with the two species of European oak, and their occurrence in northern Europe.

Of particular interest is the historical assessment that has been made by Le Roy Ladurie (1972) of fluctuations in western Europe since 1000 AD: also of changes in solar activity that have been suggested in recent years to account for the "wriggles" (changes in the level of C_{14} in the atmosphere); these have been estimated increasingly reliably as a result of the intense effort put into C_{14} measurements (Stuiver, 1982).

In recent years, western Europe has made various contributions to the study of climatic fluctuations: several lines of evidence for the period since 1000 AD were critically examined by the historian Le Roy Ladurie (1972). It includes appendices on the Retreat and Advance of Alpine Glaciers, Winters in the 16th century, French Wine Harvest Dates, Seasonal Climatic Information (17th century) for European Countries, and the climatic context of the Great Famine of the 17th century, as well as an extensive bibliography.

The oak (*Q. petraea*) chronology of Huber and co-workers (1969) was derived from many samples (on average, 57 for each year) that grew in the period 950-1980 AD. It consists of ring-widths, mean width 1.2 mm, of trees from hilly areas with moist sites in central or western Europe. It includes many "signatures" which increase its value for dating artefacts but few have been identified with a specific environmental effect mainly because many factors affect the growth of oak, as explained in the British Oak, 1974. However, the Little Ice Age (Figure 1) is indicated by relatively narrow rings.

Research by Fletcher and Tapper (1984) has been primarily devoted to the dating of medieval oak artefacts of art historical or archaeological interest.

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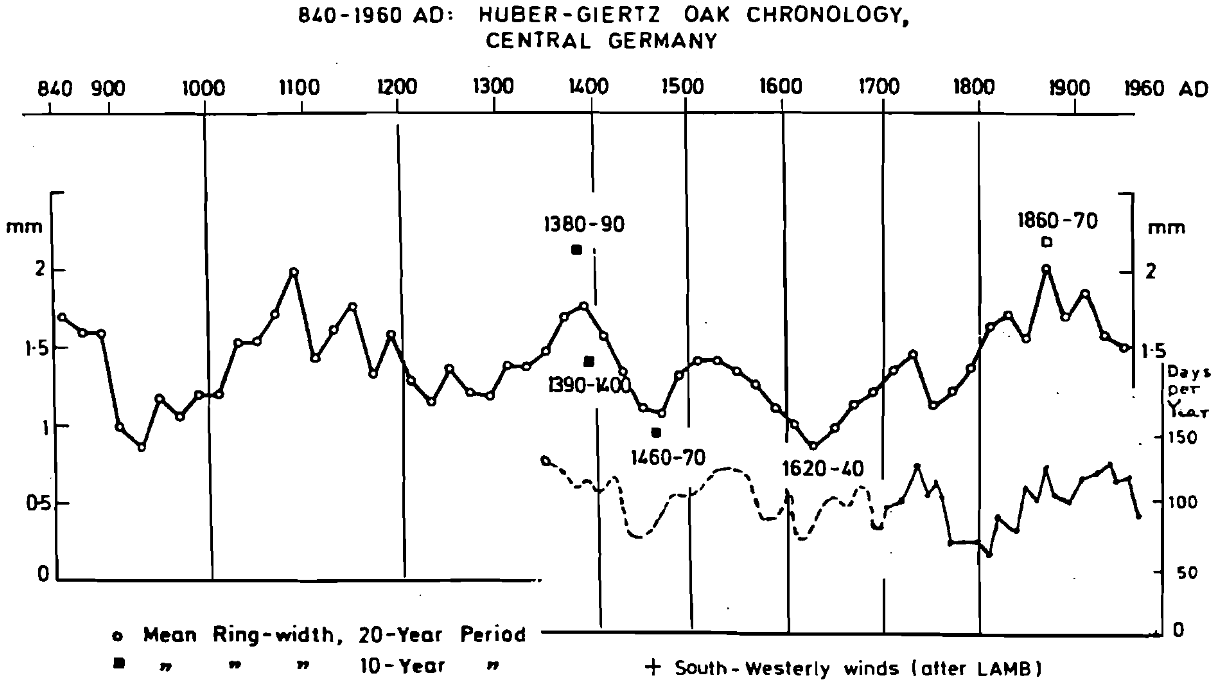

Figure 1. Comparison of Huber-Giertz oak ring-width chronology AD 840– 1960 with frequency (days per years) of south-westerly/westerly winds over British Isles (Lamb, 1977).

European oak is likely to be sessile oak (*Q. petraea*) introgressed with pedunculate oak (*Q. robur*) or vice versa. Whereas the provenance of the latter is usually decidedly eastern European, the former is more common in western Europe and particularly on hilly moist sites. We use the criteria suggested by Huber *et al.* (1941) to distinguish for several samples of medieval timber between affinity to one or the other species.

They include several paintings by Holbein; one (B.B. Fredericksen, 1982) was of particular interest as neither the subject, nor the artist, nor its motto (*E Cosi Desio Me Mena*), nor its purpose had been discovered. Yet its pedigree was impeccable: it had been in the collection of Henry, Prince of Wales, who died in 1612 at the age of 18; that is proved by the presence of his cypher HP on the back of the panel. Our tree-ring dating revealed both boards covered nearly 300 years in the period 1185 to 1490. The motto, translated as "Thus Desire leads me on" was identified, while the painting, with others probably from the same tree, originated when Holbein passed through Antwerp in 1526 (Fletcher and Tapper, 1983).

Measurements on the edges of *c.* 400 boards of such panels have led to the formation of dendroscales. The need to form oak panels free from warping to support paintings led to the use of radially split boards, while the large chests which contained the valuables of abbeys or royal treasures required comparable exceptional planks. Both types of artefact used oak for slow growth (250–400 years old), often with annual rings little more than 1mm wide. Two of the Fletcher and Tapper chronologies from *c.* 1000–1620 AD are limited to oak of slow growth. Their growth pattern (Appendix A) at times is unlike that of the sessile oak studied by Huber; that pattern (Appendix B) however, is well matched by oak on the damp sites of southern and western England where the oak is often sessile.

Lamb (1977) finds the frequency of days with westerly winds sweeping across the British Isles when plotted at 10–year intervals (Figure 1) to be a meaningful quantity. It is related not only to the prevailing temperature in England but to the average temperature value for the earth as a whole and may be an index of wide significance.

The model proposed by Schweingruber *et al.* (1979) relating the growth of conifers in central and norther Europe to oceanic, temperate and dry sites explains the influence of climate and terrain on their growth. Oak can be similarly categorised with sessile oak from wet sites in western Britain showing the same growth pattern as those of Huber's chronology (1969); pedunculate oak from dry sites, however, shows only poor agreement with Huber. Climatic changes as in the High Middle ages and the Little Ice Age would have been likely to accentuate differences in growth patterns from varying sites. Both the areas and the centuries to which the Lithuanian (Baltic) oak chronologies apply is therefore a question of considerable interest to the understanding of the growth of oak and to climatic fluctuations.

In the author's paper to the 1984 Nordic Conference on Archaeometry, he suggested that oak and pine might each have a chronology in northern Europe which would apply over a large area. An examination was therefore made of the situation for *Q. robur* using the results of Brathen (1982) for western Sweden, of Bitvinskas and Kairiukstis (1975) for Lithuania and the author's own situation for Bagley Wood near Oxford:

		1725–1834	1845–1970
W Sweden v. Lithuania	t =	1.5	4.7
W Sweden v. Oxford		Years not covered	1.7

Comparisons with other centuries may substantiate the indication from these results that the environmental background has, as Lamb demonstrated, changed since about 1850 with an effect on the agreement between oak grown in Sweden and in Lithuania.

Papers at the IIASA Workshop (Kairiukstis, 1986) have brought forward models for reconstructing and predicting radial increments in the growth of trees in many areas of the northern Hemisphere. The 11 or 22 year solar cycle at one time favoured has been amplified by recent research (King, 1973). Meanwhile, research on carbon 14 dating has produced evidence of a link in duration with solar activity. This is based on high accuracy C_{14} measurements (Stuiver, 1982) to "calibrate", i.e. to correct for the variable C_{14} content in the atmosphere. The "wiggles" found are being attributed to variations in solar activity and hence bring a new source of information to the study of dendroscales.

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APPENDIX A: Oak dendroscales (ring-widths mm) derived from edges of Anglo-Flemish oak panels (Fletcher and Tapper, 1984) likely to apply to *Q. robur* (Dengler, 1971) exported from Baltic ports and used AD. 1120-1630 (Ref. 2).

Mean width 1.2 Items 108

Ref 1 1163–1623

REF 1 (108 ITEMS) 1163–1623
(20F4.0)
5211163

220	100	230	110	125	155	120	180	145	155	140	125	140	85	145	120	113	170	133	170
147	183	140	140	147	130	87	123	127	123	137	133	133	143	126	149	124	138	158	115
153	119	155	150	147	179	143	143	122	120	146	132	126	108	118	132	138	159	115	117
107	123	119	105	99	121	98	116	105	118	129	142	123	124	117	120	125	122	131	131
162	142	136	147	159	135	110	149	145	113	122	127	139	136	145	165	153	154	140	108
137	125	122	123	120	136	118	135	139	130	113	129	111	113	113	107	146	114	101	120
114	104	127	97	123	127	135	153	142	145	125	135	109	103	107	95	126	135	105	118
125	120	132	152	143	157	154	160	167	158	159	150	172	167	144	114	146	128	110	141
117	134	125	141	125	134	134	130	164	136	155	152	146	129	113	102	127	132	136	123
144	135	147	143	133	144	144	123	135	107	117	143	140	148	142	142	143	137	142	157
141	125	123	121	99	121	138	125	144	159	155	139	151	186	153	146	126	143	151	143
129	111	138	134	134	126	113	119	128	137	115	136	132	162	124	137	154	138	162	144
123	131	144	132	151	131	138	152	148	148	151	137	115	119	87	98	149	146	122	153
166	153	143	159	159	142	129	115	139	109	121	125	135	147	161	166	149	162	182	154
147	158	128	135	127	132	156	156	140	146	141	143	108	136	84	110	134	149	127	153
112	127	123	149	139	150	131	116	143	151	150	134	149	146	136	137	101	115	109	113
86	103	120	105	88	93	119	114	107	119	113	116	118	138	133	127	130	136	154	143
159	136	160	129	144	154	125	121	134	127	109	138	127	128	136	109	117	138	98	89
84	115	105	96	111	126	130	109	116	137	113	121	125	125	118	106	96	115	133	130
114	119	115	146	156	139	145	144	101	88	102	99	123	119	110	117	121	127	158	137
133	117	127	147	142	138	138	139	135	134	122	134	156	150	144	126	125	106	136	140
131	125	133	137	140	129	112	107	109	93	114	120	130	117	131	122	119	128	130	145
142	139	156	136	132	132	137	129	145	129	152	111	132	131	113	111	99	122	121	116
109	106	116	111	105	95	113	119	123	119	107	119	122	131	136	117	136	121	136	119
123	103	121	131	117	134	125	100	98	116	112	127	126	118	130	149	138	126	104	125
140	147	127	137	115	110	115	110	120	110	100	90	110	100	150	130	130	140	120	140
150																			

Mean width 1.9 Items 68

Ref 2 1244–1611

REF 2 (68 ITEMS) 1244-1611
(20F4.0)
3681244

160	210	230	200	250	210	140	260	210	230	180	290	250	175	140	170	155	120	155	177
203	155	196	146	182	192	196	236	182	200	232	180	172	130	120	138	170	187	148	140
169	187	187	181	183	174	149	143	111	133	176	183	200	185	177	191	186	194	212	183
156	117	154	147	170	196	186	162	201	223	187	192	243	189	184	154	192	199	199	172
136	184	154	177	173	163	173	154	140	123	173	186	195	151	189	203	175	205	181	163
179	198	151	169	181	158	200	209	177	197	191	189	182	179	161	196	190	127	185	218
185	184	195	213	193	202	206	166	156	145	161	182	155	166	217	181	191	206	178	200
180	198	179	221	193	196	192	197	187	180	180	157	170	148	195	199	200	193	192	153
154	167	220	178	193	180	171	191	184	182	191	178	183	158	182	159	138	166	157	136
123	143	128	117	165	166	165	161	178	155	158	168	184	167	192	153	208	175	174	186
185	198	186	183	162	180	190	182	175	160	204	171	185	178	197	184	207	162	167	169
166	175	192	188	201	205	174	183	202	180	159	197	179	176	232	217	222	241	221	204
210	188	252	237	236	244	204	185	181	204	201	229	214	153	189	182	197	236	207	204
207	198	203	200	228	204	210	224	204	190	224	256	229	223	204	171	180	187	188	218
198	173	209	168	186	171	163	161	133	182	192	163	153	178	174	213	197	191	216	197
187	207	206	195	205	241	190	170	168	174	169	183	176	176	194	164	193	189	196	197
171	183	166	179	219	220	213	170	171	170	182	191	203	210	203	182	148	150	140	168
168	163	180	223	258	248	243	258	238	228	188	223	178	190	203	170	165	120	130	120
120	110	130	140	150	150	130	110												

APPENDIX B: Oak dendroscales (ring–widths mm) for temperate parts of western, southern and central Britain, including Wales, AD 877–1636.

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REF 67/5 (37 ITEMS) 845-1331M
(20F4.0)
 487 845
  70 120 130 110 100 190 135 225 255  85 135 151 130 173 183 145 108 150 170 173
 185 190 155 195 178 188 165 163 175 120 205 245 170 168 175 225 175 138 158  90
  98 170 168 173 155 182 198 203 158 220 128 143 130 155 175 153 140 103  98 120
 118 126 124 125 151 113 130 150 136 135 111  94 136 135 157 151 183 180 182 177
 177 137 162 168 180 156 155 154 124 163 132 151 155 146 141 133 128  95  73  98
 124 130 156 159 151 160 129 146 121 112 108  94  99 112 133 132 131 139 141 143
 120 150 149 152 121 120 124 134 124 111 137 123 154 117 149 161 126 139 145 132
 177 144 155 145 184 141 168 165 152 138 129 157 171 166 226 168 171 157 183 185
 153 173 154 196 191 169 157 173 165 126 144 141 151 131 110 120 133 144 146 129
 118 139 136 134 132 176 144 134 136 122 135 139 173 134 138 163 163 162 148 120
 139 134 160 133 140 112 111 147 131 132 168 172 126 148 141 151 147 142 159 144
 123 150 193 201 178 163 161 155 171 165 177 188 167 161 184 196 154 194 189 176
 197 181 154 180 182 163 184 214 228 221 204 199 178 204 187 243 162 139 165 185
 185 191 204 199 189 164 163 180 175 195 194 190 186 217 175 168 139 158 195 199
 168 170 161 190 132 173 167 172 165 167 151 134 112 140 130 206 216 169 187 193
 202 180 162 184 196 198 183 164 232 197 180 213 196 183 214 237 215 205 206 212
 194 193 179 222 229 197 209 203 203 204 218 212 174 184 219 189 202 228 219 164
 210 217 235 162 183 253 228 221 266 222 240 253 211 219 237 223 246 214 251 215
 231 205 169 232 210 236 237 183 209 217 216 199 202 199 226 215 209 185 176 197
 209 238 190 221 212 187 139 151 160 178 191 147 211 184 214 206 162 162 168 156
 176 186 177 154 186 185 191 166 165 157 193 163 161 137 184 182 177 194 186 174
 166 190 162 160 168 191 196 150 138 117 133 138 148 141 128 132 130 142 134 131
 132 138 117 107 139 153 153 158 136 120 126 134 123 123 117 118 129 117 106 123
 144 129 133 154 183 157 151 151 130 155 165 185 135 160 175 160 180 155 155 150
 140 160 190 120 210 220 190
MC16 TYPE H   1314-1636
(20F4.0)
 3231314
 123 150 170 150 125 106 103 125 115 125 140 180 135 140 150 165 145 130 110 103
 120 107  97  80  93 145 215 220 233 178 155 188 180 173 240 245 188 223 155 161
 210 248 283 255 250 172 151 168 146 245 250 178 160  94 127 193 145 135 135 168
 178 183 190 155 188 210 163 185 187 206 210 220 235 239 214 204 158 183 143 149
 142 150 157 160 166 195 201 206 166 197 219 172 203 187 188 228 196 199 209 168
 181 155 147 163 200 131 207 184 152 220 189 199 160 180 193 187 188 190 213 168
 165 193 169 175 164 153 171 173 148 185 186 170 147 161 160 166 164 201 175 172
 213 171 197 184 167 152 175 157 143 166 123 137 157 166 173 179 181 155 153 165
 168 246 197 181 179 193 181 211 182 167 182 169 171 187 167 164 172 151 125 141
 156 149 185 149 138 167 152 149 150 127 129 166 145 151 133 166 158 152 162 155
 133 129 129 123 135 136 121 150 145 140 157 108 128 138 174 145 128 173 127 142
 130 177 158 156 161 178 168 194 151 174 172 184 151 117 146 155 151 173 131 129
 131 154 118 104 107 119 144 126 138 125 134 115  93  85 106 134 150 133 124 136
 139 134 107 107  97 120 139 125  99  92  99 137 133 120 137 135  85 107 119 158
 190 203 166 154 118 109 128 155 125 160 135 120 145 175 140 140 120 125 105 110

  75  80 125 125 120 105 115 200 200 235 210 150 155 180 205 235 145 155 220 190
 150 145 220
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Components and origin, see Fletcher and Tapper (1974).

(i)	Oxford	Ref 6/7–5	845–1331	37 items
(ii)	Oxford	Ref H	1314-1636	32 items

3.1.9 FLUCTUATIONS OF THE RADIAL TREE INCREMENT AND THEIR APPLICATION FOR PREDICTION OF CLIMATIC BACKGROUND CHANGEABILITY

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During the process of growth, tree rings accumulate information on environmental phenomena and on changes in climatic conditions. the dendrochronological methods were established in order to reveal such phenomena according to DS. Over 400 DS have been created in the Soviet Union alone (Kairiukstis, 1981). These reflect the information on climatic changes in the past (Bitvinskas and Kairaitis, 1981; Kolishuk, 1979; Shiatov, 1972, 1977 and 1979). They have offered a reliable basis with which to predict the changeability of the background fluctuations the growth processes in the forest, and the ecological sustainability on the whole biota in the future.

The aim of our research was to investigate rhythmical fluctuations of dendrochronological indices in the DS. These indices reflect the climatic variations of a given region, the behavior of small rhythms (9-24 years in duration), and finally, secular changes in the climatic background for larger regions. Hence, the model construction and prognosis of the generalized dendroscales from different sites are particularly important.

Studies on the plausible solution of the above problems by mathematical models are to be noted. For the elucidation of a 22-year cycle in dendroclimatological time series, several scientists (Fritts and Shatz, 1975; Fritts, 1976; La Marche and Fritts, 1972; Mitchell et al., 1979; Pilcher and Baillie, 1980; Stocton and Fritts, 1971; Stocton et al., 1979) used the method of filtration and spectral analysis. A. Stupneva and T. Bitvinskas, (1978) also applied spectral analysis to study the rhythm of increment over different areas of the profile from Murmansk to the Carpathians. B. Berrie, A. Lieberman and S. Shiatov (1979) investigated rhythmical fluctuations of the increment for larch (Larix sibirica) by the method of harmonic analysis. For an approximation and prediction of increment indices, these authors suggested the following model:

$$x(t) = a + bt + \sum_{j=1}^{n} A_j \cos(2\pi t / T_j - Y_j) \ ,$$

where

a + bt = refers to a linear part of the equation,

A_j, T_j, Y_j = amplitude, period and phase of j fluctuations, and

T_j = whole numbers.

For the approximation and prognosis of the annual tree increment, D. Sipenyte and A. Zilevicius (1983) constructed the following model:

$$x(t) = M_t + F_t + Z_t \ ,$$

where

M_t = a slowly changing function,

F_t = final sum of harmonic components, and

Z_t = process of autoregression.

The object of our investigations was mainly the dendroscales of the USSR covering the following years and for the following species respectively:

- 90-200 for Pinus silvestris from the Lithuanian SSR - Stravinskiene (1979, 1981) Bitvinskas (1974, 1981);
- 270-358 for P.silvestris from Karelia - Bitvinskas, Kairaitis (1979);
- 413-505 for P. silvestris from the Urals - Shiatov (1979);
- 130-315 for Quercus robur from the Lithuanian SSR - Kairaitis (1978, 1979);
- 103-120 for Picea abies from the Lithuanian SSR - Stravinskiene (1979, 1981);
- 287 for P. abies from the Carpathians of the Ukraine - Kolishuk (1979);
- 723 for P. abies from Western Siberia - Shiatov (1972);
- 279-876 for Larix sibirica from the Urals and Western Siberia - Shiatov (1975, 1979);
- 240-385 for Pinus sibirica from the Carpathians of the Ukraine - Kolishuk (1981);
- 697 for P. sibirica from Western Siberia - Shiatov (1973);
- 90-110 for Alnus glutinosa from the Lithuanian SSR - Stravinskiene (1979, 1981).

Additional dendroscales for conifer species from the upper limits of forest growth in the north taiga have been used (Lovellius, 1979). We also studied the dendroscales covering the years 206-1251 for Douglas fir, ponderosa pine, limber pine and white spruce from the USA (Washington, Oregon) and from Canada. They were constructed by D. Croller, C. Ferguson, H. Fritts, T. Knowles, M. Parker, and C. Stocton, (Cropper and Fritts, 1981; "Tree-ring Chronologies of Western America", 1973: Vols. 1,5,6 and "Tree-ring Chronologies for Dendroclimatic Analysis", 1976).

Initially, for the model construction and prediction of the climatic background fluctuations by dendroscales, we investigated 76 dendroscale series covering the years 88-160 for Picea abies, Quercus robur, Pinus silvestris and Alnus glutinosa from the Lithuanian SSR. Approximately 13% of these are master chronologies of for the corresponding species and sites. A visual evaluation of the series allows the inference that most of them may be considered as the realization of stationary processes. On average, in 85% of these series, the fluctuations similar to the behavior of the sum of periodic components can be detected visually. In dendroscales incorporating a large amount of material (Bitvinskas, 1974; Stravinskiene, 1981) from damp sites the maxima and minima are repeated in 9-12 years. Significant peaks (95% of significance) corresponding to the periods 10-13, 3, 20-24 years are noted in density spectra of almost all series. In 70% of the dendroscales, the order of significant coefficients of the correlative function exceeds 15. The correlative function of dendrochronological series from damp sites (Bitvinskas, 1974; Stravinskiene, 1981) on the whole does not decline.

For the description of stationary temporal series (y_t) usually the following model is applied:

$$y_t = f(t) + Z_t + E_t$$

where

f(t) = determinative function,

Z_t = process of autoregression, and

E_t = independent random values.

The results of the correlative and spectral analysis of dendrochronological series indicate a cyclic trend or a great order of autoregression. At the beginning of the description of DS we used the model $y_t = Z_t + E_t$. Calculations showed that the order to autoregression is more than 3 in 70% of the dendroscales, while in 60% it is more than 4. In 70% of the series, residual disperson exceeds the dispersion of a series by 65%. Further, in DS and in the series of indices obtained logarithmically, a cyclic component was singled out as follows:

$$f(t) = A_0 + \sum_{j=1}^{n} A_j \cos(2\pi t / T_j - Y_j) ,$$

where the index T_j refers to whole numbers. We applied this method because the length of rhythms determined according to the peaks of density spectrum or according to the significant coefficients of Fourier depends upon smoothing. The values of the length of rhythms are expressed by fractional numbers (one assumption is that whole numbers conform more to reality). The correlative function of residuals $U_t = y_t - f(t)$ or $V_t = ln y_t - f(t)$ (here the index y_t refers to a series of indices) decreases very slowly. The order of autoregression U_t and V_t ranges from 5 to 10. In 70% of the series, residual dispersion exceeds the disperson of series U_t or V_t

by 70%. These series are not approximated to the series of autoregression because we need models for prediction purposes for a period of 10 to 15 years.

The results discussed above enable one to assert that the dynamics of indices x(t) of the series of dendroscales covering the years 90-150 for the Lithuanian SSR are reflected best by the models:

$$x(t) = A_0 + \sum_{j=1}^{n} A_j \cos(2\pi t / T_j - Y_j) + E_t \ , \tag{1}$$

or

$$x(t) = \exp\{A_0 + \sum_{j=1}^{n} A_j \cos(2\pi t / T_j - Y_j) + E_t\} \ , \tag{2}$$

where E_t is a random correlated series and n is selected in such a way that the actual and approximating series might show a higher level of agreement whilst the sum of squares of deviation might be as little as possible. T_j, $j=1$, and n are usually selected from the intervals 7-14 and 20-25 years (Figures 1 and 2).

With regard to the adequacy of models as shown in equations 1 and 2 above, almost all series (or average in 90%) the approximating function detects 85-90% of significant fluctuations while in master chronologies from damp sites of the Lithuanian SSR the range is 95-100%. It must be noted that considerable rises and falls in DS (8-22 years in duration) characterize the general favorable or unfavorable growth conditions. Therefore, the prediction of these rises and falls is of paramount importance. In the dendroscales for the construction of which a large amount of material (Bitvinskas, 1974) from dry sites of the Lithuanian SSR was used, the actual series have been smoothed with the sliding to three years. A comparison was made between the actual and approximating series of the dendroscales incorporating a large amount of material (Stravinskiene, 1981) from damp sites of the republic and between those of the dendroscales from dry sites. Their agreement ranges from 74-84%. The residual dispersion is less than half the dispersion of a series. In 66 of 76 dendroscales studied, the agreement between the approximating and actual series smoothes with the sliding to three years exceeds 65%. In 80% of the dendroscales covering the years 100-150 (or the last 100-150 years of the dendroscales of long periods) for other regions of the USSR between-series comparisons average over 65%.

Calculations revealed that the models shown in equations 1 and 2 are not applicable for DS with great dispersion (800 and more). Agreement values (coefficient of synchronization) and a sum of squares of deviation in this case are not convenient characteristics for the adequacy of the models. It is not difficult to find some series which reflect the fluctuations very similarly. However, they have only 50% agreement.

Since DS x(t) covering the years 100-150 are approximately stationary, it is feasible to predict x(t) for 10-15 years by equations 1 and 2. In order to verify this statement, we calculated the predicted values of the indices, the parameters of approximating functions (1-2) of 23 series of dendroscales (3, 7, 8 and 15) without the last 10-15 and 20-30 years. The

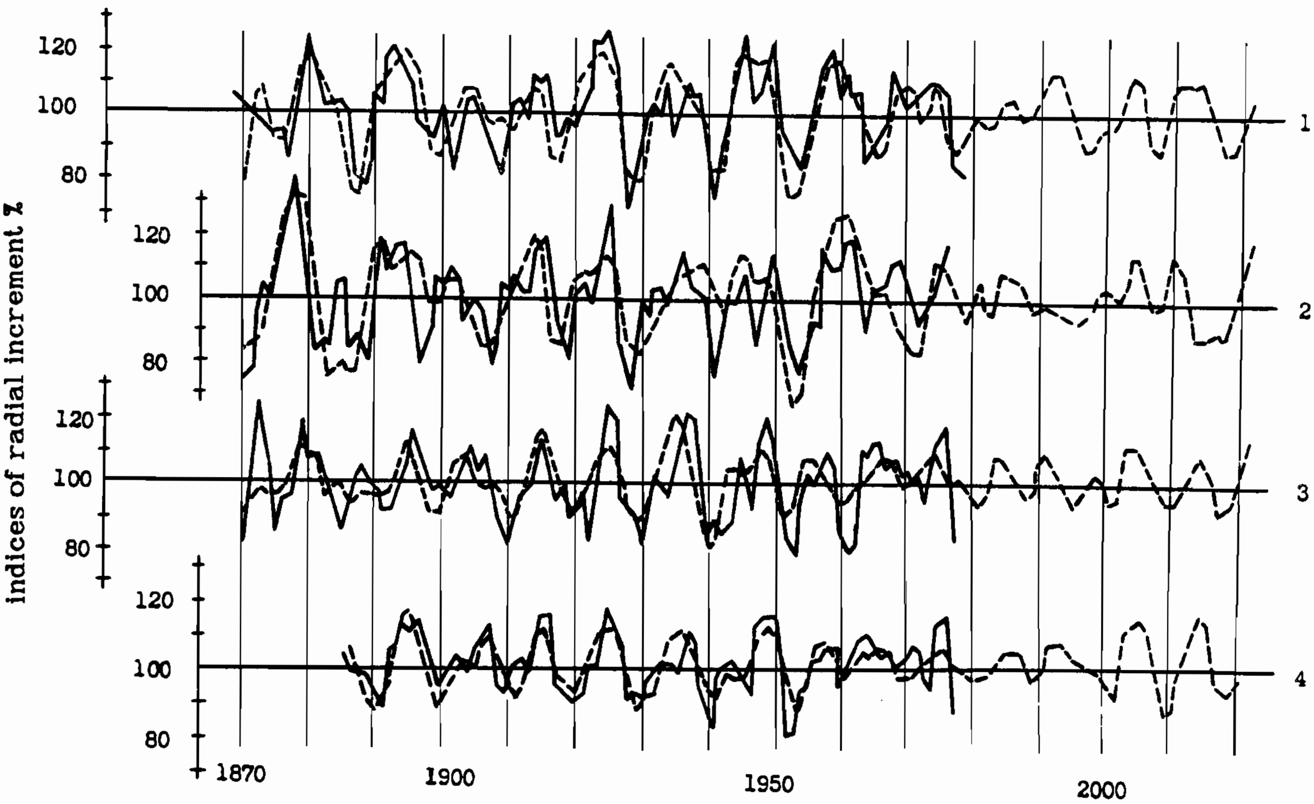

Figure 1: Actual trend of increment indices (———) and values for the approximating function (- - -).

1, 2 = Picea abies stands of Carex-Calamagrostis forest type;

3, 4 = Alnus glutinosa stands of Carex-Calamagrostis forest type in the Lithuanian SSR (according to the dendroscales (Stravinskiene, 1981).

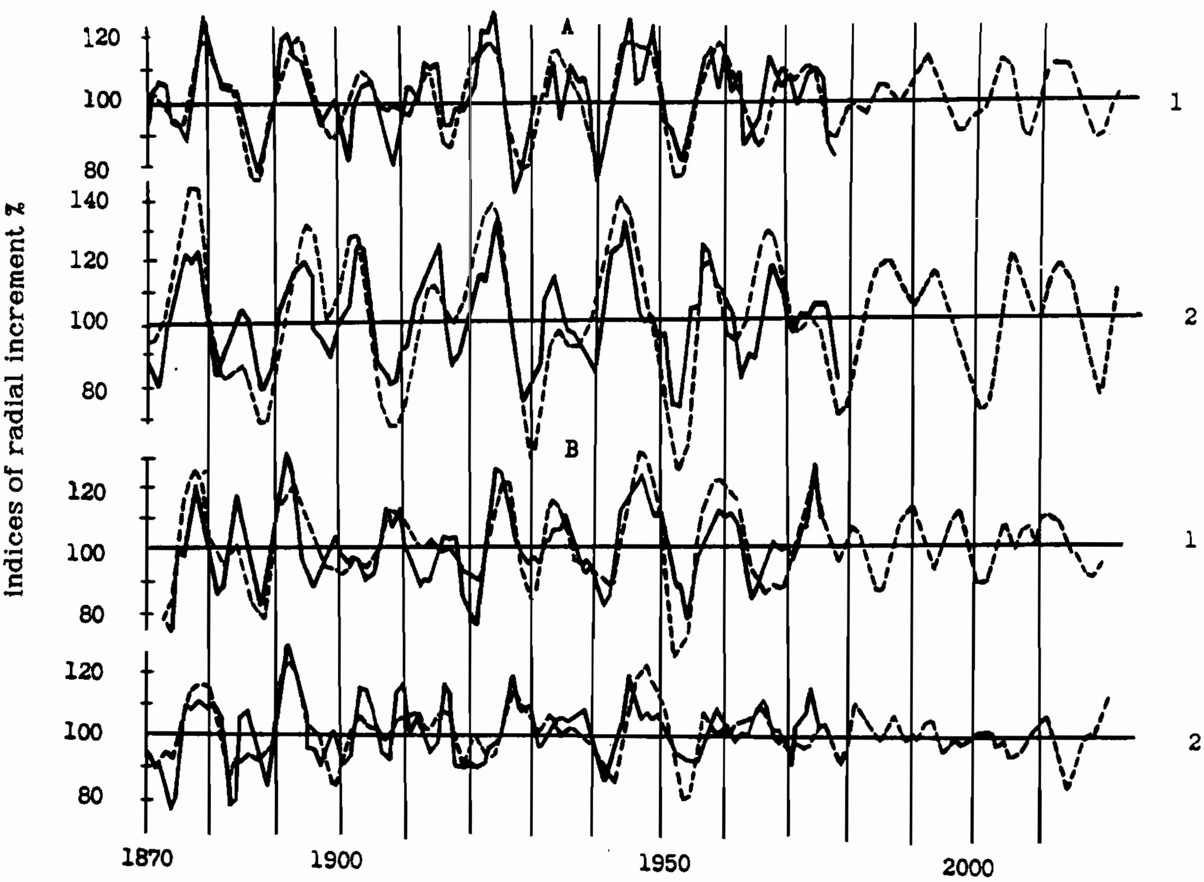

Figure 2: Actual trend of increment indices (▬▬) and values of the approximating function (- - -).

Pinus silvestris (1) and Picea abies (2) on very damp (A) and dry (B) sites of the Lithuanian SSR (according to dendroscales (Stravinskiene, 1981) (A) and (Bitvinskas, 1974, 1981)(B)).

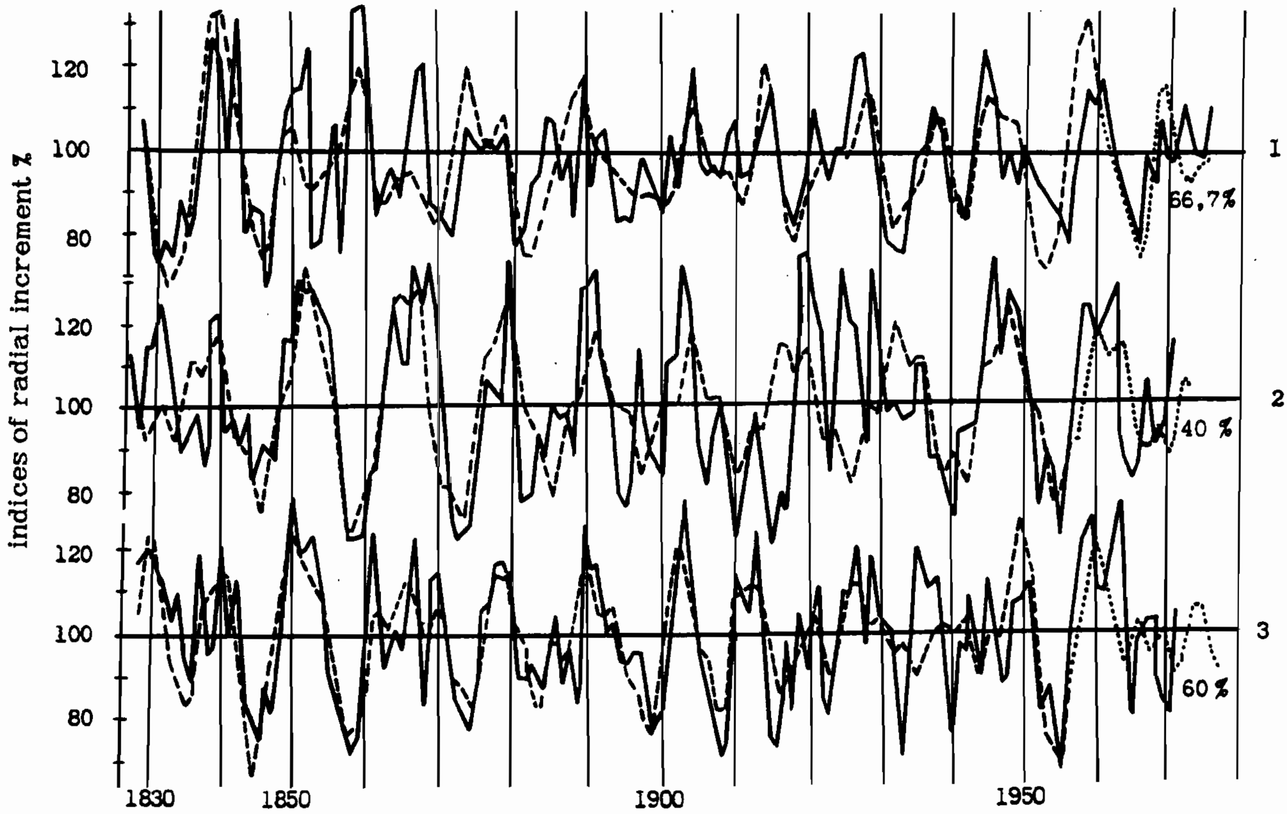

Figure 3: Actual trend of increment indices (——), values of the approximating function (---) and predicting function (....).

1 = Pinus silvestris stand of Sphagnum forest type from the Kaunas region;

2-3 = Quercus robur stands of Oxalis forest type from the Kaunas and Vilnius regions of the Lithuanian SSR (according to dendroscales (Stravinskiene, 1979) (1) and (Kairaitis, 1979)(2-3). The prognoses in 1 are calculated according to equation 2, and in 2-3 according to equation 1. The agreement values (%) between the actual and predicted data are indicated on the right hand side.

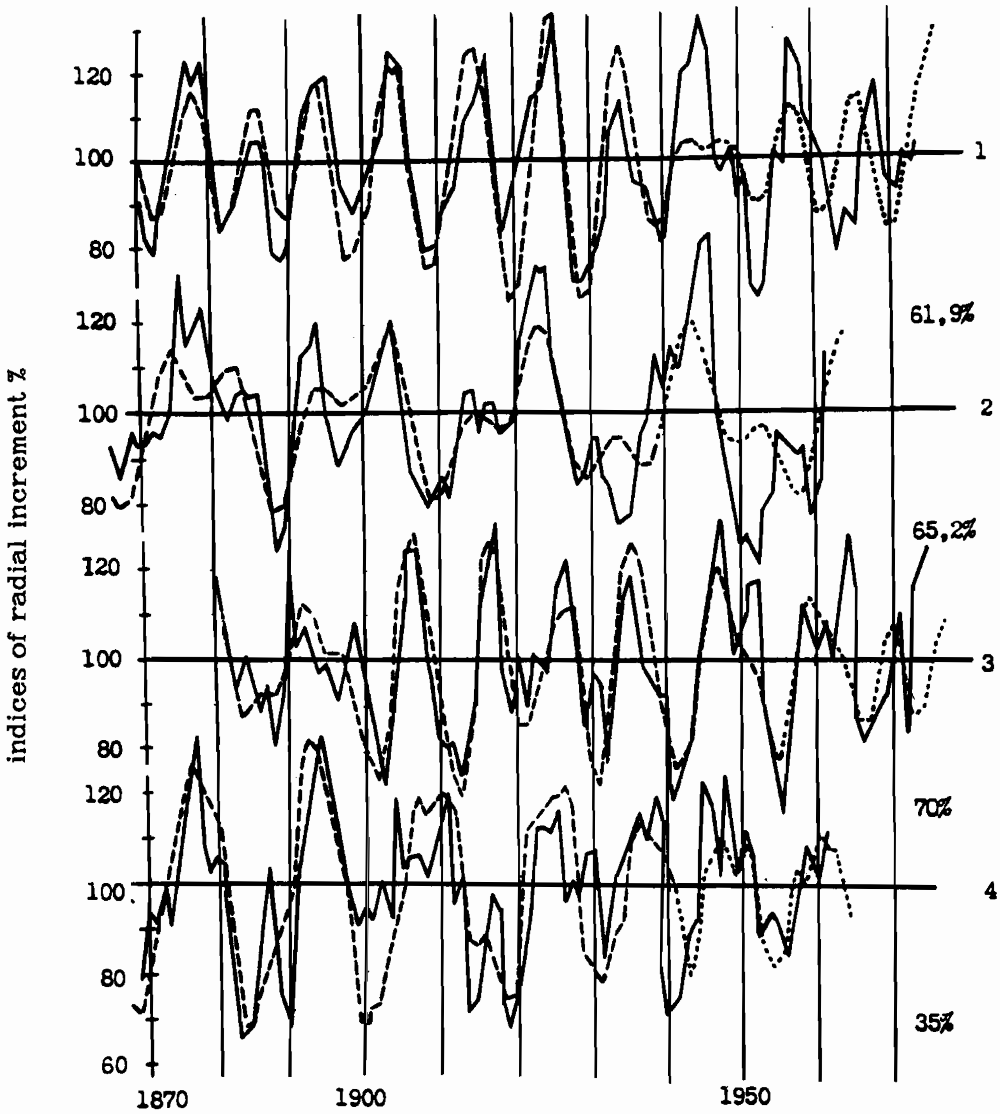

Figure 4: Actual trend of increment indices (▬▬), values of approximating function (- - -) and predicting functions (....).

1 = Pinus silvestris stand from very damp sites (master chronology for the whole Lithuanian SSR);

2 = Pinus silvestris stand of Sphagnum forest type from the Svencioneliai region of the Lithuanian SSR;

3 = Picea abies stand of Vaccinium myrtillus forest type from the Anyksciai region; and

4 = Pinus silvestris stand of Vaccinium myrtillus - Oxalis forest type from the Kaunas region of the Lithuanian SSR (according to dendroscales (Stravinskiene, 1981) (1,3), (Bitvinskas, 1974) (2-4). The agreement values (%) between the actual and predicted data are indicated on the right hand side.

results were compared with the actual data. It appeared that in 19 series significant fluctuations (8-22 years) were reflected properly, although the agreement of the ends of some series of dendroscales was less than 50% (Figures 3 and 4).

A question arises whether it is possible to apply the models (equations 1 and 2) to approximate and predict dendroscales of long periods, for instance 200-450 years. Such scales, as a rule, are not stationary; for example, in some rows this may be noted visually (Figure 5). In these series, the spectral and harmonic analysis of non-crossing intervals of 100-150 years resulted in dynamics changeability of small rhythms (8-13, 20-25 years in duration). Therefore, these rhythms are revealed best in DS covering only the years 100-150. If T_j, A_j and Y_j are determined in the whole series of DS covering the years 200-450, these models are not appropriate for an approximation and prediction of series with such rhythms.

Let us consider long-term rhythms. Suppose that long-term rhythms can reflect the general favorable or unfavorable climatic background of a region. Then short-term (8-13, 20-25 years in duration) rhythms of growth processes will be revealed on the background of a favorable or unfavorable impact of long-term rhythms. In order to elucidate the general tendency for climatic background changeability of the northern parts of the USSR and North America, we attempted to single out long-term rhythms (35 and more years in duration) in DS from these regions. For this purpose we have investigated 17 dendroscales from the northern parts of the USSR (the Urals, Karelia, West Siberia and Lithuania)(Bitvinskas, 1979; Komin, 1978; Lovelius, 1979; Shiatov, 1972, 1973, 1975, 1977, 1979) and 34 dendroscales from Canada and the USA (states of Washington, Oregon) (Cropper and Fritts, 1981; "Tree-ring Chronologies for Dendroclimatic Analysis", 1973: Vols. 1,5,6 and 1976). Each of these has a span of more than 260 years.

To single out long-term rhythms, we calculated the trigonometrical amplitudes in each series for the periods from two to half of the row. Calculations also included density spectra with different duration of smoothing. It turned out that the maxima of the trigonometrical amplitudes and density spectra in both groups of DS are revealed with a frequency corresponding to the following rhythms: 35-40, 50-54, 58-60, 76-84, 90-93, 110-117 and 171-176 years in duration in the dendroscales from the USSR, and 37-39, 46-53, 58-62, 72-78, 98-105 and 178-192 years in duration in those from the USA and Canada (Figure 6).

A synchronization is observed in all groups of cycles. The peaks of the trigonometrical amplitudes appear at points of maxima and minima of almost all (90%) fluctuation rhythms in the temporal interval 1880-1980. These points differ from the mean point of appearance of the corresponding extremum by no more than 20% of the length of the mean rhythm of the conformable fluctuation. It must be noted that almost half of the maxima of the trigonometrical amplitudes and density spectrum lie below the 95% confidence limit.

Being concerned as to whether the maxima might or not be a consequence of short-term rhythms, we formed several dendroscales covering the years 300-400, according to equation 1.

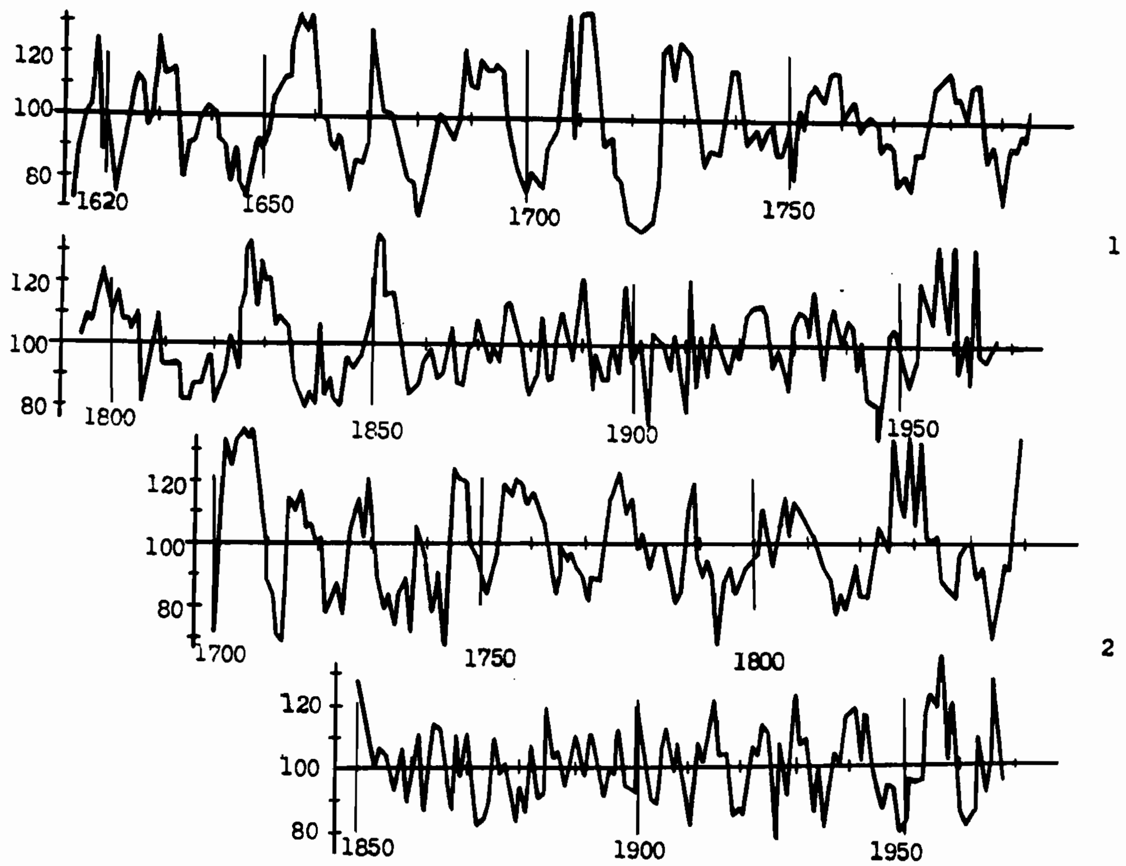

Figure 5: Examples of distinctly non-stationary DS. Pinus silvestris stands from the Kola Peninsula (1) and the Karelia ASSR (2) (dendroscales (Bitvinskas and Kairaitis, 1979)). Absolutely different dynamics of indices' fluctuations are noted in the intervals 1650-1850 and 1850-1960 (1) and 1750-1850, 1850-1940 (2).

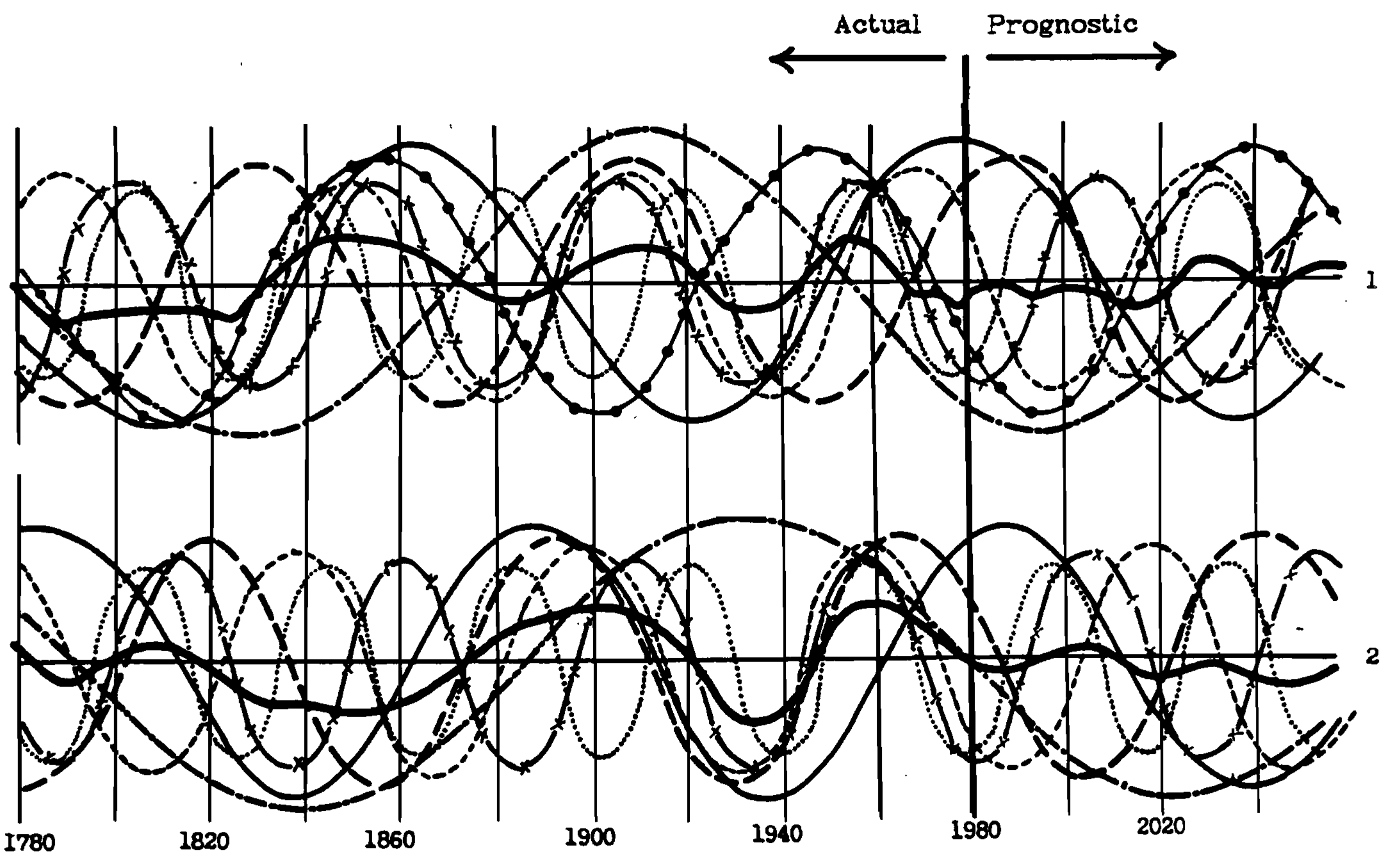

Figure 6: Rhythmical fluctuations in the dendroscales of the USSR (1) and the USA, Canada (2).

.... cycles of 30-40 (1) and 37-39 (2) years in duration;
-x- cycles of 50-54 (1) and 46-53 (2) years in duration;
-- cycles of 58-60 (1) and 58-62 (2) years in duration;
▬ ▬ cycles of 76-84 (1) and 72078 (2) years in duration;
●—● cycles of 90-93 (1) years in duration;
—— cycles of 110-117 (1) and 98-105 (2) years in duration;
-·- cycles of 170-173 (1) and 178-192 (2) years in duration;
▬▬ average variables of cycles.

We assume that $E_t = 0$, a A_j T_j and Y_j are the length of the rhythms, amplitudes and phases adequate to the predicted parameters of series of 100-150 years. For such series, we calculated trigonometrical amplitudes and density spectra. It turned out that with frequency corresponding to the long-term rhythms, the peaks of these functions were not observed. Thus, the aforementioned results confirm the presence of long-term rhythms and enable one to establish the mean duration of it T_j and phases of fluctuation Y_j where j = 6.7. Following the data of visual observations of DS discussed above and observations made by other authors (Berrie et al., 1979; Komin, 1978) the following general principle was accepted: with increase in T_j, A_j increases as well. On this basis we attributed an amplitude for each rhythm appropriate to its length. With the aid of the formula

$$\sum_{j=1}^{n} A_j \cos (2\pi t / T_j - Y_j) \ , \qquad (3)$$

$$n = 6.7 \ , \quad t = 1,2,\ldots, \ ,$$

where the index t refers to time (years) and we determined the average variables of conditional change in the ecological-climatic background.*

These values in both groups of dendroscales (from the northern parts of the USSR and North America) have a certain similarity. Hence the background impact of long-term climatic fluctuations on the rhythm of short-term fluctuations may be similar in the whole Northern hemisphere (Figure 6) during the corresponding periods (for instance, 1920-1980).

Let us analyze the application of the results mentioned above for prediction purposes. If we put the data of prognosis of short-term rhythmical fluctuations (determined by equations 1 and 2) for the Lithuanian SSR on the curve of the general climatic background determined by the model shown in equation 3, we can obtain the forecast of the general climatic background for the given territory (Figure 7). The variables of long-term rhythms (equation 3) obviously may be used for the general characterization of production processes in the Northern Hemisphere. It is also applicable for creating a number of scenarios related with the perspective of forest use and with change in the CO_2 concentration in the atmosphere, etc.

The models shown in equations 1 and 2 approximate well to the generalized DS for different species over various sites. So it is feasible to use them for predicting the yield of agricultural crops on a given region. For instance, such a prognosis has been calculated for the Lithuanian SSR.

We investigated the dependency of the dynamics of grain crops in the Lithuanian SSR on the fluctuation of series DS $x_1(t)$ and $x_2(t)$, where $x_1(t)$ refers to a series of indices of increment of Pinus silvestris master chronology from dry sites of the Lithuanian SSR, whilst $x_2(t)$ to that from very damp areas of the republic. The same climatic factors (temperature, precipitation, etc.) affect the tree increment on dry and damp sites

*The year 1500 was considered to be the start of fluctuations in ascertaining Y_j, with j = 1.7.

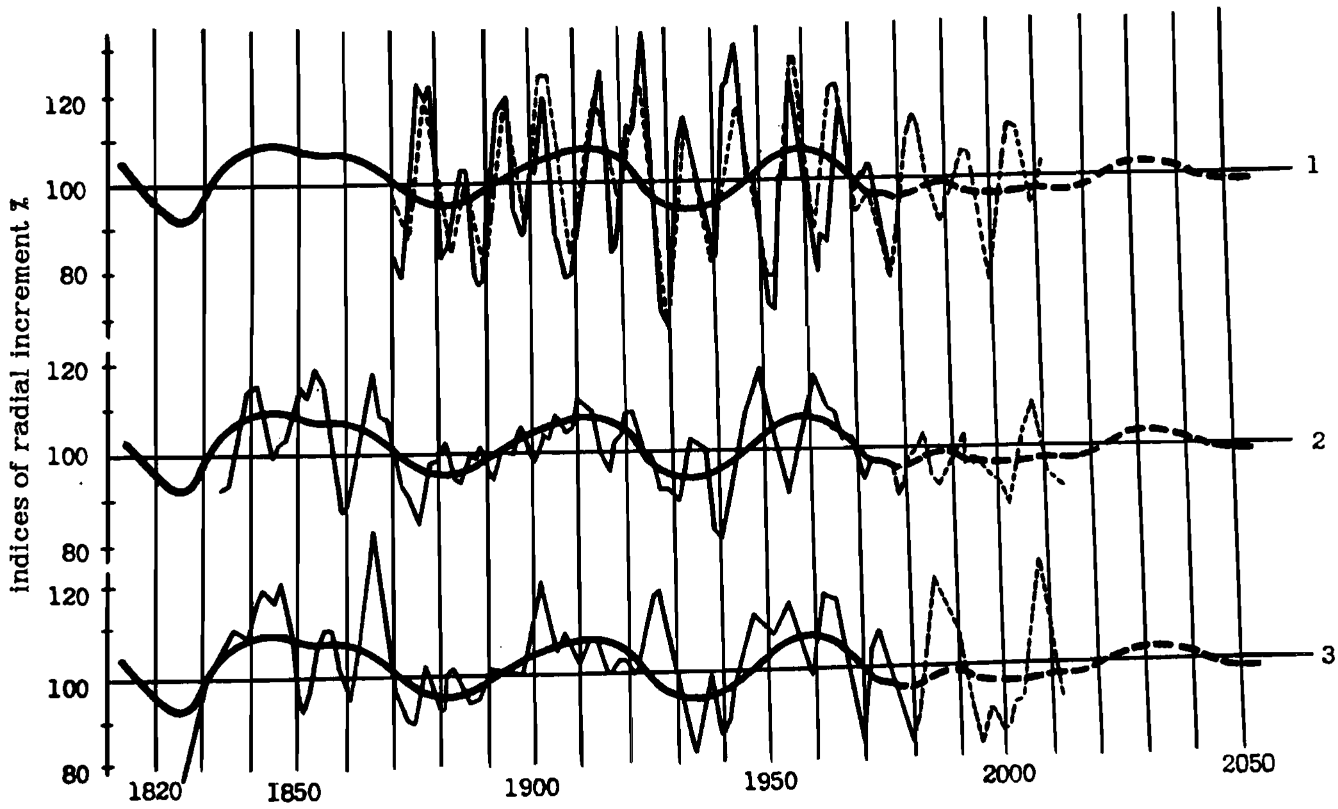

Figure 7: The average variables of actual increment (climatic background fluctuations) in long (> 35 years; ▬) and short (—) rhythms, approximation and forecast (- - -) in very damp sites (1) and dry sites (2-3) of the Lithuanian SSR.

differently. It is possible to assume that vector $(x_1(t), x_2(t))$ reflects the impact of the climatic background of the Lithuanian SSR. At the beginning of the series of yield of agricultural crops $y(t)$ (centners/ha) we singled out the $D(t)$ trend conditioned by fertilizers, agronomical practices, etc. For this purpose we applied the method of the least squares. Further, in accordance with the formula

$$w(t) = (y(t)/D(t)) \cdot 100\%$$

we determined $w(t)$ yield indices free from the trend. These depend only upon the weather conditions. With the help of the standard method of regressive analysis (by the method of exception) we obtained $w(t)$ approximation in the form of the following series:

$$W(t) = 146 + 1.07\tilde{x}_2(t-1) - 1.54\tilde{x}_1(t+2) \ , \qquad (4)$$

where

$$\tilde{x}_i(t) = A_0 + \sum_{j=1}^{n} A_j \cos(2\pi t / T_j - Y_j) \ , \quad i = 1,2 \ ,$$

is the approximation of the climatic background of the Lithuanian SSR $(x_1(t), x_2(t))$. Comparison between approximating series (equation 4) and the actual $w(t)$ indices gave agreement of 72%. On the basis of the yield trend prediction, the forecast of the climatic background $(x_1(t), x_2(t))$ and equation 4, we calculated the data of the an exemplary yield prognosis (centners/ha) (Figure 8).

A series of price indices of wheat for the period 1500-1869 was formed in England by Lord Beverige. It is one of a more widespread economic series. Series $B(t)$ was obtained from the series of price indices of wheat after removing the trend by the 2-year sliding. We studied the correlation between $B(t)$ and $P(t)$ series of dendrochronological indices from Ireland (Pilcher and Baillie, 1980). It appeared that the agreement between series $B(t)$ and $P(t-1)$ averaged to three years is 41.4%. After the year of unfavorable growth conditions, prices for wheat increase. It lends support to the explanation of the regularity described. However, in Figure 9 we note that many of the peaks of these series are of a contrary character (see, for example, 1571-1574, 1576-1578, 1603-1606, 1622-1626, 1648-1652, etc.).

Exceptions to the rule may be explained in a way by social actions: 1586-1588: war with Spain; 1642-1648: Civil war; 1756-1763: Seven-Year war; 1767-1769, 1780-1784, 1790-1792: Anglo-Mysore wars; 1799-1815: Napoleon wars; 1829: an economic crisis.

The examples mentioned above might attract the attention to DS by economists. Actually, in economic literature, there are publications about cyclical development of the economy (Schumpeter, 1915; 1939). Attempts have also been made to explain the cyclical development of the economy, particularly Kondratieff cycles, by the increase and decrease of entrepreneurial interests of people over time (Krelle, 1983). Taking into consideration that Kondratieff cycles are quite synchronic with the above mentioned (Figure 7) climatic background averaged fluctuations and that these fluctuations have a great impact on all living substances on earth, such explanations can be supported by dendrochronologists.

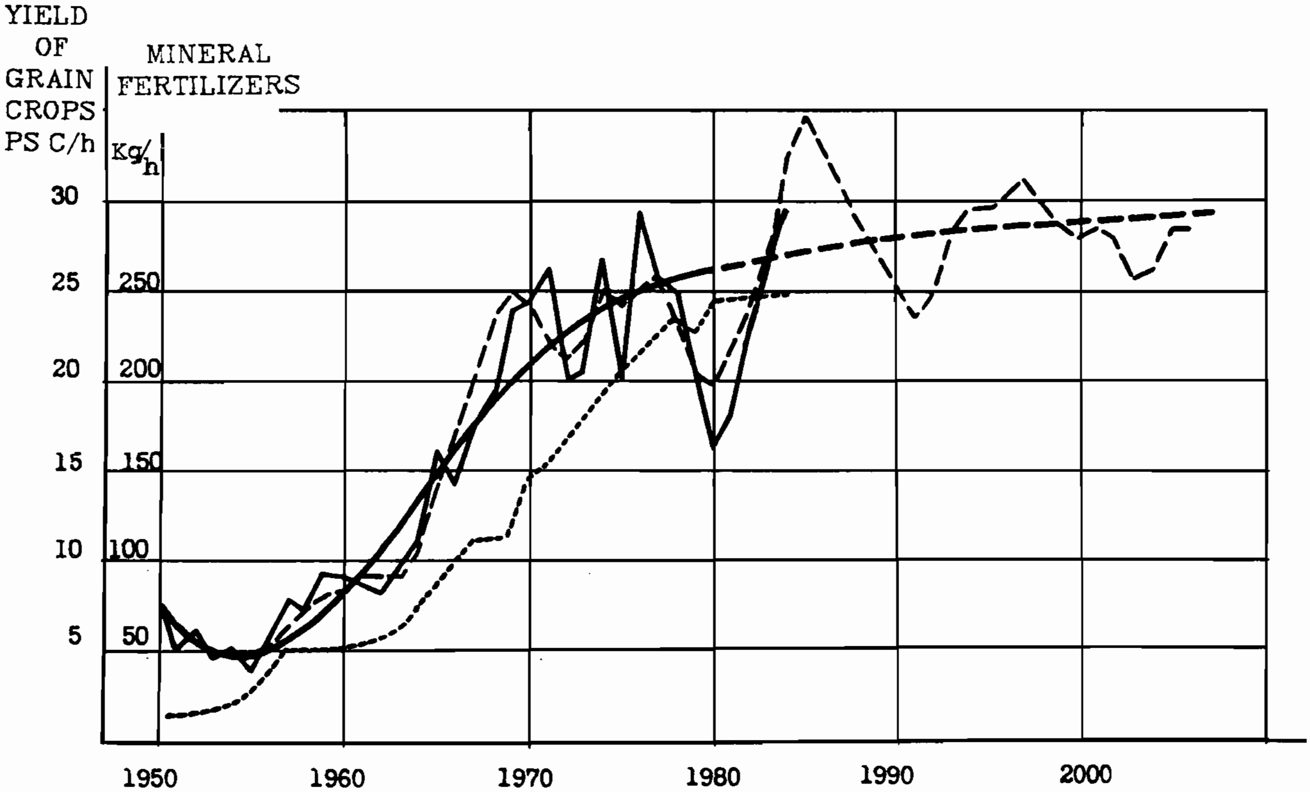

Figure 8: The yield of grain crops in the Lithuanian SSR (—), the quantity of mineral fertilizers kg/ha (...), the general trend of increasing crop yields (▬) owing to fertilizers, agro-technique improvement and its prognosis (- -), prediction of crop yields (- -) on a dendrochronological basis.

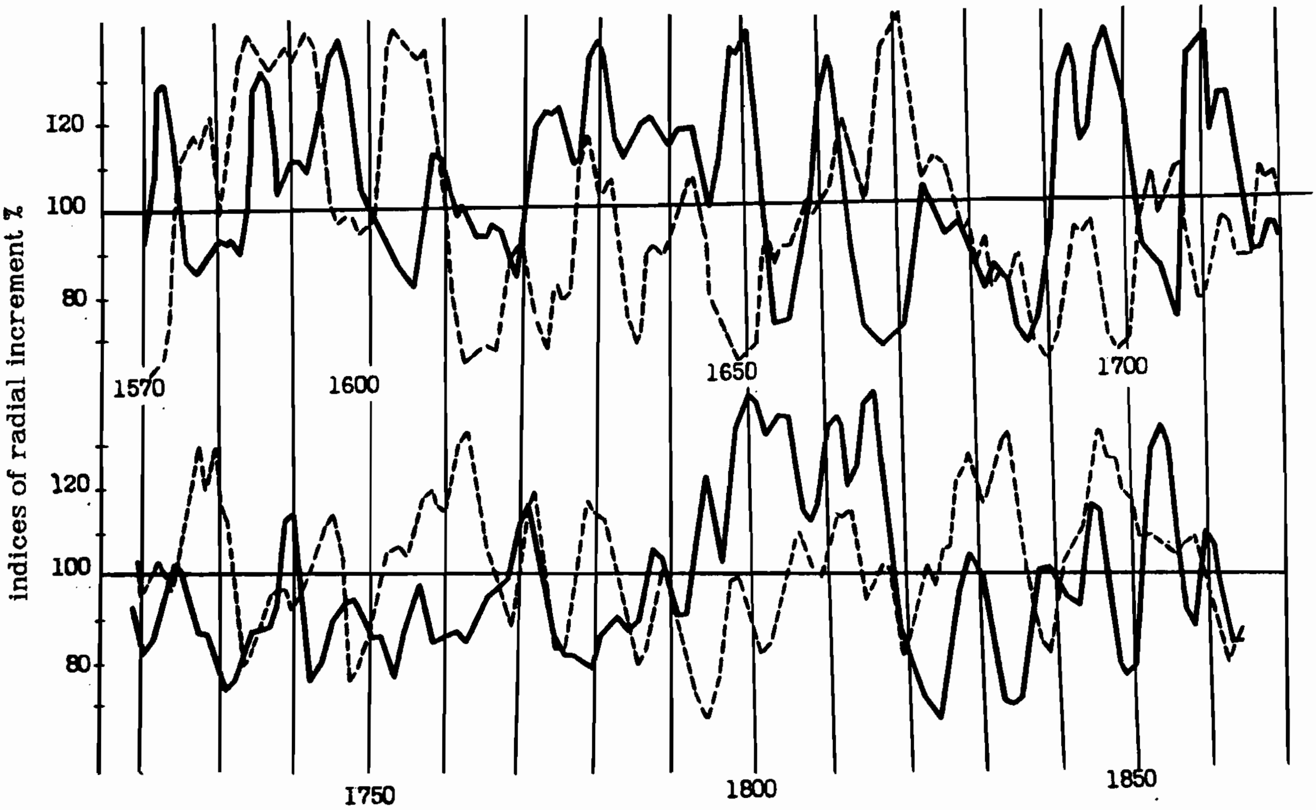

Figure 9: Price indices of Beverige after removing the trends with the 2-year mean sliding (- -) and dendrochronological indices (averaged to three years) (——) of Ireland by Pilcher and Baillie (1980).

CONCLUSIONS

1. To predict changes in climatic background of growth for 10-15 years according to DS covering the years 100-150, it is better to apply the cyclic models in equations 1 and 2. Approximating fluctuations in stationary DS detect 85% of significant fluctuations (8-22 years in duration) of a series.
2. Fluctuation rhythms of 8-13 and 20-25 years in duration are reflected best in DS covering the years 100-150. In a 200 (and over) -year dendrochronological series the dynamics of short-term rhythms (8-13, 20-25 years in duration) is changeable. The models depicted by equations 1 and 2 are not appropriate for approximation and prediction of such series in case the parameters are determined in the whole series.
3. In DS of long periods (260-1250 years) from the northern parts of the USSR and Northern America the following rhythms have been singled out: 35-40, 50-54, 58-60, 76-84, 90-93, 110-117 and 171-176 years in duration and 37-39, 46-53, 58-62, 72-78, 98-105, 178-192 years in duration respectively. Fluctuation phases are ascertained in all groups of rhythms. Variables of long-term changes in the ecological-climatic background during the last 60 years have been found (according to equation 3) to be conditional to the northern regions of the Eastern and Western hemisphere.
4. The variable of long-term rhythms of DS may be used for the general characterization of the activity of the production processes in the Northern hemisphere. Apparently it is also applicable for creating a number of scenarios associated with the perspective of forest growth, regeneration of natural resources, changes in the CO_2 concentration in the atmosphere, etc.
5. Prognoses of the generalized DS from dry and damp sites, calculated by means of equations 1 and 2, may be applied for predicting the yield of agricultural crops on a given region. Such prognoses are obtained for the yield of grain crops in the Lithuanian SSR up to 1995.

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3.2 LONG-RANGE TRANSPORT OF POLLUTION AND ACID RAIN

3.2.1 ACID RAIN IN EUROPE – An Energy-Environmental Impact Study*

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Summary

IIASA's model of Acid Rain is an interactive set of submodels with graphical output. The model has been developed in collaboration with UN Economic Commission for Europe and in the context of the Geneva Convention on Long-range Transboundary Air Pollution. The model covers five compartments of which upto now three have been implemented as submodels. Starting with energy scenarios for the whole of Europe, the first submodel calculates sulfur emissions on a country-by-country basis. The second submodel consists of a transfer matrix for the transport of sulfur emissions. The third submodel takes the deposition figures as input and converts them to forest soil pH. The last submodel calculates acidity changes in lakes in Scandinavia. The models time coverage is the period 1960-1980 for base calculations and the period 1980-2030 for scenario analysis. The time resolution is one year. The models spatial coverage is all 27 European countries on a spatial resolution of about 100 x 100 km.

The models output are several, including maps of Europe showing isolines of sulfur deposition and areas with a soil pH below a certain level which can be chosen by the user.

Future research within IIASA's Acid Rain project will focus on analyzing uncertainty, modeling of direct forest impacts, inclusion of other pollutants and economic evaluation of scenarios.

1. INTRODUCTION

THE PROBLEM OF ACIDIFICATION

Since many decades society has been confronted with increasing negative side effects of human activities. Already during the Industrial Revolution effects of air pollution were known. The character of the pollution problem, however, changed drastically during the past World War II period. Before, the pollution problems were mainly of a local and transitory character. Nowadays we are faced with a transboundary problem of a continuous character. Pollutants may remain airborne for several days and can travel over a distance of thousand kilometers.

Acidic compounds may have a direct and an indirect effect. Direct effects are those resulting from deposition of the compounds on the surfaces. These effects include corrosion of materials, deterioration of monuments and damage to human health and tree foliage. Indirect effects may occur after deposition. Increased acidity of soil can restrict plant growth, acidification of groundwater may increase the solubility of heavy metals which in turn can affect human and animal health. Through a combination of direct and indirect effects forest growth can be reduced. Both direct deposition and soil acidity are viewed as causes of recent forest

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dieback (ERL, 1983).

It is needless to say that these adverse effects also cause extensive costs for society. In a recent overview of the acid rain issues within the European Community some tentative damage estimates have been presented (ERL, 1983, Ch. 11). To give an impression of the magnitude of these damages some of the damage estimates are shown in Table 1. These figures are far from exact estimates and should not be misinterpreted.

Table 1. Damage due to acid deposition in EEC countries.

Damage category	Hypotheses, year	Costs (10^6US$ p.a.)
Forests	20% of forests affected 10% drop p.a.	100
Crops	winter wheat, barley potatoes 1981	900–1,100
Fish	Scottish lakes	0.5
Buildings	due to sulfur compounds	540–1,100

Source: ERL (1983, Ch 11).

THE EUROPEAN CONTEXT

In 1979 a large number of European countries, Canada and the United States of America, signed the Convention on Long Range Transboundary Air Pollution. In this Geneva Convention, overseen by the UN Economic Commission for Europe, the signatories state in Article 2 that they "... shall endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including long-range transboundary air pollution". Under the Convention, four major programs are carried out: Air Quality Management, Research and Development, Exchange of Information and the Co-operative Programme for the Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP).

In March 1983, the required number of countries had ratified the Geneva Convention and an Executive Body has been established. That same year a number of countries started a campaign to agree on a 30% reduction of SO_2 emissions in countries that ratified the Convention. Already in March 1984, ministers of nine countries agreed on reducing SO_2 emissions in their countries by 30% in 1993 based on 1980 figures. Later in 1984 at a Minister's meeting in Munich and a meeting of the Executive Body in Geneva the so-called 30% club extended its membership to include 18 European countries and Canada. The next step was an official protocol signed by these countries in July 1985 in Helsinki.

Although from a political point of view this achievement is very valuable, one may wonder whether a 30% rollback over Europe is an efficient way of reducing the effects of sulfur deposition. From a point of view of atmospheric linkages between a receptor area and the sources of pollution which contribute to deposition in that area the chances are high that a flat rate reduction is non-optimal. Also from an economic point of view a more cost efficient solution may be found by varying reductions among countries.

In order to evaluate the effects of different strategies, data for energy use, emissions, transportation, deposition and environmental impacts should be linked with each other.

In the IIASA Acid Rain Project work is underway to construct such a set of linked models. The purpose of this RAINS (*Regional Acidification INformation* and *Simulation*) model is to provide a tool to assist decision makers in their evaluation of control strategies for acidification in Europe. In this paper we describe briefly the ***interim state*** of the model, and show how it could be used when linked with an optimization algorithm.

Detailed information on RAINS can be found in Alcamo et al. (1985), Hordijk (1985), Kauppi et al. (1985) and Kämäri et al. (1985). A description and an application of the optimization algorithm is contained in Young and Shaw (1986) and in Shaw (1984).

2. METHODOLOGY

The design of any model depends very much on the dimension of the problem the model is used for and the users of the model. Regarding the problem of acid rain any modeling will be confronted with the following characteristics of that problem:

- The acid rain problem is transboundary.
- Many different scientific disciplines are needed.
- There exists a wide range of uncertainty in cause-effects relationships.
- Different time scales are relevant (hours of transport, snowmelt in weeks, acidification of soils in years).
- Due to the fact that acid rain is an important political issue, research is stimulated which creates a constant stream of new information.
- Acid rain is expensive to control.
- Within and between countries the levels of responsibility vary from local authorities to international bodies.

The user of the model will be on the decision making level. Therefore analysis of scenarios, interactive use of the system and quick and readable output form the main characteristics of this model.

The above notions led to a model that should

- be co-designed by analysts and potential users;
- contain submodels that are as simple as possible, but based on more detailed data and complex models;
- have interactive input and graphical output;
- consists of linked modules which can easily be replaced by other modules that represent another set of hypotheses;
- be dynamic in nature.

3. CURRENT SUBMODELS

Interaction of human activities and environmental impacts can be linked in a schematic way as is done in Figure 1.

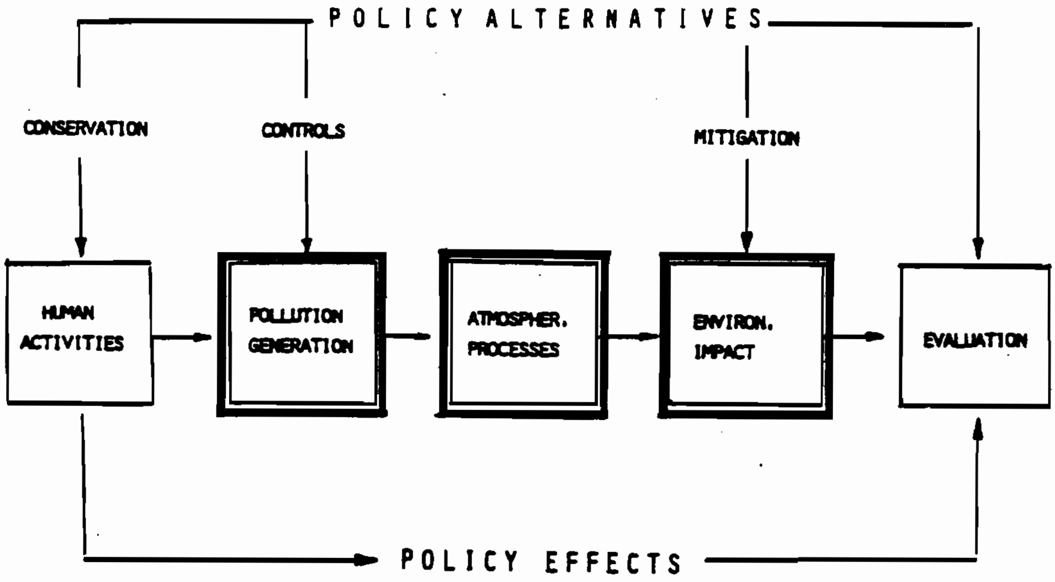

Figure 1. Interaction between human activities and environmental impacts.

For a more detailed scheme the reader is referred to Hordijk et al. (1981). The present status of the model comprises the three compartments shown with the heavy lines in Figure 1.

For each of these compartments a submodel has been developed. The first compartment, *Pollution Generation*, has been modeled for sulfur emissions based on a selected energy pathway for 27 European countries. The user has a choice of three possible pathways, based on estimates of ECE. To reduce sulfur emissions the user may specify any combination of four possible control alternatives. The second compartment, *Atmospheric Processes*, has been modeled with a transfer matrix. This submodel computes sulfur deposition in Europe on a grid square which is 150 x 150 km. The transfer matrix is based on a more complicated model of long range transport of air pollution in Europe developed under OECD and EMEP.

The sulfur deposition is input to a third submodel, the Forest soil-pH submodel. This model is a first part of a set of submodels that form the third compartment of Figure 1, *Environmental Impact*.

Forest soil-pH is analyzed as an indicator for potential forest and aquatic impacts. In this submodel acidic deposition is compared with the neutralizing capacity of Europe's forest soils. Output of the model is a map of Europe indicating areas with a pH below a level, that can be chosen by the user. Lake acidity has been modeled for Finland and Sweden. This submodel consists of four modules for meteorology, hydrology, soil chemistry and lake acidity.

The simulation period is 1960-1980 so that the model can be tested against historical data where available. The model's time horizon is 2030, which permits examination of possible long term impacts. The models time resolution is one year and the spatial resolution is a grid system of approximately 100 x 100 km. The spatial coverage is all of Europe, being 27 countries.

The model is sulfur based since it is generally accepted that sulfur is presently the principal contributor to acidification in Europe. However, other pollutants will be included in the future.

The model use is illustrated in Figure 2. The model user can start with selecting an energy pathway for each country followed by a pollution control program. The model then calculates the sulfur emissions of each country, the atmospheric transport and deposition and the resulting soil-pH. Based on this output the model user may select another energy pathway and/or control program to evaluate with the model. The model allows for comparison of two policies chosen by the user.

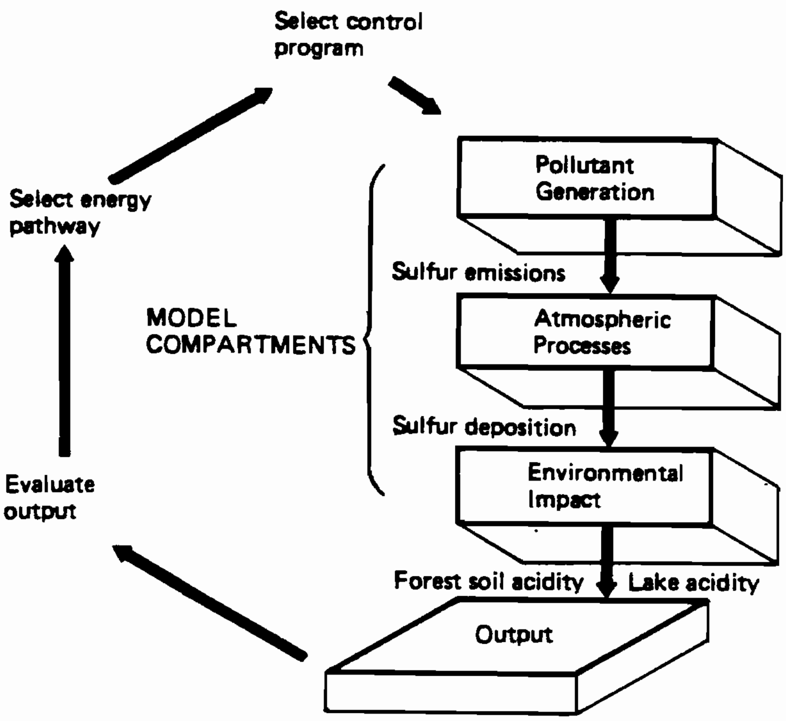

Figure 2. The use of the RAINS model.

The sulfur emissions submodel is briefly summarized in Figure 3. Input in the submodel is a set of user prescribed energy pathways for the 12 energy sectors in each country.

The energy pathways are based on ECE (1983), where two scenarios have been presented: *Trends Continued* and *Conservation*. It was necessary to modify these scenarios since they continue only to the year 2000. Altogether the user has an option of three energy pathways.

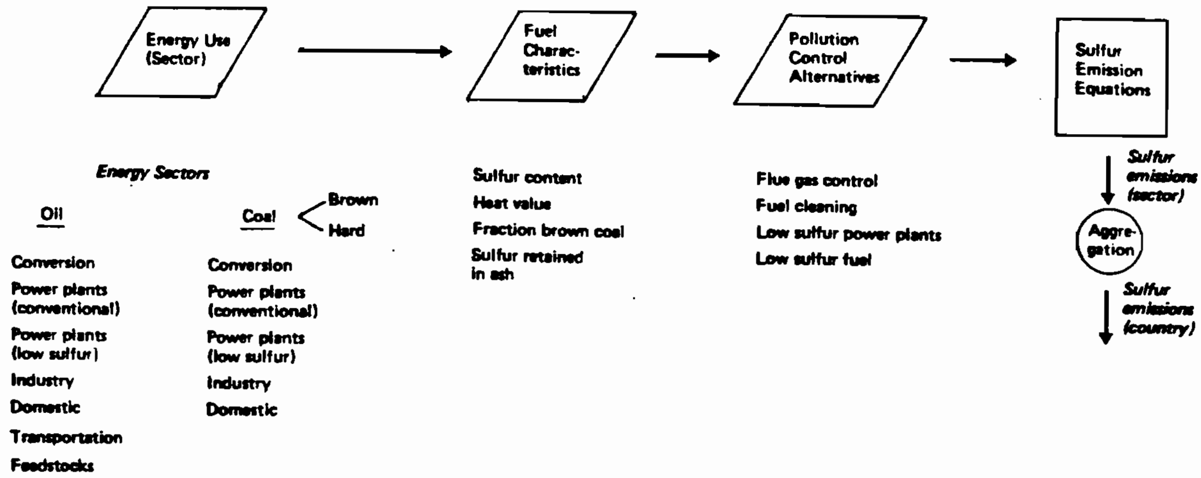

Figure 3. Schematic diagram of the sulfur emissions submodel.

Sulfur emissions are computed by multiplying fuel use in each sector by the sulfur content of the fuel taking into account the heat value and the amount of sulfur retained in the ash.

The model user may adjust these sulfur emissions by indicating a pollution control program. The alternative controls are:

(a) Flue gas control devices
(b) Fuel cleaning
(c) Low sulfur power plants
(d) Low sulfur fuel.

For all these controls the user has several options to choose a policy. These options include the fraction of "cleaning", the energy sectors involved, the year of introduction and the application to new and/or old plants or boilers.

If a refined spatial and temporal resolution of deposition patterns is required, atmospheric processes must be properly parametrized and included in a model. Very advanced models are under development at various institutes (see a.o. EPA, 1984). Once they become available, inclusion in IIASA's system of model will be considered. For the time being the atmospheric transport submodel is based on the simplified parametrization first developed within the OECD programme (see Ottar, 1978 and Eliassen, 1978), and further developed under the Co-operative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe (EMEP).

The so-called EMEP model (Eliassen and Saltbones, 1983) calculates concentrations of SO_2 and $SO_4^=$ at the center of 150 km grid elements. Every 6 hours air trajectories are computed backward from the center of each grid and are followed 96 hours. The model then solves the mass balance equations along this trajectory. The values of SO_2 and $SO_4^=$ concentrations are used to compute dry and wet deposition. The EMEP model is too demanding computationally to be used directly as a submodel of the RAINS model. To make it usable we have reduced the model to a transfer matrix. The elements of the transfer matrix are called unit transfer coefficients and have the dimension (deposition per unit area per unit time)/(emission per unit time).

In practice, the transfer matrix is linked to the sulfur emissions submodel as follows. The sulfur emissions are distributed to different grids in proportion to their 1978-1979 distribution. Thereafter they are converted by the transfer matrix to total (i.e. dry and wet) annual sulfur deposition in each grid square throughout Europe.

The purpose of the forest soil-pH submodel is to convert sulfur deposition into approximations of forest soil-pH. Models were not found in literature which would fulfill this purpose. An in-house model was constructed in collaboration with the University of Göttingen (FRG). A detailed report of the model is Kauppi et al. (1985). An overview of the submodel is presented in Figure 4.

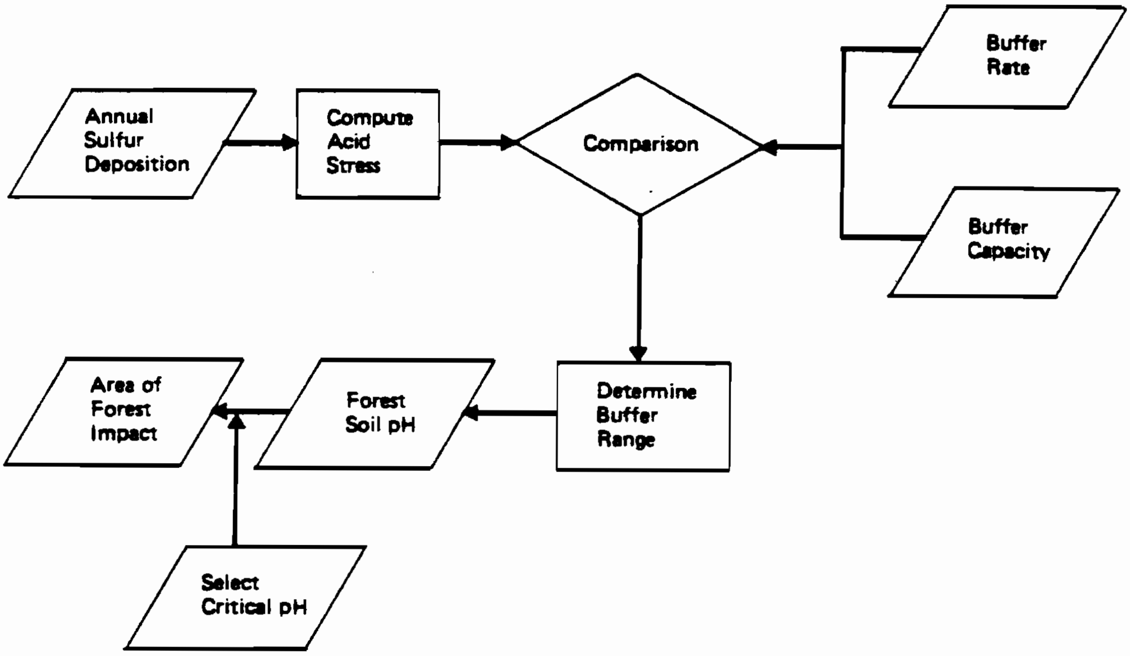

Figure 4. The Forest Soip pH submodel.

Total sulfur deposition, the output of the atmospheric processes submodel, is converted to an equivalent deposition of hydrogen ions assuming that acid deposition enters the soil solution as sulfuric acid. The buffering processes of the soil are described by two variables, one for the gross potential (buffer capacity) and the other for the rate of the reaction (buffer rate).

The buffering processes involve a large number of chemical reaction which have systematically described by Ulrich (1981, 1983). Discrete categories, called buffer ranges, are used to indicate the dominant chemical reactions.

To use the model it is necessary to input buffer rates and buffer capacities for the buffer ranges. The total buffer capacity depends on the soil type. Data for the description of the soil variables were obtained from the FAO/UNESCO Soil Map of the World and other sources. This information was stored in grids covering 1 degree longitude and 0.5 degree latitude. For initializing buffer rates and buffer capacities the year 1960 was selected as a base year.

Comparing acid stress with the buffer rates and buffer capacities the model produces pH values for European forest soils. The model user has two options to display model output. One option produces the area below a critical pH level (to be indicated by the user) in a map format. The other option displays the time development of the area of forest soils below an indicated pH level.

Figure 5 depicts the structure of the lake model. It is beyond the scope of this paper to describe in detail the working of the model. Suffice it to state that the major processes determining the level of lake acidification have been modeled in a simple fashion.

4. EXAMPLES OF MODEL USE

As emphasized in Section 2 the model has been designed for easy handling by non-technical users. Therefore in each step of model use the user is provided with a clear question on a computer screen together with a number of options he can choose. Another terminal presents the information provided by the model, given the user's particular choice. To give the reader an impression of model use we present an example of model use.

We first assume that all European nations follow the ECE scenario 'Conservation' which levels off after the year 2000, indicated with Reference Scenario in the output shown hereafter. The user then specifies a control strategy and compares it with the case of 'no action'.

The pollution control strategy includes:

(1) 30% removal of sulfur in the domestic coal sector through coal cleaning and 60% removal of sulfur in the domestic oil sector by oil desulfurization.

(2) Phasing in of flue gas control devices in the power plant and industry sectors for coal and oil in the following way:

Year	Fraction of sulfur removed
1990	0.4
2000	0.6
2010	0.8
2020	0.8
2030	0.8

This phasing assumes that 50% of all power plants and industrial boilers in 1990 will have flue gas control devices which have an 80% sulfur removal efficiency (0.5 x 0.8 = 0.4). These devices will be applied to 75% of all plants and boilers in the year 2000 (0.75 x 0.8 = 0.6) and all plants after the year 2000 (1.0 x 0.8 = 0.8).

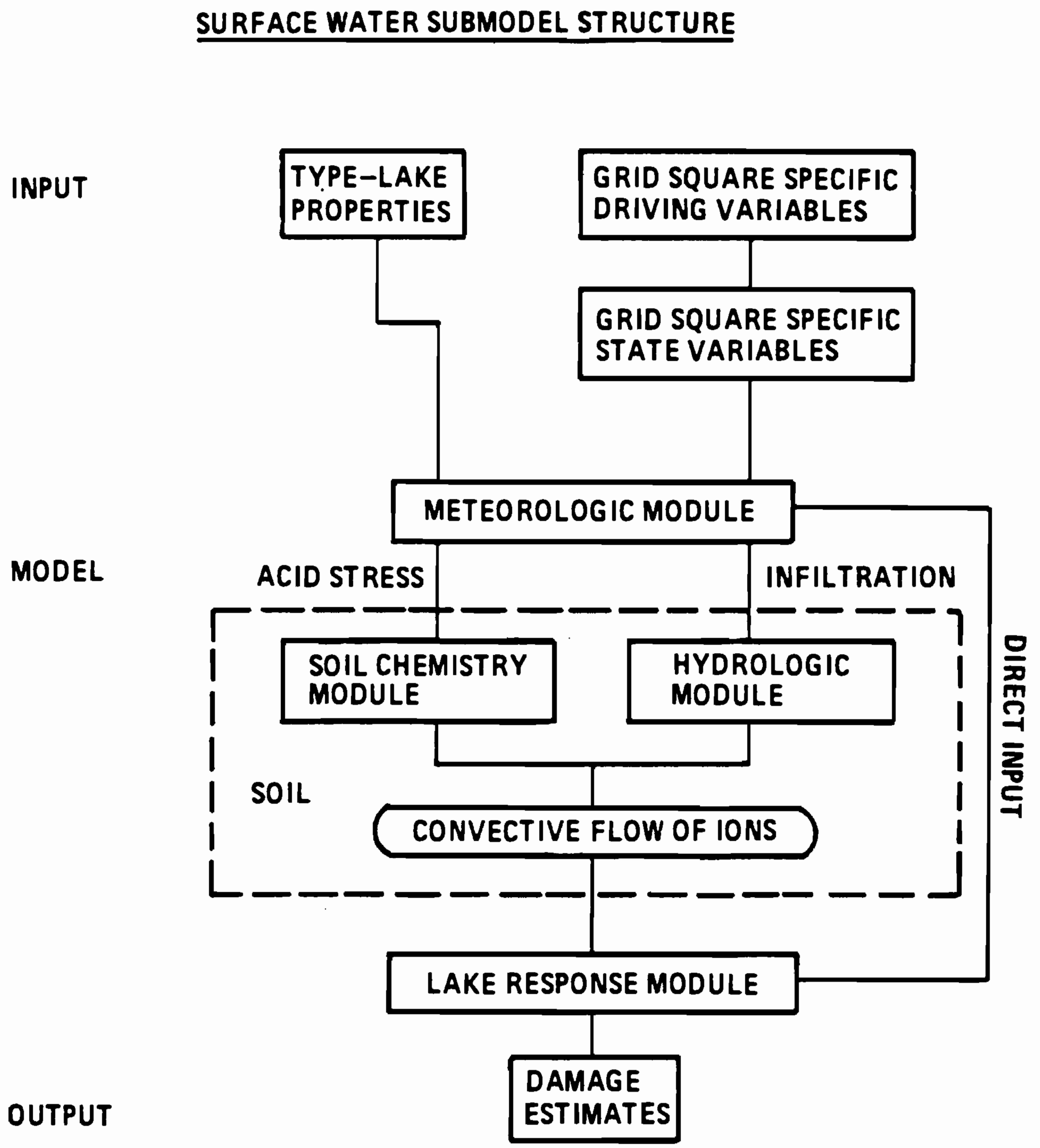

Figure 5. The Lake Acidity Submodel.

The figures below summarize the differences in the scenarios. Figure 6 presents an overview of the sulfur emissions for the whole model period. Figure 7 represents a comparison of sulfur deposition in both scenarios for the year 2030. The heavy lines refer to the energy pathway with no pollution controls, the thinner lines represent the sulfur isolines emerging from the scenario with major pollution controls. The user has chosen the 2.0 g/m^2/yr isoline as an indicator. In Figure 8 finally areas with low soil pH are shown for the "Reference Scenario – Major Pollution Controls".

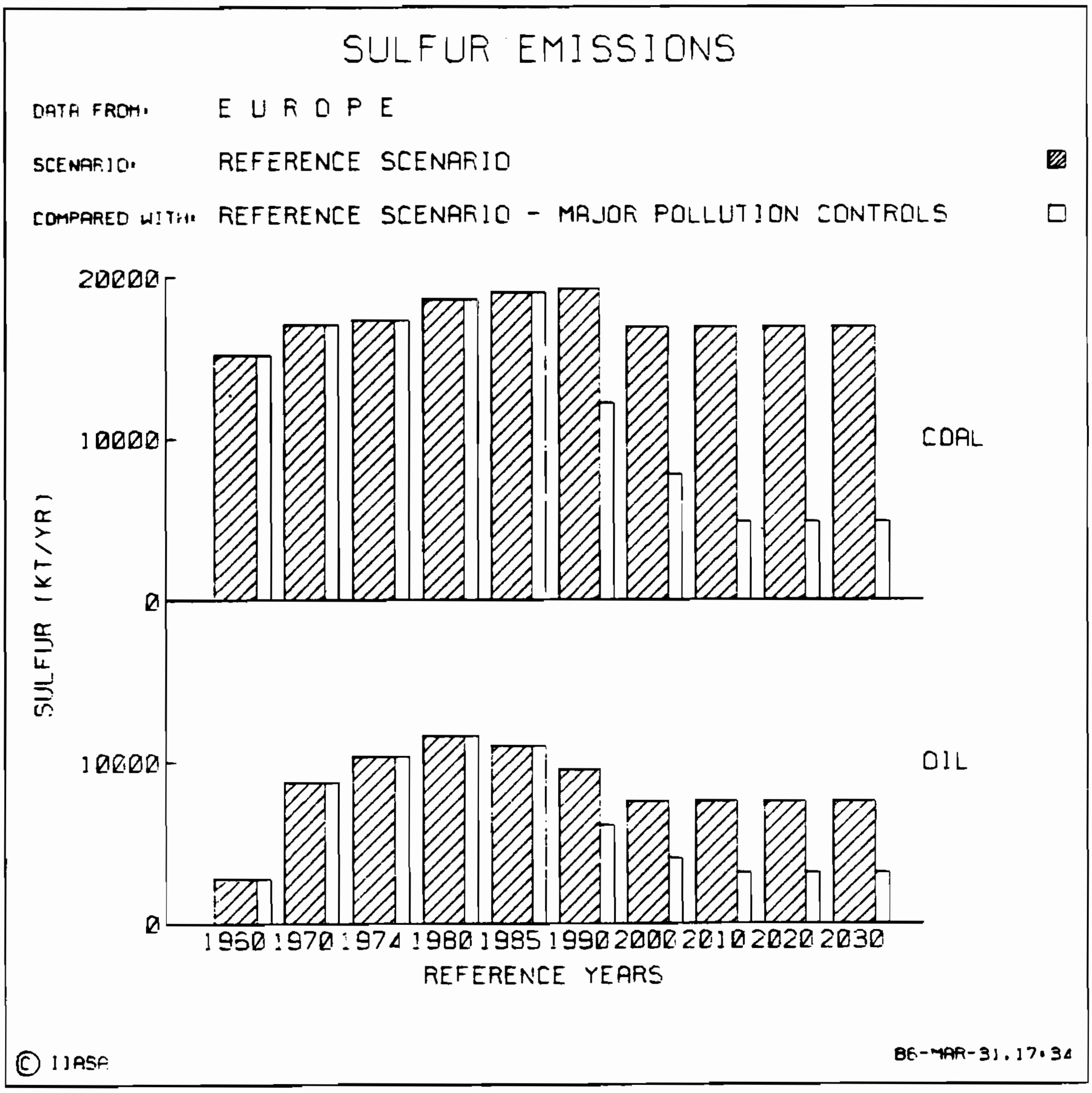

Figure 6. Comparison of computed sulfur emissions.

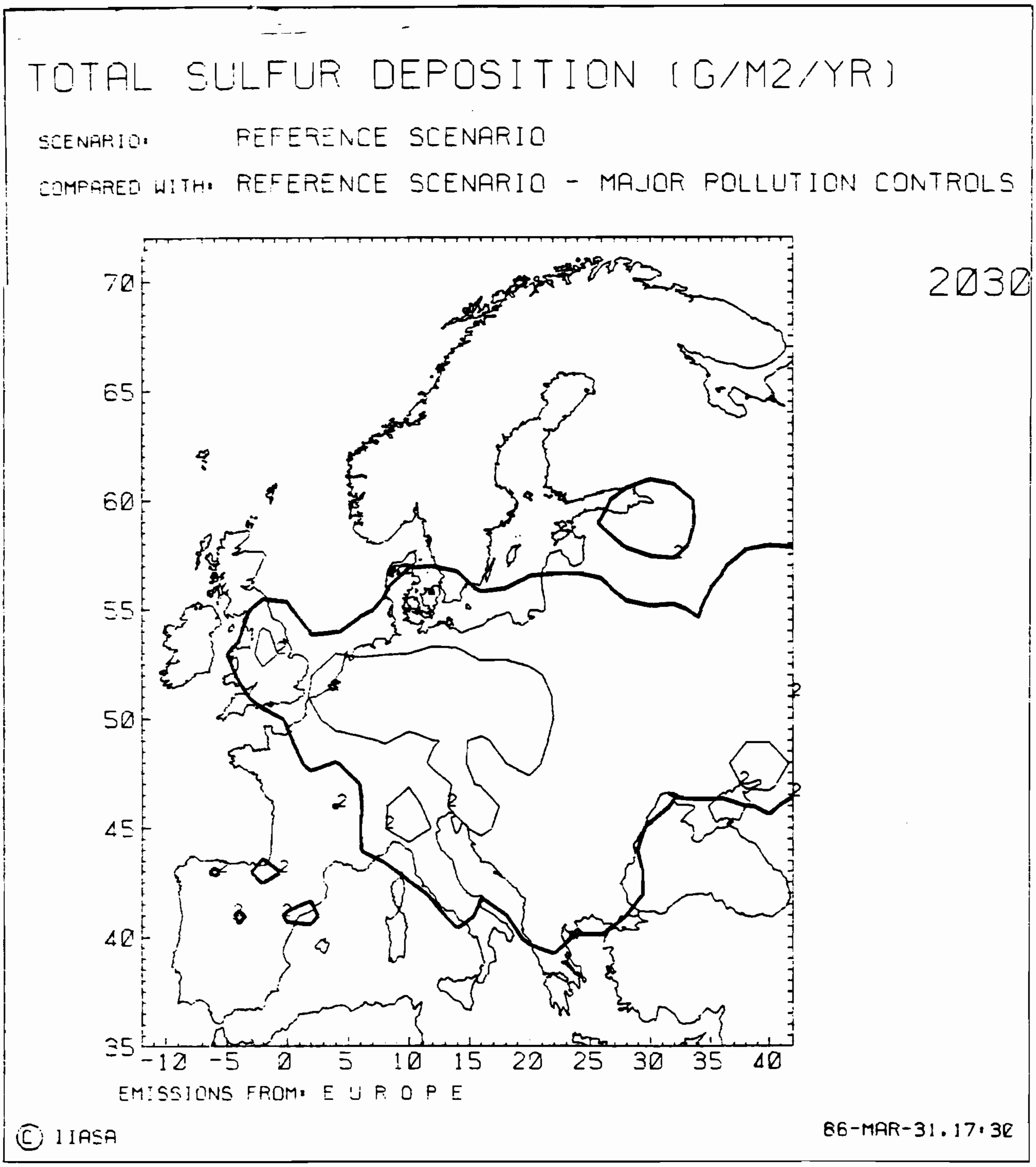

Figure 7. Comparison of computed sulfur deposition.

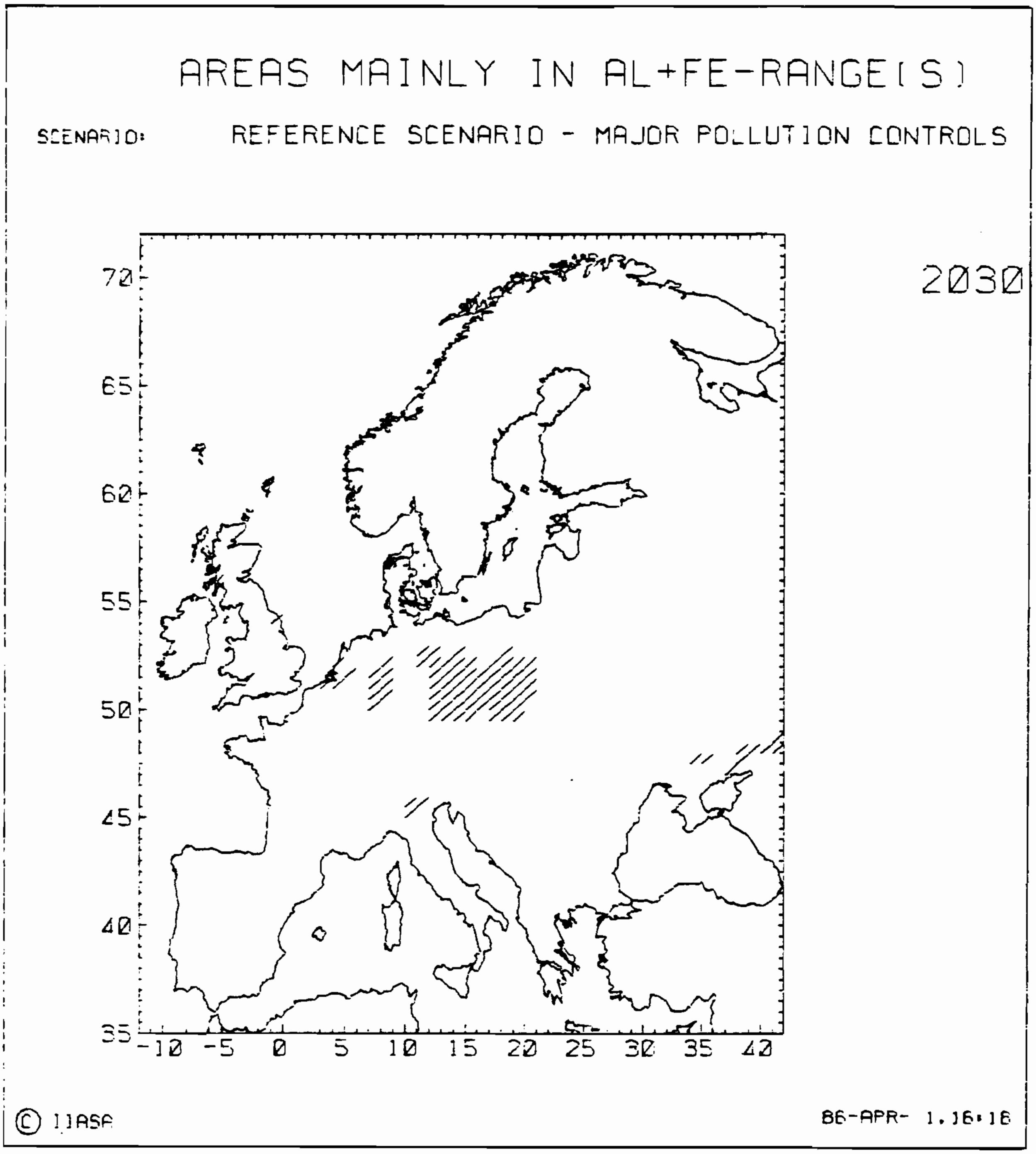

Figure 8. Computed forest soil pH.

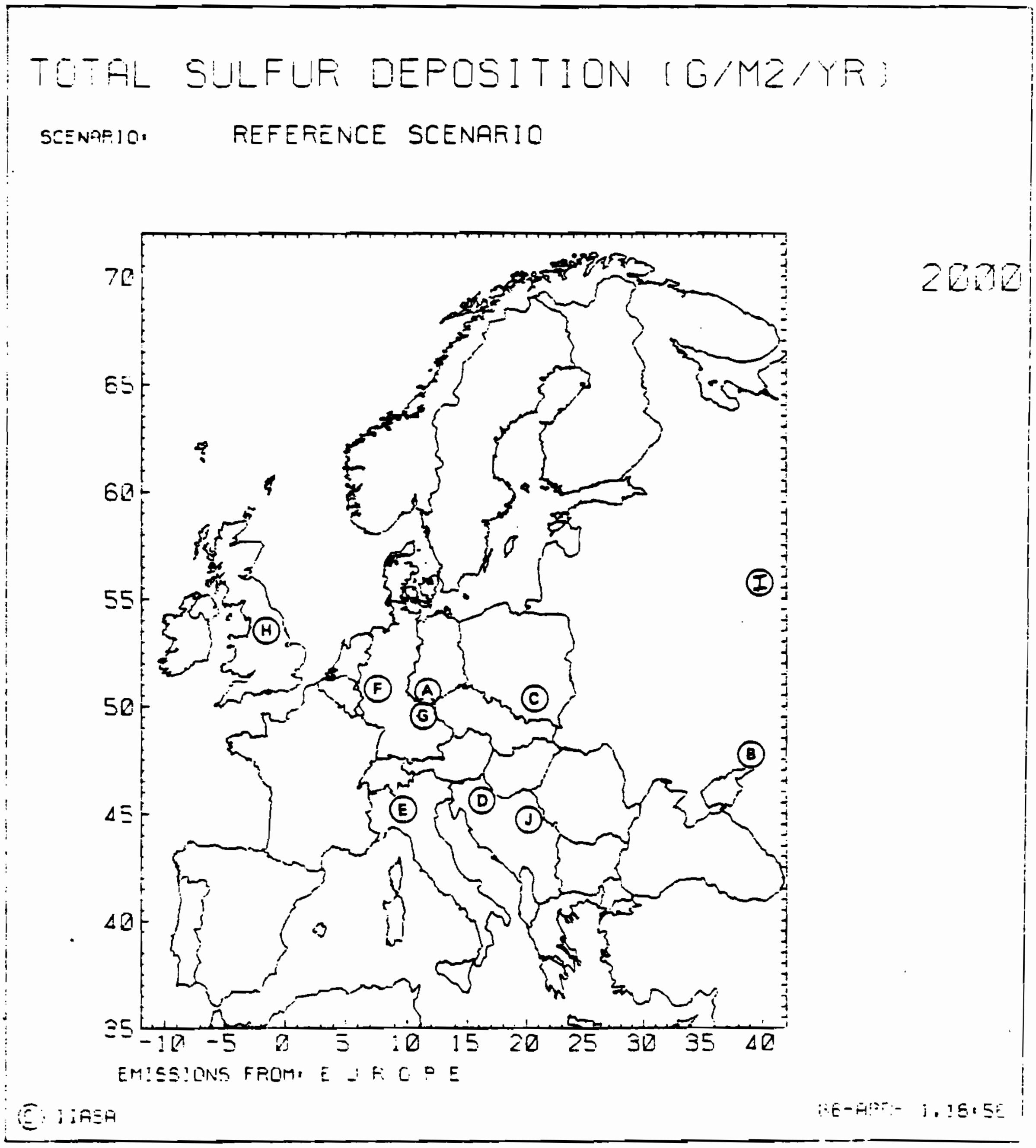

Figure 9. Geographical location of receptor areas.

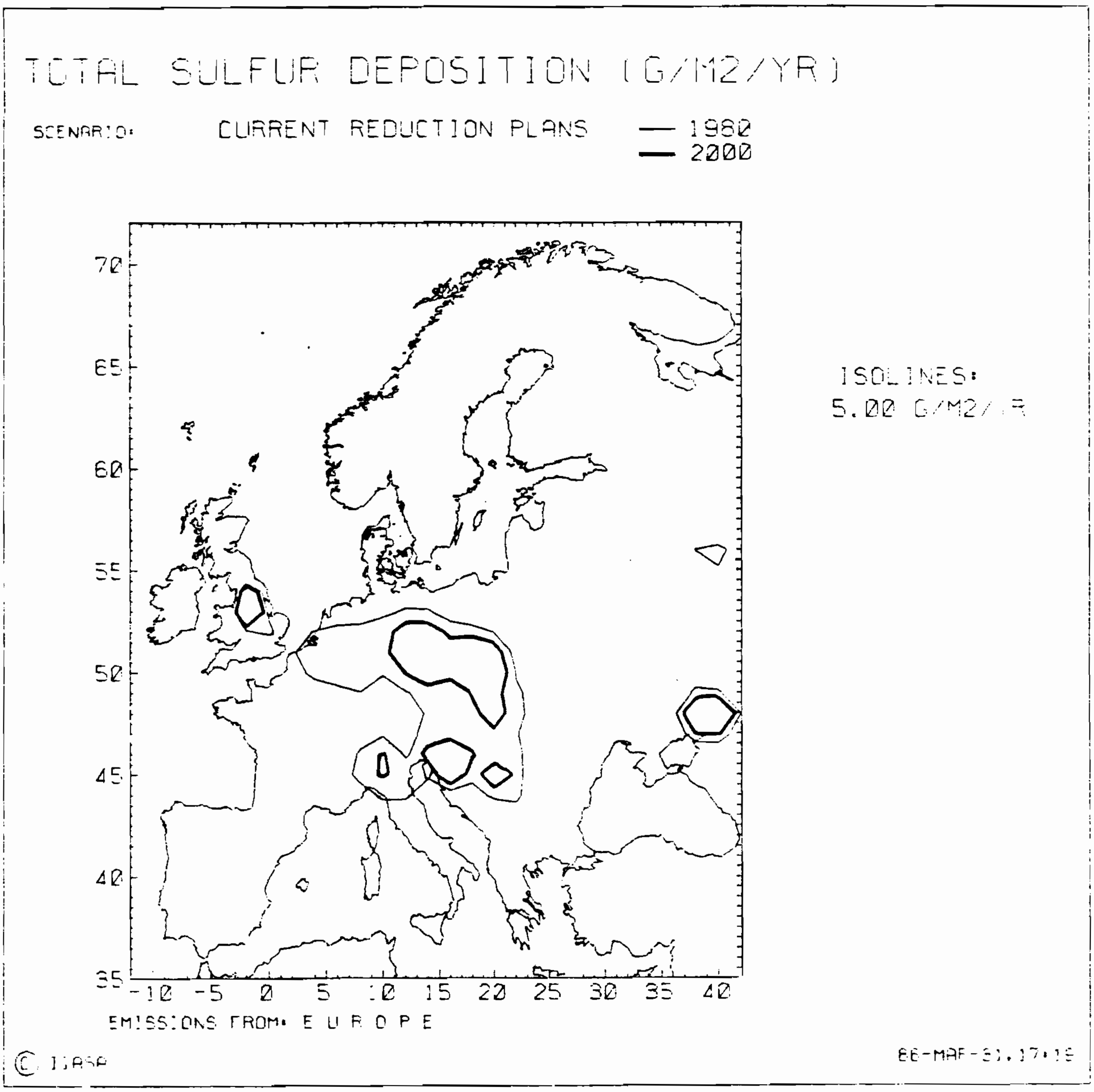

Figure 10. Current reduction plans scenarios compared with the 1980 situation.

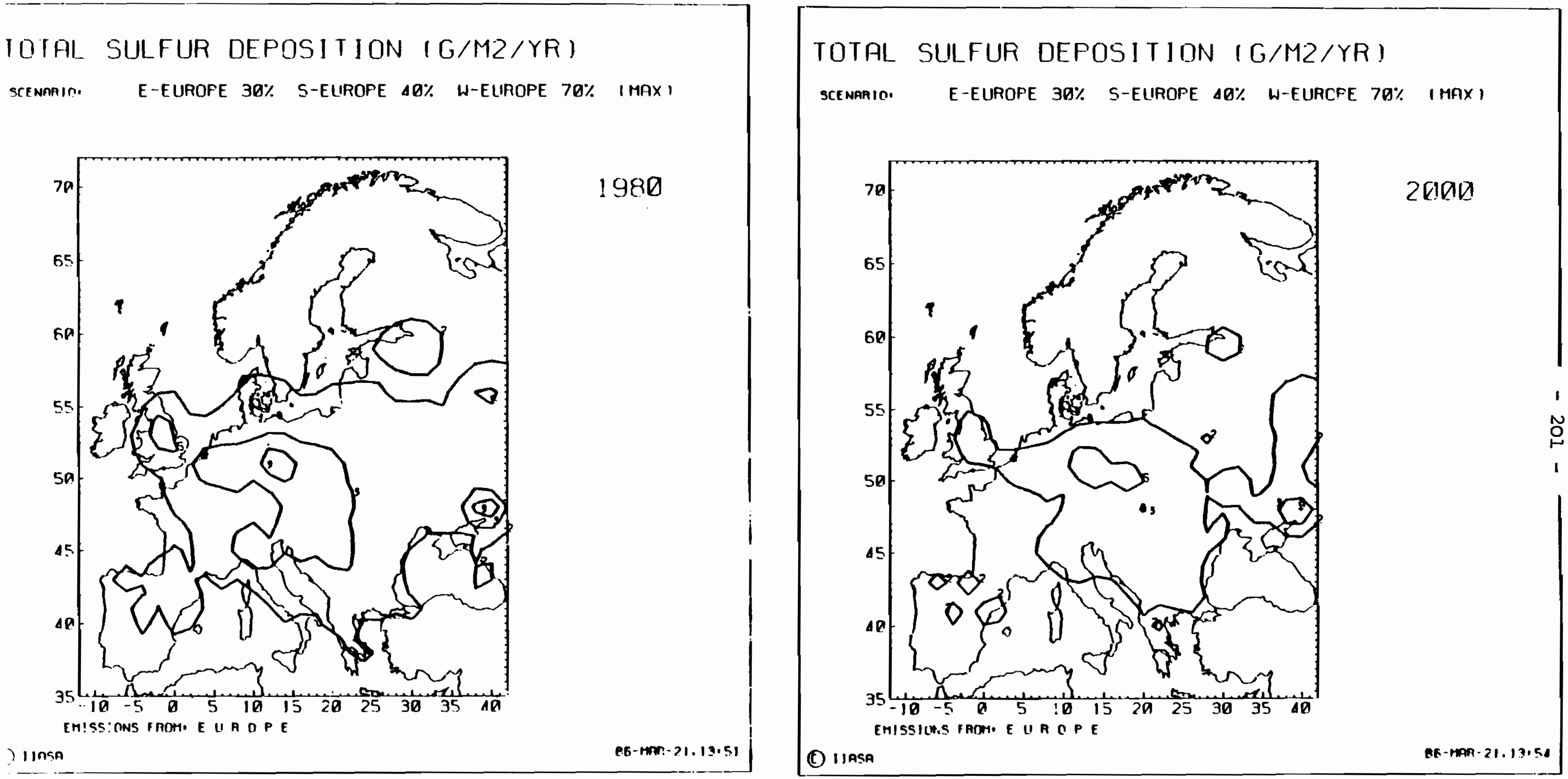

Figure 11. Deposition isolines 1980 and 2000 for 2, 5, and 9g $S/m^2/yr$, "optimum" reduction scenario

OPTIMIZATION

The example presented above represents the use of RAINS as a tool for scenario analysis. Repeated use of RAINS with a broad set of scenarios will enable the user to develop an understanding of the environmental impact of different ways of reducing sulfur emissions in Europe. However, this will not provide the user with an "optimal" reduction scheme. To accomplish this task RAINS has to be enlarged to include an optimization algorithm.

Recently Shaw (1984) described algorithms for optimizing emission reductions and Young and Shaw (1986) and Shaw (1986) described applications to North America. In short the algorithm of Young and Shaw (YS) works as follows.

As a first step a user should define the receptor areas where reduction of deposition should take place. The user should, furthermore, set the order of treating the receptor areas. Suppose the areas are denoted by j and the deposition in these areas by d_j (j = 1, ..., J). The deposition d_j is calculated using an atmospheric transfer matrix derived from a long range transport of air pollutants model. As described earlier, in this paper we use a transfer matrix derived from the EMEP model.

In their first method, YS use the unit transfer coefficients to rank emission sources for a predetermined receptor area. The source with the highest coefficient for the receptor area chosen, will be reduced first upto a prespecified minimum emission level. If the deposition at the given receptor has to be reduced further, the source with next highest unit transfer coefficient is chosen for reduction. For the following receptor areas the same procedure is followed, taking into account reductions calculated in foregoing steps.

The second method of YS uses the absolute transfer coefficients, implying that not only the atmospheric linkages between sources and receptors are accounted for but also the strength of the sources.

In their third method, YS do not use a ranking based on atmospheric linkages or sources strength, but instead reduce all sources simultaneously in steps proportional to the source's contribution to the deposition.

It should be noted that the methods of YS do not guarantee a global optimum if one applies either of the methods to a situation where multiple receptors are taken. However, other mathematical programming techniques are available for that purpose (see *inter alia* Barnett et al., 1985; Fortin and McBean, 1983 and Morrison and Rubin, 1985).

Since, contrary to North America, there is no generally accepted set of receptor points in Europe, we have chosen ten receptor areas where the calculated wet and dry deposition (measured in grams sulphur per m^2) in 1980 rank high. The deposition values in these areas are calculated using the 1980 European emissions as reported to the Economic Commission for Europe (ECE, 1985) and a four year (1979–1982) average transfer matrix from the EMEP model. Table 2 presents an overview of the ten selected areas, while Figure 9 produces their geographical locations.

First we will determine the effects of current reduction plans on deposition in the ten areas. In the meeting referred to earlier in this paper and in statements made by ministers and governmental officials several countries have indicated percentages of reduction of SO_2 emissions. In Table 3 we list these current reduction plans (further referred to as CRP) in terms of reduction percentages based on 1980 emissions. If these plans are carried out this would result in a reduction of European SO_2 emissions of 25%.

Table 2. Overview of receptor areas.

	Longitude*	Latitude	Name	Country
A	13	51	Erzgebirge	E-Germany/Czechoslovakia
B	38	48	Donetz	USSR
C	19	50	Katowice	Poland
D	16.5	46	Bilo Gora	Yugoslavia
E	9	46	Lombardy	Italy
F	7	51	Rhineland	W-Germany
G	12	50	Fichtel Gebirge	W-Germany
H	-2	53	West Yorkshire	United Kingdom
I	39	56	Moscow	USSR
J	21	45	Belgrade	Yugoslavia

*A minus sign indicates west of the Greenwich 0-line.

Table 3. Current reduction plans.

30%	Bulgaria, Czechoslovakia, E. Germany, Hungary, Italy, Luxembourg, Lichtenstein, Switzerland, USSR*
50%	Austria, Belgium, Denmark, Finland, France, Norway
60%	W-Germany, the Netherlands
65%	Sweden

*The USSR plans to reduce the transboundary fluxes by 30%.

In Figure 10 a map of Europe is presented with the deposition isopleth for 5 $gS/m^2/yr$ resulting from CRP and compared with 1980 emissions, using the emissions and sulfur transport submodel of RAINS together with the graphics of this model.

When we now take a look at the target areas described in Table 2 we may compare the deposition reduction achieved by the CRP scenario and a flat rate of 30% reduction throughout Europe. Table 4 presents such a comparison. (The last column of table 4 refers to the optimization presented below.)

Table 4. Deposition in target areas for different scenarios.

	Deposition ($gS/m^2/yr$)			
Area	1980	CRP	30%	Optimum
Erzgebirge	14.5	10.0	10.2	9.6
Donetz	17.7	12.6	12.4	12.5
Katowice	9.1	7.8	6.4	6.1
Bilo Gora	8.1	7.0	5.7	5.0
Lombardy	8.1	5.8	5.7	4.1
Rhineland	7.7	4.0	5.4	2.9
Fichtelgebirge	7.8	5.2	5.5	4.8
West Yorkshire	6.6	6.4	4.6	3.3
Moscow	6.4	4.6	4.5	4.5
Belgrade	6.4	5.8	4.5	4.0
Emission reduction (kton S)	-	7240	8785	11302
%	-	25	30	39

Obviously those areas located in countries which do not participate in the CRP benefit more from the 30% scheme (e.g., West Yorkshire). Areas where the deposition is influenced to a large degree by countries which aim at a higher reduction percentage than 30, benefit more from the CRP scheme (e.g., Rhineland).

Let us now turn our attention to optimization. At this point we would like to stress that our results are to be viewed as examples and certainly not as directions for European policies.

The receptor points in the USSR, Donetz and Moscow receive their deposition for nearly 100% from emission sources in the USSR. Since we are using a country to grid square transfer matrix an x% deposition reduction any of the USSR receptor points will be reached by an x% reduction of the USSR emissions. Therefore optimization is impossible for these areas.

In our example we will use the third method of YS. We do so because it will politically be more feasible to reach an agreement if *all* European countries reduce their emissions. The other two methods of YS lead often to optima where some countries reduce their SO_2 emissions quite drastically while others do not reduce at all. Recall that the third method of YS reduces all sources simultaneously in steps proportional to the source's contribution to the deposition in the target area. As boundary conditions for the optimization we have set the following:

- no reduction in Albania
- maximum 30% reduction in Eastern Europe, including the USSR
- maximum 40% reduction in Southern Europe
- maximum 70% in Western Europe and the Nordic countries.

The goal of the optimization is that in the target areas the deposition is minimized. In the last column of Table 4 the results of the optimization are shown. Table 5 shows the emissions and deposition figures for all European countries which are part of RAINS. We have assumed that the reduction plans will be realized in the year 2000.

Table 5. Emission and deposition for all European countries in 1980 and 2000, according to the "Optimum" reductions.

	Emission			Deposition		
Country	1980	2000	% Reduction	1980	2000	% Reduction
	(1)	(2)	(3)	(4)	(5)	(6)
Albania	50	50	0	87	61	30
Austria	220	66	70	402	226	44
Belgium	405	122	70	192	74	61
Bulgaria	500	350	30	425	296	30
Czechoslovakia	1550	1085	30	952	623	35
Denmark	219	91	58	98	55	44
Finland	298	267	10	341	259	24
France	1635	522	68	1465	740	49
W.Germany	1600	480	70	1272	596	53
E.Germany	2000	1400	30	850	537	37
Greece	350	271	23	281	204	27
Hungary	817	572	30	568	371	35
Ireland	88	66	25	78	59	24
Italy	1900	893	53	1168	631	46
Luxembourg	21	6	70	15	6	60
Netherlands	240	72	70	181	74	59
Norway	69	60	13	292	211	28
Poland	1378	965	30	1546	1027	34
Portugal	85	77	9	84	72	14
Romania	1000	700	30	935	639	32
Spain	1878	1487	21	937	725	23
Sweden	248	169	32	519	359	31
Switzerland	60	18	70	184	94	49
Turkey	500	346	31	495	364	26
United Kingdom	2340	1116	52	781	418	46
USSR	8333	5833	30	6510	4645	29
Yugoslavia	1500	900	40	1342	842	27
EUROPE	29284	17984	39	22000	14208	35

DISCUSSION

From Table 4 it can be concluded that the deposition in the target areas is considerably lower in 2000 compared with 1980. Reduction percentages range from 29 in the Donetz area to 62 in Rhineland. Compared with the Current Reduction Plans the optimum scenario performs well; at the cost of an additional

4000 Kton S reduction considerable deposition reductions are achieved in all areas but Erzgebirge, Donetz and Moscow. The obvious reason for the small reductions in these regions is that in the "optimum" scenario the same reduction percentage in Eastern Europe was taken as was already implied in the Current Reduction Plans. As an example of transboundary effects let us have a closer look at the Rhineland area in the Federal Republic of Germany. In the CRP scenario deposition in this target area has been brought down from 7.7 to 4.0 g S/m^2. This 48% reduction has been reached through a 60% emission reduction in the FRG and lower reductions in countries surrounding the FRG. In the "optimum" scenario the emission reduction by the FRG increases from 60 to 70%, whereas also Belgium (from 50 to 70%), France (from 50 to 68%), The Netherlands (from 60 to 70%) and the United Kingdom (from 0 to 52%) increase their reductions. The combined effects of these emission reductions cause the deposition in Rhineland to drop from 4.0 to 2.9 g $S/m^2/yr$, i.e. with 27%.

In Table 5 country by country emissions and depositions for the "optimum" scenario are shown. From column (3) of table 5 one may note that in 15 European countries the maximum allowable reduction is required: the reduction percentages equal the boundary conditions of the optimization problem. Comparing columns (6) and (3) it can be concluded that for roughly half of the countries the deposition reduction percentage is lower than the emission reduction percentage. The numbers in column (7) indicate whether the deposition reduction is lower (a figure less than one) or higher (a figure greater than one) than the emission reduction. Among the latter category are Nordic countries like Finland and Norway, Central European countries like Czechoslovakia, East Germany and Poland, and South European countries like Greece, Portugal and Spain. Column (7) thus is an indicator of a benefit-cost ratio which could be used to develop a basis for a joint European acidification control strategy based on cost sharing, rather than on the polluters pay principle. It is beyond the scope of this paper to further develop this possibility.

Finally, a graphical representation of the effects of the "optimum" scenario is shown in figure 11. The left hand side of the figure shows deposition isolines for 1980. The right hand side refers to the year 2000. Isolines for 2, 5 and 9 $gS/m^2/yr$ are shown. By comparing both sides of the figure one can conclude that the area where the deposition is equal to or greater than 9 $gS/m^2/yr$ reduced to almost zero in 2000. Using another option of the RAINS model one can calculate that the area where the deposition is greater than 9 $gS/m^2/yr$ dropped from 1.2% in 1980 to 0.1% of the total European area in 2000. For 5 $gS/m^2/yr$ the reduction is from 13% in 1980 to 2% in 2000, while for 2 $gS/m^2/yr$ the figures are 54 respectively 32%.

5. FUTURE RESEARCH

This paper presents an overview of the present status of IIASA's Acid Rain Model. A major current research topic is ***sensitivity*** and ***uncertainty analysis*** within and between the three existing submodels. Alcamo and Bartnicki (1985) presented a detailed description of ongoing activities. Other future research includes extension of the lake acidity submodel to include other countries; development of a nitrogen oxides emissions submodel; completion of a submodel for direct effects on forests; development of a submodel for calculating the cost of control strategies and implementing RAINS on a micro computer.

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3.2.2 INTEGRATED ASSESSMENTS OF ACID DEPOSITION IN THE USA

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ABSTRACT

A comprehensive integrated assessment model is being developed to aid in systematic studies of acid deposition and its control. The integrated framework links component models of pollutant emissions; atmospheric transport and deposition; lake acidification; fish viability; forest productivity; and damages to selected structural and cultural materials. These models are derived from more complex models and data representing the current state of science in each area. An economic evaluation framework also is provided through user-specified valuation relationships for each effects module plus a control cost model associated with emission reduction strategies. The overall modeling framework is designed to allow alternate assumptions or hypotheses to be tested easily in interactive fashion for preliminary assessment purposes and research management. The framework is implemented in a recently developed software system specifically designed to facilitate the analysis of uncertainties associated with model components or parameters. An illustration of the integrated assessment model's use is provided, and current plans for its development from a "prototype" to an "operational" stage are described.

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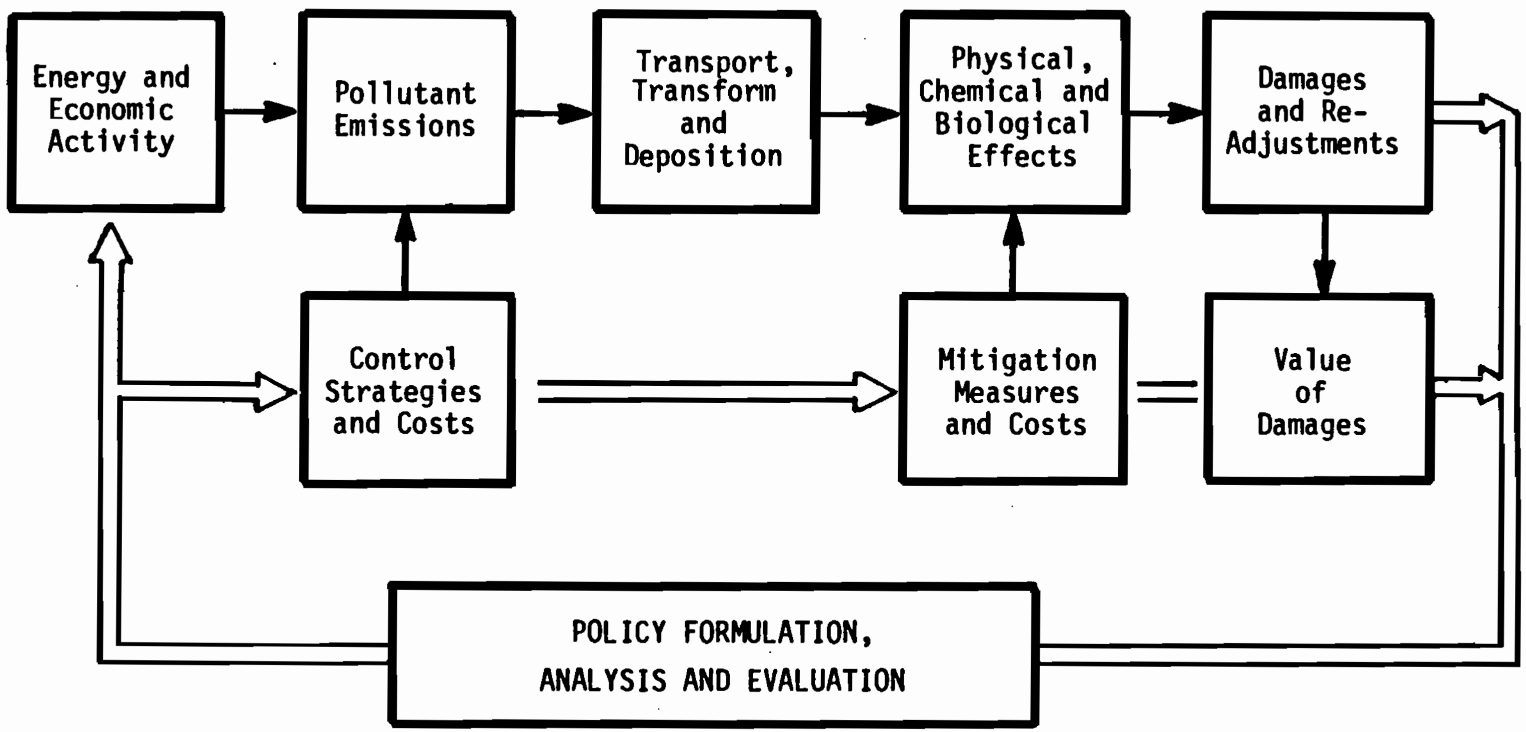
INTRODUCTION

The problem of "acid rain" has become one of the most visible and important environmental issues in North America and Europe. While research efforts are seeking to improve scientific understanding in a number of critical areas, methods also are needed to systematically examine the links between pollutant emissions, atmospheric transport/transformation, deposition, chemical/biological effects, and the resultant damages to the environment in order to assess policy measures proposed to address the problem. Such an "integrated assessment" of acid deposition poses one of the most critical needs and challenges for the development of informed decisions based on scientific evidence.

In recognition of this need, an interdisciplinary team of Carnegie-Mellon University (CMU) faculty and research staff developed a conceptual framework for integrated assessments in the USA (CMU 1984). This included a recommendation to develop a computer-based assessment model to be used as a screening tool for longer-term assessments scheduled for 1987 and 1989. This model is called the Acid Deposition Assessment Model (ADAM). Its current status, structure and uses for

Figure 1. Conceptual Framework for Integrated Assessments of Acid Deposition



assessment purposes are the subjects of this paper.

OVERVIEW OF THE INTEGRATED ASSESSMENT FRAMEWORK

Figure 1 depicts the conceptual framework for integrated assessments of acid deposition and the linkages among major components of the problem. A key attribute of the assessment process is that it should be *iterative*, continually seeking to improve the quality of information provided as new science becomes available, and as key issues, options and impacts become better identified. A formal approach to integration (i.e., modeling) also demands a hierarchy of modeling complexity. This will insure that integration is accomplished in the face of widely varying degrees of scientific understanding (ranging from detailed mechanistic models to purely judgmental ones), as well as large discrepancies in the temporal and spatial resolution of available data for different aspects of the problem. The principal uses envisioned for a formal, computer-based assessment model are, (1) as a research management tool to help organize and prioritize information; (2) as an assessment tool to identify the consequences of alternative hypotheses, policy scenarios and judgments, including the effects of uncertainty; and (3) as an educational tool to demonstrate the various components of the problem, and the linkages among them, to audiences in the research and policy communities, as well as elsewhere in the public and private sectors.

Model Structure and Implementation

Since the size, cost and complexity of many detailed state-of-the-art models currently precludes them from being mechanically linked on most computers for assessment purposes, simplified representations of detailed model components are incorporated in the ADAM design. These are referred to as "Level II" models, and are derived from more detailed state-of-the-art models of "Level III" complexity.[1] Thus, the Level II model represents a fully integrated and scientifically credible framework that can be operated efficiently and economically in a repetitive fashion. Thus, it offers a means of testing or screening a large number of cases to help select those for which detailed assessments will be undertaken using the more complex Level III components (NLC 1984).

In considering the programming language and overall design of an integrated model, four principal requirements were identified. First, the design should be modular to allow maximum flexibility in the variety of problems that could be examined. A modular structure also facilitates the substitution of alternative model formulations and the refining of research hypotheses in areas pertaining to acid deposition. Second, the model structure should be transparent, with adequate explanatory information available to the user. This would help users to more quickly develop an understanding of the model and its capabilities. Third, the model should support rapid display and modification of the values of intermediate results so that individual model components can be easily tested and explored. Finally, the selection and formatting of model outputs should be clear and adaptable to the needs of different users. For example, it should be able to easily present information in graphical or tabular form, in different levels of detail, and in different systems of units.

In light of these requirements, the recently developed Demos modeling system (Henrion and Nair 1982) was adopted for the implementation of ADAM. Demos is an interactive environment for structuring, analyzing and communicating probabilistic models. It has four features which differentiate it from most other general purpose modeling languages and make it particularly well-suited for the acid deposition assessment model. First, it allows model parameters and the structure of the model

[1] The remaining category, Level I, represents more highly aggregated models, such as ADEPT (Balson and North 1982), which is discussed in CMU (1984).

itself to be defined and edited interactively, with changes made permanently or in a trial mode. Second, the Demos modeling language is non-procedural. A user can simply define variables and their functional relationships in any convenient order, without the need to specify the sequence of control and program execution. Third, Demos allows the uncertainty of any model parameter to be specified in a number of ways. These include standard distribution functions (such as a uniform, normal or lognormal), or an arbitrary function of the user's specification. Results dependent on uncertain variables are evaluated probabilistically using a Monte Carlo sampling procedure. Demos also allows parameters to be characterized as a vector of alternative values, which is more appropriate for certain types of analysis (e.g., the effect of quantities based on personal judgments). Any variable which depends on such multiple-valued quantities is evaluated simultaneously for each value of all quantities, producing a multi-dimensional parametric analysis.

Lastly, the Demos environment encourages the user to incorporate considerable on-line documentation and explanatory text along with the mathematical structure of a model. This feature assists users in examining the model, and also facilitates the preparation of hardcopy reports. Integrated documentation also helps maintain consistency between the model structure and supporting information when variations in model parameter values or configurations are being examined.

Development of the Acid Deposition Assessment Model began one year ago and is proceeding in three phases. First, a "bench scale" version of the integrated assessment model was undertaken to demonstrate the ability to link all major components of the acid deposition problem, and to explore the tradeoffs among model speed, cost and complexity. This was completed in September 1984. In the "prototype" stage we next expanded the geographic and temporal dimensions of the model and substituted improved models of each component. This phase was completed in the early 1985. The third phase in the model development is the continued expansion and refinement of the prototype model into an "operational" model based upon the best available Level III components and data, with a menu-based interface suitable for a wider class of users. This is tentatively scheduled for completion in mid 1986. Below, we describe the current prototype model in greater detail and illustrate its use.

MODEL COMPONENTS

Emissions and Control Costs

The prototype model is driven by a dynamic emissions model which specifies the quantity of SO_2 emitted annually from sources which are nominally aggregated to the state level. Annual emissions for each state (or other region defined by the user) are projected for the 50 year period 1980 to 2030. Separate emissions trajectories are included for five sectors reflecting utility combustion, industrial combustion, non-ferrous smelters, transportation sources, and other SO_2 emitting activity. Only sulfur dioxide emissions are included in the prototype model, with the operational model to include nitrogen oxide emissions as well.

Source emission trends for each state reflect the particular scenario being analyzed. Emission trajectories can be specified either by algebraic relationships (e.g., based on a percentage reduction, a characteristic compliance year, and a measure of the acceptable rate of emissions reduction); as discrete values within the modeling period (between which linear interpolation is employed); or by supplying coefficients to one of several default trajectories available for characterizing potential emission trends (in terms of growth rates and other user-specified parameters).

In general, the Level II emissions trajectories will be developed from the results of a detailed Level III model for each source type.

Integral to these sector models are submodels which allow the associated cost of reducing emissions to be estimated. ADAM allows pollution control costs to be described in a number of ways. Control costs currently are expressed either as a levelized total cost, a cost per ton of SO_2 abated, or additionally as a cost per kilowatt hour of electricity generated for the utility sector. An algebraic function (based on a regression model of Level III results) can be used to relate control costs to emission reductions for a given set of scenario assumptions. Efforts are underway to develop multi-variate Level II control cost models based on results of the detailed sector models so that more comprehensive studies of alternate emission control strategies and associated costs can be performed more easily.

The secondary cost impacts of emission reduction strategies are not yet incorporated in the prototype model and generally are not yet well described. These include impacts on employment (particularly coal mining) and other community costs which must be considered in an integrated framework. Future research will seek to address these factors (NAPAP 1983).

Atmospheric Transport and Deposition

ADAM currently employs a set of linear transfer matrices to provide the link between emissions of SO_2 at geographically dispersed sources, and the atmospheric concentrations and deposition fluxes of acidified species in selected receptor regions. Separate matrices represent the quantities of sulfur dioxide, airborne sulfates, dry sulfur deposition and wet sulfur deposition at each receptor location per unit of SO_2 emitted. These matrices are developed by exercising detailed atmospheric transport models, such as the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model (Shannon 1981), to develop annual average values of each matrix element. The prototype model currently contains transfer matrices linking 59 source regions (one for each U.S. state and Canadian province, plus the District of Columbia) to 30 receptor sites in the eastern U.S. and Canada (tentatively chosen to reflect areas of possible acid deposition damage).

Empirical relationships based on wet sulfur deposition and local precipitation data are used to predict the annual average pH of precipitation at each receptor site, which is needed as an input to subsequent models for assessing aquatic effects. Any other atmospheric quantities needed for specific damage models (e.g., ozone concentration, relative humidity, etc.) are provided as model input data for each receptor site. The prototype model currently estimates the degree to which three types of resources — aquatic systems, forests, and man-made structures — may be impacted or damaged by some aspect of the acidified environment. Typically, the Level II effects model in ADAM consists of some form of exposure/ response function which relates a change in deposition to a change in some chemical, biological or physical measure of damage at each receptor site. This is then applied to an inventory of existing resources to estimate a regional impact.

Aquatic Effects

Models currently available to predict the acidification of water bodies and the resulting effects on fish life span a wide range of complexity and applications. Dynamic or episodic simulation models of aquatic chemistry and fish biology would combine detailed representations of the hydrologic cycle and geochemical reactions believed to occur at a receptor site with the dynamics of fish populations to assess the local impacts of acid deposition. Such mechanistic models are appropriate for detailed studies of individual watersheds but are typically incompatible with the needs of broader assessments over large geographic regions. Equilibrium models of the response of aquatic resources incorporate simpler representations of alkalinity generation, chemical weathering, and fish viability and are, in general, more responsive to the needs of regional assessments requiring the characterization of a few hundred or a few thousand lakes. However, the use of a simplified weathering model is confounded by the considerable variability in the initial alkalinities of individual lakes, their weathering rates, and their ability to support fish populations.

To avoid many of these shortcomings, a direct distribution model of the chemical and biological response of lakes at a receptor site has been developed (Small and Sutton 1985) and integrated with the upstream components of ADAM. Using this approach, the inventory of base year lake alkalinities in a region are first obtained and fit to a lognormal probability density function of a form found to be characteristic of lake alkalinity measurements in general. A recently developed transformation function is then used to obtain the corresponding pH distribution for the particular set of lakes (needed in conjunction with fish biology models). The integrated model then relates changes in the deposition concentration of acidic species in the local precipitation to shifts in the mean and variance of the lognormal lake alkalinity distribution, given a simple weathering model. Moment formulations have been developed for both the Henriksen-Wright and Schnoor Trickle-Down equilibrium models of lake acidification currently being studied in the U.S. program (NAPAP 1983). The ADAM framework allows a probabilistic specification of the regional weathering rates and correlation factors to reflect spatial variability. Using this type of Level II model, the fraction of lakes in a region with alkalinities or pH values exceeding or falling below a specified value can be easily calculated and presented as a model output.

The shifted distribution of pH values in the lakes of a particular receptor region can be further linked to a model characterizing the relationship between lake water pH and fish species viability to obtain a measure of the biological response of the lakes. Logistic curves fit to species-specific presence/absence data for waters of varying pH or metals concentrations can be applied to the chemical response of the lake. This allows estimates of the fraction of lakes in a given region able to support that particular species of fish to be mode. Such measures can be taken as the final output quantity of the assessment, or can serve as inputs to an aquatic resources valuation model.

Currently, the prototype version of ADAM contains the required inventory data on lake alkalinities and weathering rates for only one receptor location. Data currently exist to expand the applicability of ADAM to additional receptor sites to enable a wider geographic assessment of the risk to aquatic resources. This task is scheduled as part of upgrading the prototype model to the operational stage.

Forest Effects

The prototype model also contains a component linking sulfur deposition, sulfur dioxide and oxidant concentrations to changes in the growth rate of various tree stands. The model is nominally designed to simulate results from the detailed FORET model, which stochastically simulates the stand density characteristics and successional patterns of a multi-species forested area based on models of species regeneration, sapling growth, stand maturation, and species removal. To enhance the FORET model for acid rain analysis, the FORAST data project was initiated to characterize the changes in forest growth patterns associated with temporal and spatial variations in the concentrations of atmospheric pollutants (NAPAP 1983).

The simplified Level II model is designed to use results of FORET to estimate the change in stand biomass over a given time period (e.g., every decade) based on growth in earlier periods and assumptions regarding the relative importance of different pollutants to growth inhibition. However, in light of the considerable scientific uncertainty regarding the role of air pollutants in observed changes in the growth and decline of forests in the U.S. and Europe, the causal link between forest response and acid deposition (including nitrogen species and other air pollution) remains quite tenuous at this time (Cowling 1984). Nonetheless, the integrated model framework still can be used to analyze a range of "what if" questions until such time as better scientific information becomes available.

Structural and Cultural Materials Effects

The prototype version of ADAM includes a model linking sulfur deposition, ambient SO_2 concentration and local relative humidity to changes in the condition of structural and cultural materials at each receptor site. The set of materials at risk may be disaggregated into one of four material types (nominally painted surfaces, galvanized steel, marble and carbon steel), and into one of two material uses (structural or cultural). A damage function for each material type/use combination is used in conjunction with the ambient conditions and deposition at each receptor location. This function determines the fraction of existing materials in each category which would be damaged to the extent that its economic function would be lost and replacement would be required. Thus, the damage functions combine knowledge of corrosion rates or other types damage with data or technical judgments regarding how much damage can be tolerated before maintenance or replacement is necessary.

This formulation closely tracks the structure and approach of the more detailed materials effects research currently in progress (NAPAP 1983). That work involves testing the assessment method at several specific receptor sites using damage functions developed for galvanized steel and painted surfaces. Parameters for these functions include the fraction of time materials are wetted, ambient SO_2 and chloride concentrations, annual precipitation rate, and total deposition of acidic ions at the site. The output of these functions is an annual rate of material loss. A selected value of this measure is used to specify the critical level of damage dictating repair or replacement of a particular material/use. When coupled with a local materials inventory these factors define the extent of materials damage at the receptor site. Appropriate adaptations of the Level III methodology and data bases will be developed for the operational version of the ADAM, with primary emphasis first on structural then cultural materials.

Valuation of Damages

The "benefits" of a reduction in SO_2 emissions may be reported in either physical or economic terms. An example of a physical measure, for instance, would be the fraction of lakes in a region able to support one or more fish species, or the amount of a given material lost by acidic corrosion. In order to construct a closed framework in which the overall costs and benefit of emission reductions can be compared, the various measures of physical or biological change projected in an assessment scenario must have monetary values ascribed in order to compare them to the costs of control. At present, this is still an especially difficult task fraught with sizeable uncertainties. CMU (1984) discusses some of the potential valuation measures available for quantifying acid deposition damages in a number of areas, plus methods for developing them. Non-monetary measures of value are discussed as well.

The current ADAM prototype model contains a simple "placeholder" for valuation models in the form of constants which can be multiplied by the amount of projected physical damage to obtain an economic damage cost. These placeholder models (which can be made as complex as available information permits) enables a user interested in exploring cost/benefit analysis to take the additional step of converting measures of physical damage into dollars, and comparing the present value of damage costs to those of control costs using appropriate (user-specified) discount rates. The "what if" diagnostic features of the Demos modeling framework also allow the effect of alternative valuation judgments to be explored easily. This screening process may help identify valuation relationships of particular significance to the overall problem, and help focus future analysis on areas of practical importance.

OTHER AREAS OF STUDY

Several additional components of an integrated assessment have not yet been incorporated into the prototype model. These include models of effects on agriculture and human health, plus mitigation measures aimed at neutralizing the effects of acidity in the environment.

Research has been carried out in the U.S. to examine the effects of acidic deposition and ambient oxidant levels on the yield of certain crops such as soybeans, which have significant economic value and are grown in areas of the country where acid deposition might be of consequence. While recent research results have shown the importance of ambient oxidant levels on overall yields, they have not shown any significant levels of damage due to acid precipitation (Medeiros, Moskowitz, Coveney and Thode 1983). Thus, incorporation of an agricultural effects model has been deferred to a later stage of the assessment model development.

Potential effects of acid deposition on human health have not been a major element of the U.S. research program, but nonetheless have received attention in the literature (CMU 1984). Primary concerns have been the risks to human health from the direct inhalation of airborne pollutants (such as sulfates and nitrates), and the indirect effects due to trace metals and other contaminants in drinking water supplied from watersheds in which mineral leaching has been augmented by acidic deposition. CMU (1984) indicates that current information in both these areas is extremely limited. Thus, incorporation of human health effects models also have been deferred in the integrated assessment model development at this time.

A later phase of this effort also will incorporate models of "mitigation measures," particularly the effects of adding alkaline materials (such as lime or limestone) directly to water bodies to neutralize acidity. The costs of such measures would be added to the direct and indirect costs of source emission control in assessing regional costs and benefits.

ILLUSTRATIVE ANALYSIS

Use of the prototype model is illustrated here for a hypothetical assessment of SO_2 emission reductions on aquatic effects at a single receptor site sensitive to acid deposition. This example is intended to illustrate the three principal features of ADAM: linkage of component models; characterization and propagation of uncertainties; and the capability to test alternative scenarios and hypotheses. Although a large number of model parameters may be considered and displayed as outputs (depending on the particular questions of interest), only a subset of those available are presented here.

Figure 2 shows the projected trends of utility and industrial SO_2 emissions for one of the 22 source regions (including aggregates of several states) modeled in this example. The scenario being considered calls for SO_2 reductions of 50% and 10% below 1980 levels for the utility and industrial sectors, respectively (and no reductions in the remaining sectors), with half the total reductions occurring by the year 1992. For illustrative purposes all emission rates are assumed to remain constant before and after the reductions. An 80% confidence band on each emission trajectory also is shown. This is derived from the Monte Carlo simulation assuming that emission rates for each sector are known with 95% certainty to within approximately 5% with a normally distributed uncertainty. Parameter uncertainties which increase with time also can be modeled but are not shown here. Alternative scenarios of future emissions trends also can be used to indicate uncertainty.

This uncertain emissions trajectory then feeds into a probabilistic transport and deposition model, characterized here as a transfer matrix with elements which are normally distributed about a nominal value. Figure 3 shows the resulting deposition of wet sulfur at the receptor site, including the contribution of all other source regions not shown in Figure 2. The 80% confidence band for wet sulfur deposition also is shown in Figure 3, and reflects the combined uncertainties in the emissions and atmospheric transport/deposition models. The wet sulfur deposition is then used to predict the annual average precipitation pH at this location (plus the resulting confidence bands) as shown in Figure 4.

Figure 5 next shows the expected distributions of lake alkalinity at this location for the base year of 1980 plus projections for the years 1990 and 2000 (based on the median precipitation pH projection for each year). As can be seen, the mean regional alkalinity is projected to increase from roughly 5 ueq/l in 1980 to about 50 ueq/l in the year 2000 as deposition levels decrease. This change in regional lake chemistry can be reported in different ways, as in Figure 6, which shows the fraction of lakes with a pH less than some specified value (in this case 5.5).

By coupling the water chemistry model with models of the biological response of fish to acidified waters (such as shown in Figure 7), the fraction of lakes in the region able to support fish life under a particular emissions scenario can be estimated. The projected percentage of fishable lakes associated with the fish response curves of Figure 7 are presented in Figure 8 in a deterministic format. This shows a significant recovery as a result of the assumed SO_2 emissions reductions. Nominally, the two curves shown in Figure 7 represent two different fish species, one very sensitive to acidification (species A) and the other less sensitive (species B). However, these curves also could be interpreted as representing alternative hypotheses (or expert judgments) about the response of a single fish species at that location. In this case, Figure 8 would reflect the difference in fishable lake area associated with the difference hypotheses.

When all model uncertainties are propagated to the end result (taken in Figure 9 as the percentage of fishable lakes in the region), a broad band of uncertainty becomes evident and an indication of the uncertainty in the timing and magnitude of

Figure 2. Example of State SO_2 Emissions Trajectory (Showing median values and 80% confidence band) for Percentage Reduction Scenario Centered on 1992

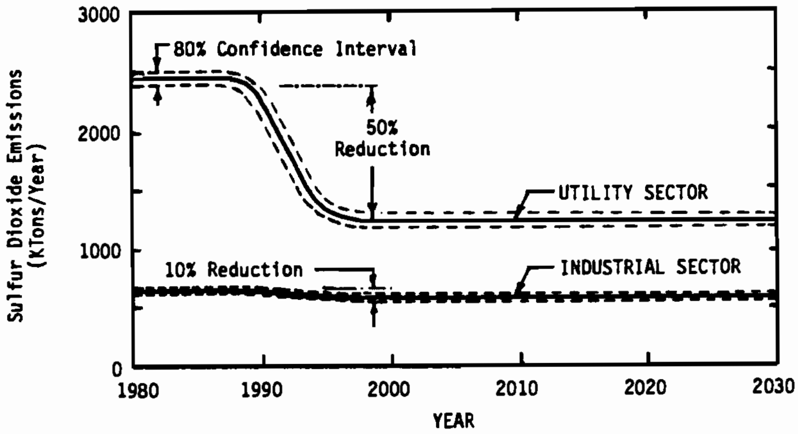


Figure 3. Wet Sulfur Deposition for the Assumed Receptor Site Due to Emissions from the Full Set of Source Regions

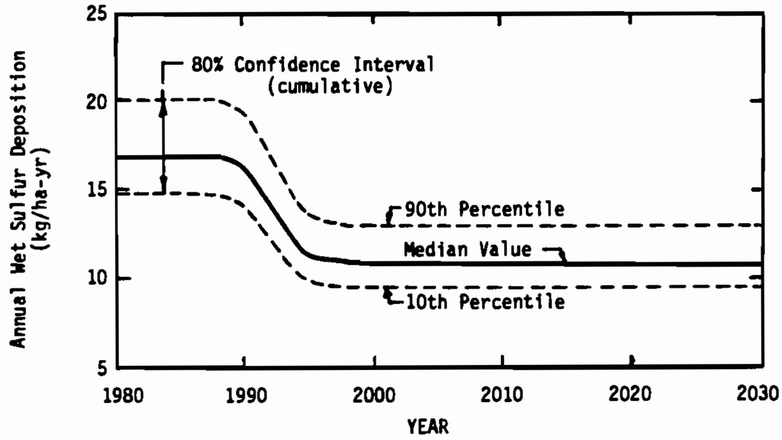


Figure 4. Annual Average Precipitation pH for the Assumed Receptor Site

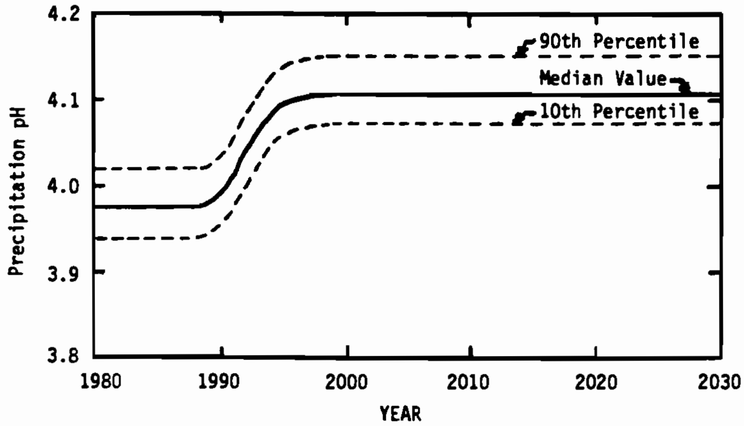


Figure 5. Distribution of lake Alkalinities at the Assumed Receptor Site (Median Values Only)

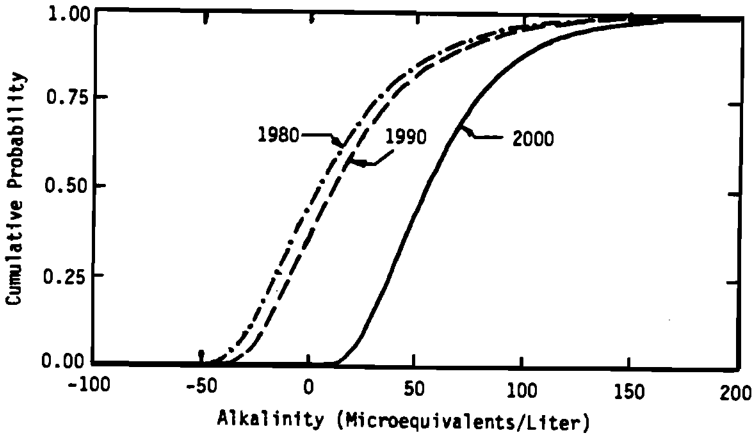


Figure 6. Percentage of lakes at the Assumed Receptor Site with Annual Average Equilibrium pH Less than 5.5

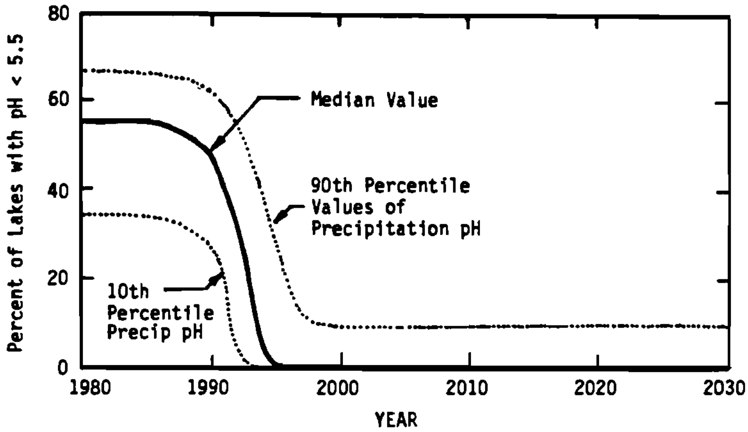


Figure 7. Biological Response Model for Two Hypothetical Fish Species (Median Values Only)

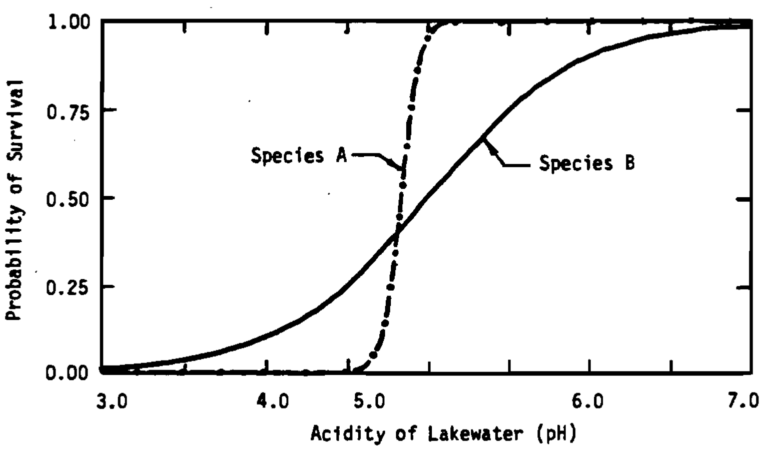


Figure 8. Percentage of Lakes at the Assumed Receptor Site Able to Support Assumed Fish Species (Median Values Only)

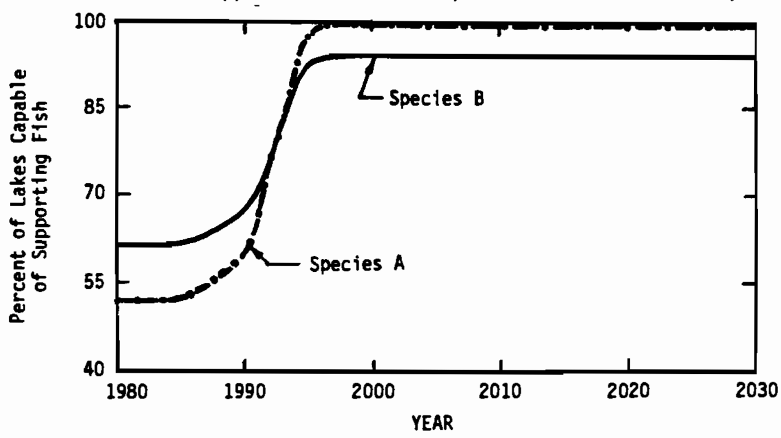


Figure 9. Percentage of Lakes at the Assumed Receptor Site Able to Support at Least One of the Assumed Fish Species

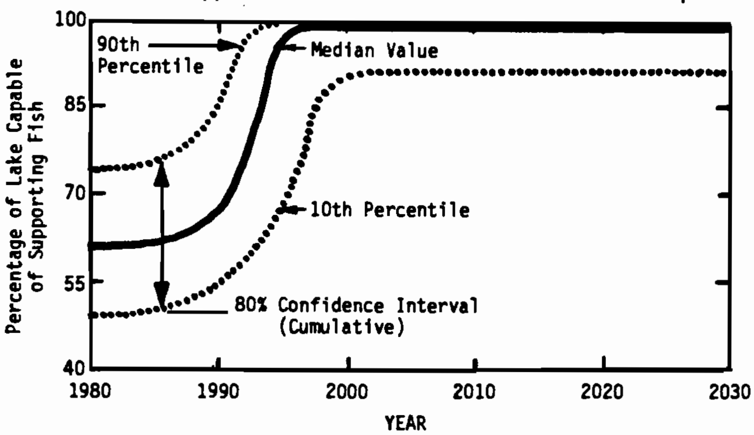
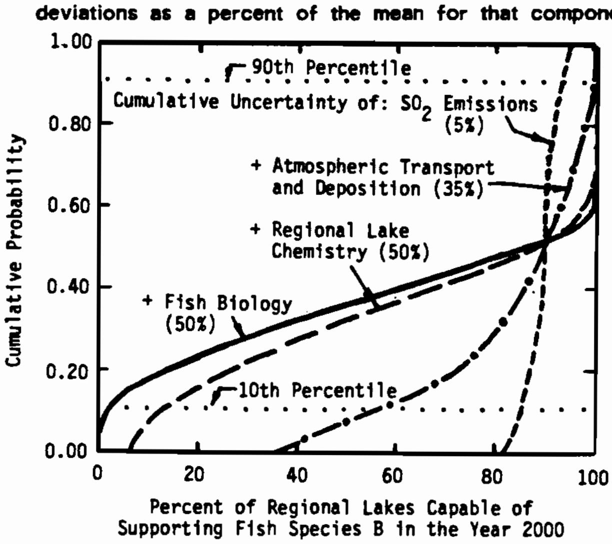


Figure 10. Cumulative Uncertainty in a Final Results (Percent of Fishable Lakes) Due to Each Model Component (Numbers shown in Parentheses are the assumed values of two standard deviations as a percent of the mean for that component)



results that can be expected from an emissions reduction policy can be gained. The contribution of each model component to the total uncertainty in any year also can be displayed with ADAM. This is illustrated in Figure 10, where the percentage of fish supporting lakes in the year 2000 has been calculated probabilistically. Each distribution in the figure represents the cumulative effect of uncertainties propagated through the model up to the component. Again for illustrative purposes, normal probability distributions with varying standard deviations were assumed for each model component, as indicated in the figure. For this hypothetical case, it can be seen that relatively little uncertainty in fishable lake area results from uncertainties in the emissions component of the problem. Increasingly larger uncertainties accrue due to the atmospheric transport/deposition, lake chemistry and fish biology components of the problem. Again, we stress that this example is hypothetical and intended only to illustrate the capabilities of the integrated model. Indeed, one of the major challenges ahead is to develop reliable estimates of uncertainty that can be used for this type of analysis. In doing so, the value of additional research to reduce key uncertainties also can be better identified.

CONCLUDING REMARKS

The modeling framework described in this paper represents an effort to address the analysis of acid deposition and its control in comprehensive fashion, linking all major components of the problem from source emissions to environmental effects. To accomplish this integration "Level II" models of each component are being developed to reflect the current state of science in each area. These represent more complex (Level III) models and data which are not readily able to be linked computationally in an automated or economical fashion. The integrated Level II model thus can play an important role in screening and testing a wide range of acid deposition scenarios and scientific hypotheses. In this way, it also can help identify a small number of cases for detailed assessment. Thus, a hierarchical approach to modeling complexity, and an iterative framework for testing hypotheses and seeking refinements and consensus, are viewed as hallmarks of long-term integrated assessment methods.

ACKNOWLEDGEMENTS

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3.2.3 ACID PRECIPITATIONS IN THE RILA MOUNTAIN

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PROCEDURE

Studies were initiated in 1979 in only one observation station in the Rila Mountain (Semerdjieva et al, 1982), and since 1981 rain samples are collected in five stations included in the system of ecological stations of the Forest Research Institute of the Bulgarian Academy of Sciences. Two transects from the stations are used. The first transect is one one and the same macroslope in the mountain (northern facing), but at different altitudes above sea level. The second transect is at one and the same altitude above sea level (1500 m) but with different facing in the mountain.

The data in Table 1 give the short physical characteristics of the studies undertaken at the stations. It should be noted that the stations are representative of the different forest zones in the Rila Mountain and for Bulgaria as a whole (Raev, 1983).

Description of Data Bases and Methods of Analysis

The chemical composition for each individual precipitation was studied whereby the pH was measured at the sampling station, and the spectrophotometric and nephelometric methods with a sensitivity of 0.01 and 1.0 μg/ml were used in order to determine the ion content. The Technicon Analyzer II was used for the majority of the samples. The latter were filtered in the station and were concentrated before the analysis. The results of the samples for a one-year period are given and discussed further in this paper.

Basic statistical analysis, correlative analysis, regression analysis and one-way analysis of variance were used while processing the data. The enrichment coefficient was calculated with respect to chlorides, since we assumed that their anthropogenic contribution in such a region should *a priori* be very small. The trajectories of air masses were traced from maps of atmospheric topography on the level of 850 mb for 0.0 h and 12.0 h G.M.T. without consideration of vertical motions.

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Table 1. Physical characteristics of the sites and their forest formations.

No.	Station	Altitude m	Expo-sition	Mean Annual Temperature °C	Mean Annual Precipi-tation mm	Forest Formation
I Transsect:						
1	Nadaritsa	1250	N	5.8	871.0	Pinus silvestris
2	Ovnarsko	1550	N	4.9	999.3	Picea abies
5	Mechit	1800	N	3.9	1022.0	Pinus montana
II Transsect:						
2	Ovnarsko	1550	N	4.9	999.3	Picea abies
3	V. Serafimov	1540	N	5.1	837.3	Pinus silvestris
4	Parangalitsa	1550	W	4.9	933.7	Picea abies

It should be pointed out that the direction and distance of acid emissions' distribution from large sources in Bulgaria have not been investigated and, considering the small area of the country, some results cannot be explained.

RESULTS AND DISCUSSION

The annual investigation results of the ion content and some important ratios for the stations are given in Table 2 and Figure 1. These ratios were calculated on the basis of mean annual values. The high percentage of acid rains at the station sites should be pointed out. The influence of the altitude is clearly expressed - a difference of 550 m is accompanied by a 2.4-fold increase. The geographic location at one and the same altitude is without significance for this characteristic.

The percentage of strongly acidic rains is very important. It is high for such a clean region as the Rila Mountain. And here there is a converse relationship: the altitude above sea level is of no significance, but the geographic location is of importance.

No.		Acid precip. %	Precipitation ph < 4.5	pH	H^+, μg/l	NO_3^-, mg/l	Cl^-, mg/l	SO_4^{2-}, mg/l	NO_3^-/Cl^-	SO_4^{2-}/Cl^-	SO_4^{2-}/NO_3^-	$NO_3^- \geq SO_4^{2-}$ %
1	$\bar{x} \pm S_x$ σ %Σ an.	62.5	48.6	4.5 ± 0.10 0.65	117.5 ± 39.8 235.7	0.53 ± 0.06 0.29 22.4	0.44 ± 0.09 0.47 18.8	1.4 ± 0.10 0.47 58.8	1.2	3.1	2.6	0
2	$\bar{x} \pm S_x$ σ %Σ an.	48.3	35.7	4.5 ± 0.11 0.53	73.4 ± 22.3 118.0	0.38 ± 0.06 0.28 21.1	0.22 ± 0.03 0.16 12.2	1.2 ± 0.12 0.55 66.7	1.7	5.4	3.1	14.3
3	$\bar{x} \pm S_x$ σ %Σ an.	43.0	0	5.0 ± 0.01 0.046	9.4 ± 0.25 0.96	0.26 ± 0.09 0.37 23.6	0.14 ± 0.03 0.12 12.7	0.71 ± 0.12 0.46 64.5	1.8	5.0	2.7	13.2
4	$\bar{x} \pm S_x$ σ %Σ an.	45.1	41.9	4.54 ± 0.08 0.49	45.6 ± 8.3 46.4	0.70 ± 0.15 0.56 15.2	1.2 ± 0.35 1.23 41.3	2.0 ± 0.55 1.45 43.5	0.36	1.10	2.8	0
5	$\bar{x} \pm S_x$ σ %Σ an.	26.0	49.4	4.6 ± 0.11 –	38.3 ± 9.9 39.6	0.60 ± 0.10 0.38 22.9	0.45 ± 0.04 0.45 17.2	1.57 ± 0.12 0.49 59.9	1.3	3.5	2.7	0

Table 2. Ion content of acid precipitations in the Rila Mountain.

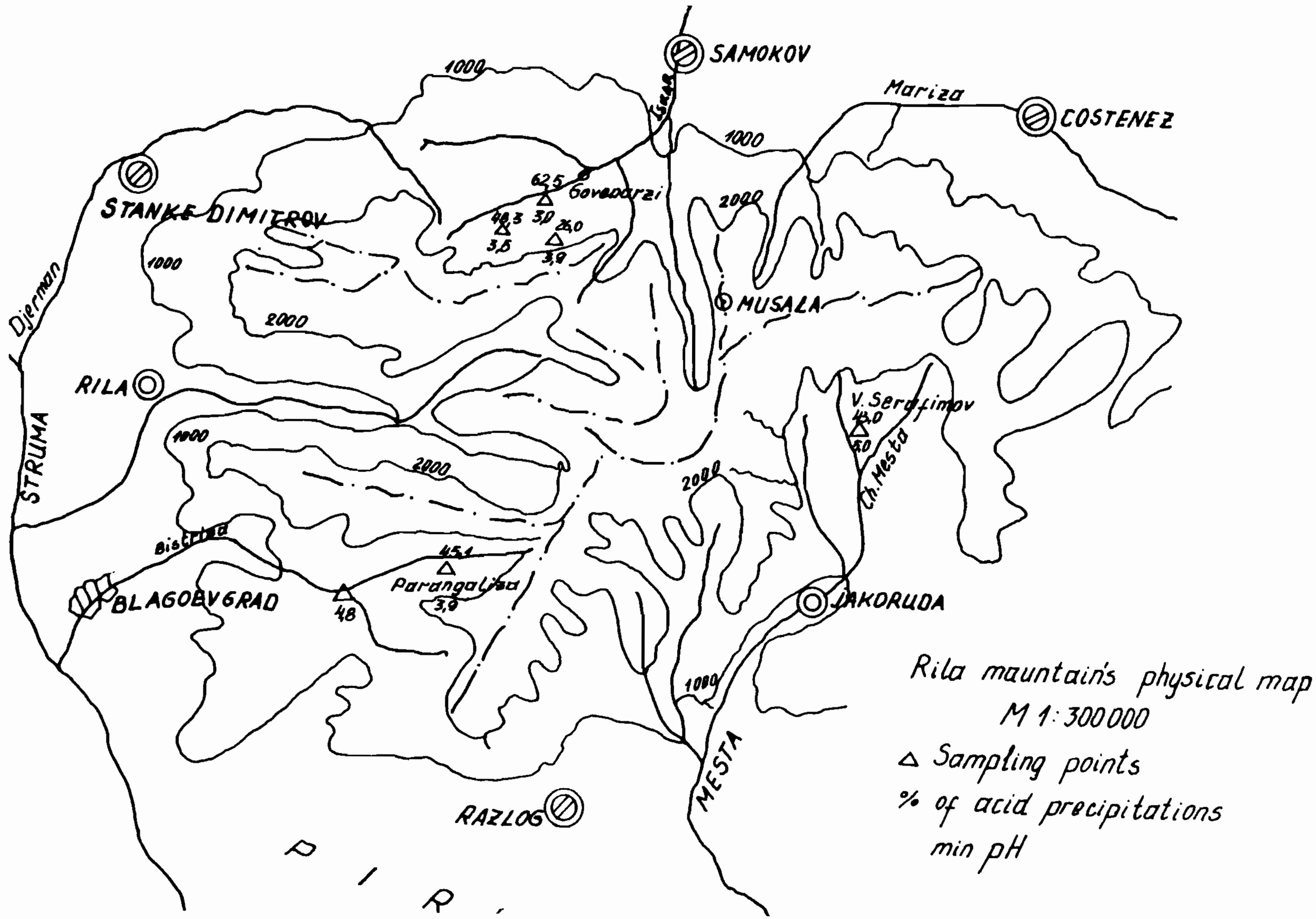

Figure 1: Map of acid precipitations distribution in the Rila Mountain region.

The annual pH values are low and, with the exception of station 3, there is no true difference between the stations; the analysis factor also confirms this fact. The geographic location is of significance and this is proven by the basis statistical and factor analyses, and is mainly due to station 3. In all the stations, with the exception of station 3, the rains showed a high acidity content (the lowest pH measured is 3). This is illustrated in Figure 1. However, acid rains are not unique cases.

Important information has also been obtained from histograms of pH distribution for the cases of acid rains for different stations and for the mountain region as a whole (Figure 2.)

The strongly acidic rains represent 36.9 percent. Of course, the pH distribution for the various stations is different (Figure 2). The altitude, as well as the geographic location are of importance. The concentration of nitrates is low and is within the limits of the data cited in the literature for background regions. In station 3 alone are the concentrations truly lower as compared with the remaining station. The altitude above sea level is not a significant factor. The geographic location is of more considerable importance. The coefficients of variations are not high, and their values are close - ranging from 54 to 80 percent, with the exception of station 3 which showed 127 percent. In the histogram for nitrate concentration distribution in the region as a whole, 54 percent of the concentrations are within the range of 0.1 to 0.5 mg/l and 34.4 percent are within the range of 0.51 to 1.0 mg/l.

The annual chloride concentrations also correspond to the background concentrations with the exception of those from station 4. It is interesting to note that there is no true difference between the concentrations in the highest and lowest station, while the concentration in the intermediate station is twice as low. For the chlorides, too, the geographic location factor is of significance. The coefficients of variance are close to those for nitrates, and are within the range of 65 to 106 percent. In the histogram of distribution, 80.4 percent of the concentrations are within the range 0.1 to 0.5 mg/l, while 12 percent (mainly from station 4) are within the range of 1.0 to 4.8 mg/l. Obviously, an additional factor exists in station 4.

The sulphate content is also at background level, and for the altitude, the relationship is the same as for the chlorides - the concentration observed in the intermediate station is the lowest. The altitude factor in this case is also not significant. There are true differences in the stations at one and the same altitude, i.e., the geographic location factor is of significance in this case. The coefficients of variance are lower by two anions in comparison with the others and are also close in values - within the range 31 to 72.5 percent. The histogram of sulphate distribution differs considerably from those of the others by two anions. In the range 1.0 to 1.5 mg/l there are only 37.8 percent of the concentrations. The share of the values up to 1.0 mg/l and of those in the range 1.5 to 2.0 mg/l is considerable.

Of the three anions, sulphates play a leading role, followed by nitrates. An exception is station 4, where the sulphates and chlorides have the same share in the sum of anions. The coefficients of enrichment are close for the different stations with the exception of station 4, and the altitude and geographic location bear no influence. These coefficients may be assumed as one of the generalizing characteristics of background regions.

The presence of a considerable percentage of nitrates in two of the stations (which equals or exceeds the sulphate content) is alarming. At the present time we cannot explain just why in these two intermediate stations this is the case, but the existence of this phenomenon should be viewed as a warning signal.

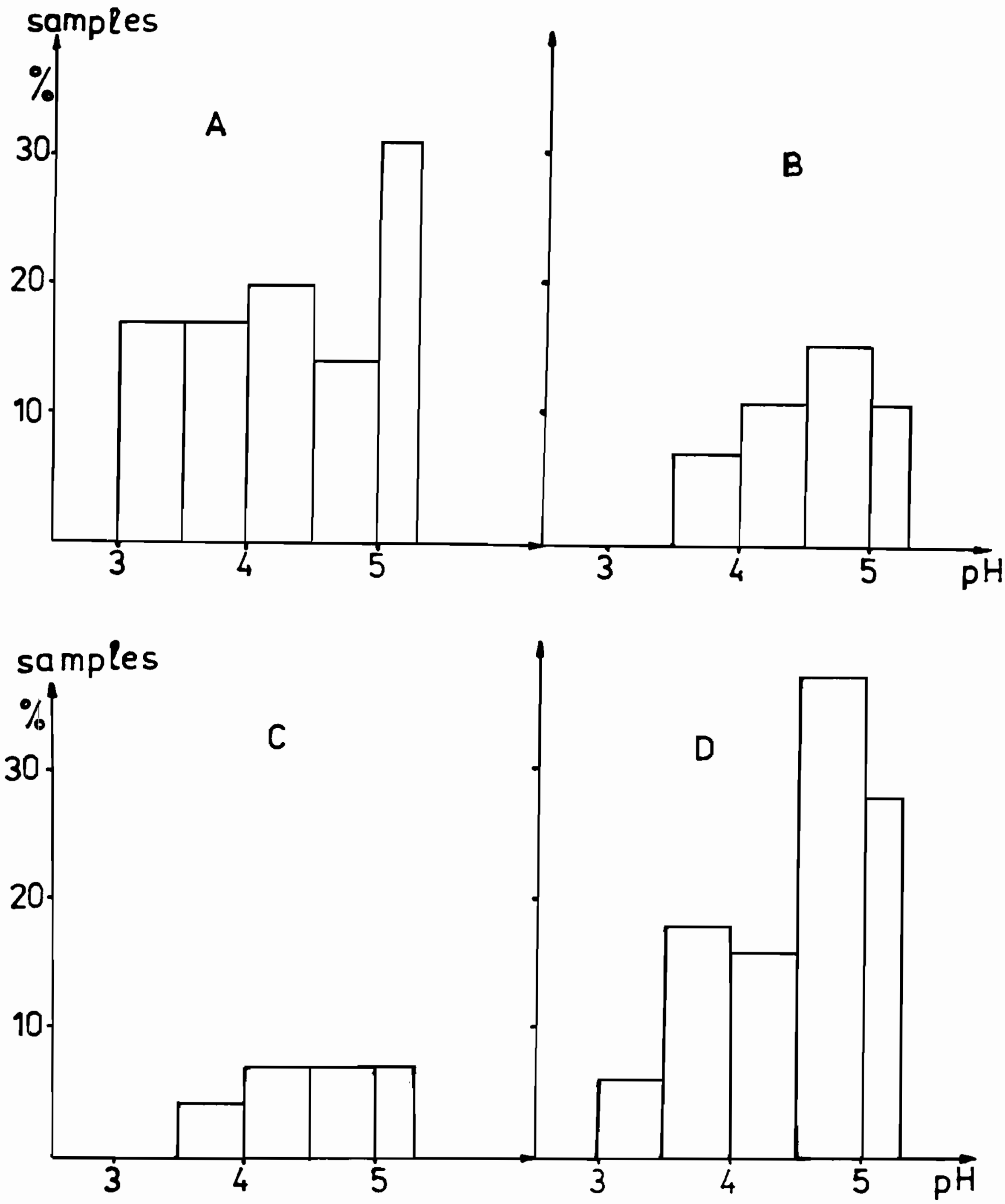

Figure 2: Histograms of pH distribution:
A = Station 1; B = Station 2;
C = Station 5; D = the region as a whole.

Among a small number of the characteristics discussed above a relationship has been established. In northern Rila, the correlations between pH and sulphate concentrations, as well as between sulphates and nitrates in station 1, are true. In the intermediate station 2 there is no correlation relationship between the sulphate and nitrate concentrations. In station 1 there is a high degree of correlation r^2 between all parameters - from 0.79 for chlorides/nitrates, up to 0.92 for sulphates/chlorides. We come across such a phenomenon for the first time. The coefficients B in this station are from 0.3 for the ratio sulphates/pH and up to 0.8 for the ratio sulphates/nitrates. Here we observe a reduction of r^2 with the altitude for the ratio pH/sulphates from 0.88 in station 1 up to 0.08 for station 5. The same is also valid for the ratio sulphates/nitrates - from 0.84 in station 1 up to 0.19 in station 5. With regard to geographic location, regularities or equal relationships are not observed.

The monthly dynamics of the components for the precipitations are shown in Figure 3 for the highest station. As a rule, the high acid content is accompanied by an increase of the sulphate concentration in the rain. The dynamics of acid rains in fractioning is of disreputable interest. It is carried out on the basis of samples from several successive days. The results are: a reduction of acidity is established in 32.3 percent, an increase in 29 percent, and a maintenance at the same level - in 38.7 percent of the cases. Thus, the increase of H^+ content can vary sharply, e.g., from 15.8 μ g/l to 1000 μ g/l. An increase in concentrations prevails for nitrates - in 47.8 percent of the cases. For sulphates, it is the opposite: a decrease in 41.2 percent and an increase in 23.2 percent of the cases.

Consequently, an active wash-out of the surface air layer is effected, as well as an active transport, in particular of acid. Of course, the question concerning the cause of the high percentage and the high degree of acidification arises. The plotting of the wind rise for all stations shows a transport of acid rains mainly from north-west to south-west. Figure 4 shows the wind rise for station 5.

A more detailed investigation was conducted on the circulation of the air masses over the Rila Mountain in several successive days during which acid rains were noted. For example, in December 1981, there prevailed over Europe a zonal circulation with well expressed west transport over the southern part of the continent. In some cases, the east transport in the surface air layer exerted an influence. It is obvious from Figure 5 that there are no special distinctions in the trajectories of the air masses and in the pH during this month.

In February 1982, a meridional circulation with ridge prevailed over Western Europe (Figure 6). The precipitations were formed mainly in the southern periphery of the anticyclone and, in some cases, in the passing over of southern Mediterranean cyclones stationed over the Balkan Peninsula. The trajectories of acid precipitations again do not differ from those of the remaining ones.

In June, July and August 1982 (Figure 7) the rains are more frequently connected with cyclones stationed over south-eastern Europe or a gradient-less relatively low-baric field, the peculiarities of which are formed over the Balkan Peninsula; the percentage of acid rains and acid content are high.

The examples discussed make it possible to assume that the acid rains recorded in the Rila Mountain are due mainly to sources of regional character - at a distance of up to 1000 km, i.e., long-range transport. For the lower sites, sources of local character are of dominating importance. Due to specific features, and to the mountainous character of the region, the atmospheric circulation varies more sharply and determines the difference in the acidity of the precipitations in the stations.

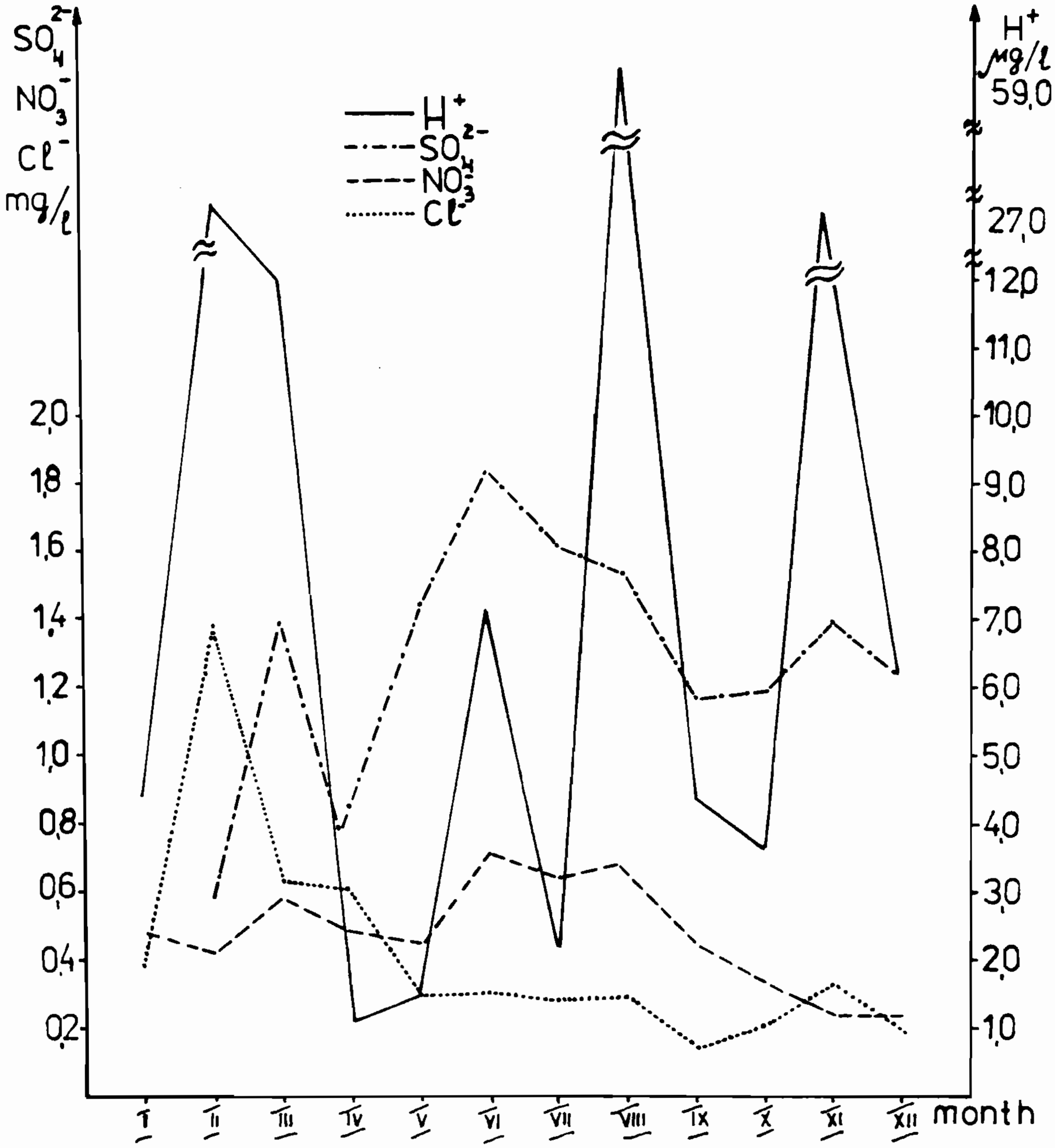

Figure 3: Monthly dynamics of the components for station 5.

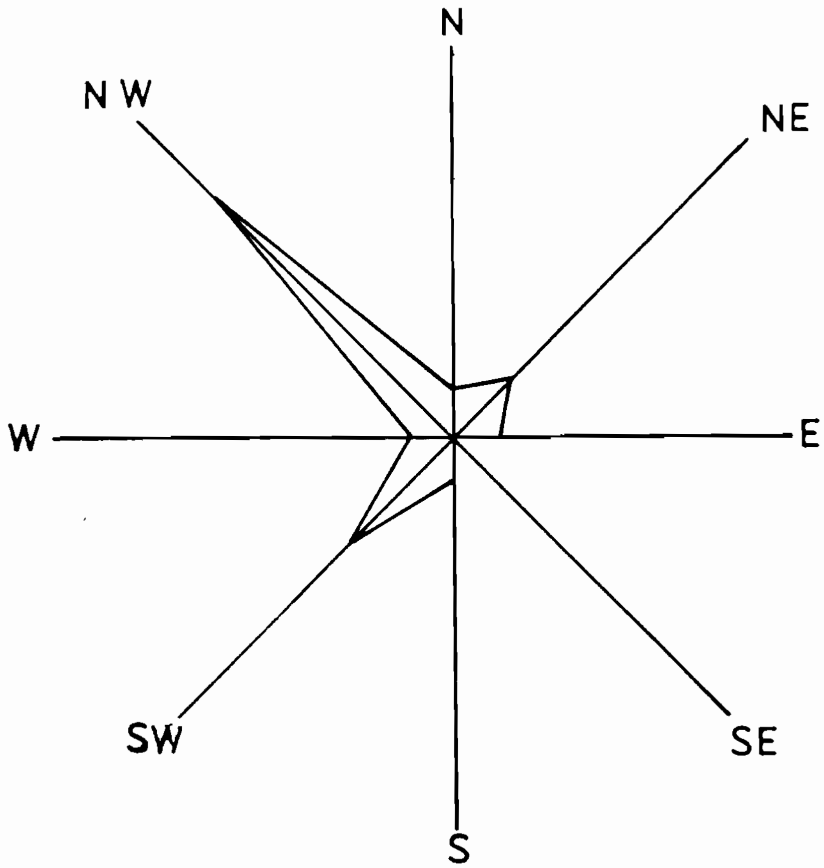

Figure 4: Wind rise and transport direction.

Of course, because of the small area of Bulgaria and the large number of sources of acid emission, the national sources also contribute to the acidification of precipitations. Evidence for this is found in the narrow intervals of the coefficients of variance of the components and the presence of high pH values in the histograms.

The wet deposition of the components as a result of the acid precipitations in the Rila is alarming with regard to acid quantity. For one year, from 7.3 to 28.4 mg/m^2y hydrogen ions have fallen with the acid precipitations on the three sites in northern Rila. Presented as sulphuric acid, this corresponds to 700 mg/m^2y for station 5 and 2726 mg/m^2y for station 1. Especially alarming is the fact that for station 2, 98.6 percent of the acid is deposited during the period May-October.

The wet deposition of nitrates does not differ substantially in the different stations - from 278 mg/m^2y in station 1 to 227 mg/m^2y in station 5. The wet deposition of sulphates is 653 and 612 mg/m^2y for stations 1 and 5 respectively and considerably lower, 444 mg/m^2y for station 3. These values are close to those cited in the literature for clean regions.

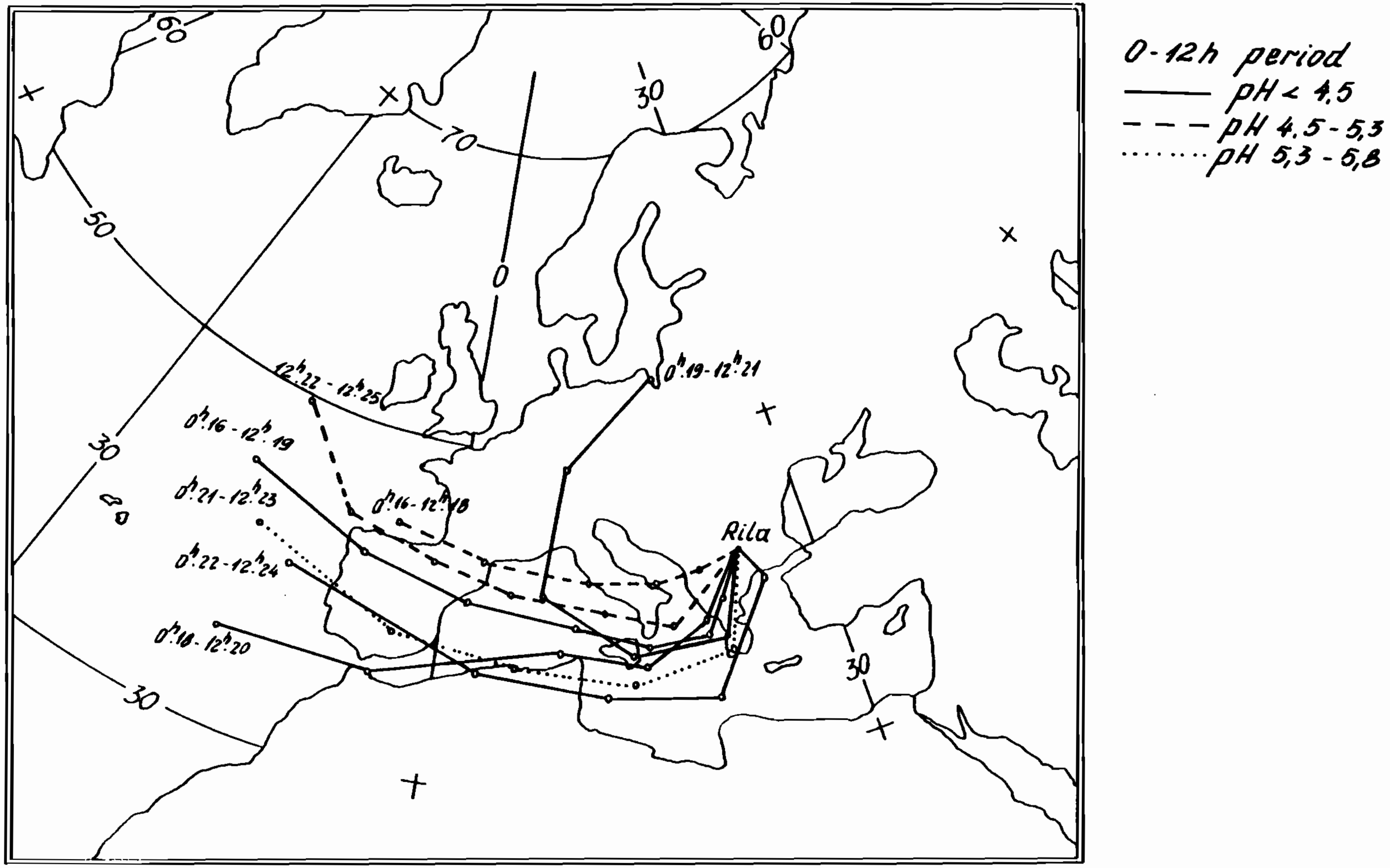

Figure 5: Air trajectories over the South Western region of Bulgaria during December.

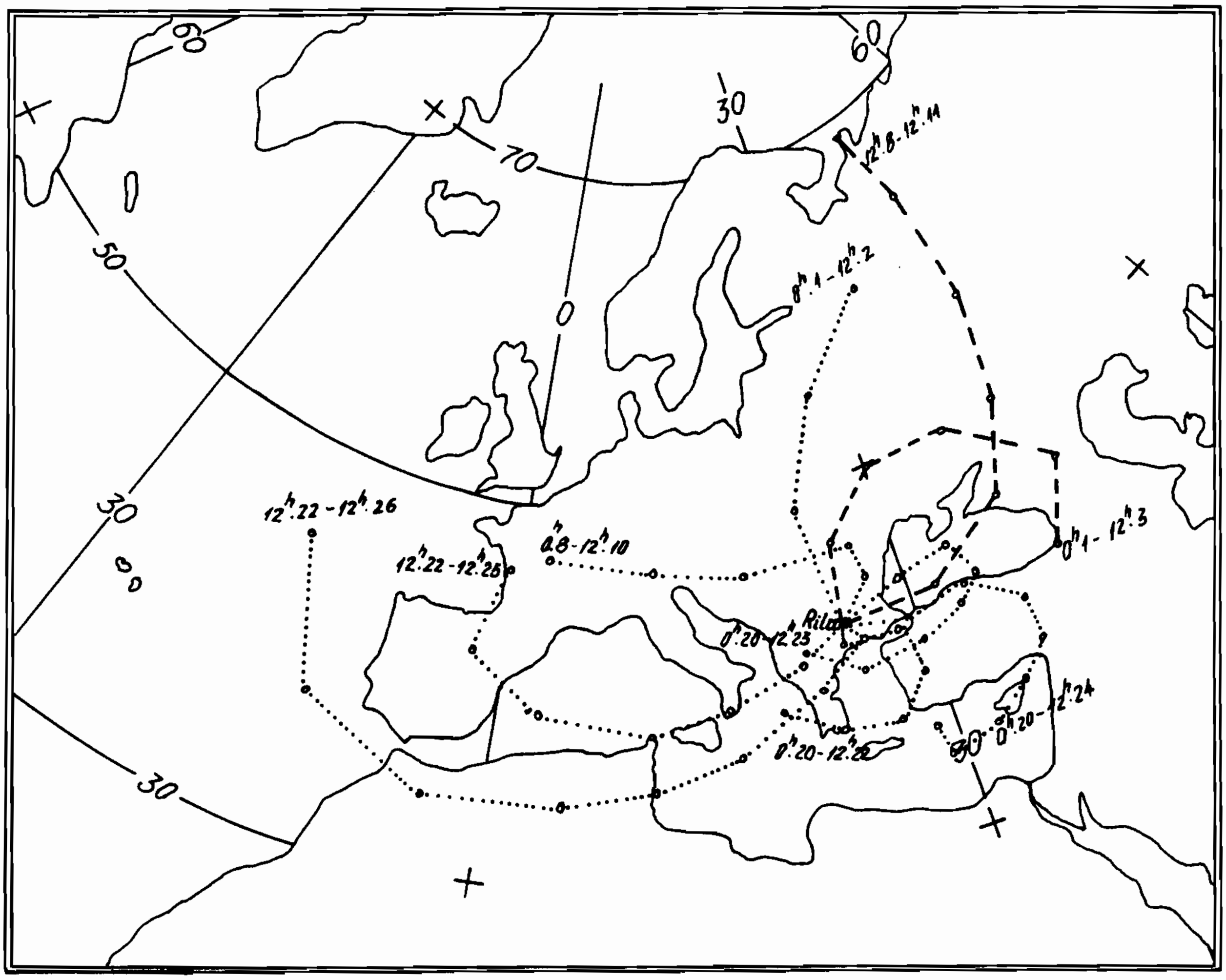

Figure 6: Air trajectories over the South Western region of Bulgaria during February.

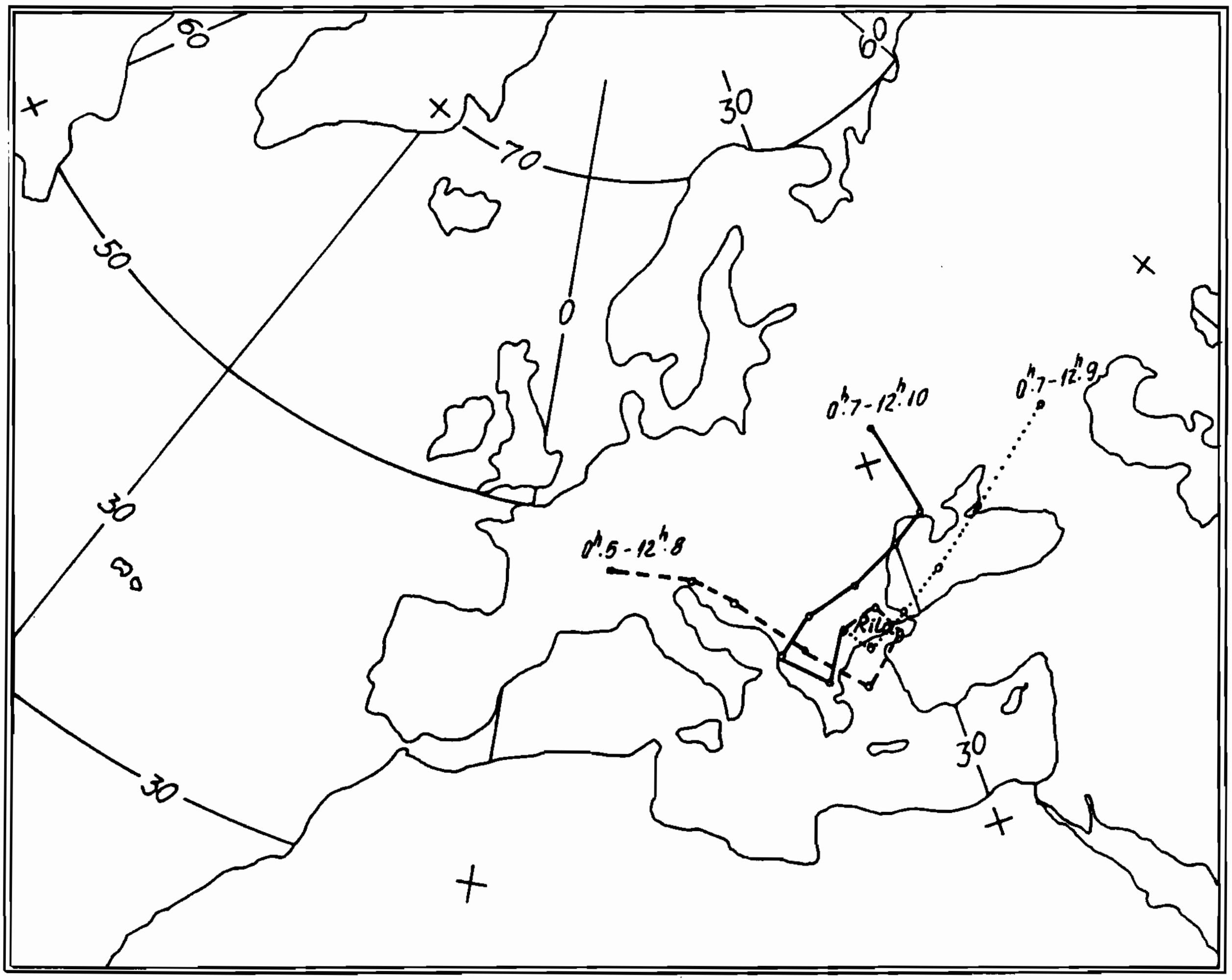

Figure 7: Air trajectories over the South Western region of Bulgaria during July-August.

The acid precipitations in Rila already affect the state of its high-mountain rivers. In the upper currents of the Haidoushka and the Blagoevgradska Bistritsa rivers, in the region of station 4, a considerable part of the samples of river water contain a pH of 4.8 to 6.4.

Debatable Questions

In the course of data processing we have come across the following important questions which it is desirable to discuss:

a) How to express the acidity of precipitations - by pH or by the hydrogen ion concentration. In the generalization of data for a longer period, the average values of both characteristics do not correspond. Moreover, the correlation between pH and the concentration of a given component does not always correspond to the correlation between the H^2 concentration and the concentration of the same component.

b) How to calculate the relative acidity - in the case of strongly acid precipitations, incorrect results are obtained for the ratio

$$\frac{H^+}{SO_4^{2-} + NO_3^- + Cl^-} \quad mgeqv\,/\,l$$

in percent for clean regions. This is the reason why this characteristic in not treated in this paper.

c) How to calculate the ion balance so that the data obtained by different authors can be compared - which ions must be taken into consideration, not only for scientific, but also for inspection activities, so that a comparison can be achieved for the different countries.

d) The different presentation of concentrations by different authors: mg/l, volume, weight, etc., makes the data non-comparable. The discussion started by H.M. Liljestrand (1985) should be continued until unanimity is reached, so that we can get a real idea of world-wide precipitations and comparability of the data can be achieved.

e) To filter the rains or only to decant them, or not to pre-treat them at all? In particular for anthropogenic influenced precipitations, the different pretreatment results showed differences of up to 30% (for example in the determination of lead content, with or without filtering). These differences are influenced by the pH value of the precipitation.

f) The problem of background values and of the limits of natural pH; here the views among the authors differ greatly.

CONCLUSIONS

In the Rila Mountain, as a representative region without local acid emissions, the following observations can be made:

- a considerable percentage of acid and strongly acid precipitations were recorded;
- the content of nitrates, chlorides and sulphates is low and corresponds to the background values cited in the literature;
- the altitude factor bears no significance on the content of the different components, but the geographic location factor at one and the same altitude is of significance;
- the presence of nitrates in concentrations greater than those of the sulphates in two of the sites is alarming;
- acid precipitations are mainly observed in the form of rains;
- the acidification of rains in the Rila Mountain is due to long-range and mesoscale transport, mainly from the north-west and south-west, but the national sources of emissions are also of importance;
- the quantity of acid, falling as wet deposition in the Rila Mountain, is high;
- the acidification of the rains in the Rila Mountain has already resulted in the acidification of the high-mountain rivers.

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3.2.4 DENDROCHRONOLOGICAL METHODS TO ESTABLISH THE DYNAMICS OF HEAVY METALS ACCUMULATION IN TREES

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1. Introduction to the Research Work

Since long ago, the method of dendrochronology has been used in forestry science and in practice to examine the dynamics of growth and productivity both of individual trees and of whole dendrocenoses. The method is based on the condition that in the biogeographic regions where the vegetation period ceases during the year, the annual rings are distinctly outlined. By these rings one can judge the age and accumulation of biomass when a cross section of the tree is made, it can be seen that the annual rings are of various widths. This points to the fact that biomass accumulation due to various factors has been an irregular process. The annual rings allow us to read the history of tree development in its different aspects. Recently, this method is also used to determine the changes in climate, apart from using it for the purposes of establishing the dynamics of biomass growth and tree age. This is done for the different years when other conditions are equal.

The dendrochronological method proved to be the right method in order to investigate different factors affecting tree growth or the so-called stem analysis which enables us to trace the dynamics of growth of different trees for hundreds of years. It is completely natural that if we are making some experiments to ascertain the influence of various factors, one researcher cannot simply wait for these hundreds of years to pass. Recently, dendrochronology has been used for experimental purposes to establish the dynamics of accumulation of various heavy metals in wood, hence we can estimate the heavy metal pollution during different periods of time. This is also the goal of our research.

2. "In sito" Research

In order to establish the dynamics of accumulation of lead and cadmium from automobile transport in the wood of some specific species, investigations were undertaken in two sites: the first one included the ecological areas of the Scientific and Coordination Centre for Ecology and Environmental Protection in the Park of Liberty, situated close to the Lenin Boulevard highway in Sofia, and the second one includes the protective shelter belts along the road just next to the international route "Sofia – Kalotino". For this purpose tests were made on various trees by using a Pressler drill. The tests were made over a period of five years. Chemical analysis of the timber samples was made for trees of different ages by means of the atomic-absorption spectrometer. The results of the tests carried out in the Park of Liberty are shown in Figures 1 and 2, and those from the international route "Sofia – Kalotino" are given in Figures 3, 4 and 5. The first four figures show the dynamics of accumulation of lead and cadmium, and the last, Figure 5, shows the accumulating ability of different tree species.

3. Comments

Figure 1 represents the dynamics of lead accumulation in mg/kg of dry substance to white pine, black pine and red oak for the period between 1925 and 1985. As seen from this figure, the amount of lead in timber is different for the different ages of tree species. However, the tendency for the amount of lead to increase with age is common, the maximum lead amount being observed during the age of 60–70. As the trees are growing in the immediate vicinity of the Lenin Boulevard, which is a much used highway, it is natural that a large amount of lead is due to that emitted by cars. It should also be remembered that the soil has a natural metal-containing background which has not been explored. The natural metal containing background, however, does not change so sharply, in some cases is does not change at all. If such a background existed in 1920 (the car transport was then insignificant), the sharp increase of lead in timber now can be accounted for by car transport. It should be noted that after 1970, the lead accumulation decreases. This is explained by the decrease of automobile transport which for its part is also explained by the fact that a round-about highway drew a great part of the cars from Lenin Boulevard. There may be some other reasons of a physiological nature. It is obvious that automobile transport emits quite a large amount of lead which accumulates in timber. Figure 2 shows the dynamics of cadmium accumulation in the timber of white pine, black pine and red oak from the same site.

It is also known that the dynamics of cadmium accumulation in the timber of different species follows the same regularity as with lead. Figure 3 traces the

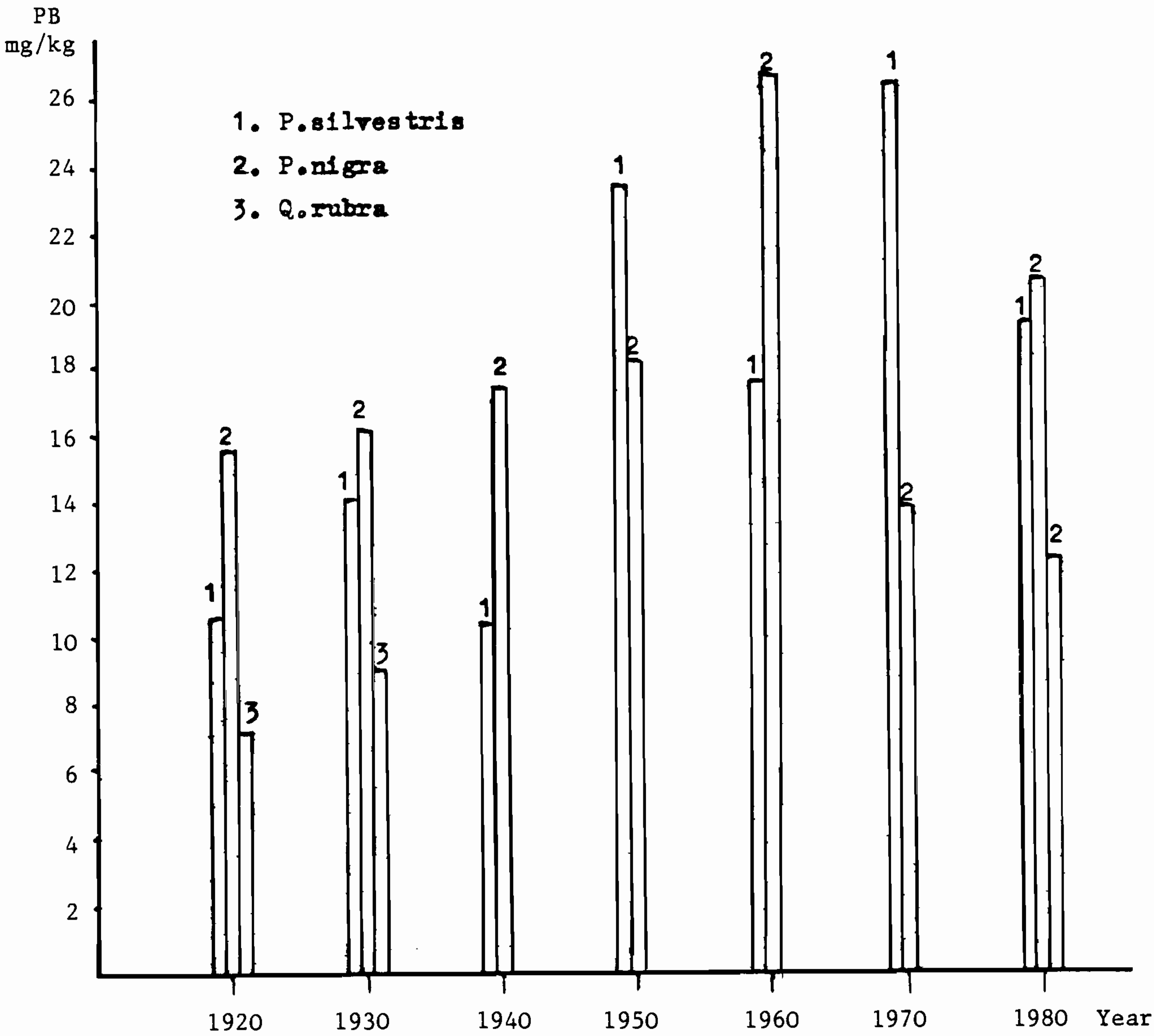

Figure 1. Dynamics of lead accumulation in timber.

dynamics of change of lead accumulation in the timber of white acacia in the site along the "Sofia – Kalotino" highway. The lead accumulation in the timber is studied at a distance of 3,5m and 80 m from the road. It can be seen from Figure 3 that lead accumulation in 1920 has been almost insignificant. It begins to increase after 1940 and increases sharply in 1950, 1960, 1970 and 1980. Naturally, the accumulation is greater in trees growing next to the road, but the figure shows that is also increases for trees growing at a further distance from the road. Figure 4 shows the dynamics of cadmium in trees from the "Sofia – Kalotino" site. The tendency of accumulation increase is equal to lead accumulation, the difference being that the latter is smaller in quantity. One conclusion that can be drawn from the examples that automobile transport pollutes to a great extent pollutes the lands along the road with lead and cadmium, which not only remain in

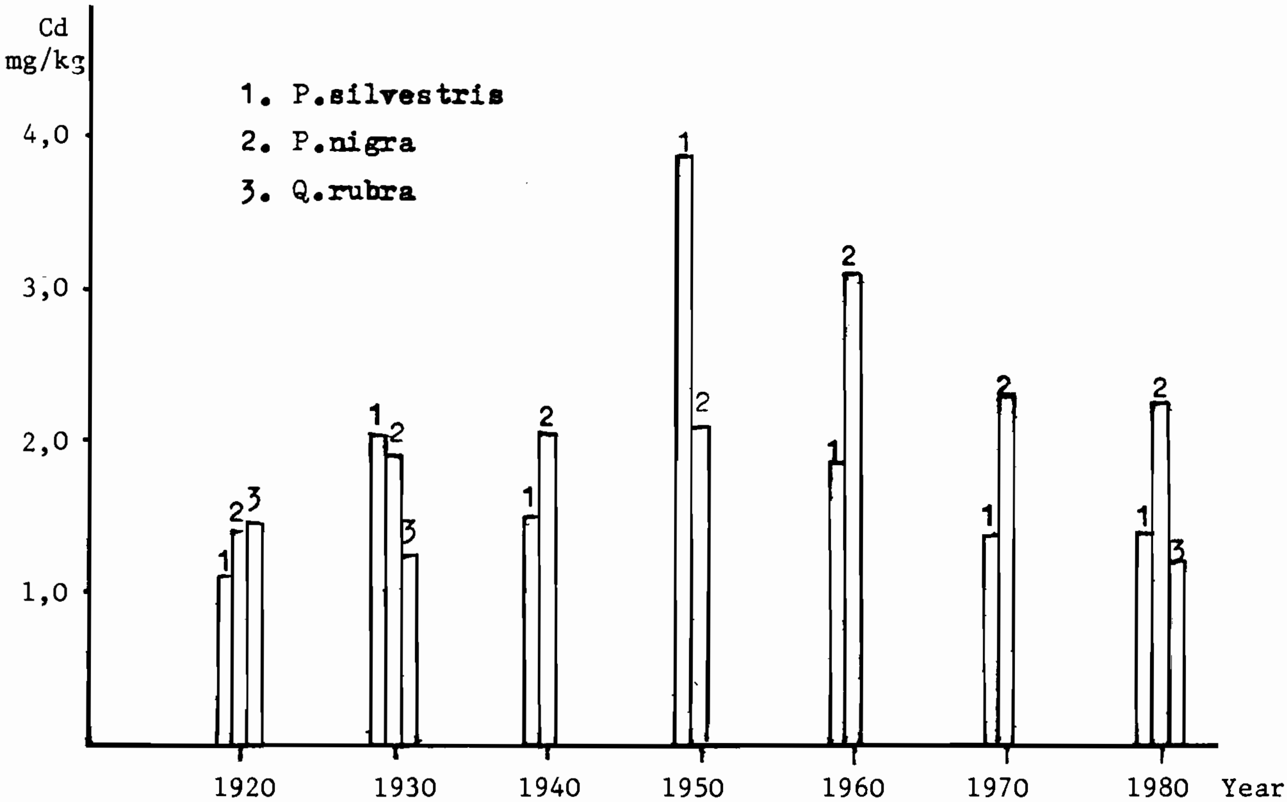

Figure 2. Dynamics of cadmium accumulation in timber.

the soil but accumulate there and stay in the timber species. The lead and cadmium accumulation in trees in the "Sofia – Kalotino" site does not show any variations but has a tendency to increase which means that transport on this highway has also increased.

As previously mentioned, the results from the ecological sites on Lenin Boulevard shows a decrease in the amount of lead and cadmium over the last years due to the decrease of transport there. As seen from Figures 1–4, the lead and cadmium accumulation is different in the various timber species. This is of great importance and should be clarified both from a theoretical and practical point of view. When investigating this particular site, at the same time lead and cadmium accumulation in acacia, poplar and white pine (Figure 5) was investigated at equal other conditions.

As shown in Figure 5, the lead and cadmium accumulation is greatest in white acacia followed by poplar and white pine. The conclusions to be drawn are very interesting from a theoretical point of view. It is quite clear that from now on we should establish the reasons influencing the accumulation processes, and the reasons can be various enough. To date, the practical conclusion has been that the planting of trees along the highways and roads with the purpose of protecting the lands from lead and cadmium must be done using such species as acacia and others which accumulate the greatest amount of heavy metal elements.

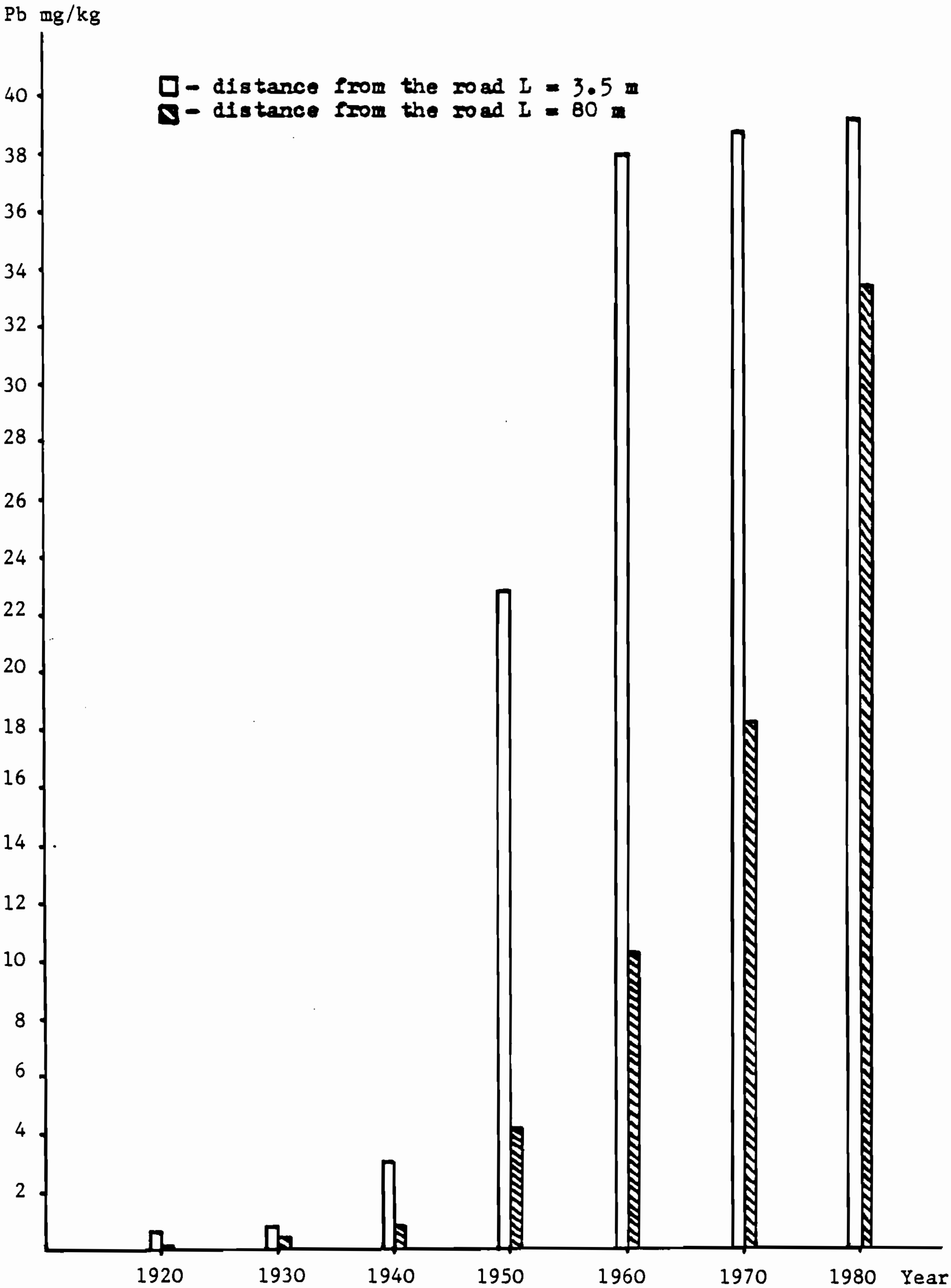

Figure 3. Dynamics of lead accumulation in the timber of acacia (*R. pseudoacacia*).

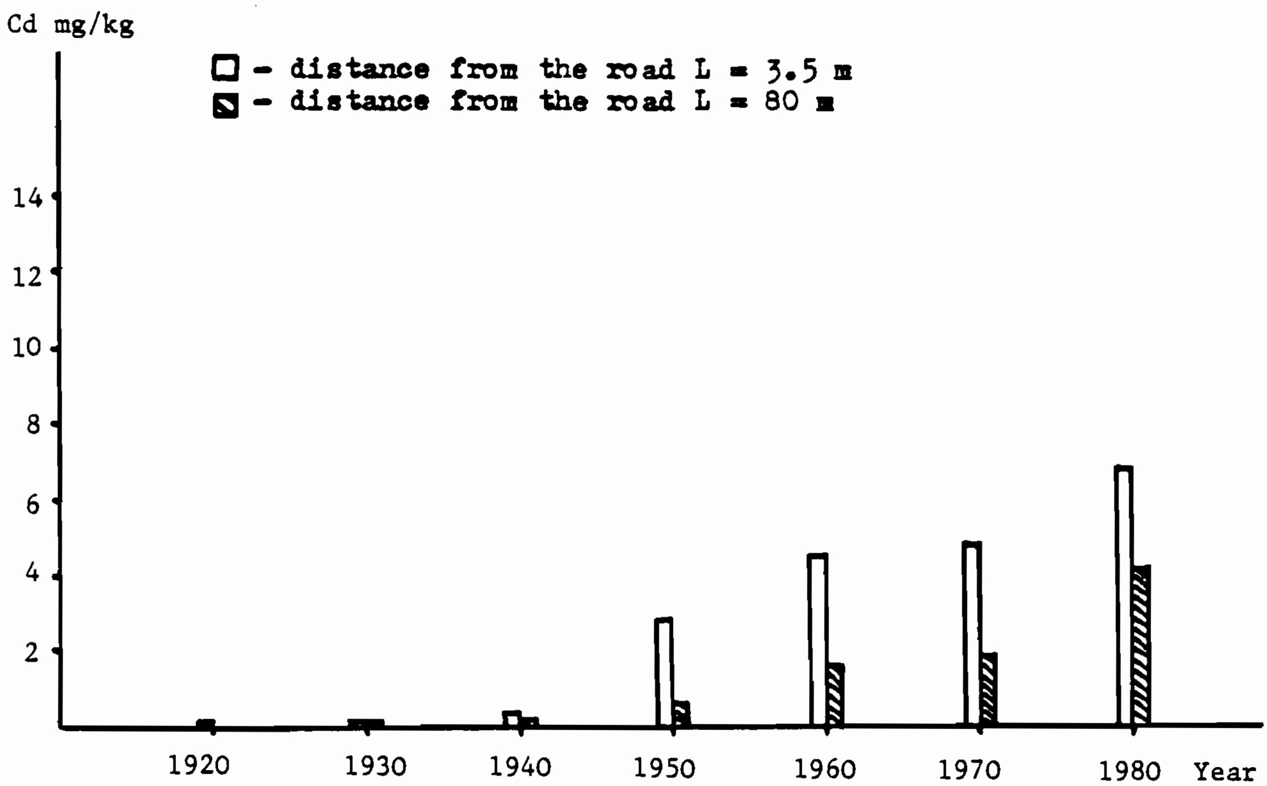

Figure 4. Dynamics of cadmium accumulation in the timber of acacia (*R. pseudoacacia*).

It is well known that heavy metals, such as lead and cadmium, cause serious damage in the human. Heavy metals enter the human organism through the traffic chain (fruits, vegetables, etc.). Lead gets into the human bones and causes different kinds of serious diseases. Trees such as acacia have large accumulation possibilities with respect to lead and cadmium. They can be used for melliorative activities in areas with strongly polluted soils with heavy metals. Through the process of timber accumulating heavy metals, the latter do not get into man's organism.

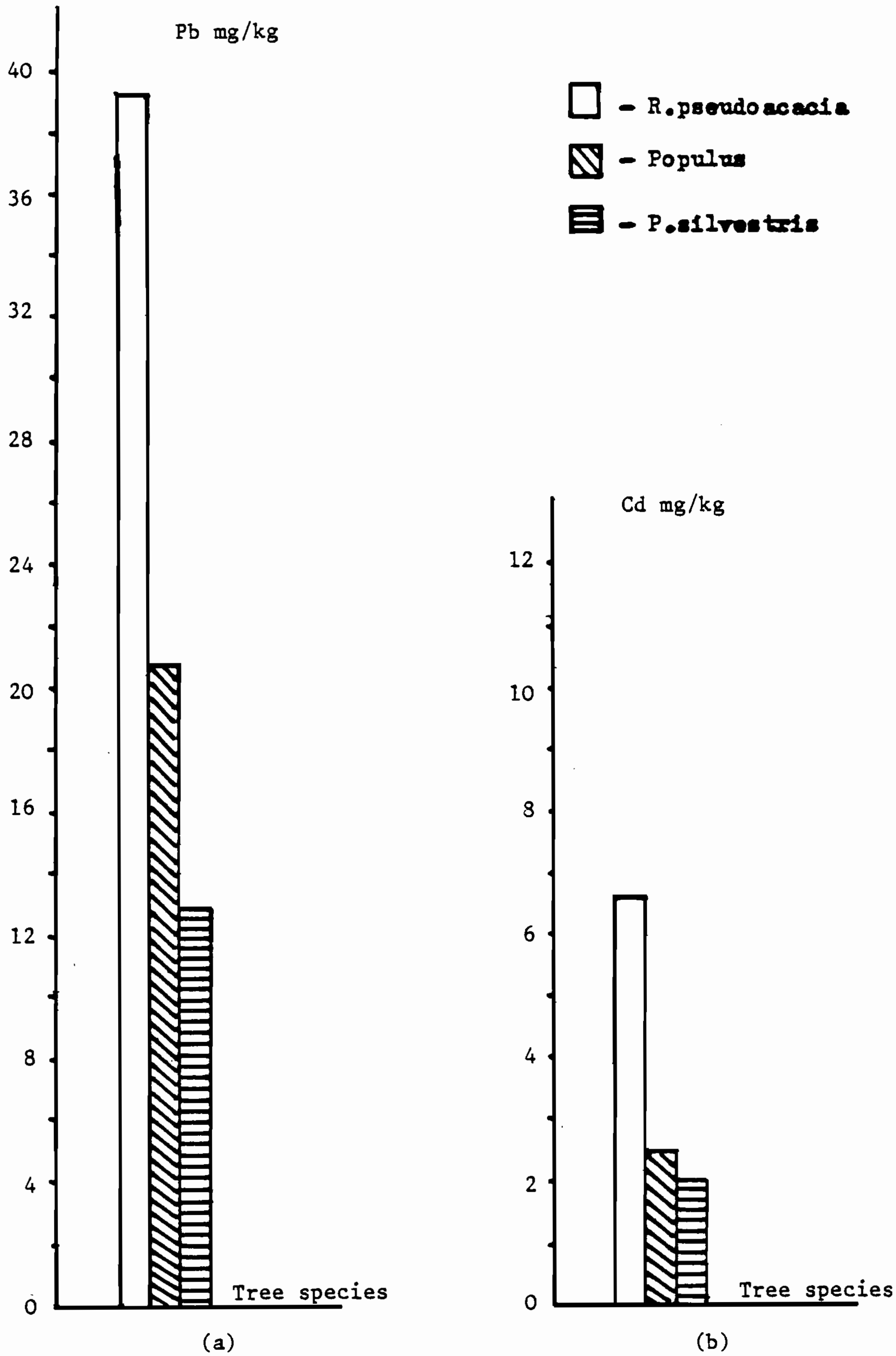

Figure 5. Accumulation of lead (a) and cadmium (b) in different trees with other similar conditions, 1970 – 1980.

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REGIONAL RESOURCE MANAGEMENT

VOLUME II

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4.1 MODELING ECONOMIC-ECOLOGICAL SYSTEMS

4.1.1 MODELING FOR ENVIRONMENTAL AND RESOURCE MANAGEMENT

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1. Introduction

Modern day environmental and resource management involves a wide score of activities. It may denote long and short term planning, day to day supervising, environmental monitoring, analysis of data, exploring options and searching for optimal control. Each of these activities, in turn, may regard one or several types of resources: non-renewable fuels and minerals, abiotic renewables such as water and sediments, and biotic renewable resources such as plant and animal populations. Even complex systems which contain all of the above resource types have become the subject matter of resource management. Examples are soils, forests, landscapes and even the complete biosphere.

From an anthropocentric point of view, ecological systems have two functional modes. The distinction is based on differences in the way a society uses these systems. If the concern is with the sources of the flows of pure energy, raw materials, plant and animal products for consumptive use, we refer to it as 'resource'. If, on the other hand, the interest is in an ecological system as the receptor of waste flows from social and economic activities and in non-consumptive use such as outdoor recreation, we refer to it as 'environment'. In economic jargon: ecological systems supply goods in the 'resource' mode and perform services in the 'environment' mode (see Figure 1).

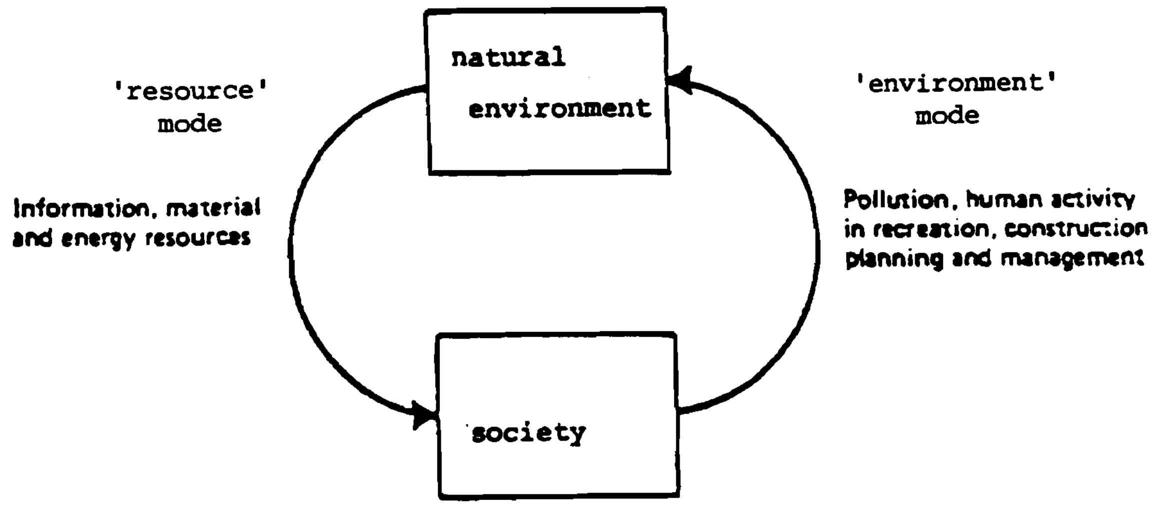

FIGURE 1 Relationships between natural environment and society

A variety of methods and instruments exist which are used to assist in and execute the many and complex tasks of environmental and resource management. A number of these tasks are carried out with help of models. In some cases only conceptual schemes are applied, in other cases sophisticated mathematical structures are used, for instance in exploring alternative management strategies, finding optimal solutions to complex problems and in making data intelligable.

By now, a great number and variety of models have been developed. Some of these have an academic purpose, most of them have an applied orientation. Many of the people working in environmental and resource management have learned to use models and in some cases, to build them. For those who model, one particular question is recurrent: How does one obtain the appropriate model for the problem at hand?

To answer this question it seems logical to start with identifying the various dimensions of the problem. This is discussed in Section 2. Having defined the problem, one needs models in order to test them for appropriateness. Two avenues are logically explored. First, one could develop an overview of models used in environmental and resource modeling and then select the most appropriate one by matching the problem dimensions with model dimensions. Such an overview of modeling approaches is given in Section 3. Secondly, one could develop a new model the specifications of which are derived from the problem dimensions. New models can be build from 'scratch' or by linking existing models or model components. This approach is discussed in Section 4. The paper is completed in Section 5 with a summary and some conclusions.

2. Dimensions of environmental and resource problems

To select the appropriate type of model for a management task, three dimensions are generally considered:

1) The objective of the management task. This determines to a large extent how much economics and how much ecology must be included in the model.
2) The cognitive purpose of the management task. This defines the technique to be selected for model operation.
3) The time/space framework of the problem. This sets the boundaries to the model and determines its size and level of detail.

In environmental and resource management three kinds of objectives can be distinguished:

1. Nature conservation objective
2. Economic objective
3. Combined (economic and nature conservation) objective.

The first objective can be characterized as: 'minimum exploitation and damage of natural ecosystems'. The second objective has the characteristic of 'maximum or continuous production of goods and services' at an optimal cost-benefit ratio'. The third objective implies 'maximum sustainable use of resources and environmental services'. The crucial concept is sustainability. It means that the various forms of use are compatible with the productive potential and carrying capacity of the natural systems involved. Depending on the objective of the managing institution or people, ecological, economic or integrated multidisciplinary analyses seem to be most appropriate to solve these problems.

The second dimension of a problem which needs to be considered is the cognitive purpose in the management task. In a management context, models are generally used to generate (alternative) solutions to a problem and to assess the impacts of these solutions. VanSteenkiste (1981) describes three types of models, distinguished on the basis of the cognitive purpose of the modeling project. For the analysis of 1) the system, 2) the output and 3) the input of the problem situation, the appropriate model types are: 1) explanatory models, 2) predictive models and 3) control models, respectively. In any study, two of the three elements are to be known (by observation, experimentation or postulation). The third can be deduced, preferably by means of objective, falsifiable mathematical techniques (see Figure 2).

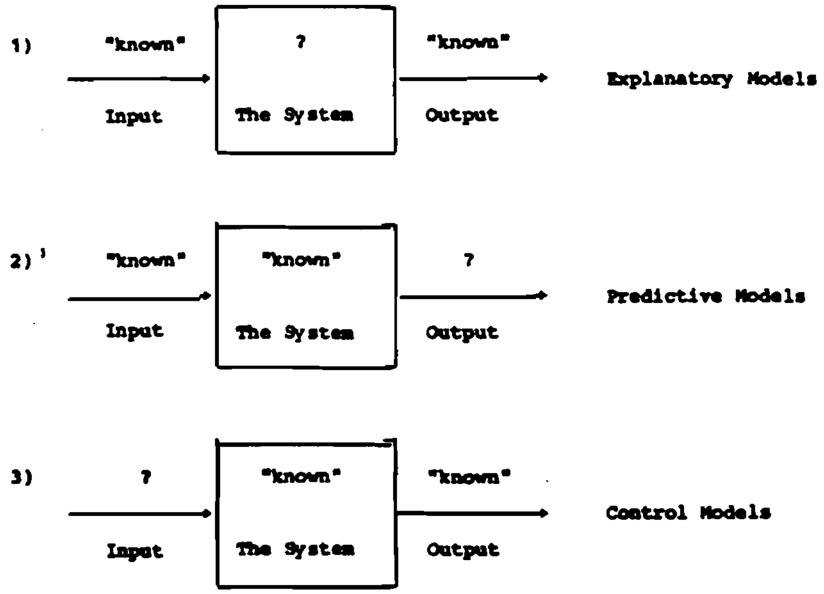

FIGURE 2 Cognitive purpose and model type **(after Van Steenkiste, 1981)**

Explanatory models are developed on the basis of observation of input and output. This may be done through descriptive observation or in controlled experiments. Predictive models assume a certain mechanism which transforms inputs which are to be known: the models subsequently predict the output. Control, or optimization models are designed with known constraints and mechanism, and with fixed objectives (the desired output). Here the models are to calculate the inputs (i.c. the management actions) required to produce the desired output.

Obviously, in management situations, explanatory models are merely considered as necessary stages in model development. After that stage, either simulation (predictive), optimization (prescriptive) models or a combination of these are applied in the actual search for feasible solutions and effective actions.

Environmental and resource problems have, of course, temporal and spatial aspects. They constitute the third dimension. Management of a fish pond is typically a local affair. Forest management for timber production usually involves hundreds or even thousands of square kilometers. Managing the carbondioxide level in the atmosphere is a worldwide problem. Not only the spatial scale of the system which must be managed is relevant. In dynamic systems the area which is affected by a particular problem may well be much larger than the area of its origin. Transboundary pollution through rivers and air transport is a familiar example.
In analogy, some management problems are clearly short term, or viewed to be so. Other management tasks, however, cover extended periods of time. Again, the lenght of the period is not the only temporal dimension to regard. Fluctuations, periodicity and stochastic behaviour of system components are aspects of temporal dynamics which need to be considered in defining the problem at hand.

There are relevant relationships between the economic, ecological, temporal and spatial aspects of environmental and resource management problems. Looking at a particular problem, one may rightly focus on either the economic, or the ecological aspects in case the problem and its side effects are restricted to both a local scale and a short period of time. Also, if a problem situation is wide spread but is expected to exist only for a short period of time, a monodisciplinary approach may still be sufficient, since some factors may then be assumed to be constant for that period and the time is too short for essential feedback and synergistic effects to develop. If, however, a long term problem is at hand, a multidisciplinary approach would seem to be much more appropriate. Because, as time proceeds, the exogenous factors generally do not remain constant, and feedbacks and synergistic processes will develop. Information about the properties of the exogenous factors is then required for an adequate analysis. It would seem, therefore, that short term analyses of environmental and resource problems may be conducted with monodisciplinary models, while long term analyses require models which include both the economic actors and activities and the ecological components and processes. Models which comply with this requirement would justly be called economic-ecological models (see Figure 3).

SPACE / TIME	SMALL	LARGE
SHORT	mono-disciplinary	mono-disciplinary
LONG	multi-disciplinary	multi-disciplinary

FIGURE 3 Temporal and spatial scales and model type

3. An overview of models

3.1. Introduction

Both in economics and in ecology, as well as in many other sciences, mathematical modeling approaches have increasingly become more important over the last few decades. The pioneer work of Lotka (1920) and Volterra (1931) in population ecology, of Lindemann (1942) at the ecosystem level, and of Tinbergen (1956) in economics, has been followed by extensive efforts to obtain more insight into the complexities of the real world by means of statistical, econometric, numerical simulation and analytical modeling techniques.

In the last two decades, academic researchers as well as policy analysts became increasingly aware of the limitations of monodisciplinary modeling for environmental and resource management. Studies were undertaken to improve the existing models. And thus came into existence the models of environmental and resource economics, which will be discussed briefly in Section 3.2, and the models of environmental biology and resource ecology, presented in Section 3.3. In the last ten to fifteen years a number of attempts have been made to bring economics and ecology together in a single framework. The integrated economic-ecological models have resulted from these initiatives. They will be discussed in Section 3.4.

Figure 4 shows the different types of models used in environmental and resource analysis. Examples and detailed analyses of models for environmental en resource analysis are given in Braat & Van Lierop (1983, 1985, 1986).

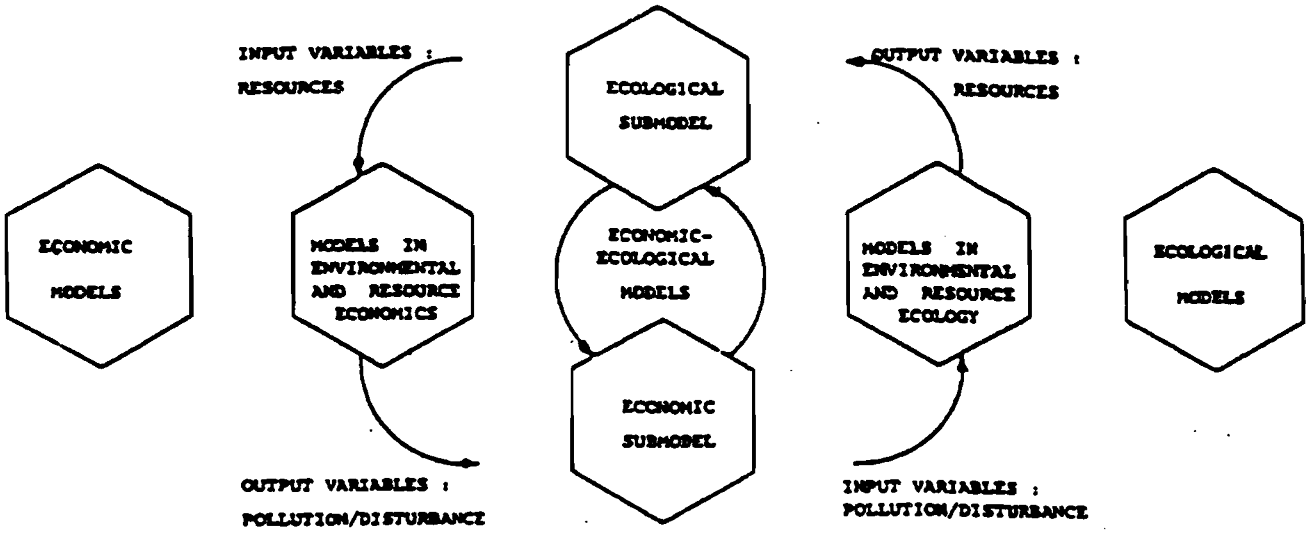

FIGURE 4 Model types for environmental and resource analysis

3.2. Models in environmental and resource economics

Two approaches can be distinguished: 1) extensions of traditional cost-benefit analysis, and 2) extensions of physical-economics models with resource inputs and waste output.

The objective of the first approach is to internalize environment and resource (as 'extra market effects') into the economic system, in order to be quantified in terms of money. A proxy for their value to the economy is the consumer's willingness to pay for them. Only when renewable resources are involved ecological information is needed: For example the growth of harvestable populations, the development of fertile soils and the flow rate of fresh water streams for reservoir build-up. Furthermore, environmental standards based on ecological and toxicological data may be included as constraints in cost minimization models.

The second approach in environmental economics is the one which in principle requires most explicitly ecological information about resource inputs and most clearly recognizes the services of waste treatment and absorption, rendered by the environment. This approach includes the materials-balance (residuals management) models which were developed at Resources for the Future (see Kneese & Bower, 1979) and the extended (with resources and/or pollution) economic Input-Output models (Isard, 1972; Hordijk et al., 1981; Hettelingh et al., 1985). These models require input data about renewable and non-renewable resources and generate information about emissions of air and water pollution and solid waste.

3.3. Models in environmental and resource ecology

As is the case in economic modeling, ecological model were extended along two separate lines: 1) Ecological evaluation models, and 2) Ecological (resource extraction and pollution) impact models.

One group of ecologists has concentrated on developing methods, techniques and theory to valuate ecosystems, resource flows and environmental services in a manner analogous to the economist's ways to valuate capital goods, production factors and products. Three types of ecological valuation can be distinguished: 1) monetary, 2) energy and 3) multidimensional.

In monetary evaluations the values of ecosystems and ecosystem functions are priced. A price is estimated by essentially economic means. In energy evaluations the whole project of system is evaluated in (embodied) energy terms to provide a common basis for cost benefit analysis (see for example Costanza, 1984; Odum, 1984). The third method of evaluating ecological systems does not employ a single common denominator, but instead comparitively evaluates ecosystems using biological indicators such as diversity of species, number of rare species, naturalness, etc., and subsequently ranks them (see Ratcliffe, 1976; Van der Ploeg & Vlijm, 1978; Braat et al., 1979). The first approach requires socio-economic information. The second approach (energy evaluation) either requires data on energy prices or, in case the economy is revaluated in energy terms, an extensive understanding and knowledge of economics. In the ecological evaluation no economic input is required.

The second extension of ecological analysis is found in the development of mathematical models which incorporate variables to indicate impacts of human use of resources and environment. These models usually have exogenous input variables denoting pollutants or produce output variables describing harvest quantities. A great number of pollution models have been developed over de last decade. They range from general pollution impact models, via the abundant class of eutrophication models to the very specific ecotoxicology models, dealing with heavy metals, PCB's and radiation. They cover all sorts of terrestrial and aquatic ecosystems, lake models being the most abundant (see Jorgensen, 1979; Van Steenkiste, 1978; Rinaldi, 1982). A similar range of models has been developed in resource ecology, notably both for abiotic resources (water, soils) and biotic resources (agriculture, fisheries and forestry).

3.4. Integrated economic-ecological models

In an operational sense, economic-ecological models are models which are capable of assessing the relevant impacts of the socio-economic activities on ecosystems, as well as the relevant effects of the development of ecological systems on socio-economic activity. In a structural sense, econo mic-ecological models are models in which both the economic and the ecological phenomena relevant to a particular problem, as well as the relationships between socio-economic activities and ecological processes essential to the problem are included in a adequate manner.

One may distinguish two major classes of integrated economic-ecological models. Firstly, there are economic-ecological models which are constructed by integration of existing models. They are sometimes referred to as 'compartment models'. The main research question in this area is: which mathematical formats are available to transform the output of one monodisciplinary model into input with the characteristics required by the other one? The second class of economic-ecological models is rooted in so called 'general systems theory' (see e.g. Van Bertalanffy, 1968) and is often called holistic modeling. These models are typically built as one consistent model, instead of being put together from separate, monodisciplinary submodels. To achieve consistency a single model operation technique and a single denominator for the variable quantities are used.

A survey of economic-ecological models (Braat & Van Lierop, 1985) indicated the following general characteristics of this type of models. Completely dynamic models dominate. More than 76% of the ecological and 67% of the economic submodels in the survey are dynamic. Less than 7% of the models is completely static.
Another aspect looked at is the operational technique of the model. In the survey we found about as many optimization (prescriptive) models as simulation (predictive) models (29% and 36% respectively). The remaining 35% consists of combinations of these two types. The ecological submodels are built for simulation experiments in 71% of the cases, a majority of the economic ones use optimization techniques (62.5%).
As to spatial aspects, the survey results indicate that the local and regional scale of modeling is most common in this multidisciplinary field. A closer look at the submodels reveals that in about 65% of the models the geographical scales are the same, either local, regional, national or global.

Now that an overview of the models has been given, we turn to the next phase in the problem solving proces: model selection and design.

4. Guidelines for model selection and design

4.1. Introduction

In this section we introduce guidelines for model selection and design. The guidelines direct these processes in very general terms only. In case a number of promising models is available, one must select the most appropriate one for the problem at hand. This is discussed in Section 4.2. If an appropriate model can not be found among the existing resource and environmental management models, a new model must be developed. Section 4.3 deals with the pitfalls and techniques of the various way to do so. Next to these technical aspects, there are institutional constraints which influence the selection or design of a model for management. A brief discussion of this aspect is given in Section 4.4.

4.2. Steps in model selection

In Section 1 we have stated that the selection of an appropriate model for a particular management problem must be based on the dimensions of the problem. Figure 5 indicates the model types considered adequate for the three management objectives distinguished in Section 2. The figure illustrates that, for example, ecological impacts of resource use can not be modeled adequately by models of resource economics. The straightforward choice would be a resource ecology model consisting of a relatively comprehensive, dependent ecological submodel and a relatively simple economic (driving) submodel. If feedbacks are relevant because one suspects that the impacts have an influence on the causing factor, then these should be included. If, in another case, a simple indicator of ecological impacts is preferred because the concern is more on the causal side, i.e. the economic subsystem, or if the simple ecological indicator is the only possibility datawise, then environmental economic models are appropriate structures. Finally, in case the management objective regards both the impacted system and the causing system, and the issue is one of long term consideration, complex economic-ecological models (most likely with feedbacks) are the logical choice.

	ENVIRONMENTAL & RESOURCE ECOLOGY MODELS	ENVIRONMENTAL & RESOURCE ECONOMICS MODELS	INTEGRATED ECONOMIC ECOLOGICAL MODELS
NATURE CONSERVATION ISSUES	adequate	-	more than adequate
ECONOMIC ISSUES	-	adequate	more than adequate
SUSTAINABLE RESOURCE USE ISSUES	-	-	adequate

FIGURE 5 Management issues and model type

The next step is included to determine the operational technique which fits the cognitive purpose of the model in the respective phases of a management process (see Figure 2 and for details Van Lierop, 1985).

4.3. Technical aspects of model design

If a new model is to be developed because an appropriate model is not available in the files to which one has access, one can choose between starting from scratch and integration of existing partial models or model parts. In both cases one needs to link variables representing different parts of the resource or environmental system; as we have seen in the previous section this implies integration of economic and ecological models and variables. For the selection of model components (submodels, variables) the steps indicated in Section 4.2. are followed.

As indicated before there are two methods to develop an integrated model:
1. integration of two, monodisciplinary submodels, and
2. integrated holistic modeling.

In the first case the modeler has different models as starting material. He has to assess the differences behore deciding on a method to connect them. In the second case the modeler starts with a problem description. In this case he has to define the variables which must then be integrated in one model.
In practice the difference between these two cases is marginal. Integration of submodels implies defining and quantifying relationships between individual variables in different submodels. Empirical models can be built if the quantitative specification can be derived by statistical analysis of data. The most common method is some form of regression analysis, either by maximum likelihood or by least squatres estimation (see e.g. Dobson, 1983). If the data set and the variables do not fit the requirements of the statistical parameter estimation techniques one can resort to theoretical model building. By comparison of initial simulation results with observed data, parameter values can be calculated. In both cases the model should be tested against data not used for parameter estimation.

If there are differences in temporal or spatial scale, then the most common solution is to aggregate or disaggregate parameter and initial condition values. Both are regularly used to facilitate multidisciplinary connections.

If the mathematical structures differ, one can sometimes adapt one submodel to fit the other (e.g. linearize equations, turn stochastic equations into deterministic ones and dynamize static submodels). Another way is to reformulate both submodels (partly) to establish the basis for connections and realize an operational model. Creativity and mathematical proficiency are necessary ingredients for such an operation to succeed.

The actual connection is sometimes done by model specifications in which the independent variables have a dummy character. Although quite simple and straightforward, this technique is still problematic due to the fact that dummy variables neglect part of the information they represent and because they can hardly be tested.

All the transformations and adaptations will only lead to scientifically adequate models if the new, integrated model can be tested against a sufficient data set. If such a data set is not available, the model may only function as a conceptual tool, which integrates knowledge and assumptions and calls for testing. Generally the data on which the different submodels are based, differ in type and quantity. Not always is quantitative information available. Several techniques have been developed to deal with qualitative and incomplete data sets. Examples are path models, scaling analysis, graph theory and dissaggregate choice analysis.

If straightforward observation, experimentation and data analysis do not provide an empirically based relationship, technical manipulation of variables, data and equations may be required to quantify the relationship. Two examples are given. Multidisciplinary relationships are regularly modeled by 'intermediars', i.e. intermediate variables or even complete variables for which a direct relationship can not be established, or provide an aggregation/disaggregation mechanism. The second example regards conversion of the dimensions of the individual variables. However attractive these tricks may appear, specific characteristics of the converted system are lost. And sometimes these are essential ones.

4.4. Institutional constraints for model design

In the process of constructing environmental and resource management models, both technical problems and institutional constraints are distinguished. The technical problems have been reviewed in the previous section. Institutional constraints include institutional circumstances and differences in objectives and views between model builders and model users. Academic modelers from different desciplinary backgrounds obviously differ as to language, concepts and theoretical views. An even greater gap of concepts of the real world exists between academic modelers and policy makers (Biswas, 1975; Frenkiel & Goodall, 1978).

The key concept in policy modeling is effectiveness. This means that a model must contribute as much as possible to solving the problem for which it is built. The objective of academic modelers, however, is adequacy. This is the degree to which a model corresponds with that part of the real world system it is supposed to represent (Majone & Quade, 1981). Striving for adequacy requires striving for a comprehensive model, which then tends to become large and complex, and consequently costly.
In policy studies this leads to a trade off problem. A model will definitely not be effective in solving a particular problem if it is not adequate at all. It is also not effective to keep improving the model ad infinitum and not use it to contribute to the problem solution. One may conceive of an optimum where the model is adequate enough to produce realistic results and is completed within the constraints of time and financial resources so it can be effective in the policy analysis at hand.
This suggests that when modeling for general policy analysis, one should keep the model 'simple'. This implies a model with a clear, and limited purpose. Also, there is no use for hiding uncertainty in complex detailed

models. It is more effective to make uncertainty explicit in alternative versions or scenarios, to design and run rough models early in the project and to pay attention to articulate documentation. In addition, the effectiveness of a model may be increased by involving policy advisers in the model design (Biswas, 1975; Dror, 1984; Environment Canada, 1982; Holling, 1978).

5. Conclusions

The selection of models discussed in this paper indicates, and not more than that, which types of technical structures and characteristics can be expected and should be selected or designed for environmental and resource management problems. Obviously, not all problems warrant a complex, integrated economic-ecological model. Much of resource management involves short term decision making, for which simple economic or ecological rules of thumb may be sufficient. If however long term strategies are decided upon, a comprehensive model which pays attention to all major processes in the resource and environmental management system is still to be preferred. We hope this paper contributes to developing the most appropriate, adequate and effective model for those occasions.

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4.1.2 ORGANISATION FOR REGIONAL RESOURCES MANAGEMENT

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INTRODUCTION

My aim in this paper is to discuss concepts relevant to the management of complex human activities. Since I'm not an expert in regional resources management I will keep the discussion at a general level; my hope is that it will provide insights to those who do have an in depth knowledge of regional issues.

In the first part of the paper I explore the "regional system" from the point of view of its performance vis-a-vis societary demands. In particular I discuss the relationships between environmental changes and organisational responses and suggest some of the options open to managers if their problem is to improve performance in the context of an ever increasing rate of environmental changes. In the second part of the paper I deal with the more specific issue of organisational design, in particular with the issue of coordinating organisational activities. Since all the discussions up to this point are fairly abstract I will endeavour in the third and last part of the paper to illustrate concepts by making reference to my experience with Local Government in England and Wales.

The Regional System

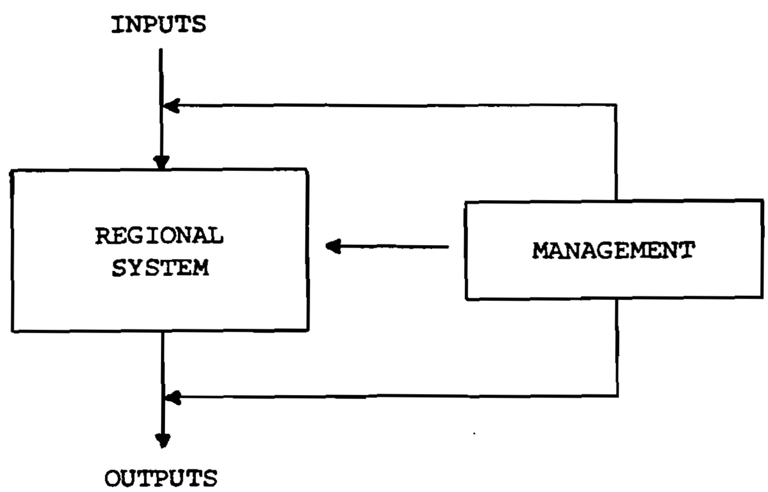
I define the regional system as the set of institutions and institutional parts concerned with the transformation of regional resources into regional output. For all my purposes these institutions are a "black box" with resources as input and products and services as output. While the management of these transformations is distributed between many institutions and between several structural levels within each institution, I suggest that there must be a set of managerial instances concerned with the management of the region as a whole (Fig 1). If this were not the case then the region would not have a recognisable identity. (Of course for analytical purposes it may well be that studies make reference to regions which do not possess cohesion at all; however, if this is the case, the "regions" would only be creations of the analysts and not organisations in the world.) In other terms the boundaries of any existing regional system are defined by the highest structural level at which cohesion exists with reference to particular regional "missions".

At the risk of oversimplifying I suggest that the mechanism which is used to manage this regional system is of the following kind:

The structure of the black box i.e. regional system, defines the transformations that are possible. Management sets - as an outcome of complex policy processes - the criteria of performance for the regional activities. This criteria defines the "target set" (T) or the regional outcomes which are perceived as adequate (from the viewpoint of stability) by the multiple people affected by the regional transformations. The comparison of regional outcomes now (actual outcomes) and in the future

Figure 1

The Black Box



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(expected outcomes) with the outcomes within the target set (T) triggers "errors". These errors require the production of "response strategies" either to bring back the system's outcomes within the target set or to anticipate potential problems in the future. The set of response strategies (R) contains strategies to manage the regional resources. However, this deceptively simple mechanism is constantly upset by a set of environmental "disturbances" (D). By and large the regional system should be able to absorb these disturbances by itself and hence it should be able to maintain the outcomes within the target set by self-organisation and self-regulation. However, in a number of situations the "strength" of the disturbances is going to be such that the system will go out of control (out of the target set T). It is for these latter disturbances that management either finds a response strategy or it will lose control of the situation (Fig 2).

Indeed the complexity that management has "to see" in the regional system is defined by the set of disturbances (D) for which it must produce a set of responses (R) to keep the outcomes within the target set (T), The relationship between these three sets is defined by Ashby's law of Requisite Variety (Ashby 1964). If it is assumed that each response is adequate only for one disturbance then the relationship is as follows:

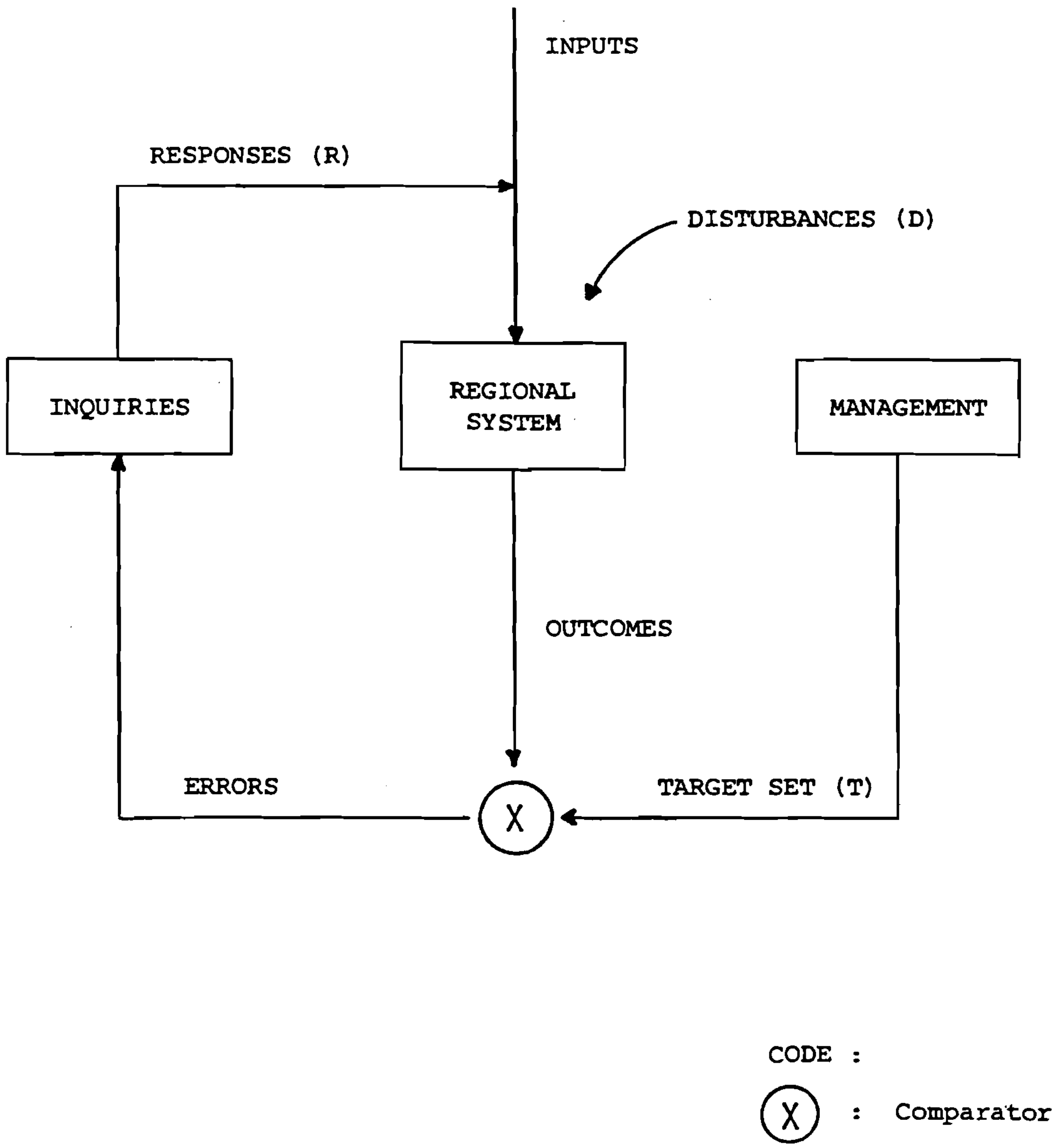
$$(T) \geqslant (D) / (R)$$

"The variety of the outcomes of a system is larger or equal (but not less) than the ratio between the variety of disturbances and the variety of responses".

This law is defining an upper limit for the regulatory capacity of the regulator. If the criteria of performance to maintain stability in the

Figure 2

Control Model



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regional system implies that the target set (T) has to have fewer outcomes than those implied by the ratio between the varieties of disturbances and responses then the regional system is bound to be in an unstable state.

I have developed elsewhere a general discussion of this law (Espejo & Howard 1982) and it is not my purpose to do the same in this paper. Perhaps one insight to get out of this proposition is this: if policy-makers, in their interaction with the regional system, perceive relatively low complexity in the disturbances but large complexity in the outcomes then, the likelihood is that they are finding it difficult to control the regional system. This is the case simply because they are unlikely to produce responses for disturbances which they don't see.

I think the above discussion is particularly relevant in today's society where it is evident that people are more and more concerned by the indiscriminate use of limited resources at all levels. Somehow today's higher concern for the environment is an expression that society is not prepared to accept the benefits of regional resources at any cost. In our terms this means that there is a greater stringency in performance requirements: the target set (T) has today fewer elements than in the past. This social definition of the target set is indeed creating problems: firstly, it is forcing upon us new boundaries for the regional system, boundaries which emerge from the need to take into account more and more regional variables, secondly, it is forcing upon us the need to pay attention to more and more environmental disturbances.

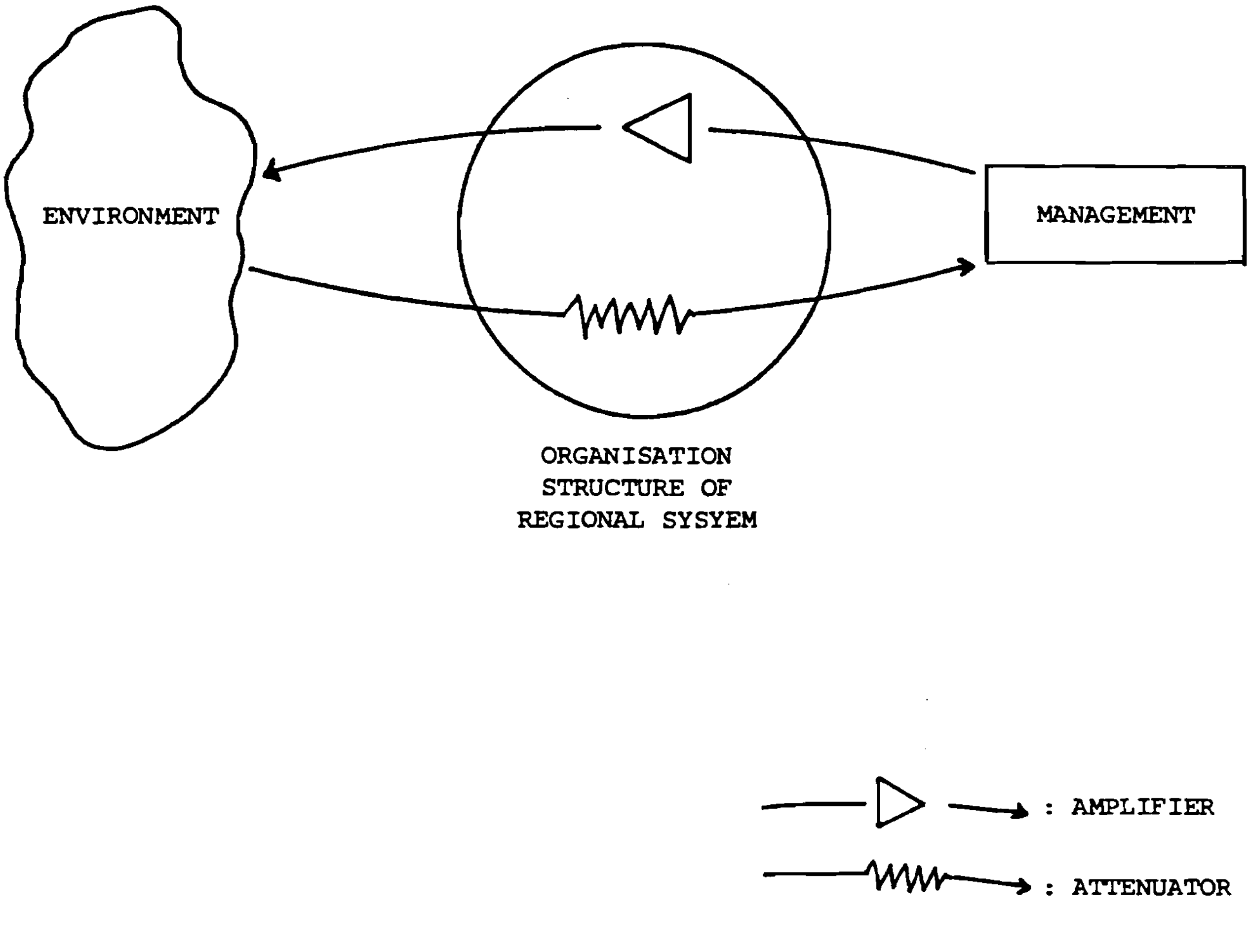
From the viewpoint of policy-makers the complexity of the regional system is growing rapidly. They haven't got the choice - as it is often the case in situations where there are slacks - to drop performance as the valve to absorb any mismatch between their actual responses to disturbances and the responses required to match the new "socially implied" level of environmental complexity. To do so would create large instabilities.

Unfortunately, the fact is that we live in very unstable environments. However, if we accept that the problem is to find means to keep the outcomes of the regional system within the "socially implied" target set then, the law of requisite variety offers useful guidelines to achieve this by design and not as an outcome of expensive and painful trial and error.

The law of Requisite Variety suggests that policy-makers and managers in general have to develop - directly or indirectly - not only capacity to appreciate more complexity in the environment but also, and most importantly, more capacity to produce responses to these disturbances. The meaning of directly and indirectly is important in this case. The point is that managers, as any other human being, have a limited capacity for information processing, and therefore they cannot increase their appreciation of complexity beyond that which is allowed by their natural limit. Since the imbalance between the complexity of social tasks and the complexity of managers is indeed very large, there is a need for an organisational structure to bridge the gap. On the one hand the organisation structure is a means to attenuate the complexity of the environment vis-a-vis the managers, on the other it is a means to amplify the managers' complexity vis-a-vis the environment's complexity (Fig 3). The organisation structure links managers to the social reality they are concerned with; if the filtration is poor i.e. if the organisation is ineffective, managers will develop a poor appreciation of that social

Figure 3

The Organisation as an Amplifier
and Attenuator of Complexity



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reality. Equally, if the amplification is inadequate, however good the policies might be, they will not have the intended effect in the environment.

Hence the relevance of organisational design as a means to achieve the "socially implied" criteria of performance for the regional system. Of course by organisational design I do not mean the design of an "institution"; I mean the design of the multiple institutions and/or institutional parts dealing, locally or not, with regional issues.

Though the above propositions are general in nature they do permit to draw useful implications for the management and policy making of the regional system. I elaborate on this point in what follows:

- Management is interacting with the environment through the regional system. If regional policies are going to be implemented effectively then the organisation structure of the regional system has to develop - due to the limited capacity of managers - a capacity to respond autonomously to environmental disturbances.

- It seems important to realise that part of the (potential) environmental disturbances to the regional system can be absorbed directly in the environment itself, and therefore that only the residual part is complexity relevant to the regional system, for which it has to develop its own response capacity. The level at which this residual variety is matched by the variety of the regional system defines its performance. Hence it should pay off to the organisation if managers produce strategies i.e. policies, aimed at reducing the residual complexity that is relevant to the regional system.

- Of the total complexity in the regional system, the complexity that is relevant to managers is the residual complexity which is left unattended by the processes of self-organisation and self-regulation in the regional system. If they fail to match this residual variety then the system will be out of control. This would be the case if the residual variety were larger than the information processing capacity of the managers. The implication is, since their information processing capacity is indeed limited, that managers have to manage the resource information itself, they cannot leave to chance the choosing of the issues and options under their attention; they have to control the processes underlying the choosing of these issues and options. The complexity they can see in policy issues is very limited and therefore they should realise that their best chance to improve policy making is simply by monitoring the organisational interactions and not by getting involved in the details of their content.

- From the viewpoint of complexity the greater stringency of the "socially implied" performance requirements implies the need "to see" more complexity in the disturbances upsetting regional outcomes. For this purpose policy makers have two kinds of (extreme) strategies: they can either find more effective forms (than those currently available) to attenuate the complexity of environmental disturbances or they can add responses (to their response set R) to cope with the larger set of relevant disturbances. However, a mix of these two extreme strategies is likely to be the most effective approach. By discovering constraints in the environment it is possible to simplify multiple apparently independent disturbances into one disturbance. The discovery of an analytical function which permits implementing one simple response to cope with a range of as yet unrelated disturbances illustrates the point (Espejo & Howard 1982). Indeed I see this as a major contribution of "Applied Systems Analysis" to societary issues. However, more effective attenuation whether it is the outcome of (analytical) simplification or of a larger organisational capacity to discriminate disturbances, needs to be matched by a related capacity to produce responses. The case in which particular policy makers have the support of powerful tools to attenuate the complexity of the environment but have no related structural capacity to produce responses i.e. have inadequate amplifiers, is not uncommon and makes apparent the fact that attenuation and amplification have to go hand in hand to be effective.

All the above implications should make apparent that an effective management of the regional system implies a continuous process of organisational design (adjustments).

About Organisational Design

While organisational design should take into account a variety of structural and human aspects, in this paper I want to limit my discussion to one aspect of structural design: the design of structures to support the coordination of the regional activities.

A greater stringency in performance requirements suggests that the regional system may need to take into account more activities and more relationships: among other factors, there is a need for more effective means to coordinate these activities. I intend to explore, at a conceptual level, the meaning of coordination in complex systems.

It seems important to distinguish two major types of activities in any organisation; firstly, there is a group of activities implementing the purposes ascribed to the organisation i.e. its missions, and secondly, there is a group of activities regulating the implementation activities. I think, and I argue about this below, that a precise distinction between these two types of activities is important for design purposes. In practice, however, the distinction may be blurred by the fluid nature of organisational purposes.

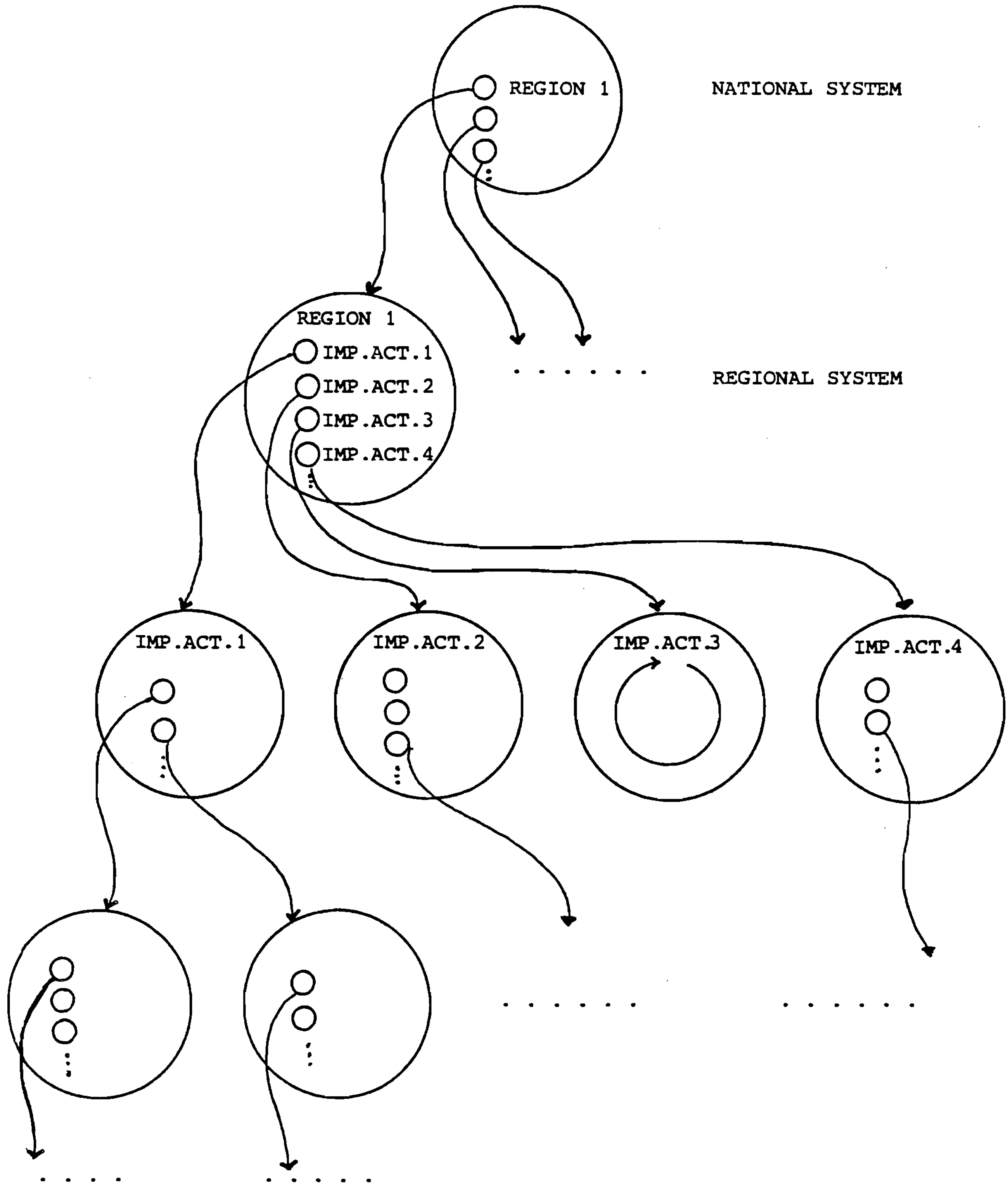
In line with my earlier definition of the regional system, implementation activities for this system are those producing the regional services and products (producing was the tacit purpose ascribed to the regional system). These are the activities defining the technology of the regional system, that is, the activities transforming the regional resources into products and services for users in the environment. Hence, for instance, a regional agency "producing" energy would be an implementation activity, however, an agency in charge of environmental controls would not be an implementation activity. The output of the latter agency exists only because there are activities like producing energy which make necessary environmental regulations. Equally, activities like promoting, marketing, planning, investigating, organising.... the production in the region would be regulatory and not implementation activities. However, all activities transforming resources, at an initial, intermediary or final stage, into the outputs implied by the purposes of the regional system, are implementation activities.

The importance of this insight is that it helps to define, at different structural levels, the objects of managerial concern. Clearly the regional system as a whole is an implementation activity; it is implementing national policies and therefore it is one of the "objects" of management concern for that level. Within the regional system, as in the level above, there are implementation activities as well as regulatory activities. For instance, the institutions responsible for the provision of services to the community, like transportation, housing, health or the agencies responsible of industrial activities, are implementation activities in the regional system. On the other hand institutions or institutional parts responsible for the planning, regulation or management of implementation activities are instances of regulatory activities. Equally, the regional implementation activities, at this structural level, have implementation and regulatory activities. This "unfolding" of complexity takes place as many times as it is necessary to absorb in full the complexity of the regional tasks (Fig 4). While implementation activities define systemic entities in their own right, the entities performing regulatory activities get their meaning only with reference to implementation activities (Beer 1979, Davies et al 1979).

The mechanism underlying the formation of structural levels is described below. Structural levels are an outcome of processes balancing task complexity with regulatory complexity. One managerial level cannot penetrate in full the complexity of its implementation activities. At the point where this management (regulatory) level finds difficult to maintain its cohesion vis-a-vis its implementation activities, a new structural level, with its own regulatory activities, becomes necessary. The need to devolve autonomy to a lower structural level may also be necessary at this new level, and the same may well be the case at this new structural level and son on, until the full complexity of the tasks is absorbed. Of course this is very much the outcome of self-organising processes.

Figure 4

Implementation Activities : Unfolding of Complexity



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The number of structural levels inbetween those which absorb in full (at the front end) the complexity of the region's outputs and those responsible for their overall management, is a function of the control strategies in-use in the region and the complexity of the environment. In this sense the partitions of the overall implementation activities into sub-activities are a function of the managerial strategies in use. Hence, with reference to similar implementation activities, a setting which gives emphasis to action planning is likely to need more structural levels than a setting relying in overall performance controls. This is the case simply because the former setting needs to rely more on direct supervision as a mechanism for coordination and therefore it is likely to overload sooner the related management. More direct supervision creates the need for more intermediate levels to cope with unavoidable information overloads. On the other hand in a performance oriented system "mutual adjustments" (self-regulation) is more likely to be the dominant coordination mechanism.

The above discussion suggests two important mechanisms of coordination: direct supervision and self-regulation. Of course these two forms of coordination exist in all settings. However, if the purpose is to increase the capacity of a management level to deal with interdependencies, the former approach puts the emphasis in the coordination of regulatory activities, while the latter approach puts the emphasis in the coordination of implementation activities. The former approach aims at amplifying the capacity of managers vis-a-vis implementation activities, the latter aims at attenuating the complexity of implementation activities vis-a-vis their management. Indeed it should be possible to assess the costs and benefits of each approach.

However, since in general the complexity of implementation activities is much larger than the complexity of regulatory activities the impact of designing coordination mechanisms for the former activities is also likely to be much larger.

The design problem is reducing the complexity that managers need to see in implementation activities without hindering overall performance. Partition of implementation activities is a way of achieving this aim. If this partitioning is well thought out, then it should be possible to reduce the complexity that is perceived by managers. On the contrary, chance partitions or poorly worked out partitions are likely to increase the demands on management to the point of hindering performance.

The simplification of implementation activities vis-a-vis their management suggests effective horizontal interactions or coordination between the implementation activities themselves. The more self-regulation is made possible among these activities the less complex they will be perceived by management.

The important insight is that if achieving a particular level of performance implies that management has to recognise more complexity in the implementation activities than it can cope with, then clearly many implementation states will go unrecognised or undetected reducing de facto the level of performance. Adjustments or design of the structure may permit this undesirable state of affairs to be altered. One particular adjustment is precisely to change the decomposition of the organisational implementation activities.

The problem is how to break down implementation activities in order to increase the chances of mutual adjustments. I think prescriptively it makes sense that the partitioning of global policies should aim at achieving a balanced distribution of complexity between all the lines along which complexity unfolds: ideally all these lines from the global tasks to the final operational activities should have the same number of structural levels. This approach makes possible a maximum use of self-regulation (mutual adjustment) as a mechanism for coordination.

Of course this is not always possible. If the perceived relevance of a low complexity activity (e.g. an activity whose complexity can be fully absorbed by one structural level, as it is the case of activity 3 in Fig 4) is high, the likelihood is that it will need to be regulated at a high structural level, creating an imbalance in the distribution of complexity. However if - as noted earlier - these imbalances happen by chance or as a result of inadequate design their cost in terms of less effective coordination can indeed be high.

The problem seems to be how far it is possible to anticipate the need for interrelations among implementation activities. Indeed, in designing structures it should help to take into account interdependencies and dimensions as perceived by experts in the activities of the regional system. As suggested in the first part of this paper the attenuation of the organisation structure must have the capacity to discriminate all the interdependencies and dimensions that are recognised as relevant in the policy process. A mismatch between the structural attenuation and the models currently held by managers (as an outcome of the socially implied performance) is a sign that structural adjustments are necessary. Managers will perceive an inadequate performance of the regional system.

Indeed the tacit structure of the implementation activities, that is, their network of communication channels, defines the current tasks of management concern. If, by comparing these tasks to any "acceptable" expert model available for the interrelations of the regional resources it is found that there are mismatches,then it is likely that there is room for structural improvements. This type of mismatch is in fact a very common situation; the evolution of institutional forms may lag behind the "current" appreciation of the interdependencies between activities. However an intellectual understanding, while necessary, is quite insufficient to respond to the threats posed, or the opportunities offered, by this current appreciation. Specific communication mechanisms must be designed if the interrelations of the expert models are going to have a realisation in the "real world".

The Case of Local Government in England and Wales

Though Local Government in England and Wales may not be a good example of a regional system as defined above, it provides an instance of the problems emerging from an inadequate partition of implementation activities.

A major restructuring of the system of Local Government in England and Wales took place in 1974. The 1972 Local Government Act had created a two tier system of metropolitan and shire authorities; county and district authorities were created for 6 large conurbations (metropolitan areas) and 40 odd urban-rural shires. Though the new system was a two tier system with county authorities being responsible for whole counties and district authorities being responsible for districts within the counties, the new system did recognise the principle that local authorities had to be accountable mainly to their own communities and therefore that any formal attempt to put districts under the control of counties was unworkable. Hence, four types of independent authorities emerged from this restructuring:

- Metropolitan Counties
- Metropolitan Districts
- Shire Counties
- Shire Districts.

However, the partition of implementation activities between county and districts was very different for metropolitan and shire authorities. The distribution of functions was such that in the former authorities most of the important implementation activities (e.g. education, housing, social services...) were left within the districts. Metropolitan counties were conceived mainly as strategic planning authorities. In the shire authorities implementation activities were split between the two levels; counties had the control, among others, of education and social services, while districts had the control of housing (of the main implementation activities). Counties, as in the case of metropolitan authorities, were to be the main strategic planning authorities.

From a systemic point of view the above partitions of implementation activities permitted to foresee two very different patterns of evolution i.e. self-organisation, for the newly created authorities.

Metropolitan counties emerged as organisations with large regulatory activities in charge of few implementation activities and with a limited influence, if any, over the districts. Anyway most of the spending was in the hands of the districts and they found no pay-off in working within the context of their counties. Each district found it could operate independently. Thus, there was no organisational framework to make possible the self-regulation of implementation activities for the county as a whole. Metropolitan counties turned out to be monsters with large heads but weak limbs. As such they could not survive for very long. Indeed, after 10 years of operations they were officially abolished, at a great cost, earlier this year. Unfortunately, it seems to me that the British Government has missed the point in pursuing this abolition. The structural ineffectiveness of an institution cannot be confused with the irrelevance of its functions. The need for a strategic view of large conurbations is indeed very necessary and abolishing metropolitan counties does nothing towards improving the management of the many operational interdependencies between districts.

On the other hand, shire counties emerged as organisations not only with important implementation activities of their own but also with a great ascendancy over the districts in their areas. Systemically this implied that de facto, perhaps against the long tradition of independent authorities, districts were not only geographically embedded in the counties but also organisationally i.e. they were implementation activities of the counties. Indeed, for reasons which, most likely, were not in the minds of those responsible of the restructuring, self-regulation of implementation activities has been a major factor in making more effective the work of shire counties. Shire districts do find it necessary to work in cooperation with the implementation activities of their counties - they are major spenders in their geographical areas - and also to work within their County's planning framework.

As I said earlier, it was possible to anticipate this evolution of the newly created authorities and I did so in a study I made of Local Government in England and Wales in 1975 (Espejo 1975).

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4.1.3 REGIONALIZATION OF ECOLOGICAL REPRODUCTION PROGRAMMING AND ENVIRONMENTAL STRATEGIES

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1. APPROACHES TO REGIONALIZATION OF PREFERENCE REGULATING TENDENCIES

The regional parametrization of economic dependence technological progress and the analysis of their effect on the growth being localized on a scale of the programmed territorial development with account of expenses of rational utilization of natural resources are realized on the basis of a multi-level and multi-sectoral system. The latter provides a conjugated simulation of the endogenization of technological progress and economic utilization of ecological resources in reproductional systems of a planned economy (Figure 1).

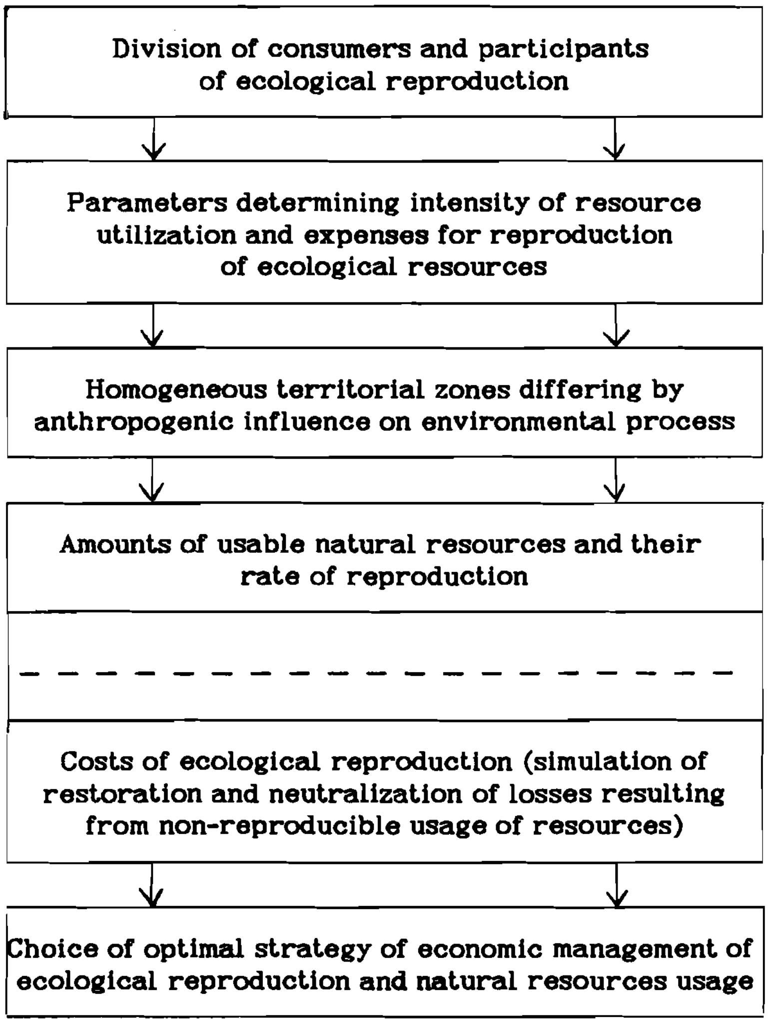
Regional localization technological progress and reproduction of ecological resources can be realized analytically, on the one hand through simulation of material and financial stocks and flows in the branches of the national economy within a certain territory. The existing conceptual instrumentarium of production functions is suitable mainly for the comparable interterritorial macro-analysis of the technological process and for formulation of variants of structuralized intensification of the alternative technological process within a territorial (or regional) frame in a generalized macro-economic form. The limitations of the traditional approaches mentioned above, is compensated to a certain extent by detailing measurable materialized parameters of production factors, such as the average level of training and progressional structure of labor, age and technological structure of capital production funds, etc.

On the other hand, internal mechanism and scales of the technological progress in the process of regional reproduction in general (including ecological variables) are covered adequately enough with direct endogenization of components (i.e. the technological progress and reproduction of ecological resources) on the level of both actual and alternatively admitted (while characterizing perspective variants) technological decisions with account of total expenses.

The perspective direction of sub-branch endogenization of technological progress with conjugated parametrization of integrated processes of social and ecological nation-wide reproduction and that on the level of separate regions of the country is realized by managing matrices corresponding to alternative technological methods of achievement (final or intermediate) within the system of forecasting of perspective development of the planned economy. The profundity of the endogenization is determined, on the one hand, sub-branch detailing of output with due regard for economic parameters of alternative technological decisions; on the other hand, by an interrelation of output and perspective structure of needs of the population.

The regionalization of technological progress and endogenization of ecological reproduction makes it possible to spatially localize into relevant

Figure 1. Aggregated scheme of macro-economic management of ecological reproduction.



periods of perspective development single- and inter-industry technological displacements and ecological disturbances of territorial units and accordingly, to construct the tree of purposes. Simultaneously, the purposeful normative regulation of selecting alternative directions of regional development acquires stable decisive importance on all levels, aspects and fields of multi-sectoral systems of forecasting — in the process of *intergrating of such levels* as a Union republic and a territorial-production complex, urban agglomerations and *agro-industrial* complexes, aspects of the limitations of R & D economic capacity and return of investments on their capital funds, etc.

It should be taken into consideration that institutional structurization is of great importance for the retrospective and prediction limitation of regional processes equally, and specifically, concrete levels of economic independence and forms of management. For instance, the prognostic systems used as in an instrument for the investigation of progressing technological directions in the economy and conjugated socio-ecological displacements should be modified differently in conformity with large regions of the Russian Federation's vast subordination to industrial-planning bodies of the given republics (R.S.F.S.R.) on the one hand, and Baltic and Caucasian regions consisting of legislatively independent to a significant degree through closely connected economic systems of the corresponding Union republics, on the other hand.

Along with the task of corrective imitation of formed regional peculiarities of development, the systems of territorial attachment of technological progress to economic growth should provide a complete evaluation of the trends of rationalization of regional potential utilization and, consequently, the intensification on a corresponding technological basis of regional needs satisfaction with the general economic and ecological strategy of the country's development. The complexity of the multi-aspect interconnections of regional development can be observed on the basis of multi-sector territorial systems of models that give insight into the perspective development and improvement of both the above mentioned interconnections by the most complete realization of purpose criteria and their conjugation with economic, social and technological structures of the development of the country as a whole and determine the most advantageous specialization of the region (under endogenized ecological variables and restrictions).

2. REGIONALIZED ORIENTATION OF ECOLOGICALLY-BALANCED PROGRAMMING AND ELABORATION OF DEVELOPMENT SCENARIOS

Socially-oriented programming of ecological reproduction conformably to the developing socio-economic activity under the accelerated technological progress unites macro-economic and industrial, territorial and social tasks of purposeful orientation. It is necessary to point out the most important elements that should be taken into consideration in the process of elaborating scenarios of programmed management:

- the utilization of non-reproducible resources (including the possible destruction or depletion of certain species) in the process of economic activity intensification;
- the improvement of background cleanliness of the environment up to standardized levels; and
- the realization of possible mechanisms of self-reproduction of the species under consideration and the conjugated resources, etc.

Simultaneously, it is necessary to elaborate an adequate conjugated system of legal rules and corresponding instructions for administrative institutional control (felling, ect.) and adequate criteria of complex economic evaluation of social (recreation, etc.) utilization of ecological resources and their technological and economic commensurability with expenses for the restoration of the reproducible components of the resources.

The criteria of complexes of normative orientation within the development of reproductional systems differ on the levels of national macro-economic and concrete inter-industry structurization. Under present conditions, it proved impossible to separate the above mentioned complexes when solving the tasks of providing rational utilization of natural resources and technological transference of forestry and/or industrial branches using these resources directly without mutual coordination of ecological and economic reproduction management. Consequently, the structurization of interactive scenarios in the process of selecting complexes of activities within a certain branch of industry, is predetermined by governmental perspective programmes of distribution of production forces according to the task of territorial development and general technological advancement and their socio-economic and ecological consequences, of solving the tasks of satisfying the needs in food-stuff, also annual, five-year and perspective plans of national economic development.

Moreover, ecological measures and industrial means on the branch level aimed at the improvement of economic activity resulting in some environmental damage represent elements of the large-scale programmes pointed out and should provide for a considerable effect in the cleaning of the atmosphere and water resources, oppose soil erosion due to different counteractions in economic activity.

The state of conceptual instruments and methods of decision-making, informational supply and level of computerization (memory, access) can be mentioned as methodical problems closely relating to the elaboration of scenarios of management of ecological resources reproduction and rationalization of their socio-economic utilization. Instrumental provision presupposes the elaboration of formalized scenarios on the basis of modeling systems and programmed provision for their consideration with the help of special software proportionate to certain accessible awareness of consumers responsible for the preservation of ecological resources (integrating material decisions on different levels of administration). The programme of technological progress endogenization is supported or guided by multi-sector systems of economic models of basis parameters of social reproduction on the regional level with due regard for problems of planned control of the environmental parameters in interaction with complex development of national economic of a Union republic.

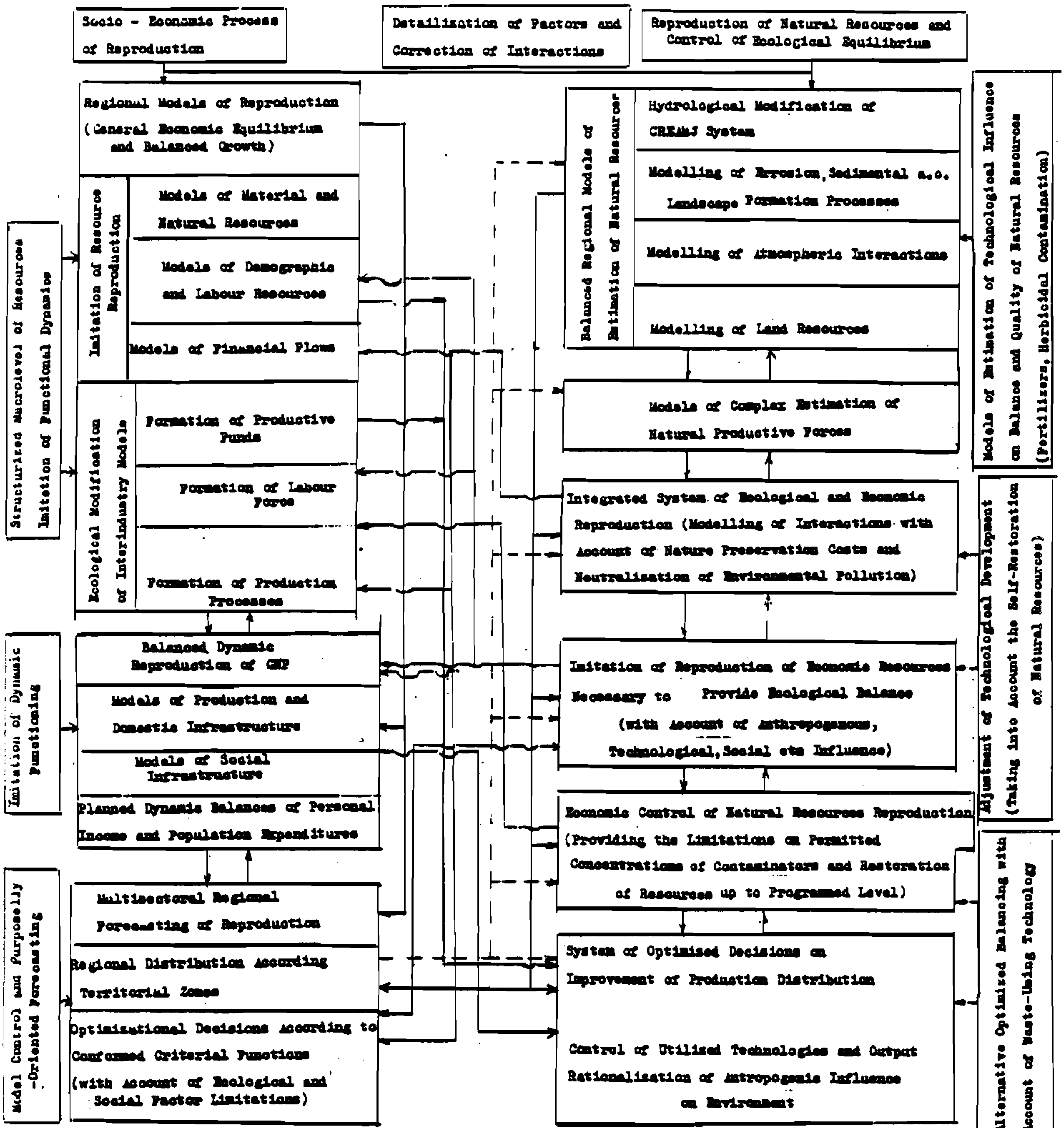
In the hierarchy of criteria of socio-economic orientation of technological development scenarios of a Union republic, it is necessary to stipulate the criteria, the realization of which makes it possible to coordinate the conditions of multi-stage numerical optimization of industrial utilization by separate ecological resources (with an account of expenses for complex processing of raw materials, neutralization of other negative anthropogenic influences of sub-industries, production distribution and improvement of technological decisions on product output, preservation of recreation zones and natural reservations.

The regional simulative system of social and ecological reproduction is presented in Figures 2 and 3. This system makes it possible to forecast the coordination of simulation submodels of socio-economic processes with economic imitation of ecological processes presupposing the calculation of labor, financial and other material resource restrictions.

The system serves as a basis for detailing structurized scenarios of integrated economic and ecological management of large-scale development (rates, proportions, directions of formation in branches and conjugated processing industries as well as their provision with required investment, production capacities, and proceeding from the supposed criteria of purposeful orientation.

Figure 4 shows the regional management criteria of an environmental preservation complex. The criteria of ecological macro-zoning are taking into consideration to some extent as well as alternative functionalization providing rational parameters of the technological progress integration into reproduction with account of region development proportions and parameters.

Concrete scenarios based on the system of inter-industry models of balanced and optimized parameters with resource-by-resource and industry-by-industry detailing of the reproduction imitation on the first stage of this system adaptation to the problems of environmental preservation are limited by a set of managerial decisional approaches to the improvement of the given block coordination



Detailing by-factors and correction of decisions on separate levels and block of model system are expected to be realized following each next iteration of calculations in accordance with dependencies of multisectoral simulation of integrated regional reproduction (both economic and ecological).

Figure 2. System of regional reproduction forecasting considering environmental limitations and re-utilization of natural resources.

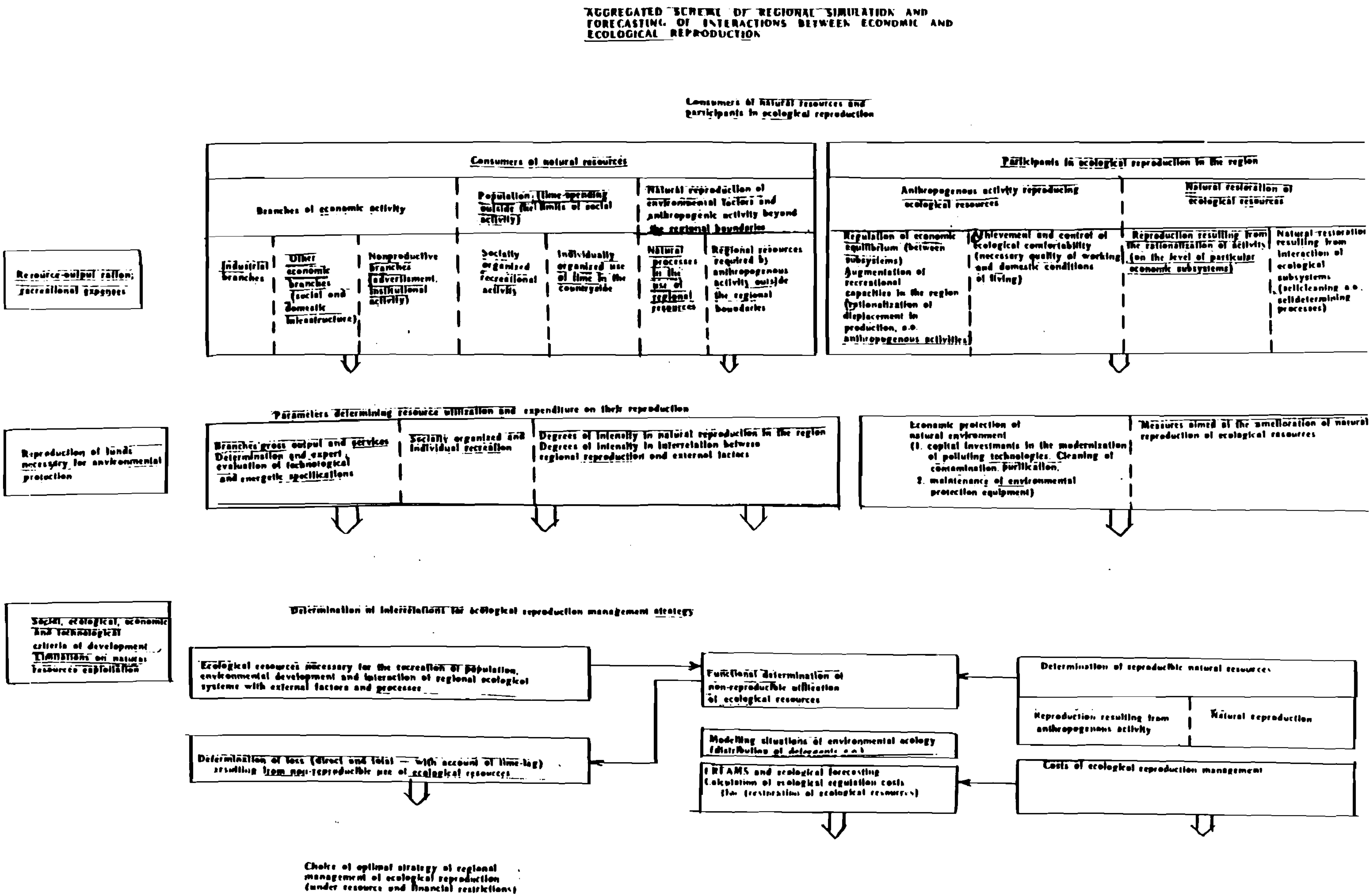


Figure 3. Forecasting of interactions between economic and ecological reproduction.

mechanism within the regional system of social and ecological reproduction. Planned users of interactive dialogue scenarios on personal computers will be able to obtain a correct flexible consideration of alternative estimation variants according to the possible achievement of aims and selection of suggestions concerning the optimized strategy for middle- and long-range decision-making.

The following sequence may be singled out in the elaboration of basic alternative scenarios.

First stage: Perfection of the regional scheme of production development and distribution taking into account possibilities of rationalization and anthropogenic exploitation of natural resources:

1. Determination of structure and aggregated levels of parameters of demands for resources.
2. Determination of capital investments necessary for the enlargement and improvement of reproductional structure of natural resources in regional territory (taking into account other limitations).
3. Determination of the volume of capital investments necessary for the formation of basic productive funds in the extraction industries processing materials and establishment of their rational structure.
4. Specification of volume and structure of the import of resources and export of processing necessary for the perspective period.
5. Evaluation of influence of various variants of anthropogenic exploitation of regional resources on general rate of its economic growth.

Second stage: Regional simulation of development of industrial branches aimed at improving the ecological resource balance and environmental preservation activity for the perspective period.

1. Determination of regional resources value within the system of factors forming the regional environment.
2. Estimation of expenses on reducing background contamination up to a normative level.
3. Recommendations concerning the change of formed and perspective structure of anthropogenic (industrial as well as agricultural) productive activity aimed at the stabilization of the ecological situation withing problematic areas.
4. Evaluation of expenses for rational re-organization of regional industrial complex and other anthropogenic activities taking into account costs (including creation and maintenance of national parks and reserves, waterside preservation plantations on the sea coast and other zones, etc., acclimatization of valuable biological species, creation of ago-protective forests, etc.).

According to coordinated methods, corresponding disaggregated sectors (subjects) of natural resources utilization and types of ecological resources are singled out on a regional level. In the process of by-factor detailing and by-stage decision-making on the level of submodels (blocks) of the integrated system, the interaction parameters between components of socio-economic and ecological reproduction are correlated within some cycles of iterative calculations and in accordance with regularities of multi-sectoral simulation set up with the structure on the macro-level.

3. RESOURCE LIMITATIONS OF SOCIAL DEVELOPMENT AND ALTERNATIVES OF GOAL ACHIEVEMENT

The achievement of alternative goals in regional development on the basis of integrated economic and ecological reproduction assumes the determination of:

- full substitution, regional and branch displacements in funds and capacities, migration of labor resources;
- interchange and substitution of products (with regard to meeting demand);
- interchange and substitution of industrial technological means; and
- alternatives of goal-oriented hierarchy with regard to the interconnection and complementary (public) demand and values as a means for their satisfaction (extension of touristic and recreational network or service system and highways for transport).

Alternative development means should be estimated by commensurement of expenses (for the technological organization, production of substitutes, etc.) and results (utility with regard to final consumption), taking into account the value of usable natural resources and neutralization of industrial contamination of the environment.

Resource limitations concerning the selection of alternative concepts of regional development technological innovations should be taken into account in detail with a conditional singling out of competitive scenarios of directive programming depending on their maintenance with:

- demographic and labor resources
- fuel and energy resources
- investment and financial resources
- resources of industrial infrastructure
- resources of social infrastructure (health, public education, culture), R & D, and the network of institutional infrastructure (the latter is significantly connected with the social one)
- natural resources (these are directly related to fuel and energy resources and, partially, to production processing when labor activities become entangled with natural processes).

The structurization of the basic systems of regional socio-economic and ecological reproduction models is organized adequately to meet all objective constraints.

The evaluation of alternative resources limitations on technological innovations influences the technological determination of both branch and inter-branch industrial tasks. Depending on the approbation by state and other official managing institutions of preferable local variants of interbranch coordination within the defined territorial scheme, the following distribution of national economic complexes is expedient:

- complex of capital investments and building industries
- territorial complex of energy and fuel
- agro-industrial complex

- complex of industrial infrastructure, etc.

In the nearest perspective the integrated development of regional systems in the Baltic socialist countries has already required the projection and formation of the following supplementary complexes:

- trade-industry complex
- complex of social infrastructure
- complex of biocenosis regulation and rational preservation of favorable natural environment.

Model structurization of the complicated interrelated branch and inter-branch systems of interacting national economic complexes provide for specific ways of imitational contacts between these structurized regional distribution models on the one hand, and general economic and ecological and interregional systems of universal models, on the other. The character of imitational constructions and interrelations of different levels of imitation should be determined with regard to the hierarchy of institutional infrastructure and interactional peculiarities of departmental regional and central bodies of government and other managerial levels.

It is possible to elaborate the following groups of Union republics each of which requires corresponding modification of the standard methodology of regional integrated forecasting of ecological and economic reproduction and rational exploitation of natural resources under technological and organizational innovation process:

- large Union republics consisting of regions and zones (R.S.F.S.R., the Ukraine) and processing a complicated institutional and departmental structure with regard for the existence of internatal organizational modifications of councils (Soviets of autonomous republics, other regional, territorial and district Soviets).
- Union republics coinciding with regional divisions (Kazakhstan) and/or embracing comparatively large territorial zones (Uzbekistan, Byelorussia)
- small Union republics making up part of a large territorially geographic region (Baltic and Trans-Caucasus, Tadzhikistan, Kirgizia republics).

Typologization of regionality should help to specify the characteristics of organizational criteria on the corresponding levels of regional hierarchy and provide normativity of determination when analyzing the realization of alternative controlled activities. Thus, both perfection of rational interregional distribution and available industrial resources on the basis of model analysis and assistance for the corresponding determination of problems resulting from the open character of regional reproduction (range and structure of ecological regulation, import and output, interregional migration of the labor force, money, technological innovations, water, soil and air pollution) should be ensured.

As a result, the typologization (including the stage of software projecting) helps both to filter non-characteristic data and improve the integrity between normative and genetic forecasting of social, economic and ecological reproduction.

4. EFFICIENCY OF PREDICTION CONTROL AT THE STAGE OF INTEGRATION OF REGIONAL SOCIO-ECONOMIC AND ECOLOGICAL REPRODUCTION

According to the elaborated structurization of complex activity, programming of social and technological forecasting for the next 20 years, methodical principles and propositions have to be formulated in conformity with preferred alternative trends in social development. In turn, the methodic regulations should be used in estimating cardinal indices and proportions of socio-economic reproduction and in restricting the range of practical regions depending on available resources and preferable tendencies in general development.

The software programming of integrated socio-economic and ecological systems of multi-sectoral regional reproduction is to be targeted at multi-variant structural analysis of tasks in long-term planning and forecasting with a view to assess the influence of socio-economic processes on the growth rate of the region. Moreover, account is taken of the fact that functional needs are more constant in character than object-oriented needs (i.e., needs for particular material goods and services which follow the change of assortment and fashion). Identical subordination is observed in functional and object targets manifested in the fluctuating intensity of developing demands as well as in the indices of supply and consumption of particular goods and services.

A matrix model, whose columns indicate the singled-out target components of the republic's perspective development and lines show their programmed stage-by-stage realization in conformity with the resources and other restrictions, may be utilized as a means of correlating the complex of both ecological and socio-economic targets in the branch and territorial development of the republic within the period in perspective.

Application of the multisectoral economic and ecological system of reproduction models provides for its variant solutions with account of such exogenously formulated criteria as increase in public welfare and intensity of social reproduction, optimization of proportions of material production branches and those of social infrastructure. It also enables a limitation of the interrelated totality of social and economic indices represented by endogenous variables of the simulative system. Such a regime of functioning of the forecasting system ensures a realization of the basic methodological principle thus safeguarding the trustworthiness of prognoses made by socio-economic systems which are characterized by a great number of interrelated parameters and verifying the conformity of prognostic calculations with different aspects of social development.

The formulated numerical problems (variants) of regional socio-economic development are, as a rule, approximated by methods derived from theoretical inquiry into operations research, mathematical and logical programming. However, functional correlations between particular economic alternatives such as dependence of the volume of capital investments in production on the volume of gross output by the branches, between the volume and structure and productive activity of the population manifest themselves in complex analytical forms. Hence, practical realization of the system of model analysis and the prognostication of GNP reproduction may encounter computing difficulties in the adopted software programming. With the increase in the number of earmarked industrial branches and the development of descriptive methods of economic activity, including the consumption habits of the population, and on the assumption that all or the majority of the earmarked items represent endogenous variable systems, the number of restrictions concerning problems occurring in the scrutiny of concrete scenarios considerably increases and amounts to several tens of thousands. This call for an artificial linearization of a formal description of the actual dependencies and for an application of correspondingly simplified methods of mathematical solution.

The technological amelioration of alternative scenarios for integrated economic and ecological reproduction processes based on a developed system of regional prognostication models should take into consideration the following peculiarities:

a) intersection of different social priority systems (including interdependent systems)
b) multi-extremality of social criteria of stochastically interpreted social processes (especially those including obscure preferences difficult to formalize adequately)
c) inadequacy of benefit (usefulness) criteria or disproportion with regard to different social groups in the formative stage of aggregated target function
d) changes in the interrelation between typology (established stereotypes) and normativity in the priority system for different time periods, territorial units, and the like.

Perspective scenarios in the field of imitation of social reproduction with due regard to the interaction between regional development and ecological environment should, in particular, allow for the following circumstances:

- imitation of coordination between branch and large-scale regional management decisions aiming at ecological preservation with regard to tasks of socio-economic development
- branch-by-branch imitation of land, water, and air purification from technological pollution in conformity with available and required resources
- substantiation of expert and programmed targets in the field of development and distribution of individual branches (industries) in compliance with total and direct damage by pollution and expenditure for refinement
- substantiation of trends in the amelioration of industrial structure, domestic and social infrastructure, with due regard to the effect of industrial development on ecology as well as with a view to improving the comfortability and recreational facilities of the environment (working conditions, recreation, and everyday necessities) for the micro-population of any particular region.

Consistent detailing of a structured model system of multi-sectoral regional imitation of integrated economic and ecological reproduction supplemented with a key subsystem for tackling variable problems of distribution and modeling in the interactivity dialogue should ensure:

- an elaboration of coordinated estimates for maximum capacities of major units in the branches of chemistry, fuel, energy, etc.
- an alternative choice of a construction site for any such units taking into account implied risks of upsetting the ecological balance of the natural environment of the region.

Thus, the scenarios discussed are subordinated to the strategy of long-term socio-economic development of the region taking into account the rational utilization of ecological resources furthering the formation of the optimum environment for vital activities of the population (with regard to integration of technological progress into interconnected processes of social reproduction).

5. SIMULATION OF ECOLOGICAL AND ECONOMIC REPRODUCTION MANAGEMENT ON THE REGIONAL MODELING SYSTEM

As it is well known, the interaction between a specific branch and national economy is characterized in general by direct dependencies between the amounts of output $\hat{X}$ and natural resources P necessary for its production:

$$P_{ij} = P_{ij}\ (\hat{X}_{ij})\ ,$$

where:

P_{ij} = volume
j = applied resource
i = branch applied resource j if
$\hat{X}_{ij}$ = index (or complex of indexes) describing industrial activity of i branch within the period under discussion.

It is necessary to stress than even in productive industries, the index j does not necessarily coincide with the gross output.

In turn, the national economy provides the ecological resources reproduction. Moreover, it is necessary to single out the supplementary expenses for natural resources reproduction and considerable material losses both in the estimated and unestimated properties and items to the unrestorable part of these ecological resources.

The terms "resource usage/consumption and production" implie pollution and purification or production and distinction of potential contamination respectively (including employment or production of natural resources *per se*).

The total volume of the resources utilized within all the spheres (i) of regional activity (P_j), i.e.,

$$\sum_i P(tij) = P(tj)$$

consists in its turn of the restorable or reproducible part P_j^b and unrestorable part P_j^H. Hence,

$$P_{tj} = f\,(P_{tj}^b + P_{tj}^H)\ .$$

This possibility should be taken into consideration when ecological and industrial resource production raises its utilization.

The final economic losses Π_j resulting from the anthropogenous utilization of j resource consists of the resource reproduction costs Π_j^b and losses resulting from unrestorable resource application:

$$\Pi_{tj} = f\,(\Pi_{tj}^b + \Pi_{tj}^H)\ .$$

Expenses on ecological resource reproduction are fixed in accounts by branches and hence, may be compared with the ecological social and economic preservation effect. A considerable part of the information evaluating the effect and expenses on resource reproduction is reflected only in departmental accounts and cannot be found on the level of centralized macro-economic evaluations. This is a serious drawback in determining the qualitative relationships between the effect and expenses in ecological resource reproduction.

When resource reproduction implies its protection and destruction of its potential contaminator, expenses on environmental preservation consist of the capital investment on the construction of protection (technological objects) and expenses of operation on the attendance and maintenance of the existing/functioning basic funds (cleaning and purification equipment).

Since reproduction of the basic environment protection funds does not differ radically from reproduction of the basic industrial funds, and sometimes their foundation even coincide (in place and time), there is a reason for the simulation of environmental fund reproduction based on the same scheme as basic fund reproduction:

where:

F^o_{ij} - basic funds of i branch for j resource reproduction at the end of the base year

$U_t P_{ij}$ - indices characterizing the log of capital investment (U_{tp} = the part of funds introduced in the year which is formed from investments in $t-p$ year)

t_{ij} - coefficient of funds amortization

B - the function characterizing evenness of fund formation

P^{-b}_{tij} - the amount of funds necessary for reproduction of j resource.

The volume of capital investment E^{kbn}_{tij} is determined by the following function:

$$E^{kbn}_{tij} = \sum_{s=o}^{k} U_t + sij \frac{1}{B(t+sij)} [S_t + sij\ P^{-b}_{t+sij} + (1+B_{t+sij}) :$$

$$\sum_{p=1}^{t+s-1} (-1)^p S_{t+s-ptj}\ P^{-b}_{t+s-pij} + (-1)^{t+s} (1+B_{t+sij}) F^o_{ij}] \ .$$

where: $t = \overline{1,T}$; $i = \overline{1,n}$; $j = \overline{1,n}$.

The volume of operative expenses for attendance and maintenance of funds for environmental protection (E_{tij}) is determined by the amount of these funds:

$$E^{bk}_{tij} = e(F_{tij}) \ ,$$

where:

F_{tij} - the average volume of basic funds of i branch for branch i for the reproduction of resource j within year T.

The total amount of expenses E^{Σ}_{tij} is expressed by the sum of E^{kbv}_{tij} and E^{bk}_{tij} :

$$E^{\Sigma}_{tij} = E^{kbv}_{tij} + E^{bk}_{tij} \ .$$

The total economic expenses on reproduction of j resource, E^b_{tj} is equal to:

$$E_{tj} = \sum_i \overset{\Sigma_{tij}}{E} \ .$$

Hence, the total expenses on all resources are equal to

$$E^b_t = \sum_j E_{tj}{}^{b} \ .$$

Calculation of the total expenses on environmental protection of reproduction of j resource would be supplemented by structural matrix calculations of environmental protection expenses by i branches M_{tij}, reflecting the way these expenses are allotted for the reproduction of j resource applied by i branch for its (i) products (though the corresponding structural matrix for specific spheres of environmental protection expenses should be of great value). In the last case the vector of expenses on the reproduction of the j ecological resource equals:

$$(E_{tj}^{bn} = M_{tij}\ (E_{tj}^{sum})\ ; \qquad (t = \overline{1,T}\ ,\quad j = \overline{1,n}\ ),$$

where:

$$(E_{tj}^{sum}) = \begin{pmatrix} E_{t1j}^{sum} \\ \vdots \\ E_{tnj}^{sum} \end{pmatrix}; \quad (E_{tj}^{bn}) = \begin{pmatrix} E_{t1j}^{bn} \\ \vdots \\ E_{tnj}^{bn} \end{pmatrix} .$$

The vector of total expenses on all resources E_t^b equals to the sum of expenses on specific resources j :

$$(E_t^b) = \sum_j (E_{tj}^b) \ .$$

With no regard for the principal differences in the methods of estimating reproduction expenses on the separate stages of calculations, they are substantiated by uniform methodological valuations and produce comparative results. Calculations of losses or expenses, resulting from unrestorable resource application are more complicated. They have been worked out with methodologically simple principles of theoretical estimation of expenses necessary for the reproduction of the usable natural resources. If the existing observations of reproducible resources and the distinguished expenses allow identification of some sufficiently universal dependence of expenses on the volume of restored resources, then by extrapolating the indices of reproduced resources and necessary expenses, we would analyze the case resembling to that of complete reproduction of the usable resources.

A perfect example of this approach serves the model for estimating the losses resulting from the contamination of water basins. This method refers to the calculations of the conditionally indispensable water volume for the dilution of the contaminator up to the desired standard and the cost of natural resource unit.

However, the practical realization of the methods discussed suffers from a number of considerable shortcomings. Firstly, observations do not represent adequately the whole resource amount; secondly, these methods afford only approximate theoretical analyses of environmental protection variants. In reality society does not and will not restore the whole volume of natural resources applied within the nearest future (at present, this task is beyond our economic powers). Hence, we must also learn to estimate these parameter exactly. In this case we shall face the problem of analyzing a significantly larger number of parameters affected by an unrestorable supply of economic resources. Even according to the Temporary standard methods (1983), simultaneous estimations of water, air, land and forest contamination requires the evaluation of environmental protection effects by the following parameters.

For the basic industrial funds: terms of material depreciation and duration of interrepair cycles; industrial equipment damages and demurrages, and their duration; conditions of goods (cargo) traffic; ecologically determined efficiency of machinery and mechanisms; funds-output efficiency index (in natural measures); the costs of basic productive funds in the territory (zone) contaminated as a result of industrial activity.

For agriculture (farming), forestry and fishery: productivity of land and water reservoirs; quality of agricultural and forestry crops; changes in volume of tree planting and supervisional wood-cutting areas; areal of contaminated land areas and water reservoirs; eutrophic water reservoirs; quality of fish schools (with regard to their nutritious value); pasture productivity for cattle.

For communal (municipal) economy and social infrastructure: duration of depreciation of basic consumption funds; periodicity of current and planned repairs of dwellings and public buildings; duration of capital interrepair cycles; duration of equipment demurrage (in the institutions of social infrastructure); areas of town provision and green plantations.

For the population: ecologically determined working capacity, morbidity and disablement of every kind (with regard to age differences, duration of illness and temporary or constant invalidity); expenses of health resources for in-patients (stationary) and out-patients (ambulatory) treatment; social insurance and maintenance payments in cases of temporary or constant invalidity; the volume of unproduced output during invalidity of the employed in material industries.

This enumeration convincingly proves the complexity of quantitative estimations of expenses on environmental protection and their efficiency. Hence, with no regard for the above mentioned limitations, we should reasonably coordinate the principles of the theoretical scheme analyzed earlier for the estimations of necessary expenses resulting from unrestored supply of natural resources with principles of immediate expense estimations for every environment protection factor. The experimental variant calculations attempt to draw out evaluations using functional meanings of the damages which result from unrestorable supply of resources determined by the loss function identified through observation data resulting as for examples from water contamination. Thus, the total volume of losses E^T_{tij} resulting from an unrestorable application of j resource in i branch is determined on the analogy with simulation principles previously presented as the function of the unrestorable part of the resources P^H_{tij} and the funds volume F_{tij} necessary for the reproduction of the resources:

$$E^T_{tij} = \bar{e}(P_{tij}\ , F_{tij})\ .$$

Hence, the vector of expected total expense on the reproduction of the applied natural resources E_t may be described by the following dependency (under the assumption that the structural matrix of environmental protection expenses by branches are identical with the structural matrix M^E_t previously analyzed:

$$(E_t) = \sum_i M^E_t\,(E_{tj}^{sum} + E^T_{tj})\ \| M^E_{tij} \|\ .$$

The prospective total monetary expenses on the macro-level economy E_t are equal to:

$$\sum_{ij}(E_{tij}^{sum} + E^T_{tij})\ .$$

If technological reproduction of ecological resources cannot be introduced within the scheme of resource purification analyzed above or the destruction of a potential contaminator is impossible, it is necessary to take into account the peculiarities of reproduction by separate resources. The solutions of numerous ecological targets obtained, with no regard for the theoretical differences of the objects discussed, could hardly perform the role of applied conceptual instrumentaria. The assumption that it is possible to use various methods of technological development makes productivity an integral part of the targets of territorial distribution of productive capacities. This supposition concerns both the development of reassimilated and already completely cultivated ecological territories.

If this task seems well founded for the reassimilated territories, it is hardly tangible drawing out a choice among the numerous technological methods for the completely assimilated ecological resources in territories with their firmly settled regional production technologies, just because there is no reliable completely quantitative description of numerous methods. In this case the question of applying already settled production technologies to modern achievement of social and technological development and their interaction with the changing resource maintenance situation seems less expedient. We should admit that understanding the changes in the technological method or solution becomes more and more conventional. Sometimes, even unsubstantial changes in technologies accompanied by the modified volume of environmental protection expenses are interpreted as new ones.

The description of the analytic forecasting system of GNP is realized using an inter-branch input/output and econometric simulation system (Rutkauskas, 1984). The subsystem of territorial detailed reproduction is presented through the block of economy and ecological environment interaction models.

As the **territorial subject**, the complex of natural processes and anthropogenic subjects are implied; they modify, apply or produce one or several resources, services or products. For example, the natural water and air purification processes are analyzed on the levels of branch, ministry, town, village, and a definite group of inhabitants.

The **territorial zone** or area is a definite regional unit characterized by a common index of natural resource exploitation and reproduction. For example, it is a forest, village, town, administrative area, highway.

The territorial subject's activities imply the characteristics of change in natural ecological resources and social activities aimed at personal need satisfaction. This means production of material wealth and services with reference to the inter-branch modeling system which has been singled out.

Let t be the period (year) under analysis, k is the territorial subject, l is the territorial zone, i is the activity of the territorial subject, j the usable regional resource, X_{tik} the efficiency index of K-subject in i-activity; the $\hat{X}_{tic}$-index reflecting efficiency of resources used in i activity by k territorial subjects at t period; P_{tikj} the index of j resource exploitation by k-subject in i activity. P_{tikj} is the function relating P_{tikj} and $\hat{X}_{tik}$, i.e.,

$$P_{tikj} = P_{tikj}(\hat{X}_{tik}) \ ;$$

where:

P^{H}_{tikj} - unrestorable volume of j resource used by k-subject in i activity;
P^{b}_{tijk} - restorable volume of j-resource:

$$P_{tikj} = P^{b}_{tikj} + P^{H}_{tikj} \ .$$

The volume of expenses Π^{b}_{tjk} on the reproduction of P^{b}_{tikj} is its functional relation:

$$\Pi^{b}_{tikj} = \Pi^{b}_{tikj}\,(P^{b}_{tikj}) \ .$$

In addition, the economic losses Π^{H}_{tikjl} in l-zones owing to the unreproduced exploitation of P^{H}_{tikj} are functionally dependent:

$$\Pi^{H}_{tikjl} = \Pi^{H}_{ikjl}\,(P^{H}_{tikj}) \ .$$

The final economic losses resulting from the reproduced or unreproducible exploitation of j resource by all territorial subjects are equal to:

$$\Pi_{tj} = \sum_{i,k} \Pi^{t}_{tikj} + \sum \Pi_{tikjl} \ , \quad j = 1,2,\ldots,P \quad .$$

Finally, the total economic losses Π_{t} resulting from reproduced or unreproducible exploitation of all ecological resources:

$$\Pi_{t} = \sum \Pi_{tj} \ ,$$

In turn, the losses Π^{l}_{tij} resulting from the reproduction of the restorable part of j-resource in i-activity may be presented as a sum:

$$\Pi^{b}_{tij} = \sum_{k} \Pi^{b}_{tikj} \ .$$

and expenses Π^{b}_{tjk} resulting from the reproduction of j resource used by k subject for the realization of this activity – as sum:

$$\Pi^{b}_{tkj} = \sum_{i} \Pi^{b}_{tikj} \ .$$

Expenses Π_{ti} resulting from the reproduction of all restorable resources used for the realization of i activity in the region equal to the sum:

$$\Pi_{ti} + \sum_{\gamma} \Pi^{b}_{tkj} \ .$$

Analogically, the economic losses Π^{H}_{tikj} resulting from unreproducible exploitation of j-resource by k-subject in i-activity equal to the sum

$$\Pi^{H}_{tikj} = \sum_{l} \Pi^{H}_{tikjl} \ ,$$

and losses Π^{H}_{tij} resulting from unreproducible use of j-resource in i-activity equal:

$$\Pi^{H}_{tij} = \sum_{k} \Pi^{k}_{tikj} \ .$$

Losses Π^H_{ti} resulting from unreproducible use of total resources in i-activity in the region equal:

$$\Pi^H_{ti} = \sum_j \Pi^H_{tij} \ .$$

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4.1.4 SUSTAINABLE COASTAL RESOURCES AND ENVIRONMENTAL MANAGEMENT FOR THE SETO-INLAND SEA AREA IN JAPAN

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1. Introduction

Recently much attention has been focussed on the sustainable development of resource use and the sound environmental management based on the ecological balance in local, regional and global levels. The scope of resource development and environmental conservation includes such development and preservation problems as:

1) land and water use management
2) ecological resource management
3) pollution and eutrophication control
4) nature conservation (open space, wild life, coastal vegetation, coastal landscape, water transparency, etc.)

The concept of sustainability in relation to the ecological resource management, was first raised in such ecological sciences as fishery, grass land, forestry in order to maintain a level of fish population, herbage and tree production under some catching, grazing and cutting pressure by human being, cattles and other animals, respectively. The term of "Maximum Sustainable Yield (MSY)" or "Maximum Economic Yield (MEY)" is a typical example that has been applied to the practicable problems in the fishery management such as whales in Antarctic Ocean and Salmon in the Pacific Ocean (May et al, 1979). Further, resource economics presented the idea of optimal sustained yield over a finite time horizen by the use of bio-economic equilibrium which takes account of economic costs of catching efforts under market price mechanism (Clark, 1985).

On the other hand, the concept of environmental carrying capacity was proposed in the domain of environmental economics or environmental sciences as the environmental purifying capability of watershed or coastal zone, and is understood as one of most important scarce natural resource to be preserved in order to maintain environmental quality from the damages by dumped industrial and municipal wastes.

It is quite clear that two concepts have close interrelationship and that they should be dealt within an unified framework of regional resource development and environmental preservation. River watersheds or coastal zones contribute not only to regeneration of ecological resources but also to washing, absorption and decomposition of the pollutants or hazadous materials into non-toxic substances in long-range recycling process in the natural environment. However, past experiences have shown that increased use of watershed or coastal zones by multiple users such as transportation, cultivation, recreation and various economic activities, have prevented adequate management within sustainability of ecological resources. The depletion of major fish stocks has become common in such cases of herring in North Sea or in Hokkaido of Japanese Sea, and anchovy in Peru and California. Local extinction of fish species of high economic value are widely seen in Japanese coastal sea. Excess fishing capacity, increase of consumer's demand for specific types of fishes and lack of management for preventing water eutrophication are the typical management issues in the fishing sector of the Japanese economy.

This paper is concerned with the methodological aspects of sustainable resource and environment management in regional coastal area. The coastal area consists of land, marine and their interface of coast zone and shallow water area, which has both the highest productivity in terms of biological production and the highest potential of environmental carrying capacity in terms of purification ability of dumped pollutants. Thus, coastal area has

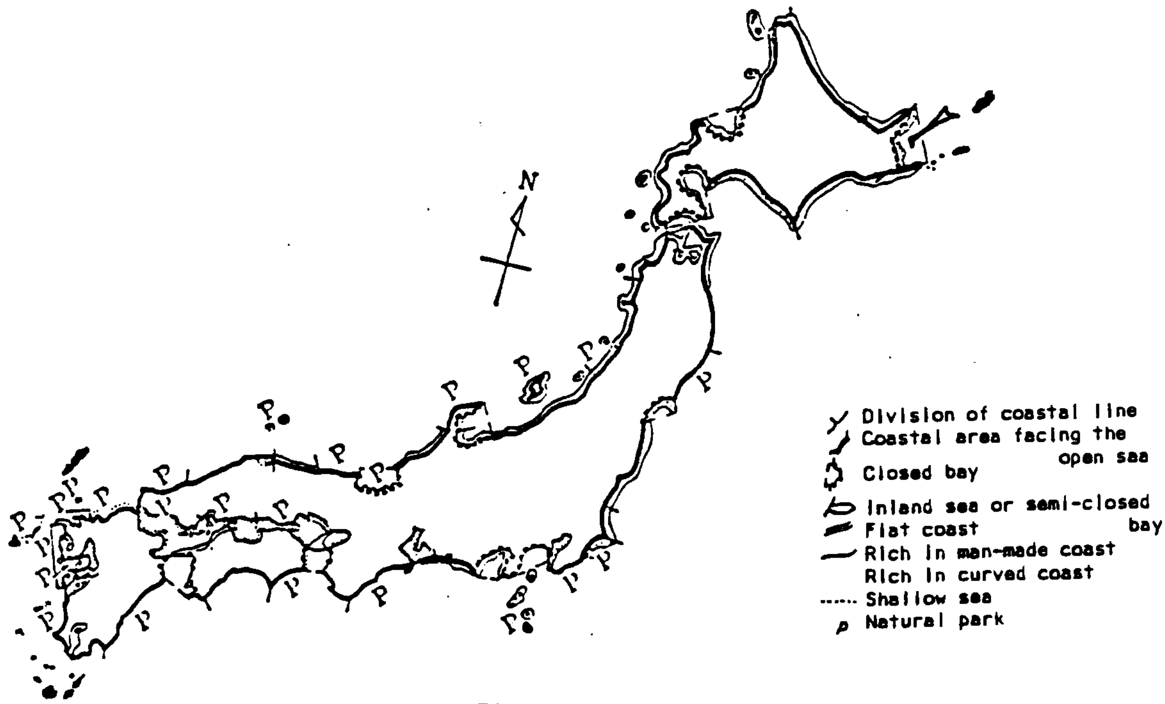

Figure 1-a Classification of Japanese coastal areas by natural conditions

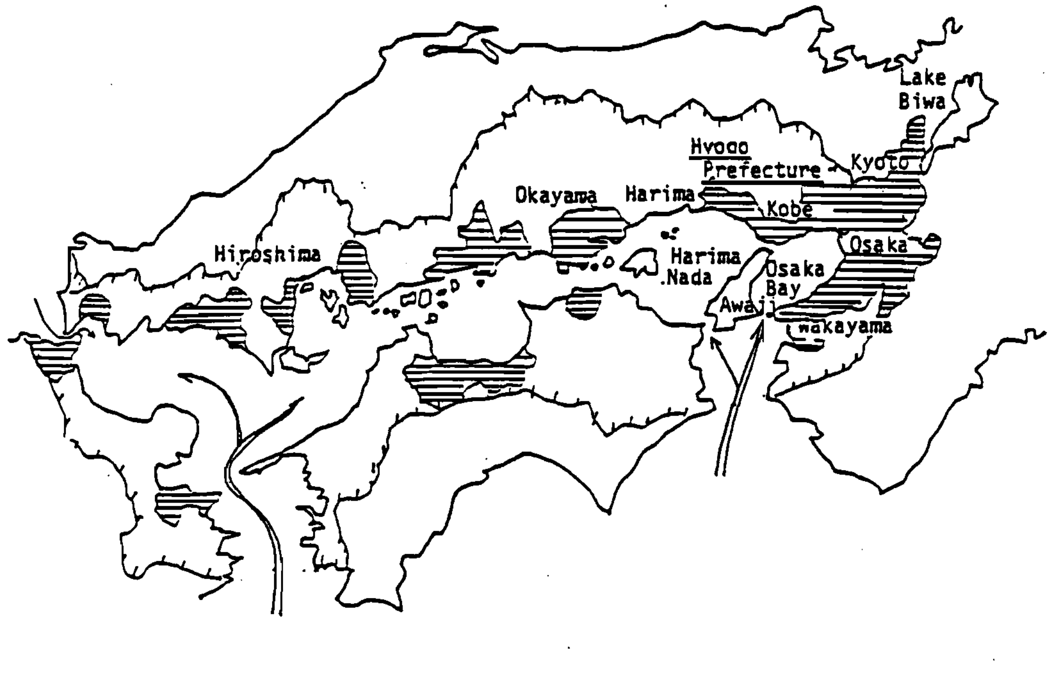

Figure 1-b Sketch of "Harima-Nada" in Seto-Inland Sea

2. Problems of Coastal Resource and Environmental Management in Japan

The Third National Comprehensive Plan authorized in 1977 by the Japanese Cabinet recognized that Japanese national land has a limited resource in terms of inhabitable or cultivated land, and that it should be grasped as an integrated unit of "space" where various living and natural environmental conditions are intricatedly interrelated. The concept of "River Basin Space" for land area and "Coastal Space" for coastal sea area is the principal idea as a basic unit of planning for national land and marine management. This has been a new understanding of planning space different from such a traditional tendency that unit space of planning is considered to be only administrative and economic devisions. Both unit spaces contain either fresh water or sea water as key component of resource management.

As far as the physical dimension of coastal area is concerned, Japanese shallow water area less than 20 m depth that may be highly utilized as coastal resource, is about 3 million km^2 and total sea area less than 100 m depth reaches 16 million km^2 which amounts 40 per cent of Japanese land area. These coastal areas can be classified into three types: i) open sea, ii) open bay, and iii) inland sea and closed/semi-closed bay, as shown in Figure 1. Among these three types, inland or closed/semi-closed bay areas have been historically developed for various reasons, and therefore highly utilized for fishery and industrial production, transportation, urban activities and recreation and marine sports. Tokyo, Ise and Osaka bays and Seto-Inland Sea are the major coastal areas where industrial and urban activities have been centered. Table 1 displays the present status of coastal use and future demands estimated by the expert group based on the

Third Comprehensive National Development Plan (Ishii and Konno, 1979).

The demand by three major coastal areas in 1990 will be close to 50 % and 100 % increase in terms of usable coast lines and shallow water area less than 20 meters depth, respectively. The marine recreation has the highest increasing rate in comparison with other users. It is clear that intensive use of such a large portion of shallow water area might give a great impact to the resource sustainability and environmental capacity unless a full scope of environmental considerations has to be taken. The multiple-use or complemental use of shallow water area might provide a possible solution to the increased demand. But it is essential to establish an adequate institutional arrangement between competitive users and clear guidelines to make regulatory decision on how to set priorities for trade-offs between users.

Table 1 Demands for Coastal Spatial Resources in Japan

Year		1981			2000	
Depth of water	0-20	20-50	50-100	0-20	20-50	50-100 (m)
fishery & farming	5,410	2,220	2,150	17,300	3,421	40,760 (km^2)
harbor	6,620	-		18,000	-	
sea course	199	-		540	-	
marine recreation	282	-		2,780	-	
reclamation	1,190	-		1,880	-	
wastes sites	37	-		140	-	
miscell	-	-		40	-	
total demand	13,740	2,220	2,150	40,680	34,210	40,760
total space	30,880	49,850	79,740	30,880	49,850	104,150

been one of the most critical sites for both sustainable resource development and environmental management in the urbanized regions in Japan. Heavy industry requires a water-front location for transportation and industrial water-use. Fishery has kept traditional fishing wrights to access fairly large portion of sea area. Public demand for bathing, sport fishing and other marine amenities is rapidly increasing. Municipalities seek the sites of not only waste disposing but also new land for urbanization by reclamenting the seashore and coast lines. In particular, marine environment of shallow water area provides an opportunity of "multiple-use" for the marine resources which accommodate two or more uses within same area unless each user gives irreversible damage to its sustainability and environment capacity. So far these demands in Japanese inland sea and semi-closed bay areas seem to have exceeded over a physical and biological limit of scarce resource and environmental capacity. The management problem, thus, requires new approaches to cope with such complex situation that "multiple use" of the marine space and ecological resources could be settled within the some levels of resource sustainability and environmental capacity.

3. Approaches to Coastal Resource and Environmental Management

3.1 Methodological Issues of Sustainable Resource Development

The issues which we have faced for the sustainable resource development can be summarized as follows

1) dynamic interdependence in multi-species ecosystem
2) multiple use of marine resource in competitive situation
3) intergeneration equity in resource economics
4) spatial and temporal externalities in environmental pollution

The first issue, could be discussed in the framework of "Adaptive Environmental Management" which primarily aims to respond to the dynamic nature of resource management in terms of short-term and long-term variability and vulnerability of ecological system by the human intervention. The adaptation of policy-making process to these long-range dynamics is facilitated by inter-disciplinary contacts and communication through a series of workshops in natural resource planning by creating general ecological principles and attitude toward ecological uncetainty and finally interactive use of system models of ecological dynamics (Holling 1978).

The second issue of multiple use in competitive situation has been extentively studied in the decision theoretic framwork of "Multiple-Objective Analysis". A variety of methodological tools has been applied particularly to the water resource planning and energy resource management (Keeney & Raiffa 1976, Haims et al 1975). The conflict between beneficiaries or between losers within same coastal region gives increasing importance to the distributional consideration in setting priority for resource utilization in view of diverse nature of ecological response to the development activities depending on the very local and spatial conditions. There has been a little number of empirical studies on the marine ecological resource management in terms of multiple-objective or multiple use of coastal resource due to substantial uncertainties involved in structured relationship of marine ecological system and the lack of social and economic evaluation of the externalities brought by competitive users (Hite & Larrent 1972, Zucchetto et al 1980, Ikeda and Nakanishi 1983).

We are able to discuss the third issue within the framework of welfare or environmental economics which concerns with the intergenerational irrationality of discounting on ecological resource on the basis of welfare evaluated from the viewpoint of present generation. Uncertainty and irreversibility related to natural resource development are major focal points when some policy-actions are taken by the current generation's utility or evaluation. The concept of "option value" or "guardian value or existence value" for future development would be one of possible instruments which tries to evaluate preservation values of environmental goods or services for future resource scarcities based on either keeping the option to consume the environmental goods or services in future or setting generation equality in terms of ethical sense (Fisher and Krutilla 1975 and 1982, Page 1977).

The forth issue has been studied in the domain of environmental externalities in both economics and regional science (Pearce 1976, Nikamp 1980). Adverse environmental externalities such as air pollutants, ground water contaminants and dumped toxic chemicals might be spatially transferred or pollution abatement activities may convert the pollutants into another type of materials which might be appeared as hazadous one in future activities. Thus distributional aspect of pollution externality has been getting much concerns which regional environmental management has to pay. Acid rains and PCB contamination in birds or fishes through ecological food web and the typical examples. Although some pollution externalities are so broad in scope that they are difficult to be internalized into the current decision-making mechanism of resource management, there are several methodological tools to evaluate such pollution externalities in terms of "oppotunity cost", "consumer's surplus" or "hedonic cost" by measuring i) direct costs for compensating damage or computing a reduction in property values or recreational use, ii) asking public's willingness to pay for preserving natural environment (Smith 1981).

3.2 Framework of Economic-Ecological Models for Coastal Resource and Environment management

In order to cope with the methodological issues of sustainable resource management in coastal area let us, first set up a conceptual structure of the management model in the regional land-marine system's framework. Figure 2 is an example of such conceptualization which takes account socio-economic activities and marine ecological resource system.

The regional economic model gives the levels of socio-economic activities associated with the utilization of coastal resource in the following five sectors:

1) fishery sector,
2) recreation and amenity sector,
3) industrial production sector,
4) transportation sector,
5) urban services and consumption sector.

It is in this submodel that the land use pattern of sea coast, levels of public investment for construction of social-infrastructure or pollution control, recreational demand by household, etc. are estimated either in "motetary" term or "resource" term (material balance or energy balance). The demand and supply of these private or public goods and services are subject to ecological resource and environmental contraints within spatial and physical dimensions of the concerned region.

The "Marine Ecological Model" in the right-hand side of Figure 2 simulates the biological, chemical and physical interactions among multi-species of ecological components taking place in such a spatial environment as river-basin and coastal zone and marine sea area. Some of the ecological resources are utilized not only by human activities but also by other living things through prey-predator relationship in hierarchical trophic network. It is this ecological model that needs a great deal of consideration on non-homogeneous nature and non-linearity in the dynamic behaviors of ecological components such as primary production of phyto-plankton and various types of fish populations. These biological resources are more vulnerable to the artificial impacts than natural ones. For example, the recent deterioration of water quality (excess eutrophication of water body) in semi-closed basins, bay or coastal zones surrounding urbanized area requires a detailed consideration about nutrients loadings and wasted oils (nitrogen, phosphorus and other organic matters) with respect to:

- o where and when nutrients come into and flow out, and
- o from what sources they originate and what chemical substances they might contain

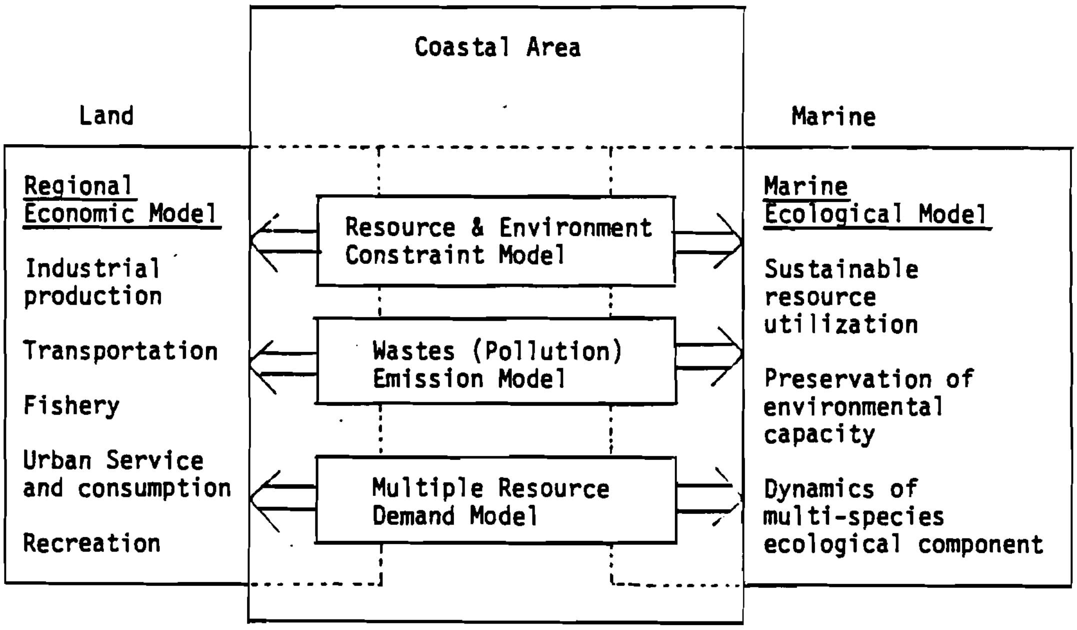

Figure 2 Conceptual Structure of Economic-Ecological Model for Sustainable Resource Development in Coastal Area

Table 2 Illustrative Examples of Ecological Components of Coastal Marine Ecological-Economic Model

Man's Activity for Resource Utilization	Fishery (fish catches, farming)	Recreation (swimming, picnicking, fishing)	Transportation (harbors, ship service)	Industry (industrial bases)
Ecological Resource Demand	fish population planktons feeds	fish populations coast vegetation		
	shoal water area underwater grass	natural coastline beach/shore water quality	bay/inlet open sea	coastline shallow open sea
Wastes and Pollution	nutrients	oil spill wastes	oil spill	wastes nutrients oil spill
Environmental Constraints	fish stock open sea	coastline beach	bay/inlet	coastline shallow open sea

This information is essential for the economic ecological models not only to predict a degree of water eutrophication but also to estimate the control cost and the damage cost to the fishery, recreation, incurred by the frequent occurrence of phytoplankton blooms (red tides).

The middle section in Figure 2 is composed of:

(A) multiple resource demand model,

(B) wastes (pollution) emission model and

(C) resource and environment constraints model,

that work as an interface between the economic and ecological models.

The first one is to calculate the demand for ecological resources of services which are to be utilized by socio-economic sectors (1)-(5) when the production and consumption levels are given by the "regional economic model". The second one is to estimate the amount of wastes and pollutants to be generated and discharged into the coastal environment after cutting down by means of adequate control scheme. The third one is to evaluate resource sustainability and environmental capacity to maintain prescribed levels set by natural and societal conditions.

The focal point is how to set and who makes decision or how to regulate such threshold levels of resource sustainability or environmental capacity in the regional setting. It seems to be clear that we certainly need again not only to collect enough scientific and technological information on the spatial distribution of ecological components but also to use iteratively the models of coastal economic-ecological system so as to determine these levels of the environmental constraints. Table 2 illustrates and example of ecological components which are taken into consideration in this interface section in the case of coastal resource management model. The major policy issues to be addressed in the present model framework are:

i) to predict primary and secondary effects or responses to the sustainability and environmental capacity which might be brought about both by utilization of coastal ecological resources and by discharge of wastes and pollutants.

ii) to estimate benefits and damages incurred by adopting alternative combinations of resource allocation options.

iii) to bring the comprehensive or total systems views into the coastal resource and environment management plans beyond a traditional economic or ecological evaluation with spatially aggregated cost and economic or ecological efficiency.

3.3 Theoretical Framework for Economic-Ecological Model from Environmental Economics

From the theoretical viewpoint of environmental economics, our economic-ecological model of coastal resource use can be formulated by the following equations of societal utility maximization subject to such restriction that no user (sector) of coastal resource is made worse off and the outcomes are feasible (Fischer 1980):

Maximize

$U(u_1, u_2, u_3, u_4, \underline{Q})$: societal utility in regional coastal system (A)

$$\left\{\begin{array}{ll} u_1=u_1(x_{11}, x_{21},\ldots,x_{i1},\ldots,\underline{Q}): & \text{utility of fishery industry} \\ u_2=u_2(x_{12}, x_{22},\ldots,x_{i2},\ldots,\underline{Q}): & \text{utility of recreation and amenity service} \\ u_3=u_3(x_{13}, x_{23},\ldots,x_{i3},\ldots,\underline{Q}): & \text{utility of industrial production} \\ u_4=u_4(x_{14}, x_{24},\ldots,x_{i4},\ldots,\underline{Q}): & \text{utility of transportation services} \\ u_5=u_5(x_{15}, x_{25},\ldots,x_{i5},\ldots,\underline{Q}): & \text{utility of urban services} \end{array}\right\} \quad (B)$$

subject to

$u_j = u_j(x_{1j}, x_{2j}, \ldots, x_{ij}, \ldots, \underline{Q}) \geqq u_j^*$: minimum utility of the j-th sector $(j=1,\ldots,m)$ (C)

$f^k(y_{1k}, y_{2k}, \ldots, y_{ik}, \ldots, \underline{Q}) = 0$: production function of the k-th sector $(k=1,\ldots,p)$ (D)

$\sum_j x_{ij} - \sum_k y_{ik} \leqq R_i(\underline{Q})$:constraint for i-th resource $(i=1,\ldots,n)$ (E)

where x_{ij} is the amount of resource or good consumed by the j-th sector, y_{ik} is the amount of resource or good i produced ($y_{ik}<0$) or used ($y_{ik}>0$) by k-th sector, u_j^* is a minimum requirement for j-th sector's utility function u_j, and $f^k(.)$ is a production function of k-th sector. The variable $\underline{Q}$ in (A)-(E) is a vector of environmental pollutants that brings the environmental externalities into each sector's utility, production and constraint functions.

However, since we have not yet established a workable and practicable measures for evaluating societal utility which includes the values of environmental goods or services such as recreation and amenities of coastal landscape, wildlife and marine vegetation, it is almost impossible to carry out such maximization scheme as defined by (A)-(E). Even if we could succeed in identifying the utility functions (A)-(C) by any means, it would be misleading for us to determine a resource allocation scheme by applying some mathematical optimization algorithm to solve the equations (A)-(E). Because there is a great deal of uncertainty involved in the data of input-output structure and discrepancy between industrial products and recreational services or fishery sector in the current monetary measure of utility evaluation.

3.4 Systems Approach to Economic-Ecological Models of Coastal Resource and Environment Management

While the theoretical framework of environmental economics provide to a qualitative structure of our problem, it is sometimes of little use for us to build a practicable and empirical model for the policy making. It is systems approach that could deal with such a complex socio-economic and ecological problem of coastal resource management. Our approach is a simplified version of the former theoretical framework. This approach aims not only to stand on a solid theoretical basis of environmental economics but also to reach a practicable result as efficiently as possible in terms of cost efficiency of model building. Figure 3 shows the overall structure of this simplified version of economic-ecological model for the coastal resource utilization and eutrophication management in water body.

The major simplifications in our proposed approach are as follows:

i) Instead of having explicit forms of utility or production functions, a kind of input-output table is set up to assess the economic activities associated with coastal marine resource utilization which includes specifically, fishery, recreation and transportation as well as industrial and urban activities.

ii) The pollution loads of nutrients (N), (P) and oil spills are calculated based the final demand and total coastal production in such sector which should include pollution abatement activities. Then, total amount of these pollution loads is discharged into the coastal oor marine environment. The models of marine ecosystem simulates the dynamic process of biological, chemical and physical resources in marine water area, and will determine the sustainable yield of each ecological component subject to the pollution externalities $\underline{Q}$ (see right hand side in Figure 3).

iii) The evaluation of such policy issues of societal utility maximization by (A)-(E) will be carried out in an iterative way through the conversation type of communication between scenario writing on policy alternatives and outcomes of the computer simulations for them. This evaluation process is based on the conceptual framework of "Environmental Economics" which takes into consideration resource sustainability and environmental capacity R(Q) subject to the environmental externalities $\underline{Q}$.

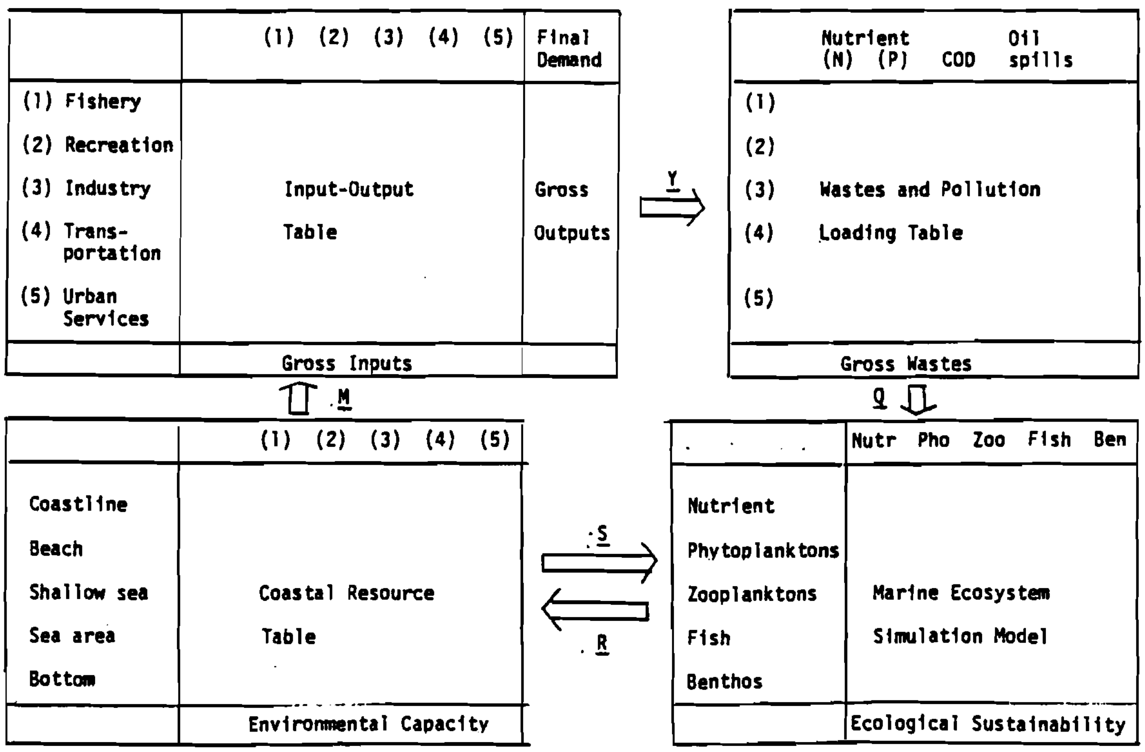

Figure 3 Structure of the simplified coastal resource management model

4. Case Study: East Seto-Inland Sea (Harima-nada) in Japan

4.1 Introduction

The progress of eutrophication in recent years, particularly in semi-closed sea area such as the Seto Inland-Sea has brought about serious problems: death of fishes under cultivation due to the "red-tides" of plankton blooms which often appear in summer, the changes in fish population structure that can be notably seen in the decrease of fishes of high economic values such as sea breams and prowns, and deterioration of amenity values of sea coasts and beaches.

So far a number of model studies have been made over marine environmental management taking acount of the ralationship between nutrients loading and eutrophication of sea water (Cashing 1975, Kraus 1977). There are a number of models which dealt with comprehensively both economic and ecological components in the sense of sustainable resource development or environmental preservation. However most of these combined models may be regarded as tools for the assessment merely by economic measures, for example, a simple comparison between the decrease of fish catches and the increase of industrial productions by a foreshore reclamation.

A typical ecologic-economic model for the land-marine area development was constructed by W. Isard (1970), and it has given many suggestions to the present study. However, our concerned area, the Seto Inland-Sea Area, is comparatively big and much more complicated than his target area from the geographical and social viewpoints. Specific features of the Seto Inland-Sea Area could be summarized as follows (see Figure 1).

(1) Geographically, it is a semi-closed sea area whose water is exchangeable only by a couple of channels with that of the outer sea. The sea is

relatively shallow, i.e., the average depth is about 30 meters.

(2) It is surrounded by highly developed industrial and urbanized regions such as the Hanshin, the Harima, the Mizushima and the Tokuyama regions. Hence it has suffered from heavy inflows of nutrients such as nitrgon (N) and phosphorus (P) contained in industrial and urban drainage.

(3) Reclamations and dredgings which have been carried out at the greater part of the coastal zones along industrial bases and urban areas.

(4) Due to heavy sea traffic, the dischanged oil from ships which reached 1,600 per day passing Akashi channel in 1981, has contaminated the sea.

The objectives of case study are:

i) to understand the interactions between coastal land-use plans and marine-use plans that used to be administrated separately by different organizations scattered in various decision-making levels.

ii) to assess the dynamic changes of coastal resources sustainability and environmental capacity in terms of social cost (benefits and damages) for their utilization and preservation multiple or competitive use.

iii) to aid decision makers to grasp distributional aspects of ecological commodities and services subject to environmental externalities such as "red tide" of hazadous phytoplankton bloom due to overeutrophication or fishes contaminated by dumped oil and chemicals in spatial and time perspectives.

4.2 Coastal Resource Table for "Harima-Nada"

The coastal resource table can be defined by

$$M = B\underline{S}$$

where M is a matrix of marine spatial and ecological resource $\underline{S}$ such as length of coast line, beach, shallow water area, sea water area, bottom, planktons, benthos, fishes that are required by the production sectors. B is a coefficient matrix of unit input of coastal resource for the unit production of each sectors in the I-O table. Table 3 is a preliminary estimation of unit input coefficient for i) fishery, ii) recreation and amenity, iii) industrial base, iv) urban services of wastes treatment on the basis of current state of coastal resource utilization. Only physical coastal resource such as coast line, shallow sea area, bottom for carry capacity of sediment accumulation are taken into consideration in this table (Data Book on Marine Resource use in Japan 1983).

This table has a lot of over-simplification with respect to the unit resource inputs to production sector as far as ecological and environmental quality is concerned. Bathing area need a clear and calm foreshore, but marine sports does not necessarily requires as good as water quality that sea bathing does. The same may be said of fishery and fish farming in terms of necessary water quality and marine physical conditions.

Table 3 Preliminary estimation of Marine Resource Table

	Fishery		Recreation		Industrial base (land reclamation)	Transportation (port)	Urban Service (wastes treatment)
	fishing	farming	bathing	fishing			
Coast line	-	-	0.12 (m/person)	-	-	0.73×10^{-3} (m/ton)	-
Shallow sea	2.21 (ha/ton)	0.057 (ha/ton)	15 (m^2/person)	0.66 (ha/person)	9.5 (ha/10 yen)	0.43 (ha/ton)	3.5 (ha/$10^6 m^3$)
Sea area	1.01 (ha/ton)	-	-	-	-	-	(Env. Capacity)
Bottom	3.21 (ha/ton)	-	-	0.66 (ha/person)	-	-	(Env. Capacity)

4.3 Input-Output Table for "Harima-Nada"

For mapping out the interdependency among "multiple users" of coastal resource, input-output analysis provides a simple and practicable way to catch the quantitative figures of direct and indirect production or comsumption effects on resource sustainability accompanying alternative development plans in the regional levels. We used the data and statistics on the industrial input-output table constructed by planning bureau of Hyogo Prefecture which occupies most of the northern part of the "Harima-Nada". Hyogo Prefecture shares more than ninety per cent of total nutrient loadings into the concerned sea area. Table 4 shows the aggregated result of input-output table for "Harima-Nada" which contains such major users of coastal resources as:

(a) fishery (natural and cultivated),

(b) recreation and amenity,

(c) industry (including agriculture),

(d) coastal transportation,

(e) urban services and household consumption

(f) other sectors.

There are, of course, a number of difficulties and ambiguities for aggregation and decomposition of data in prefectural level into such a small size of sectors as fishery, recreation and coastal transportation. Major ones are: i) the problem associated with the creation of recreation and amenity sector which does not classified in the original I-O table, and ii) applicability of macro input-output structure in prefectural level to the small scale of input-output structure in the coastal region. The second problem is partially solved through minor modification by using the other statistics

Table 4 Input- Output Table of Regional Economy in Coastal Zone, Hyogo Prefecture, 1978

	(1) Fishery (fishing, farming)	(2) Coastal Recreation Service	(3) Industry	(4) Coastal Water Transport.	(5) Transportation & Distribution	(6) Urban Service	(7) Unclassified activities	Total Intermediate sectors	Total Final Demand	Total Coastal zone Production
(1) Fishery	653 (354 299)	296	33,936	0	1	8,856	34	43,776	-14,054	29,722
fishing	(192 162)	(160)	(18,397)	(0)	(0.5)	(4,801)	(18)	(23,731)	(-7,619)	(16,112)
farming	(162 137)	(136)	(15,539)	(0)	(0.5)	(4,055)	(16)	(20,045)	(-6,435)	(13,610)
(2) Coastal Recreation Service	0 (0 0)	0	0	0	0	0	0	0	32,377	32,377
(3) Industry (1st and 2nd)	6,080 (3,296 2,784)	9,230	3,906,584	20,329	249,635	502,991	84,139	4,778,988	2,739,801	7,518,789
(4) Coastal Water Transportation	64 (35 29)	133	24,133	2,833	29,661	3,134	549	60,507	38,356	98,863
(5) Transportation & Distribution	592 (321 271)	1,274	160,580	1,730	77,554	104,516	40,776	387,022	329,917	716,939
(6) Urban Services	1,405 (762 643)	6,512	821,493	11,714	99,053	509,624	65,020	1,513,821	2,104,453	3,618,274
(7) Unclassified Activities	689 (373 316)	332	118,115	2,624	5,827	60,929	0	188,516	26,327	214,843
Total Intermediate sectors	9,483 (5,141 4,342)	16,777	5,064,841	39,230	461,731	1,190,050	190,518	6,972,630	5,257,177	12,229,807
Value Added	20,239 (10,971 9,268)	15,600	2,453,948	59,633	255,208	2,428,224	24,325	5,257,177		
Total Coastal-Zone Production	29,722 (16,112 13,610)	32,377	7,518,789	98,863	716,939	3,618,274	214,843	12,229,807		

(Unit: Million Yen)

Table 7 Activity Coefficients of I-O Table in Coastal Zone of Hyogo Prefecture

	(1) Fishery	(fishing, farming)	(2) Coastal Recreation Service	(3) Industry	(4) Coastal Water Transport	(5) Transportation & Distribution	(6) Urban Service	(7) Unclassified activities
(1) Fishery	0.0220	(0.0220 0.0220)	0.0091	0.0045	0.0	0.1×10^{-5}	0.0024	0.0002
fishing		(0.0119 0.0119)	(0.0049)	(0.0024)	(0.0)	(0.7×10^{-6})	(0.0013)	(0.0001)
farming		(0.0101 0.0101)	(0.0042)	(0.0021)	(0.0)	(0.7×10^{-6})	(0.0011)	(0.0001)
(2) Coastal Recreation Service	0.0	(0.0 0.0)	0.0	0.0	0.0	0.0	0.0	0.0
(3) Industry (1st and 2nd)	0.2045	(0.2045 0.2045)	0.2852	0.5195	0.2056	0.3481	0.1391	0.3915
(4) Coastal Water Transportation	0.0022	(0.0022 0.0022)	0.0041	0.0032	0.0287	0.0414	0.0009	0.0026
(5) Transportation & Distribution	0.0199	(0.0199 0.0199)	0.0393	0.0214	0.0175	0.1082	0.0289	0.1898
(6) Urban Services	0.0473	(0.0473 0.0473)	0.1702	0.1093	0.1185	0.1382	0.1408	0.3027
(7) Unclassified Activities	0.0232	(0.0232 0.0232)	0.0103	0.0157	0.0265	0.0081	0.0168	0.0
Total Intermediate sectors	0.3191	(0.3191 0.3191)	0.5182	0.6736	0.3968	0.6440	0.3289	0.8868
Value Added	0.6809	(0.6809 0.6809)	0.4818	0.3264	0.6032	0.3560	0.6711	0.1132
Total Coastal-Zone Production	1.0	(1.0 1.0)	1.0	1.0	1.0	1.0	1.0	1.0

of regional specialities in terms of employment structure (Sakashita 1984).

Only "bathing in the beach" and "sport fishing" are counted as the amount of service values in the "Recreation and Amenity Sector". Other amenity services including leisure activities at the coastal resorts may be included in the urban services as long as they consume urban services. To estimate such input and output values of "bathing and sport fishing", we used the field survey on the tourists conducted by Hyogo Prefecture which included the number of tourists by their purposes and amount of averaged money spent for accomodation, transportation, food and drink, etc. A part of this survey is shown in Tables 5 and 6.

Table 5 Survey of tourists in Hyogo Prefecture, 1978

Sub-region in Hyogo Pref.	Total tourists	Bathing and fishing	Day's tripper	Lodged tripper
Kobe	14,706	-	-	-
Hanshin	18,288	28	94.8%	5.2%
East Harima	10,866	434	95.8	4.2
West Harima	5,523	820	84.8	15.6
Awaji Island	6,360	1,772	74.7	25.3
Total		3,054	2,458	595 (thousand people)

Table 6 Averaged consumption by tourists in 1978

	Total	Trans-portation	Accomo-dation	Meals	Miscell
Day's tripper	5,100	1,400	0		3,700
Lodged tripper	33,400	10,500	9,600	9,500	3,800

The input values into the sector of "recreation service" are extracted from the intermediate sectors of accomodation, meals and miscelleneous services into "urban services" sector in such a way that there exists a consistency within the input-output table. The estimated final demand for "recreation service" is about 32,377 million yen which accounts almost equal values for "fishery industry". The activity coefficient matrix A is shown in Table 7 which corresponds to standard notation of the input-output table: $\underline{X}-A\underline{X}=\underline{F}$: i.e., total coastal production $\underline{X}$ less intermediate output $A\underline{X}$ equals net final demand $\underline{F}$. Thus matrix A represents the technological production structure of coastal resource utilization in this area, and can be used to analyze the various resource allocation options and pollution control policies.

4.4 Simulation Model of Marine Ecosystem for "Harima-Nada"

In the marine ecosystem model in Figure 3, specific emphasis is put on the dynamic process of eutrophication phenomena and its impacts to the production structure of marine biological resources. The basic elements and the relationship of their biological processes are illustrated in Figure 4. This model consists of two parts. One is to determine the tidal or wind-induced currents which are numerically calculated by Navier-Stokes equations of fluid dynamics on tidal and wind forces in the Harima-Nada. The other is to calculate biological interactions among ecological compartments with diffusive and advective transportation in the current field of the Harima-Nada. We devide the concerned sea area, Osaka-Bay and Harima-Nada, into 62 x 36 square meshes horizontally and into two layers vertically. The length of each mesh is 2.5 km and the mean depth of upper layer is set at 10 m, which is an averaged depth of the stratification in summer in terms of water temperature profile and salinity difference. General dynamic equation which describes a horizontal and vertical movement of biological resource B is given by three-dimensional ecological-hydraulic model:

$$\frac{\partial}{\partial t}B = -\frac{\partial}{\partial x}(uB)-\frac{\partial}{\partial y}(vB)-\frac{\partial}{\partial z}((w+w_s)B)+\frac{\partial}{\partial x}(K_x\frac{\partial B}{\partial x})$$
$$+\frac{\partial}{\partial y}(K_y\frac{\partial B}{\partial y})+\frac{\partial}{\partial z}(K_z\frac{\partial B}{\partial z})+ \text{(Biological dynamics)}$$

where u, v, w and w_s are averaged current velocity in x, y and z directions, and vertical migration velocity respectively, and K_x is a turbulent diffusion coefficient.

Figure 5 shows the computed results of tidal residuals which are presumed to constitute an important part of "steady flow" in the Harima-Nada. Given these current field in the sea and nutrient loading from the major rivers flowing into the sea which are to be given by the "wastes and pollution load table" of Figure 3, we are able to simulate the dynamic behavior of ecological components in three dimensional space.

Figures 6–11 are some examples of these simulation results after 6 tidal cycles from uniform initial state with constant boundary conditions at the "Bisan-Seto" and the "Kii-Channel". The details of these computation are given in the forth coming paper (Ikeda and Kishi forth coming).

4.5 Wastes and Pollution Table and Environmental Carrying Capacity for Nutrient Budget

The model of "Waste and Pollution Loading Table" intends to quantify not only amounts of wastes or pollutants generated by each production or consumption sector, but also amounts of actual loadings into the coastal area. It is, however, a quite difficult and time consuming task to get empirical or experimental data for this purpose. The extensive study is currently going on to summarize and review the research reports concerning nutrient loading data which are suitable for coastal zone (Nakanishi and Ukita 1984). In this case study, preliminary data of loading coefficient matrix L is used to generate amount of pollution externalities, Q–(N, P, COD, oil spill), based on the final demands F from the input-output table.

$$Q = L \cdot F$$

Figure 12 illustrates nitrogen budget in "Harima-Nada" which estimated approximately 70 ton/day nitrogen loading based on the observed facts and data (Okaichi 1985). These data are again used to identify the coefficient matrix L for coastal resource use. This budget is calculated by summing up results of the marine simulation model in section 4.4. Apparently inflows of nitrogen from Osaka Bay is comparably high in volume in comparison with the nutrient loading in this coastal area. The biomass volume of "chattonella" of red-tide organism (3,080 ton) shares a fairly large portion of nutrient budget within total 18,000 ton. It is, however, quite clear that this amount of "red-tide organism" is subject to large fluctuation in climatic and biological condition, and this makes the marine ecosystem unstable and vulnerable in terms of resource sustainability and environmental capacity.

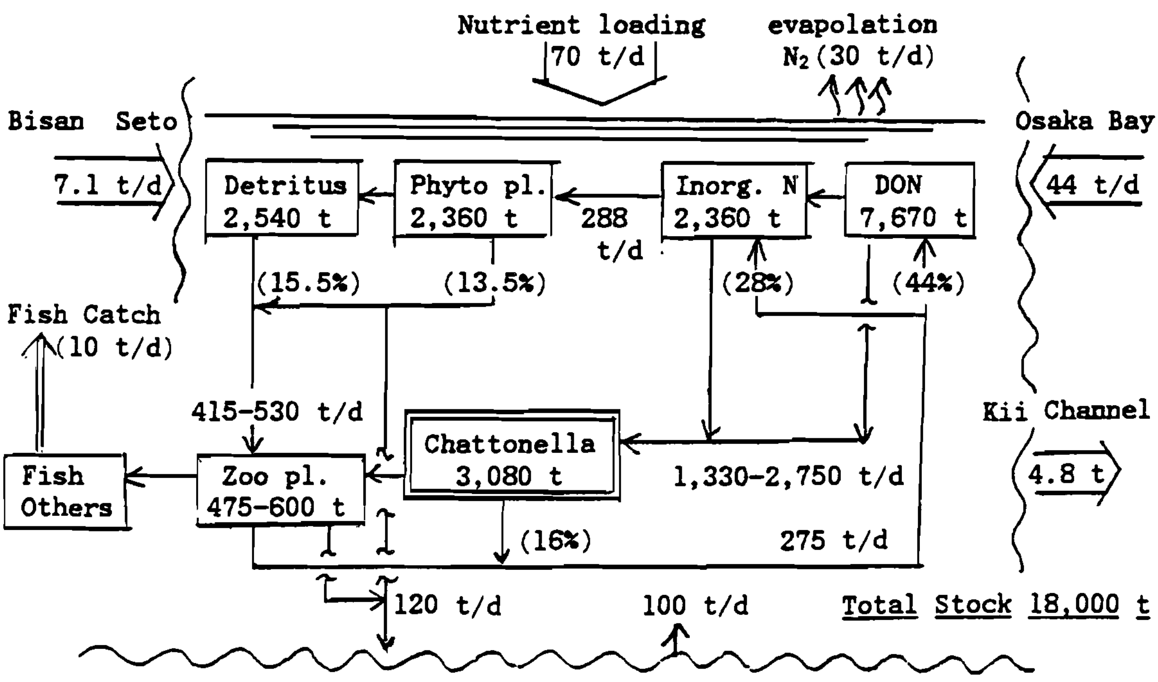

Figure 12 N circulation in Harima-Nada (Whole Area)
Harima-Nada, area; 3,425 km², volume; 88.7 km³

5. <u>Conclusion</u>

In this paper we discussed the methodological problems of dealing with both resource sustainability and environmental capacity in coastal resource development. Coastal area is a new challenging sphere of natural and socio-economic environments which requires new planning ideas and concepts different from traditional ones for land development planning. Because coastal area is one of the richest areas in terms of ecological variety, biological productivity as well as environmental purifying capability which are left for the nations of post-industrialized countries such as for Japan, as a very precious and scarce resource for the future develpment. However, both concepts of resource sustainability and environmental capacity become valuable and workable only if ecological productivity is combined with adequate management technology and institutional arrangement of human socienty. Total fish stock might be increased to the extent as the primay production of phytoplanktons are enough to be fed. This has been a development course of fish production from 13.1 ton/km^2 in 1958 to 21.2 ton/km^2 in 1977 in the Seto-Inland Sea.

However, the lack of management capability to preserve foreshores and spawning sites has made stocks of benthic fishes of high market value decreased (Report on Marine Bioogical Productivity, Science & Technology Agency, Japan 1981). The large number of commercial fishing wrights in these coastal zones has been throwing up in exchange for compensation fee from the industrial and municipal users for land reclamation (206 km for past 40 years), industrial wastes pollutants.

Further, excess eutrophication in sea water body caused a drastic change of production structure of pelagic fishes due to algae blooms of a single species of plankton domination in large part of Harima-Nada since 1975, destroyes the complex and intricated network of biological interactions in multiple-species of ecological society (Ikeda and Yokoi 1980). There would be a threshold level of eutrophication that are beneficial both for a variety of planktons and for a number of fish species, but not necessarily for other use by human-being. For example, the fish farming in the Seto Inland-Sea occupies a fairly large portion of water area in good water quality and in calm current condition. But it eutrophicates the sea water by itself due to excessive feeding or wastes from the dense fish populaiton in the fish firm. The farming of sea weed which shares over one third of fishery production needs a relatively eutrophicated sea water to promote the primary production of photosynthesis. But, these areas for the sea weed farming are also competitive for recreational or industrial uses due to access conveinience. The rapid increase of demand for recreation and amenity such as bathing, boating, sport fishing as well as picnicking along the marine coasts and resorts is raising a question whether or not we should promote such artificial farming of fishes and weeds in these area. Instead we may be able to rely on natural farming in the Seto-Inland Sea as a whole by implementing an adequate eutrophication management plan for preserving a sustainable fish stock in the form of natural marine park.

In order to explore such a policy issue, there is still a large gap between management of marine physical resource (sea coast and shallow sea), management of biological resource (fish stock) and amenity resource (open space). The gap, for instance, lies between eco-spatial information with respect to fish stocks, their dynamics and sustainability, and economic information on fishery industry (supply and demand structure for a variety of fishes through market mechanism and public demand for marine amenity). Nevertheless, given the recent progress ın economic-ecological modeling from a total viewpoint systems would become more and more practicable and feasible to build such a management model of economic-ecological system to aid the decision-makers for their determing a levels of resource sustainability and environmental capacity in spatial environments.

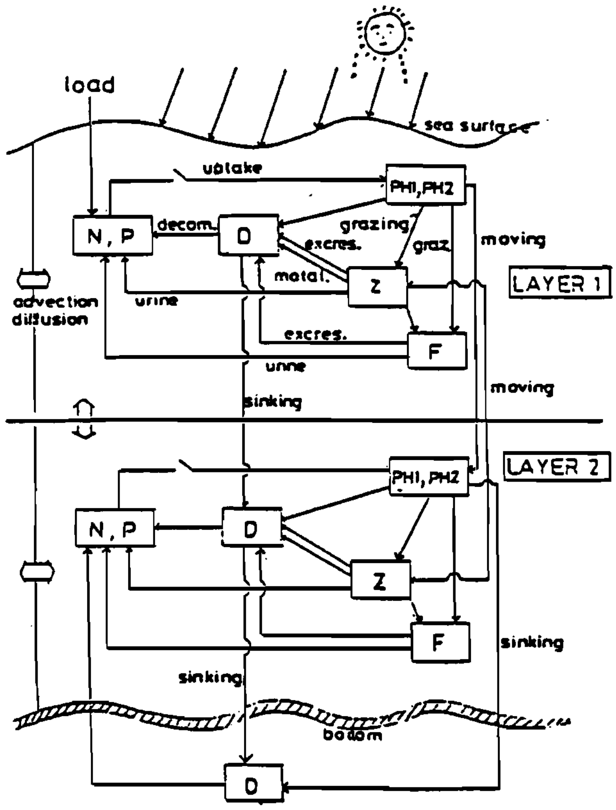

Fig. 4 Schematic Diagram of Marine Ecosystem

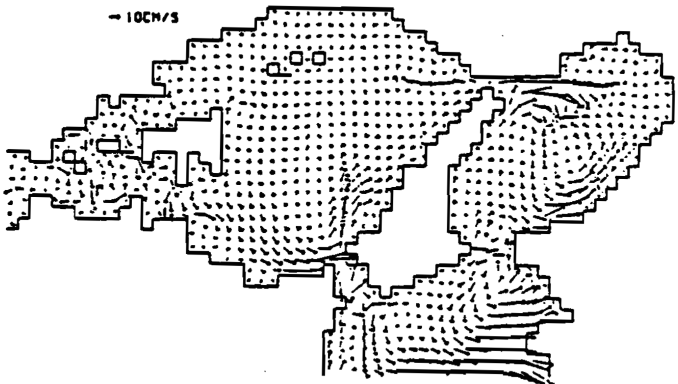

Fig. 5 Tidal residual with wind (upper layer)

Nutrient Inflow (ton/day)

No	P	N
1	1.3	17.2
2	2.1	27.8
3	1.5	19.8
4	1.2	13.0
5	2.0	24.4
6	7.0	62.7
7	3.4	62.7
8	2.1	31.4
9	0.9	10.7
10	0.1	1.1
11	1.4	18.0
12	0.7	10.0

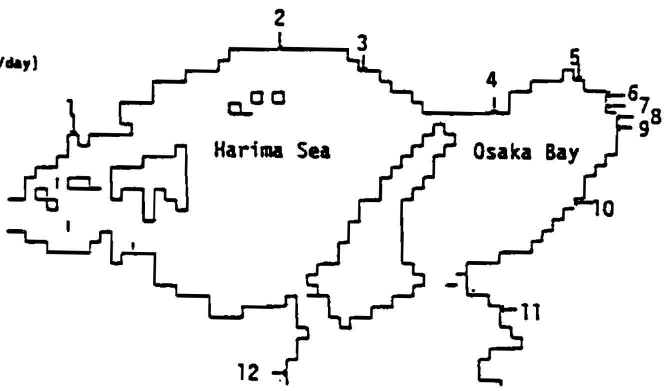

Fig. 6 Nutrient Inputs to the Harima Sea

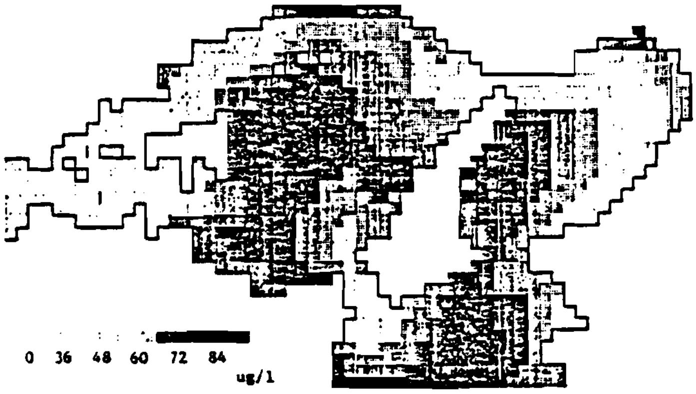

Fig. 7 Distribution of Chattonela (upper layer)

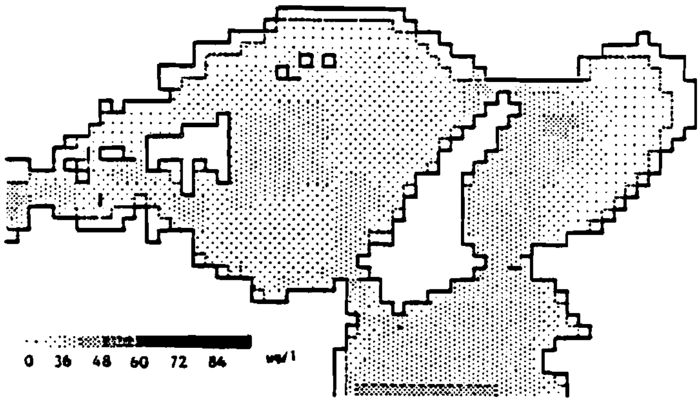

Fig. 8 Distribution of Chattonela (lower layer)

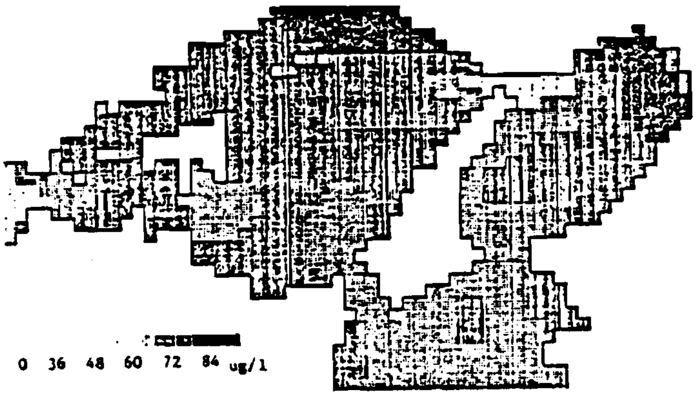

Fig. 9 Distribution of Skeletonema (upper layer)

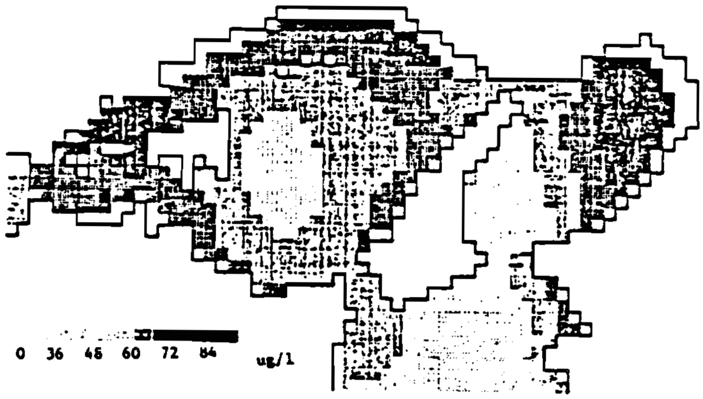

Fig. 10 Distribution of Skeletonema (lower layer)

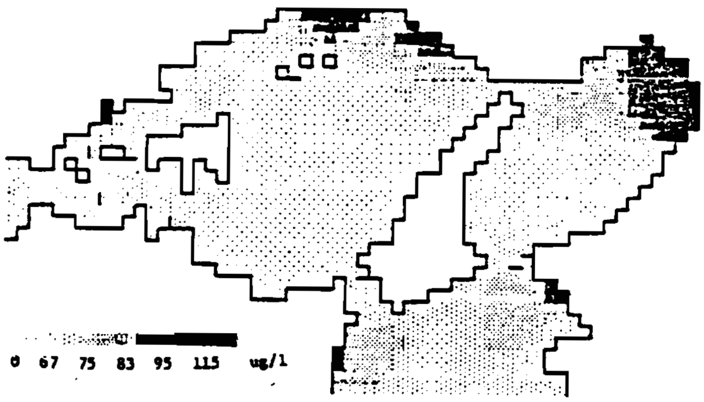

Fig. 11-a Distribution of Inorganic-P (upper layer)

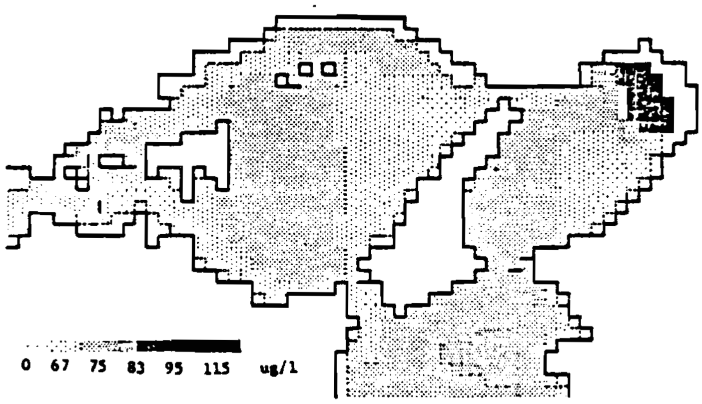

Fig. 11-b Distribution of Inorganic-P (lower layer)

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4.1.5 PRINCIPLES OF COORDINATING THE TECHNOLOGICAL-ECOLOGICAL-ENVIRONMENTAL MODEL OF THE REGION WITH THE CHOICE OF ITS ECONOMIC DEVELOPMENT

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Any modern production operates on the basis of the mutual exchange with the natural environment, drawing out of it various inanimate and animate natural resources - the land, water, air, mineral resources, raw materials of vegetable and animal origin, and discharging products that in the majority of cases affect the natural equilibrium, deteriorating the living conditions in the biosphere.

The time has come when it becomes necessary to take into account not only the limited resources - to which we are accustomed long ago, but also the strict limitations of the total impact of the objects of production activities on the deterioration of the environment, when solving the tasks of the economic development of a separate region and the country as a whole. Otherwise the growth of the volume and nomenclature of production will lead to an inadmissable degradation of the quality of life and will call in question the existence of separate biological species.

Thus, the choice of the strategy of economic development of mankind, and also of separate regions, countries and parts of a separate country must unconditionally take into account the limits that are imposed on the human activities by the demands of the environmental protection. And the consideration of the demands of the environment bears a universal character. It is conditioned by the lack of borders in the atmosphere and waters, and also due to the economic interrelationship and interdependence of the development of countries and the peoples on Earth, the more so of the separate regions and parts of separate countries utilizing natural resources.

Particularly favourable conditions for taking into account these demands are created in a planned economy where the natural resources are owned by the State. Precisely for these conditions the following approach to the solution of the task of selecting an optimal strategy of economic development for the region seems possible.

The entire task of the choice of the optimal strategy of the social and economic development of the region within a considerable time span of 15-25 years - is a multistage iterative procedure that can be articulated as:

1. Choice of the conception of the development of the country as a whole.

2. Choice of the conception of the development of interrelated complexes of industries, separate industries in separate regions of the country.

3. Choice of the optimal development plan of interrelated complexes of industries, separate industries.

4. Choice of the optimal development plan of separate regions, interindustrial regional balance of all kinds of resources, natural included.

5. Correction of the initial data of optimization accounts prior to the achievement of the complete balance of industrial and regional plans.

6. In case item 5 is not achieved, it is necessary to introduce changes into the industrial initial conditions, include the consideration of new technologies, new kinds of production and their new location points.

7. In case item 6 is not solved, it is necessary to correct the targets of the conception of the national-economic development plan of the country.

One of the numerous difficulties in the realization of this approach is that frequently the economic regions and even smaller territorial-production complexes do not coincide with the limits of the ecological regions, and the ecological regions themselves are not equivalent to the dimensions of the air and water basins and are under the constant influence of juxtaposed ecological regions.

Generally speaking there is a necessity of solving the following regional task. A system of operating productions exists in a certain region and there is also (or exhausted completely already) a certain amount of natural resources that may be utilized in this or other regions. The environment of the region under consideration is characterized by the vector of the initial condition $\vec{S_o}$. Besides that, for each region, including the one considered there exists a certain limiting normative condition vector $\vec{S_n}$. The vector of the initial condition $\vec{S_o}$ can be considered not as a constant, but as a function of time or other vectors.

The production activities of the existing enterprises is characterized by the discharge of a certain amount of harmful wastes into the environment (the water, air, soils) that are marked by the vector $\vec{D}_0$, and in the planned (forecasted) prospect these wastes will be measured by vectors $\vec{D}_1$, $\vec{D}_2$ ... $\vec{D}_t$ ... ... $\vec{D}_n$, where n - is the total number of the sections of the planned period - five years, years, etc.

Environmental specialists establish quantitative interrelationships (operators) between the vector of points-sources discharging harmful wastes in the area under consideration, the vector of the transgressively flowing harmful discharges from juxtaposed regions, and the vectors of the initial and current conditions of the territory we are interested in. The contents of harmful elements in the air, water and the soils can act as components of the vector of the condition of the environment. The current content of the same components in the biota, presumably is a variable, a derivative of the content of these components in the threé principal environments of life in retrospect and at present.

Having these algorithms of the links between the harmful discharges from production technologies chosen for introduction and the condition of the environment, all we have to do is to include into the economic-mathematical model the limitations of the condition of the environment, for instance the extreme possible content of harmful elements, alongside with the national-economic production costs in the considered region and the usual qualitative limitations concerning resources.

The establishment of the extreme possible content of harmful elements in the environment is the prerogative of the physicians and biologists.

Presumably the possible content of harmful elements in the three main environments of life must be different for separate regions, depending on the initial condition of the biocenosis. It can be supposed also that the ecological regionalization in the conditions of the Soviet Union can coincide with the union republics without the provincial division, the administrative units and (better) regions. But considerable difficulties arise under such fractional territorial division. The modelling of the condition of the environment and receipt of integral national-economic estimates concerning the economic decisions taken in the country require the solution of problems of large dimensions.

In order to overcome these difficulties we can use the constructive ideas of academician L.Kairukshis and other Lithuanian scientists on the optimization of the development of the republic on the basis of the specialization of territorial landscapes, and also the ideas of the specialists of the All-Union Systems Analysis Scientific Research Institute concerning the presentation of the voluminous amount of harmful wastes discharged into the environment with the help of a certain amount of aggregated variables. The second difficulty is linked with the construction of the ecological-territorial division of the country that would be close to or coincide with the administrative-economic territorial division. In this case it would facilitate the receipt of the corresponding initial data concerning the condition of the environment for modelling the alternative forecasts of the development and location of the productive forces in prospect.

But inspite of the enumerated difficulties the choice of the mode of economic development of any region must be carried out with the help of technological-economic modelling. It is necessary to solve this problem taking into account the factors that determine the health of the people, as those that are living now, and of the coming generations, taking into consideration the necessity of preserving the entire biological variety of the living Nature. That is why even the greatest efforts that will be undertaken will be historically justified.

In conclusion it should be emphasised, that the planned socialist economy opens particularly favourable opportunities to solve interrelated ecological and economic problems not only in separate countries and their separate regions, but also within the framework of the co-operation of nations.

4.1.6 REGIONAL RESOURCES MANAGEMENT – SOME SWEDISH EXPERIENCES

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The Regional Dimension

It is highly interesting that a IIASA-workshop at this time is being devoted to REGIONAL resource management problems. Since the early 1970ies there have been studies going on devoted to the regional dimension both internationally as well as in Sweden. This holds true especially for water-management issues. However, during only the few last years we have seen an increased interest more generally in the regional and local levels of administration. In Sweden maybe the clearest example is the proposed Natural Resources law. This law system has as its main ethos a very distinct direction of expanding the responsibility even for far reaching decisions on natural resources use down to local administrative units ("kommuner").

The basis for this tendency of decentralization from the national level to the more regional or local levels is of course not to be found within the natural resources management domain itself. It reflects long term trends in overall policy as expressed in various coalitions in Parliament with this direction on a wide spectrum of political issues ranging from distribution of responsibility for the health care system to town planning.

This corresponds I think also with a general trend of decentralization, starting at least in the west during the 1970ies in the tendency to give emphasis to the "grand" global issues of long term survival. [1] To make the point clear (and thereby maybe falling into the trap of over-generalization) we could say that we have had a historical development during the last decade or so according to which we have had the following sequence of emphasis:

mid 1970ies	think globally - act globally
around 1980	think globally - act locally
mid 1980ies	think locally - act locally

The 1970ies saw the birth of the big UN Conferences on various global topics like the natural but also the built environment, food, population, the new economic order, the mobilization of science and technology for the long term development of especially the developing countries and the issue on the renewable energy resources.

Mid 1980ies we see very little of this. It is a period of consolidation, maybe critical reflexion on past experiences and a fresh interest in more operational issues and then on a more local (or regional) level.

It is so illustrative of this tendency that the word "regional" itself has shifted meaning during this decade. When in connection with the discussions of the world models in the early 1970ies and mid 1970ies someone talked about the need for a more "regional" split up, then by "regions" normally was meant entire continents like Africa, or at least sub-saharan Africa, or Latin America.

Natural and social contexts merge

When we to-day talk about regions it is more in terms of much more geographically restricted areas. In certain areas where the natural conditions are similar, this becomes the basis for the systems enclosure. This holds true to a large degree on water recources management issues where concepts like "river basin strategies" is a good example. (An international conference was held in Sweden in Linköping a year ago just on this very theme.)

However, in many cases the more restricted entrepreneurial spirit of the mid 1980 in many instances corresponds to local administrative or political systems boundaries. In many cases exactly this double-sidedness of choice of limits for the selected area of study ("nature" or "political geography") constitutes one of the important study issues for "regional resources management". It is exactly this merge of the natural dimensions of availability and given conditions (be it soil, weather, plant distribution etc) with those issues dealing with socio-economic-cultural dimensions that are at the heart of the game right now.

Earlier, when the operational aspirations were globally minded it was much more difficult to envision exactly what this socio-economic-cultural dimension constituted. It was aggregated away and smeared out. On lowering the level of aggregation to more local or regional levels these issues will be more possible to reach by analysis. But they will also be more relevant at these levels. It could even be said that many of the problems now confronting us on the regional level of natural recources management just at it's heart has the character of the dialogue between the "nature-given" and the "socio-economic-cultural". This holds true for drinking water quality problems in an agricultural region in relation to the patterns of legislative or administrative set ups. These patterns highly influence these problems despite the fact that these regulation mechanisms might in the first place have been set up for other purposes as well. In Sweden we have just this year launched a 3-year project in the county of Halland to study such issues with regard to fresh water availability in an area of agricultural practicies[2].

Another example of this merge of "nature" and the "socio-economic-cultural" dimensions is land-use conflicts. Work has been going on in Sweden not only with regard to various river basins like the Göta Älv-Valley but for larger regions as in the just now completed "Land-use-North" project[3]. This project has studied the balance in the northernmost part of Sweden between the conflicting aspirations of forestry-reindeer herding-turism-water power exploitation. (Here co-operation with the IIASA environment adaptation "Obergurgl" methods group proved to be very valuable).

Still another example concerns studies of coastal regions of Sweden where especially the regional dimensions of the land-coastal zone interface is the central planning issue[4].

New analytical tools needed

But it is not only the stronger emphasis on operational relevance and possibility to act which, according to my mind, has pushed the level of scrutiny "downwards" from the global via the national to more regional and local levels.

It is also the demonstration of analytical problems of large aggregates as was the experience from the large systems modelling attempts of the 70ies. On coming down in scale - as was earlier indicated - the relevance and importance of the inclusion of the socio-economic-cultural factors increase. But the knowledge analytically how to combine an analytical machinery e.g. from ecology (e.g. in terms of energy flow analysis) with that of economy (in some way or another mapping some features of social life) is still to high a degree something which scientifically is under experimentation. One example of an interesting event to give a state of the art in this field was an international Wallenberg symposium held in Stockholm in 1982 under the title "Integration of economy and ecology - an outlook for the Eighties"[5] from which now the proceedings have emerged. Similar events, sometimes with IIASA connotation, have been held elsewhere during the last few years[6].

I think it is highly appropriate to see this interest of merge between social/economic theory with that of ecological theory in the light of the fresh interest in the regional choice of level of analysis of natural resources issues.

One Swedish example of attempt in this direction is the "Gotland project"[7]. It is a project which has chosen the large Swedish island Gotland situated in the Baltic to be a region with a natural boundary (due to its island character) as well as also being an administrative county unit.

The study, which is now completed after almost half a decade, took as its starting point an energy analysis approach of the Odum school type. This analytical tool was then used to compile all energy flows - natural as well as man-oriented - on the island. Figure 1 gives an overview of the major flows identified. (They were of course subdivided along the process of finer analysis.) At the same time and in parallel to this the economic flows in and out from the island in terms of a regional input-output econometric model was built. These two model systems were then compared.

The project has thus followed through all the intricacies of mapping of these flows fairly much in detail.

Thus, the project has provided a case example not only of Gotland itself but also providing some picture of what types of information and clues such an approach at all can give. First of all it must be stated that the project has a great interest due to the very careful work involved in it on the descriptive level. At the same time there are some more general considerations that could be drawn from the experience with a high level of relevance to the regional resources management issue.

First of all, still acknowledging the professional level of a good and well balanced description, one might ask oneself which types of questions such an analytical tool might be used for. As the analytically selected systems border was chosen to be the edge of the island (plus some surrounding waters for fishing) the tool seems easier to lend itself to questions raised on the "nature" side of the two-sided problematique I mentioned earlier. When it comes to mirror this existing energy flow pattern into questions of societal goals one is directly in for trouble. Is is - as is the case in the Gotland situation - bad or good that the energy consumption for the local cement industry is so high. In short: could you use the one-dimensional indicator energy amount to judge the social value? My answer is in general no. (However it is useful to know for a discussion about the social value of the cement industry what energy options there are; and even more so for a more direct environmental impact assessment as part of a larger assessment activity.)

Another problem is that the set of information based on a "closed system" (the island) lends itself best to explore social situations which also are "closed", e.g. what happens to Gotland if it is cut off from oil import. But is that a socially very important issue, except for some war scenarios. In most cases such a cut-off scenario is not socially very relevant for day to day planning on the island. This led during the period of the project to some sort of enstrangement between the project and the participating representatives of the county's planning authority. In short, they could imagine that such a model activity could have some general relevance - but the relevance was not seen for their more direct planning purposes. In my perspective, I would interpret it such that the method itself has some inbuilt restrictions to what type of questions that could be asked through this analytical machinery. Maybe more direct methods scrutinizing e.g. land use conflicts etc. (i.e. on the societal level directly) might be of more societal relevance.

On top of this the regional input-output econometric activities had other problems. If at least "nature"-wise Gotland could be regarded as a well defined system in itself with inflows and outflows on the border, this abstraction is very much more difficult to carry through concerning the relation of regional economics with overall national economics. Here the links between the system and its surrounding also look very much different in character than that which holds true for Gotland as a "natural" unit.

So there are problems. The important thing is that such study endeavours have been undertaken providing us all with clues to the nature of the problematique. The coming few years will see further attempts to come to grips with these "merge" problems between the "natural" and the socio-economic dimensions.

Another example in this realm of investigation is the attempts to link energy production patterns spatially in Europe (including choice of technology) with those model systems that try to map air born pollution flows. Some work in this direction has been suggested e.g. by the Beijer Institute at the Royal Swedish Academy of Sciences.

Attempts have also been done to discuss the question on exploitation or conservation of forrests in remote mountain districts within the framework of an improved economic theory. It has been the attempt not only to consider direct gains of exploitation (after costs have been deducted) but also include more long range optional values of various sorts including the future options for recreation.

Societal goals, values and planning

We have talked about the modelling attempts on the nature side and their struggle with maps of economic activity. But on the societal end of the spectrum there are several phenomena which have to be dealt with in new ways. One of rising importance is that of societal value and goals. When it comes to landscape planning future scenarios of landuse might be difficult to envisage. In a very interesting 5-years project ecologist Lars Emmelin and painter Gunnar Brusewitz[8)] just this autumn present the final results of an attempt to merge the ecologically based construction of future landscaping possibilites with that of visual representations of such alternative scenarios (compare figure 2a and 2b). These type of representations might in the future enanble us to improve the dialogue between various planning agencies and the public. In that process the implicit goal structure becomes explicit (here with regard to what people judge as important concerning visual indicators of landscape features). At the heart of the scientific issue of such attempts is to have control over the scenario building in such a way that it gives a fair chance to discuss relatively unbiased options.

It is very interesting to note that another future oriented study of the Swedish forrest as a general resource has created such a discontent and stir within the forrestry profession. The study was undertaken by the Secretariate for Futures Studies[9)] and has suggested a stronger local control of forrestry resources. At the same time a reevaluation of the forrest was suggested, the forrest not only regarded as a source of economic gain, but also as a cultural value e.g. for recreation and leasure. The re-balancing between these various societal goals has much similarity to that problematique which was demonstrated in the land-use-north project we touched upon earlier with regard to conflict over use of land between "classical" forrestry-turism-waterpower exploatation and samic hearding raindeer activities. It also means that methods for a greater sensitivity to cultural aspects of natural resources use has to be developed. As part of such an identification process another Swedish project called Natural Resources in a Cultural Perspective is now coming to a close[10)].

Towards diversified regional goal patterns

In fact what much of this calls for on the regional scene is a much larger receptivity on local varieties of resources use. New patterns of combination of uses of the resources have to be developed. This could bring regional specific patterns not only of the use of resources itself, of regional specific management patterns but also of regional specific ways of life support and life in general. Such a move away from too much of national unformity in management practices in forrestry, agriculture, land-use-patterns etc. are more and more called for and is opening up as possibilities for the next decade. In Sweden we are just now trying to set up a project with such diversifying attempts under the name "Regional Resource Use Patterns". Two forrestry counties have been chosen: Värmland and Jämtland. We are even considering working over national frontiers in setting up appropriate systems boundaries of supra-regional kinds.

Such diversifying-support-policies would indeed move towards a more culturally sensitive use of nature and thereby contribute to the merge of the "nature" close approach and that one of societal goals and intentions.

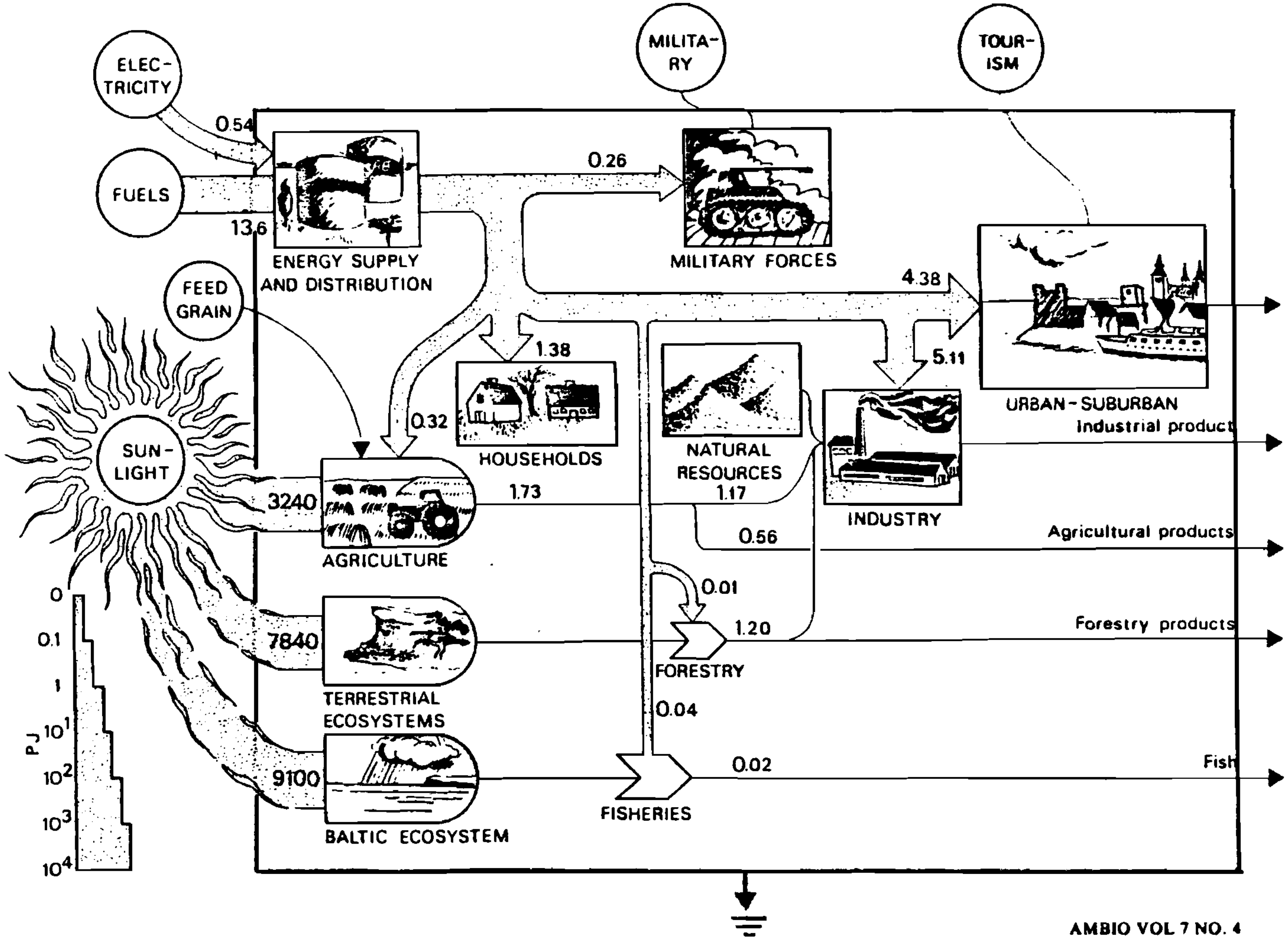
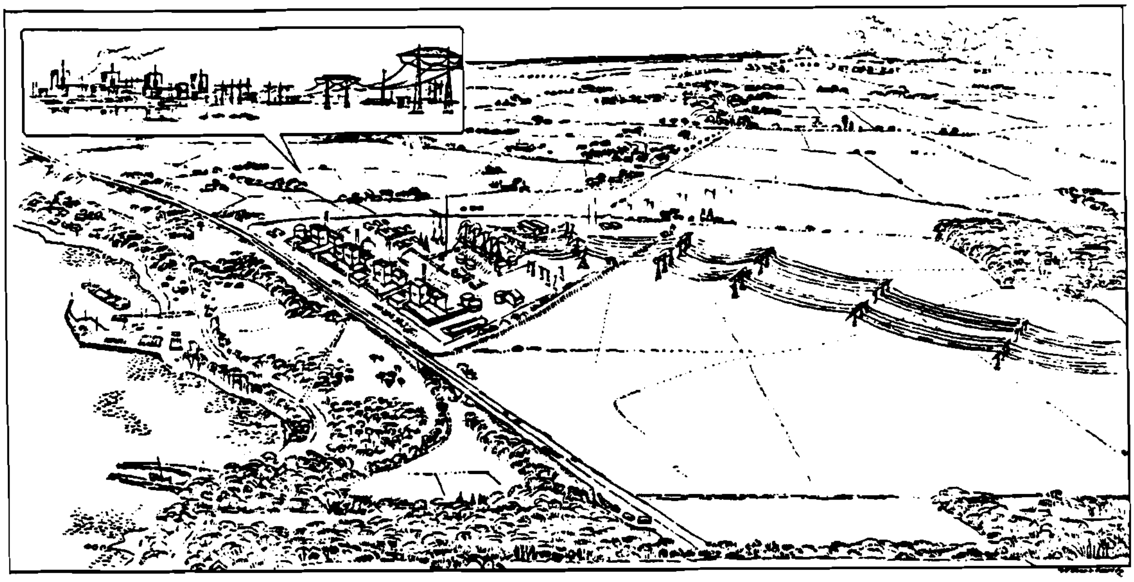


Figure 1. Energy flow diagram of Gotland, showing the main subsystems studied. The distribution in 1972 of fuels and electricity (added) to the different activities is shown together with energy contents of feed grain, food, wood and fish. All energy values expressed in GJ/year (1, 2).

Ref. 5

Figure 2a "Nuclear-Sweden" 2015



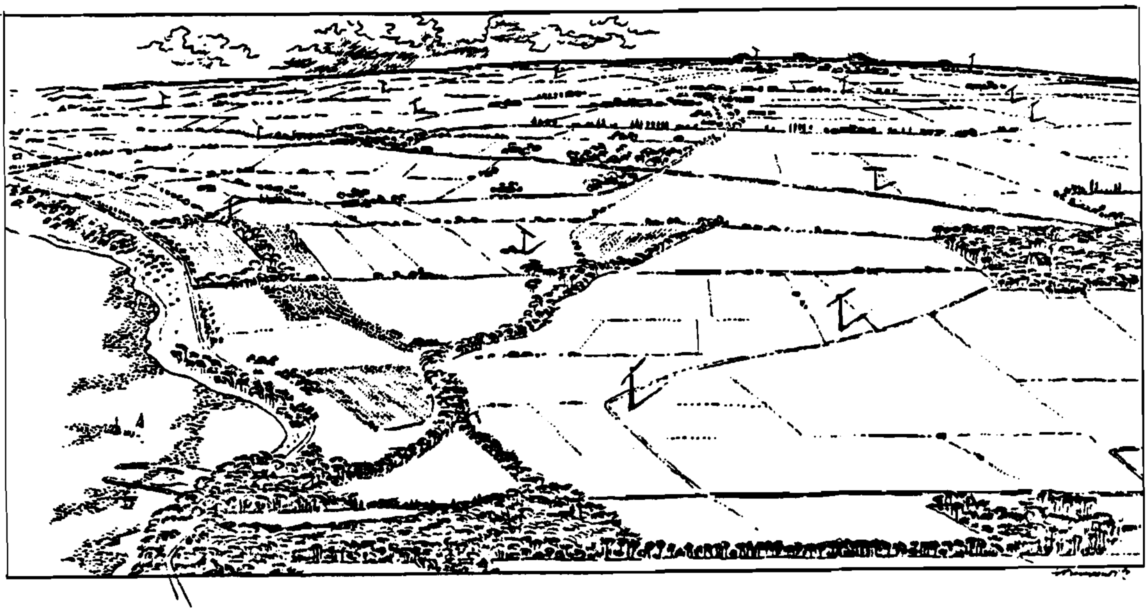
The area was the designated second site for a nuclear power plant in the southernmmost part of Sweden.

The picture shows 4 1000 MW reactors. The location and configuration based on the Barsebäck plant and information supplied by Sydkraft AB. The double 400 kV power lines leave the station to join the grid by a route designated in the planning documents concerning the site.

The road is as projected in long term road plans. The construction of the power plant is assumed to facitilate the simultaneous realisation of this plan.

Land use outside the immediate vicinity of the power station is not assumed to be affected or drastically changed. The scenario does not call for this.

Figure 2b Solar-Sweden, 2015



Ref. 8

Wind power development with a group station of 4 MW wind turbines. Height approx 100 m and blade length 80 m.

The configuration follows present guidelines for location relative to each other, buildings, major roads etc as discussed by the National Board for Energy Source Development. Due to soil conditions cables connecting the power plants are under ground. In less favourable conditions this would not be the case. The sites have an area of approximately 1000 sq m covered in asphalt.

In the picture are also indicated a number of energy plantations in the wetter areas; again these do not show up clearly in b/w.

Otherwise land use is unchanged as in the other scenario.

Both this picture and the "Nuclear-Sweden" one are complemented with ground views to give a more realistic impression of the landscape effects of various installations

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4.1.7 REGIONAL MANAGEMENT OF NATURAL RESOURCES IN THE ESTONIAN SSR

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SUMMARY

Specialists of the Estonian SSR have long-term experience in carrying out nature conservation activities in the conditions of the intensive utilization of local natural resources. The goal of taking maximum consideration of regional natural conditions is being realized through scientific investigations, central planning and practical measures according to a corresponding management scheme. If the utilization and protection of nature are regarded to be an integral process, it is possible to estimate the state of territorial ecological-economic systems, to investigate and prognosticate their behavior which is necessary for good decision making. The hierarchy of ecological-economic systems (beginning with an ecosystem to global processes) demands international cooperation if success in solving environmental problems is expected.

ABSTRACT

The Estonian SSR (4.52 million inhabitants) is situated in the northwestern part of the USSR on the coast of the Baltic Sea. The republic is relatively rich in natural resources (oil-shale, phosphorite, peat, building materials, timber). The ESSR is a republic with advanced industry and agriculture.

Activities in the nature conservation field started in 1910 when the first reserve was set up. Nature conservation laws were adopted in 1935 and in 1957. A national nature conservation agency was set up in 1957, since 1966 all kinds of activities in the nature conservation field are coordinated by the Ministry of[Forest Management and Nature Conservation that directly administers 40% of the total area of the republic.

A number of problems connected with the rational use and protection of natural resources have been solved in the republic:

- its economy is based on a state plan, a perspective territorial nature conservation plan, and schemes for the use and protection of all natural resources have been elaborated;
- forest management is based on the multiple use of forests which takes into consideration all the resources on a certain territory, the share of forests in the environment, and recreation;
- protected areas embrace 7.4% of the territory of the republic including the national park, 5 state nature reserves, 57 areas with a partial conservation regime, many species of flora and fauna have been taken under protection;
- a monitoring system (including ecological monitoring) is being implemented, a data bank of natural resources and ecological-economic models of certain areas are being built.

INTRODUCTION

The Estonian SSR is one of the smallest republics in the Soviet Union. The relatively intensive development of industry and agriculture is based on local natural resources (oil-shale, phosphorite, peat, the area under forests forms 40%, agricultural land 34% of the whole territory) on the one hand and on the raw materials obtained from other union republics (for machine building, textile industry, etc.) on the other. As to the output of oil-shale (27.5 million tons in 1984) and the production of electric energy per capita the Estonian SSR holds one of the first places in the world.

Due to the pressure of the intensive management of natural resources on the natural environment, nature conservation measures have been used for a considerable period already.

The Estonian SSR represents a relatively integral ecological-economic system (region) where the utilization and protection of natural resources have been developing hand in hand. We consider the objective of nature conservation to be - guaranteeing the management of natural resources in such a way that a minimum amount of natural matter should be used for manufacturing the products needed by the society (low-waste technologies) and waste products should be harmless as possible for the people and the environment. The balance of matter and energy within a territorial unit should be the criterion of human activities.

This paper will give a survey of the work done and of the principal directions in solving nature conservation problems in the Estonian SSR.

MANAGEMENT OF FOREST RESOURCES

The utilization of not only natural resources but also natural processes for the good of man is considered essential. Forests, as the most powerful natural resource of the republic, give the largest amount of bioproduction (and also so-called ecological production). The total area of woodlands (with bogs) comprises 53% of the territory of the republic. Rational management of this territory and the resources located there can essentially influence the ecological state of the republic as a whole. These circumstances are being taken into consideration on decision making about the utilization and protection of the republic's natural resources.

Estonian SSR forest management and nature conservation have existed as an integral system for over 20 years. This kind of organizational alliance has proved to be expedient as

- the forest - a complex natural resource;
- forest lands lodge several other essential natural resources (oil-shale, peat, building materials); and
- the forest, an important environment stabilizing component.

In forest management the importance of natural processes surpasses human activities. Due to the specific character of our system, the Ministry of Forest Management and Nature Conservation of the ESSR is responsible only for afforestation, clear cutting is the responsibility of another ministry – toxic chemicals are not used in the forests of the republic, the quantities of fertilizers used are small, other natural resources are taken into consideration when carrying out forest melioration work which has a substantial influence on environmental conditions. Water regulation is bilateral – drainage water of one district is stored in reservoirs of another, raised bogs are not drained in order to preserve peat. We have 200 thousand hectares of peat reserves. Habitats of valuable berries (cranberry) are excluded from the melioration fund.

A forest is an important landscape element in our national park and in other protected areas.

Special forestry measures are taken in the vicinity of towns and settlements, in so-called forests of green belts and recreational areas. Protection forests have been established, special water protection belts are being planted on the banks of rivers and lakes. Ecozones (a system of environment stabilizing territories) where intensively used territorites are interchanged by more natural ones (forests, bogs, protected areas, etc.) have been established.

In the Estonian SSR the aims of forest cultivation and utilization are the following: to receive complex production (timber, game, berries and mushrooms, shortly, the usable bioproduction) from the territory, to guarantee the stability of environmental conditions (included pure water, oxygen, local air purification) and pleasant landscapes.

In the calculation of forest resources besides site classes (which mainly determine the timber production of the soil) forest types are taken into consideration. Forest types characterize the capacity of bioproduction of the forest as a whole. In the Scientific Research Institute for Forestry and Nature Conservation, the necessary forestry and nature protective measures (for afforestation, tending of forests, melioration, utilization of forests) are identified according to forest types which form the ecological basis for forest management. The ecological-economic production of forests (timber, berries, game products, recreation, some environmental aspects) have been calculated by the author also on the basis of forest types. At that the ecological potential and the economic profitableness are in harmony while in more fertile sites timber is the main product, in less fertile types by-products give essential supplement. Accounting by-products considerably increases the profitableness of less fertile areas which very often give good yields of berries, mushrooms (Cladonia and Calluna types) and honey (Calluna type). Wet intermediate type peat bogs and raised bogs represent the best cranberry habitats of the republic.

Another example where nature conservation principles have been applied in forest cultivation is the recultivation of exhausted surface (quarries). In the industrial district of the oil-shale basin more than 5000 hectares of former mines have been converted into new landscapes, places of rest and more productive forests than before.

Complex approach to forest utilization enables not only to increase the productivity of a territory but also, especially in the case when ecological criteria are added to economic ones, to take into consideration existing natural inter-resources connections (forest-oxygen, forest-water, forest-peat, forest-game, etc.).

Having continued the analysis we came to the conclusion that in our conditions forests begin to fulfill their environmental functions at the age of 20 years on the average. This age was fixed as the ***environmental maturity of a forest***.

TERRITORIAL APPROACH

Natural resources located on a certain territory are historically interconnected due to the natural conditions at the period of their formation. It is not difficult to build static and dynamic data bases of territories not influenced by human activities on the basis of data obtained with the help of various natural sciences (geology, geography, soil science, geography of flora and fauna, climatology). On most territories the impact of human activities is noticeable, utilization of local natural resources has influenced naturally established environmental conditions. Therefore, building dynamic data bases of environmental conditions is more complicated and ecological-economic modeling is necessary.

The supplies of natural resources and the dynamics of their utilization can be estimated with local efforts, but observation and prognosis of changes in environmental conditions needs international cooperation – the existence of international monitoring system and the exchange of data. Biological (ecological) methods must be used in addition to physical-chemical ones. Here retrospective investigations (and conclusions) are needed as we know. Forests and peat represent objects for investigations (determining the age of timber by carbon methods, using dendrochronology). In our conditions peat, besides timber, also contains information of 11,000 years, i.e., since the last glacial period. Protected areas as untouched natural resources influenced only by airborne pollutants also represent important objects for scientific research.

All the issues mentioned here are being dealt with in the ESSR. Ecological monitoring is being implemented on the basis of protected areas and data banks of the most important natural resources are being built (on the basis of them territorial data banks will be made up in the future). Cooperation is being developed with nature conservation and scientific organizations of our geographically nearest foreign neighbors Sweden and Finland.

SOME PROBLEMS

A number of environmental problems can be solved only by means of international collaboration. What are they?

First, airborne pollutants which with prevailing winds (in the Estonian SSR southwestern winds) are transported into the republic and also out of it.

Second, guaranteeing the purity of the Baltic Sea. The problem is being solved on the basis of international cooperation according to the Helsinki Convention.

Third, inner-republican problems of which the complex use of natural resources (oil shale, phosphorite, etc.) in the northeastern part of the Estonian SSR and the utilization and protection of large inland water bodies are essential. Lake Peipsi in the ESSR, like Lakes Ladoga and Onega, belong to the largest lakes in the European part of the USSR.

According to diverse environmental problems connected with the republic, three territorial units may conventionally be distinguished.

1. The Estonian SSR as a (ecological-economic) region consists of five subregions. Of the five microregions, northeast Estonia locates abundant oil shale and phosphorite supplies. The experience acquired in the field of the complex use of oil shale, utilization of its waste products and recultivation of exhausted areas might be of interest for anybody who plans to make use of this local fuel.

Special attention must be paid to the archipelago of about 1000 islands and islets in west Estonia unique in the whole western part of the USSR. Three state nature reserves have been set up here, complex investigations of natural processes, especially of those in the conditions of the rise of the earth's crust, are being carried out.

The republic is affected by transboundary air pollution. Because of harmful effects of acid rains on our forests, we are interested in collaboration in this field with our nearest neighbors as well as with the countries from which the emissions are being released.

2. The meso-region embraces the Estonian SSR, the Latvian SSR, the Lithuanian SSR, the Pihkva and Leningrad territories, and the Karelian ASSR.

   Management of large inland water bodies is one of the main environmental problems of this unit. When organizing the protection and utilization of the water resources of Lake Peipsi, experience acquired in the basin of Lakes Ladoga and Onega would be of great use. Prevailing winds transport atmospheric pollution from the ESSR to the Leningrad territory and the Karelian ASSR.

   Management of large inland water bodies is one of the main environmental problems of this unit. When organizing the protection and utilization of the wateqr resources of Lake Peipsi experience acquired in the basin of Lakes Ladoga and Onega would be of great use. Prevailing winds transport atmospheric pollution from the ESSR to the Leningrad territory and the Karelian ASSR.

3. The macroregion which may be established by adding to the territorial units mentioned under p. 2, the northern part of the Baltic Sea, the Finnish Bay, the southern part of Finland, the southern and central parts of Sweden.

   Here the protection of the Baltic Sea represents a problem of common interest for all the territorial units which influence and depend on it. Estonian scientists are interested in exchanging monitoring data and information of the protection of ecosystems on islands with Finnish and Swedish scientists. Work in this field is being carried out according to Soviet – Finnish and Soviet – Swedish plans of cooperation in the field of nature protection.

The problems mentioned above form only a part of out environmental concerns. The utilization and protection of natural resources needs complex methodology with ecological-economic modeling as an essential component of it.

4.1.8 REGIONAL-COMPANY APPROACH TO STRATEGIC ECONOMICAL-ECOLOGICAL POLICY

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ABSTRACT

In this paper are described the main features of the innovative regional–company approach to strategic policy and its implication for problems of regional resource management. It is shown that such an approach permits the determination of more correct relations between economic and natural regional subsystems with respect to their long-term dynamics. Under this approach it becomes possible to more accurately predict changes in the economical-ecological balance, taking into account technological, economical, and managerial capabilities at both regional and company levels. In terms of the regional-company some analytical, methodological findings and conclusions are formulated.

INTRODUCTION

In spite of obvious advances in developing solutions to environmental problems in recent decades, the situation in this sphere remains urgent. The pollution level of the environment in many regions has not decreased and, in some cases, has even increased (Haisiugh, 1982). The main reasons for the continued presence of environmental problems are the unsolved contradictions between economic and environment protection requirements. The growing complexity of economic developments has resulted in declining rates of investment in projects with environmental objectives. In the 1980s these rates have not exceeded 2.5% of the gross domestic product. As a result, the share of ecological investments in most countries is 1.5 to 2 times lower than is necessary. At the same time, the proportion of basic funds allotted to ecological objectives by many industrial plants has reached 20-25%. For many small enterprises, the ecological burden exceeds the acceptable level of investment (Hoover, 1975). The spatial, interregional movement of production forces is also determined by economic considerations rather than by ecological ones. It is characteristic that, despite some technological advances, the efficiency of raw material utilization remains low: about 95% of raw materials are waste (Kchachaturov, 1982).

Taking into account the high complexity of environmental problems, many researchers have naturally concluded that a more comprehensive approach to the solution of these problems is necessary (Evers, 1980; Kochetkov, 1981; Peters and Waterman, 1982). The focus of such a comprehensive approach to environmental problems consists of the interdependent analysis and development of economic, technological, and managerial capabilities, at both national and subnational levels (Ansoff, 1982; Kapp, 1985).

In moving to more comprehensive considerations of strategic solutions to environmental problems, IIASA has developed, within the framework of the Regional Project, a regional–company approach, including the basic methodological ideas and their computerized versions for choosing strategic solutions.

Regional–company approach: general outlines

It is very important to acknowledge that a regional economic decline shows itself as the declining of companies' economies. And, on the contrary, companies' prosperity always supports the regional economy and can potentially lead to the successful solution of environmental problems. Likewise, most environment protection measures are undertaken by industrial enterprises and other business companies, since they are the main users of natural resources and the main polluters of the environment. Accordingly, the efficiency of environmental protection activity strongly depends upon the scale and organization of ecological actions by the companies (Malecki, 1984).

Discovering the interdependences, we can show that regional labor markets affect all companies' basic strategies: technological, growth, diversification, and others. The capacity of a regional infrastructure influences the rates of capital investment assimilation, plant modernization, production relocation, and consolidation of a company's economy. The regional spatial–functional cooperation of companies supports the intensification of R & D, thus increasing corporate technological capability and agglomeration. The regional, natural ecological system determines the permissible pollution level and adequate criteria and standards for functioning plants and factories. Many companies have established special departments that are responsible for the maintenance of the economical–ecological balance. These departments fulfill the monitoring aspects of quality and pollution standards in air, water, and other ecological components, and control, in ecological terms, the basic technological process and equipment for refining.

At the same time, company strategic policy, from the point of view of the region's environment, is very contradictory. It is known that a company's cost control has led, in many countries, primarily to the relocation of companies to areas of low-wage labor. A company's quality control requires that plants with considerable R & D capacity locate in areas that are preferable to qualified workers. There is a real tendency for high technology industrial companies to locate in areas with highly intensive R & D activities (Kochetkov, 1977). There are also many specific, spatial strategies for intermediate companies (Hekman, 1980; Malecki, 1984). Such company decisions have, in many cases, undesirable consequences for the natural environment. Many companies assume that ecological standards will be disturbed as a result of undesirable effects of technological processes. As usual, the small companies suffer from insufficient state subsidies, etc.

The reasons for this are the refusal of many companies to establish special ecological departments, the weaknesses of ecology-oriented incentive mechanisms, and the complexity of the applied methodology for calculating damages and losses at the regional and interregional (intersectoral) levels.

During 1984-1985, under the framework of the IIASA Regional Issues Project, the following general outlines of a strategic regional–company approach and its application to economical–ecological problems were developed.

The widespread, comprehensive approach to developing economical-ecological strategies at the subnational level should be expressed in terms of the regional–company economy (RCE) as an integrated system. Such an RCE approach enables more balanced strategic choices – to find ways to solve economic problems while observing social and environmental protection equilibria. It is possible, of course, that due regard for mutual regional–company interlinking criteria could limit the projected economic growth rate.

limit the projected economic growth rate.

It is very important to acknowledge that a sustainable economical–ecological balance can be achieved only on the basis of a rational spatial–sectoral division of labor, which in turn can be well-grounded by a study of RCE strategic development. Such a division could be considered as a generalization of specific product-line competitiveness of actual companies located in the given region.

This means that the determination of a sustainable economical–ecological development implies modeling interdependent processes between RCEs and the competitive environment as a basis for making structural changes in policy of a strategic nature. Structural change strategies, based on technological innovations, in their turn can be considered as long-term revitalization programs intended to restore the national and international competitiveness of RCEs. The study of RCE competitiveness closely links with environmental balance, because competitive pressure inevitably limits the possibilities for improving ecological standards (Porter, 1980). Therefore, interregional analysis of RCE competitiveness in national and international frameworks will increase the validity of strategic economical–ecological policy. Such analysis, apart from its strategic cost–benefit study, includes modeling technological impacts on the economical–ecological balance in the RCE, in terms of economic growth rates and restructuring processes, taking into account the increasing role of internal and external company cooperation in developing RCE technological capability. It implies also that special attention must be given to considering and searching for reliable, sound strategies of RCE development under possible conditions of economic stagnation or other unpredictable circumstances. Another feature that should make such an analysis more oriented to problem solving is the calculation of implementation sequences of strategic action on the basis of establishing economical–ecological problem priorities, resources, and time characteristics.

To meet these requirements, the regional–company approach is based on building a strategic policy-aids system using advanced methods of computerized forecasting of the RCE long-term development as the early warning system of competitiveness prospects and of the necessity for structural changes for improving economical–ecological balance.

As a result, the regional–company approach is designed to provide policymakers with tools and data for addressing a variety of general issues:

- What are the structural, long-term environmental changes (constraints) and competitive requirements that essentially influence the strategic behavior of regional–company systems?
- What are the key characteristics of regional–company systems that are closely linked with environmental changes?
- What models are available for describing the relationships (interaction processes) between the natural environment and regional–company economic systems? How can such RCEs increase their strategic capability for flexible and well-timed responses to a shifting, competitive environment and at the same time maintain environmental standards?
- What long-term product-line specialization is most effective for a given RCE, taking into account its natural, production, human, and other resources (which determine its strategic advantages and competitive positions, as well as the economical–ecological balance)?
- What time trend of structural change is acceptable, taking into account the balance between short-, medium-, and long-run economical-ecological objectives?

- What performance of RCE could characterize it as the most sound and well-balanced according to economical–ecological aspects (among other RCEs)?
- What specific, natural ecological characteristics and consequences associated with given strategic, structural, and market changes are normal?
- What is needed (for example, in relation to state support of new, high-technology ventures) to maintain and develop economical–ecological balance in the declining regional–company segments?

The research needed to answer these questions should originate from a deeper understanding of the regularities in the behavior of the regional–company system and should aim at resolving the difficult problem of how to connect explanatory theory with organizational design and computerized analytical techniques.

Technological capability and economical–ecological balance

As practice shows, the actual economical–ecological regional balance depends on many situational factors: RCE scale, internalization level, resources availability, management capability etc., but it is worthwhile to keep the solution palette within the framework of the main technological choices to improve RCE competitiveness.

It is important to note that the role of technological factors in the economical–ecological balancing mechanism is not understood to the necessary degree. In many cases, regional economic recession and disturbance of the ecological balance are accompanied by technological stagnation and a priority is given to financial and administrative strategies. This means that the resource-saving role of technological innovation often has only a theoretical sense. The more comprehensive, strategic approach focuses on the problem of increasing both the economic and ecological effectiveness of technological development as a resource and controlling variable in the long-term, with practically unlimited possibilities (Arthur, 1984). And the strategic alternatives for sustainable, regional development include, of course, measures for achieving more balance in the social and ecological aspects of technological and economic changes. This means that the real economical–ecological problem is devolved to the correct application of strategic tools to technological progress. Many researchers link modern technological revolution with such discoveries as computers, microprocessors, genetic engineering, biotechnology, etc. These discoveries essentially influence the structural changes by way of production robotization, flexible and unwasted technologies, the creation of new materials, new kinds of technical links, etc. (Lynn, 1982; Stoneman, 1983). High technology can be considered as, generally, the most important means of improving environmental standards and maintaining economical–ecological balances. It includes implementing the most effective environmental protection measures – the manufacture of pollutant-free products. At the same time, at present the main problem of RCE development is to minimize the costs of meeting environmental quality standards (Orishimo, 1982).

To take into account these opportunities, within the framework of a regional–company approach, it is necessary to model the technological choice as an alternative means of balancing the ecological aspects of RCE development. The main difficulty here is the comprehensive nature of technological choice, which aims not only at environmental objectives, but also at economical and social ones. This means modeling technological development by taking into account the export orientation of the RCE basic industrial sectors as well as its lifecycle and the possibility of coinciding with economic activity dynamics, prospective changes in market prices, demands, production, and the organizational structure of companies (especially in relation to diversification), as well as other anticipated changes in RCE development (Clark,. 1983).

It is also necessary that the modeling of technological choice, both in entering the market with a new product, which insures technological advantages, and in improving the production processes of existing products, results in reduced cost and improved quality (Printice, 1984). It is essentially important to consider the appropriate speed of diffusion and adoption of technological innovations among RCEs, taking into account differences in regional conditions (social, economic, and cultural disparities); firm's scale; R & D level; fixed available resource potential; as well as the impact of competition level within RCEs.

The other side of technological development is connected with the uneven dynamics of aging processes in the basic industries of RCEs. As a result there are obsolete manufacturing plants and factories that not only erode the RCE competitive edge, but also, at the same time, produce a high level of pollution in the regional environment. Because of this it is worthwhile to include in analytical models of the regional-company approach indicators of the average age of the RCE industrial plants. For example, in the 1980s efficient RCEs have an average age of manufacturing plant of about 7–8 years. At the same time, RCEs with increasingly obsolescent plants, of average age more than 10–12 years (in some cases 15–20 years), have lost their competitive positions. To emphasize, there is a correspondence between indicators of RCE competitiveness and economical-ecological balance on the one hand and the average age of industrial plants on the other hand. Therefore, increasing RCE competitiveness and improving environmental standards within the framework of long-term structural change alternatives presupposes that the corresponding dynamics (diminishing) of average age in the basic industries should be reflected in adequate investments in high technology and modernization of manufacturing plants.

Considering this problem, it is necessary to take into account the pulsating nature of technological changes, according to which time periods of quantitative changes of evolutionary accumulation transmit into time periods of qualitative revolutionary leaps. There are three basic phases of technological progress (Yakovecs, 1984).

First, the more widespread choice relates to the change of product/process models in the framework of the same technology generation. Second, the model choice could be made based on the replacement of the technological generation, while remaining at the same time in the framework of the existing technical level of the economy. Third, the choice of product/process models could be connected with the appearance of fundamental new technologies, which qualitatively determine the transition of runs of other model generations. Each of these technological trends adds its particular contribution to the structural changes of the regional-company economy and economical-ecological balance. Practically, for the phases between fundamental technological revolutions, it is more efficient to focus resources at the regional-company level, primarily on the modernization of existing product/process models. On the other hand, during the next technological revolution there is the prospect of resolutely refusing routine choices and making structural changes based on a transmission to the more promising technological models.

The main difficulty here is the contradictory nature of technological innovations, such that no single pattern of structural change exists (Nijkamp, 1983). The routine measures are here directed to alleviating developing pollution threats. But, in practice, this approach carries more failure than success (Storper and Walker, 1984). Apart from general regularities, often one cannot reliably orient the strategic economical–ecological policy of particular companies, because such policy depends on many changeable factors and situational conditions. It very often occurs that companies located in regions with growth potential cannot be sure of reliable prospects because of unpredictable technological changes and structural shifts in the world economy. Traditional economical–ecological spatial regularities also change under the influence of new interregional networks of telecommunications and computers – new ways of interregional integration based on information technology (Porter, 1983).

Supporting principles of the regional–company approach

It is worthwhile considering some supporting principles of the regional–company approach to establish and maintain the economical–ecological balance.

One of the main principles of the regional–company approach is the consideration of a region not in the routine sense, but as a multiproduct line company and/or a set of companies whose strategic behavior depends on interactions of internal (economic structure, social, and environmental balances) and external (competition environment) factors. Such an approach results from the fact that changes in the economy occur, to the greater degree, at the regional level in the main, not only as a result of centralized, top-level policy directions, but also as an output of companies' business activities.

These regularities, until recently, have only been considered in application to market economy countries, but in the 1970s to 1980s it became apparent that the East's state-owned companies had increased their economic independence and considerably broadened their sphere of strategic policy (Aganbegjan, 1979; Kochetkov, 1982; Gvishiani, 1984). Such modern tendencies confirm the possibility of, and necessity for, considering RCE as a new objective, in total or in parts, of strategic policy related to both private and state-owned companies in the West and state-own companies in the East. To make this task more practical and to use the methodology for comparative analysis, it is necessary to study how to define and calculate competitiveness for West and East companies.

It is necessary also to take into account the self-organizing nature of environmental processes within the framework of regional systems, as well as the existing differences between environmental protection interests of different social groups and the effects of environmental protection over a projected time horizon.

The other important supporting principle stipulates the inclusion of a traditional set of resource strategies (these may be called direct strategies) and some indirect ones (Hart, 1984). The main idea in using indirect maneuver strategies is to overcome or diminish the resistance associated with implementing new economical–ecological balanced regional–company strategies. Such resistance has a number of well-known causes: inertia of thinking; the use of outdated, traditional means; bureaucratism; a narrow disciplinary approach; etc. To overcome these problems, indirect strategies, including specific environmental education and training, may be used. The increasing role of resource maneuvers inevitably implies building implementability into the regional–company approach. In accordance with this principle, it is necessary to provide a careful preparation of the implementation conditions already present in the policymaking process. It is important to notice that the current market mechanism itself is not able to put into practice integrated economical–ecological structural change strategies. Some weaknesses characterize also the existing direct (budget policy) and indirect (taxation policy) mechanisms of public regulation. Therefore, we can make here two remarks. First, the main role in this implementation process should belong to a planning system oriented to the long term, but as the strategic horizon shortens the role of the market mechanism increases. Second, to overcome the dangerous economical–ecological balance stage of regional–company development it is possible to use a range of strategic compensatory mechanisms, that return the regional system to a balanced state.

One of the most promising supporting principles of the regional–company approach is the introduction of an integrated assessment of environmental damages, with the calculation, on the basis, of special payment by companies for their pollution. Such an integrated assessment would provide an estimation of the sum of local damages: deterioration of product quality, speeding up of funds where additional expenditures for purification, and changes detrimental to human health, as well as to that of the flora and fauna. In most cases, the effect of environmental protection measures that are undertaken by a company can be assessed on the basis of prevention of damages. The calculation of such ecological effects could be added to the traditional set of company activities. Likewise, possible tax privileges connected with ecological equipment, etc., could be taken into account.

Analytical tools of the regional–company approach

The policymaking process in the framework of the regional–company approach will inevitably be complicated, taking into consideration a set of spatial and sectoral (internal and external) feedbacks, as well as time intervals between strategic actions and their economical–ecological effects. And, of course, some qualitative techniques will be needed to evaluate the exogenous parameters in the formal model, to create the right conditions for involving policymakers and experts in the decision-making process, and to interpret the results of the quantitative calculations. At the same time, because of an inevitably incomplete description of the regional–company system it is necessary to combine formal and informal analytical methods.

This means also that the initial basic calculation for the strategic choice of economical–ecological parameters should be considered only as a trajectory that is close to the ideal; one that approaches reality requires regular revision of the priorities in objectives and means, and proper correction of strategic, tactical, and operational actions. One could say that the main methodological aim is not to build a system that can find the parameters for future structural change, but to build a system that is able to conduct regular analysis of changing economic, environmental, social, political, and other conditions.

To meet these requirements, special analytical programs have been developed for the IIASA Regional Issues Project, under the name ISSMI: Integrated Strategies of Structural and Market Improvements. The mechanism of ISSMI program involves the computerized verification of a range of hypotheses about the strategic behavior of a given regional–company system, taking into account the corresponding behavior of competitive systems (those producing the same products). The strategic behavior of each regional–company system, in turn, is determined by structural change and has a number of alternative forms.

The ISSMI program takes into account the requirements imposed on economic structural changes by social (e.g., employment) and environmental (primarily pollution) balances. In the more complete framework, the ISSMI program operates by a set of ecological characteristics of land, forestry, air, and water, as well as mineral resources.

The land aspect includes the assessment of losses that result from extending a company's constructions, from chemical pollutions, and from erosion, secondary salting of soil, etc. The most effective contribution of a company's environmental activity is created by the introduction of biotechnologies.

The water aspect includes assessment of the impact of a company's activity on pollution by production flows (mainly in the metallurgical, chemical, cellulose, and some other industries). Here, the most effective impact on the economical-ecological balance is achieved by the combination of resource-saving technology, technology for refining, and the application of a circulating water supply.

The air aspect requires an assessment of industrial concentration levels closely connected with the concentration of pollutants. The largest polluters here are heat and energy companies, which, together with metallurgical ones, produce about 65% of regional pollution (Hoodoley, 1978). Refining equipment, as a rule, is very capital-intensive and does not solve the problem of air quality. This means that the main method for restructuring company activities to achieve an economical–ecological balance is to improve the basic technological processes, with the introduction of technologies, that are not wasteful.

Essential contributions to maintain the economical–ecological balance could be made by companies that specialize in mineral resources industries, because they use 75-80% of the total volume of raw material utilized. The company could contribute to maintaining the economical–ecological balance by using more complex and complicated technologies to ensure the multilateral and more intensive treatment of material.

Finally, more general strategies regarding the influence of companies on the economical–ecological balance are:

1. Installation of refining techniques.
2. Change of basic technologies.
3. Change of production specialization.
4. Spatial redistribution of production and pollutants.
5. Managerial restructuring.

As a result, the ISSMI program operates by using information on the integrated economical–ecological (and social) strategy alternatives of the regions, which are considered as a single multiproduct company or as a set of companies whose strategic behavior depends on the interrelations of internal and external factors.

Similar SSUs are in competition with each other and their strategic parameters are determined by, on the one hand, economic effectiveness characteristics - cost of transport change, price, profit, investments, stage of lifecycle, correspondence with the market sector, and so on. On the other hand, these economic performances are closely connected with the environmental standard adopted.

The evaluation of technological, investment, labor force, and ecological capabilities of region allows policymakers to examine the factors that are important to a long-run, sustainable economic growth, in addition to more immediate values of profitability.

The data base of the preliminary ISSMI program consists of about 60 items, descriptive of the characteristics of the market conditions, strategic policy actions, and strategic results obtained. It is planned to introduce a set of standardized forms, to be completed by the participant RCEs; the ISSMI staff will record the information in the computer data bank.

There are two computerized versions of the ISSMI program. The first is a softeware system that is applied to the analysis of mathematical flow models (FMAs). The approach used for the elaboration of the FMA system allows the user to account for both parametric and structural changes, as well as the dynamic and multicriteria aspects of modeling (Umnov, 1984). The FMA system also includes highly effective input–output data generators, which facilitate its use by new users after relatively minimal instruction.

Another feature of the FMA system, which is very important in practice, is the possibility of using the system for "incomplete" models, i.e., for those that do not include all the links and constraints that define the behavior of the modeled object. The basic algorithm used in the FMA system is equivalent to the multistep solving of a special case of the Chebyshev approximation problem. In its turn, the latter is reduced to the interactive solving of a linear programming problem, subject to changing its statement during the process of solution.

The second computerized version of the ISSMI program presents the application of a particular kind of optimization technique to strategic choice in the framework of the regional–company approach. This means that ecological requirements are included in the model as constraints: the pollution level in a region cannot be more than the acceptable standards. Likewise, these standards are considered as a dynamic system and, importantly, change during the various stages. Second, to have more flexible solutions, it is possible to change, to a limited degree, the standards in the framework of each time stage, taking into account the competitiveness of the regional–company economy.

For instance, the introduction of stricter environmental standards in many industries leads to an increased ecological investment share, up to 40–45%. As a result the cost of a product will increase.

In addition to the basic mathematical models, the programs assume the development of a number of subsidiary models that will calculate the necessary information as regards the forecasting of market demands and production growth rates, and the determination of the effects of investment, technology, etc. One specific structural modeling technique is also being developed for the treatment of expert information. This technique based on interactive computer usage, is called STRUM (structural modeling system) and allows one to analyze interconnections between objectives, problems, conflicts, functions, and actions.

CONCLUSIONS

The regional–company approach to develop and carry out measures on the re-establishment and maintenance of the economical–ecological balance creates a new, comprehensive focus in strategic environment policy. This approach is based on the real regularities of environmental protection activity and stimulates the implementation of such an approach. At the same time, the appiication of more thorough analytical tools is also necessary.

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4.1.9 A CASE OF ENERGY-RELATED DEVELOPMENT IN AN AGRICULTURAL REGION

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ABSTRACT

Large-scale lignite strip mining and related power generation development in a predominantly agricultural region of central Poland has brought about important changes in the socio-economic and natural resource environment. It therefore had become necessary to generate and analyse potential policies for coping with these changes and their consequences, regarding, in particular, agriculture. Within a range of studies on geology, land reclamation, hydrology, etc., carried out for the above problem, a modelling study was also undertaken, meant for pointing out the possibilities efficiency and directions of agricultural development under given changed environmental conditions, and for suggesting policy options securing chosen development directions.

1. Regional characteristics

The area in question is located in central Poland. It is characterized by traditional family farming, with farm sizes equal to Polish averages, that is small, and little diversified production based upon rye, potatoes and milk. Soils are light and precipitation is low. Forest area is slightly lower that the national average, and wood quality is not too high.

Industry is much less developed than in most of the sorrounding areas. There are no important urban centres, no university tradition. In fact, this region was, but for a short period, a second-rate Poland throughout history, although it always was in its geographical centre.

Delimitation of the area considered is defined by the influence of a large-scale lignite strip mining and power generation related to it. There is a number of such influences, environmental, economic and social. Some of them shall be commented upon further on. Each of them has a different geographical stretch.

Ideally, in delimiting the area of concern, one would take into account all the geographical stretches of various influences exerted by the strip mining and related developments. Adaptation of such a strict approach, however, would require: quantification of all the influences over the geographical space, determination of appropriate thresholds of influence and spatial aggregation. This seems to be quite a formidable task.

It is, therefore, convenient to take certain proxies in order to represent the region. Thus, Fig. 1 shows the maximum area of the envisaged groundwater table drop resulting from strip mining of ar least 1 meter, as located against the local /voivodship/ administrative boundaries. This area shall be referred to as "groundwater crater". Since the rest of the Piotrków voivodship, in which approx. 85% of the crater is located does not differ substantially in its features from the crater area, therefore some of the characteristics given at the beginning of this section are illustrated with data for the Piotrków voivodship in Table 1 /Piotrków voivodship may, for some purposes, be also taken as a proxy for the region in question/.

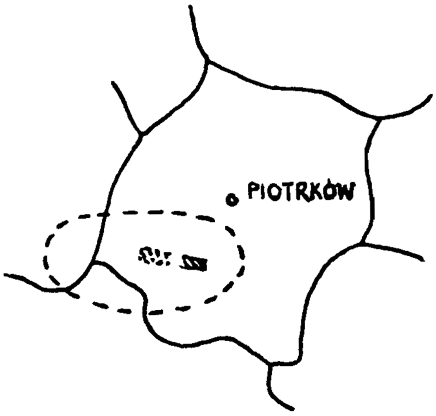

Fig. 1. Schematic view of the maximum area of the envisaged groundwater level decrease of at least 1 meter

——— voivodship boundaries

- - - - - boundary of the groundwater drop area

[symbol] strip mine, actual and planned

Table 1. Some indicators relating Piotrków voivodship to Polish averages.

Item	Polish average	Piotrków voivodship	
		average	as % of national average
1. Urban population share	59.1%	43.1%	73%
2. Population density, persons per sq. km	115.3	97.8	84.8%
3. Employment in state economy per 1000 inhabitants	333	301	90.3%
4. Value of capital assets per capita, in 10^3 zlotys	214	207	96.7%
5. Global value of annual state-controlled production per capita, in 10^3 zlotys	66	57	86.4%

When assessing the data of Table 1 one should remember that Poland is a flat central European country, relatively evenly developed, with the most industrialized and densely populated areas sorrounding the Piotrków voivodship.

2. Strip mining and related developments

Poland is devoid of oil resources and has quite limited gas fields and therefore, to a large extent, Polish energy is oriented towards coal. Poland is, besides that, traditional exporter of anthracite, which is treated as a financially very important export item. In conditions of shrinking coal resources and increasing costs od exploitation it becomes expedient to find and put in operation new reserves. Luckily enough, the Central European Plain, stretching from the Rhine beyond the Vistule has in its upper part several rich lignite fields. These lignite fields are exploited as strip mines in FR of Germany, German DR and Poland.

The opencast mine in question in one of the biggest in Europe. Its depth reaches 300 metres while the total length will near 20 kms. It is composed of two parts, of which only the first one is now in operation. The first part is supposed to contain more than 10^9 tons of lignite, while the second - a little more than $0.5 \cdot 10^9$ tons. It is anticipated that, under the presently assumed operation conditions, the lifetime of the whole mine will reach approximately 40 years. Most probably, after the operation is finished, some 80% of the mine surface shall be covered by lakes. Meanwhile, the "brown hole" draws water from the sorrounding aquifers.

In the vicinity of the mine a lignite-fueled power plant is in operation. Its capacity is 4200 MWatts. Another power plant is planned to start generating when the second part of the mine starts producing coal. The capacity of the other power plant is envisaged at 1500-2100 MWatts.

Direct employment in power generation and mining is envisaged to grow in the next few years from the present 5 thousand to 8 thousand. This would account for approximately

10% of the overall voivodship's industrial employment and proportionately more for the direct influence area considered.

The "groundwater crater" surface is now approaching 450 sq kms. Its envisaged maximum is 1300 sq. kms. /Compare with 6250 sq. kms of the whole Piotrków voivodship/.

3. <u>Agriculture</u>

As mentioned, regional agriculture is relatively little diversified and technologically traditional. Rye, potatoes and fodder crops make up for most of the cultivated area. Permanent grasslands occupy, typically for Poland, about 15% of the whole agricultural surface. In some parts of the region vegetable and fruit cultures become more important. Livestock breeding is not very intensive neither. It is less-feed-oriented, i.e., for instance, more towards milk /dairy cows/ than quick meat /hogs, poultry/. Soils are relatively poor, sandy and clayey for the most part. Average annual precipitation - approximately 55-58 cms.

Some important indicators describing the position of local agriculture are given in Table 2. To the picture thus formed one should add three important remarks. It should be emphasized first, that in spite of its low intensity and traditional character this local agriculture is an important net food exporter to other regions. Besides that, this traditional agriculture is, with respect to many resources - excepting land and labour - very efficient. This feature enables subsistance of this sector in conditions of a heavy underinvestment. Third, it must be remembered that at present agriculture is still providing jobs and incomes for quite an important share of regional population, someplaces exceeding even 50%.

Two comments are due on the numbers given in Table 2. They concern items 9. and 10. Farm size 15 hectares indicates the greatest private farm category in Polish statistics. On the other hand it is a widely accepted conviction in Poland that a farm can secure appropriate income and development capacities, in conditions of absence of other special opportunities /closeness to market, start up capital for installing

I t e m	Polish average	Piotrków voivodship average	Piotrków voivodship as % of national average
1. Cereal net yield, in tons per hectare	2.6	2.2	85%
2. Potato net yield, in tons per hectare	17.7	16.5	93%
3. Cattle number, per 100 hectares*	67	60	90%
4. Milk production, in tons per hectare	0.87	1.03	118%
5. Meat production, in tons per hectare	1.6	1.4	87%
6. No. of tractors per 100 hectares	3.7	2.8	76%
7. Share of agricultural area in private farming	74.9%	92.5%	123%
8. Average surface of a private farm**, in hectares	5.0	4.7	94%
9. Surface share of private farms above 15 hectares	5.7%	2.3%	40%
10. Share of population in post-productive age	11.8%	13.8%	117%

Table 2. Some indicators relating the Piotrków voivodship agriculture to Polish averages.

* here and further on: hectares of the overall agricultural area

** this indicator errs on the lower side, since "farms" having surfaces 0.5 to 2 hectares are also accounted for.

highly specialized production etc./, if it is at least 10 hectares large, with appropriate spatial organization. This, it seems, quite applies to the regional situation considered, for there is only a very limited farm subpopulation who can afford e.g. construction of greenhouses in order to sell vegetables or flowers in agglomerations some 60 kilometers away. Thus, the margin shown in Table 2. represents, provided all necessary resources are there and economic situation does not change sharply, the forms which can ensure jobs, adequate income and economic resilience. It can be estimated that the total of such forms in the region does not exceed, under the present economic situation, some 35-40% of all farms.
Other farms secure incomes lower than national average and do not allow important investments to be made.

Item 10. of Table 2, although it applies to the whole of local population, has special bearing on agriculture. It is sufficient to compare Item 1 of Table 1 with the datum to see the connection. Rural population there is an old one, at least in Polish terms.

4. Problem structure

There are a number of regional effects resulting from introduction of the large strip mining and power generation developments into the region in question. The most important of them may be listed as follows:

1. Agricultural land appropriation and landscape changes,
2. Employment in industry,
3. Diversion of labour from agriculture,
4. Lack of water and "groundwater crater".
5. Increased personal income,
6. Crop decrease,
7. Ecological deterioration,
8. Crop quality decrease,
9. Changes in human environment.

Fig. 2 shows schematically interrelations between various aspects of the regional system, resulting from introduction of the development in question.

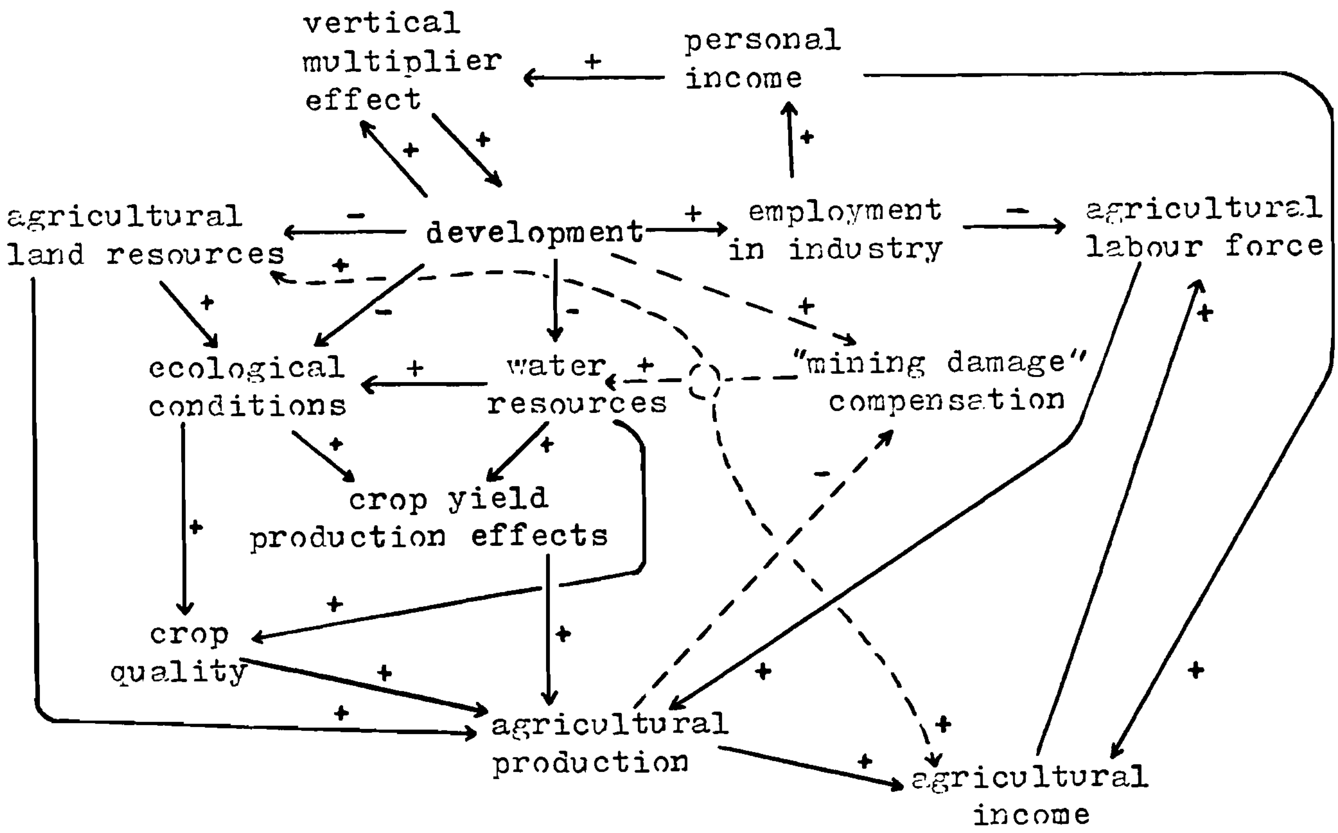

Fig. 2. Interrelations among some aspects of the regional development/agriculture interface
⟶ causal links
⊃-→ links subject to decisions

It can be noticed that "Changes in human environment" /effect 9./ do not appear in Fig. 2. This is caused by the wish to keep the diagram possibly clear, and by the fact that asessment of this effect is highly subjective.

Two general remarks on Fig. 2 are due. First, while the general outline of interrelations is as presented, the actual course of events depends as much on the specific strength of these relations and on the magnitudes of causing phenomena.

And that is just where the discussion centres. Of main actors on this strip mining/agriculture scene all do agree that such-and-such effect /may/ exist, but, in reality... For the sake of this introductory paper assume there are just two actors: local agriculture, as represented by the voivodship department of agriculture, and mining and energy, as represented by the mine management.

Thus, for instance, the mining side says that although it is true that: the "brown hole" had already consumed several villages, deprived tens of others of their water, destroyed soil and changed landscape on a certain surface, it is nevertheless also true that appropriate compensations were paid, water supply organized and land reclamation set up. Furthermore, they say, the "groundwater crater" is not as of now having any significant effect upon the crop yield in area, emissions from the power plant are by far less pollutant-charged than it was envisaged, and, on the top of all that, agriculture is not using the very valuable by-products of both mining and power generation, proper as fertilizers and in general for soil improvement.

Opinions of the other side do, naturally, differ quite a lot from those.

Besides, however, the question of evaluation of the present outcomes of the dynamical system sketched in Fig. 2, there is the problem of the long-term perspective. The mining, as mentioned, will go on for approximately 40 years. This implies a long-term dynamics, whose characteristics are shown in Fig. 3.

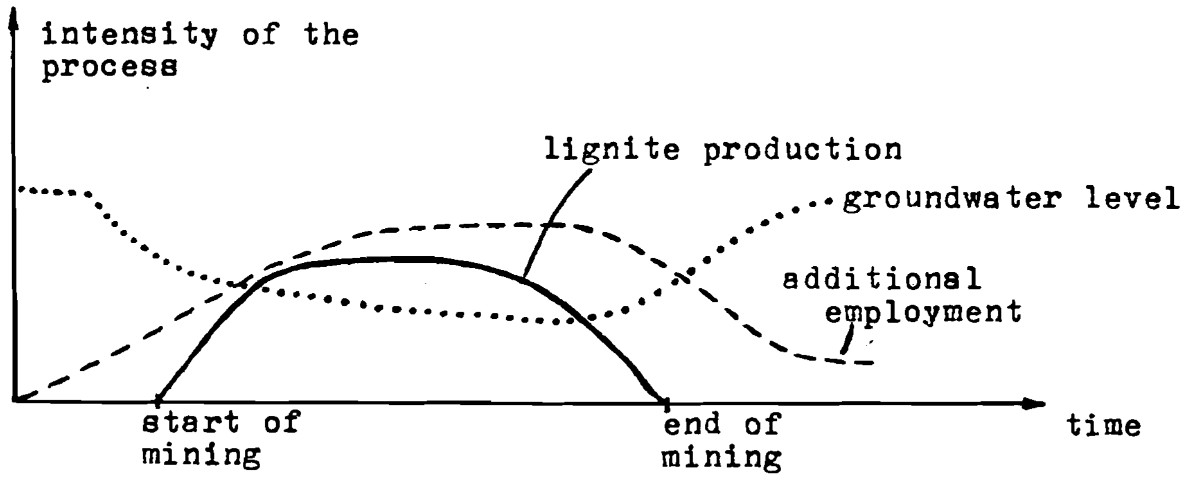

Fig.3. Long-term processes decisive for the regional dynamics.

Thus, it becomes obvious that the effects listed have to be taken in the analysis over the whole cycle of development. For the sake of this presentation it should be mentioned that although some of the effects may have a reversible character, e.g. groundwater level in the vicinity of the mine, most of them are hardly, if at all, reversible.

Groundwater will approximately return to its previous level when the mine is abandoned and let to be filled with water. In fact, some areas may even become more humid than before. Soil quality, however, will in some places /e.g. peaty areas/ deteriorate in an irreversible manner. For the best soils, which can thus degenerate, located either within the mine or close to it, it may turn out cost effective to transport them to other locations or use it for greenhouses. Pollution will certainly diminish at the end of the cycle, but its consequences shall linger quite some time afterwards.

Within the domain of socio-economic effects, if abandonment of agriculture occurs on a greater scale, so that neither labour force, nor productive infrastructure can any longer be found afterwards, a return, if wished, may be difficult. /Note that abandonment itself inflicts large social costs of income and job provision, as well as production substitution and transportation increases./ On the other hand the most practised reforestation policy, in view of ecological conditions, may prove quite inefficient during the cycle.

Thus, a problem arises of securing a smooth and loss-minimizing change during the cycle, and a feasibility of a return, if wished, afterwards. The policies undertaken should, of course, not be incompatible with a possible profile shift of the region.

In the actual decision process a compromise was reached, according to which the mining operators were obliged to both supply water to villages located next to the "brown hole", and pay the direct mining domage compensations to farmers. Additionally, an important overall compensation was to be paid by mining and energy to voivodship authorities with the purpose of introducing special agricultural operations and policies.

5. Regional agricultural policy model

Whether this region will remain in the future agricultural or not, the problem structure, as seen now, is centered around agriculture, for both the development cycle and afterwards.

In creation of agricultural policies related to the development in question the voivodship authorities may activate their proper policy /e.g. zoning, infrastructural instruments, certain supplies/, highly augmented by the mining and energy compensation. Because of the complexity of situation the authorities have contracted a modelling study oriented at production structures and policies related to regional agriculture.

It should be mentioned that, in view of the magnitudes of envisaged changes a number of other studies were also undertaken. These studies concerned geological and hydrological systems, soil changes, crop yield sensitivities, farm economies etc. In particular, certain studies related to crop yield and farm organization and economy were undertaken and are continued within the Field Research Station of the Environmental Engineering Institute. Owing to these studies the data set necessary for the agricultural model construction was in fact ready prior to model development.

The regional agricultural policy and production structure model is meant for analysis of medium-term development alternatives, for choice of best structures and for evaluation of conditions of agricultural operations and changes. The time horizon of the model results from its linear form. In fact, it is an LP construct, relatively detailed, allowing quite precise balancing of resources and products. Thus, the model can presently help in policy setting for the initial stage of the cycle, taking into account such effects of mining development as labour force diversion from agriculture, water deficit, land availability decrease and crop yield decrease, and their consequences /Fig. 2/. Hence, the model can represent most of the processes related to the development/agriculture interface. Furthermore, if the model is run for the end-of-cycle scenario, it can also be used for long-term policy analysis. In order, however, to obtain an internally consistent end-of-cycle scenario, another, dynamic model would have to be developed and run.

Model structure and functioning

The model, called further on SEMORA B, resulting from a series of previous works on the subject, see Albegov et al. /1982/, Owsiński /1982/, Straszak et al. /1982/, is constructed as a two-level LP problem. The lower level, composed of 7 submodels, represents individual subregions of the area. Subregions are delineated according to administrative breakdown, contiguity and location with respect to the mine /see Fig. 4 for the scheme of breakdown./ Each submodel describes in quite a detailed way agricultural economy of a subregion. The submodels contain approx. 1700 variables and approx. 500 constraints each. The main groups of variables describe:

1. Crops grown,
2. Livestock kept,
3. Sales of crop products,
4. Own consumption of crop products,
5. Crop products for livestock feeding,
6. Sales of livestock,
7. Sales of livestock products,
8. Own consumption od livestock products,
9. Livestock slaughter,
10. Purchase of crop products for human consumption,
11. Purchase of crop products for livestock feeding,
12. Purchase of livestock products.

These variables are subject to following groups of constraints:

1. Land, crop rotation and secondary crop,
2. Crop product balances,
3. Herd balances,
4. Livestock product balances,
5. Feed balances,
6. Labour force balances,
7. Pulling power balances,
8. Fertilizer balances,
9. Water balances /annual and peak period/,

10. Sales and purchase balances,
11. Capital investment limits,
12. Minimum income requirements.

Two objective functions were maximized, alternately:

1. Total agricultural net-income from subregional agriculture;
2. Total agricultural subregional production value.

Three other criteria/agricultural trade balance of the region, protein trade balance, diet content trade balance/ were treated as reference indices.

The variables and constraints were classified according to the following aspects:

a. crop types /16 various crops considered/,
b. soil quality types /4 + permanent grassland/,
c. crop technologies /3/,
d. farm types /5/,
e. animals /7/,
f. husbandry technologies /2/,

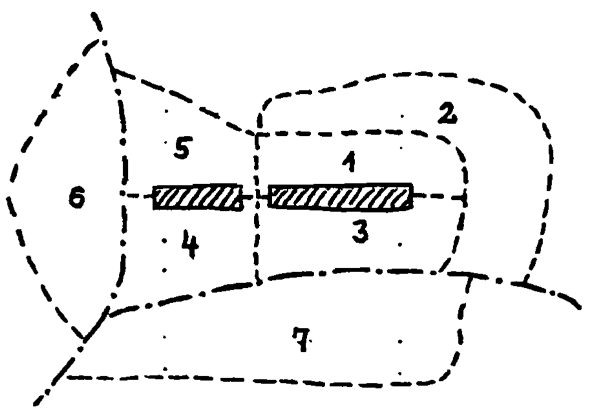

Fig.4. Outline of the breakdown into subregions

▨ mine

—·—·-voivodship boundaries

----subregional boundaries not coinciding with those of voivodships

g. fertilizer contents /4/,
h. sales and purchase markets /3/.

With thus detailed specification the submodels are quite accurate, but, simultaneously, rather large. They communicate with the upper level, i.e. the master model, representing a regional policy centre, via a coordination procedure, Owsiński and Zadrożny /1985/, see Fig. 5.

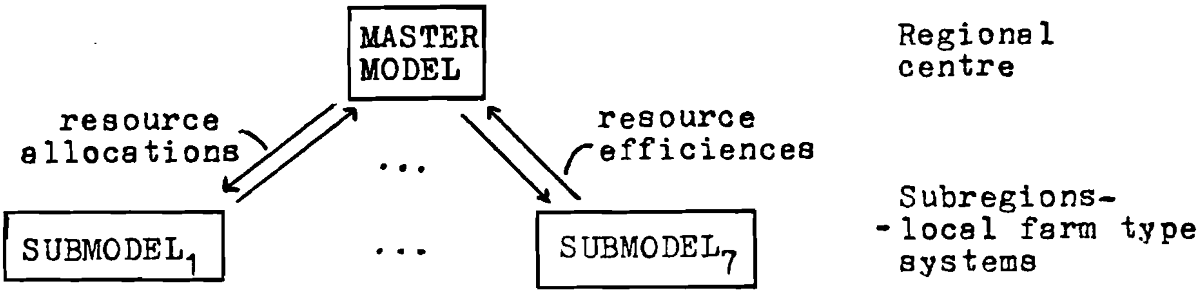

Fig. 5. Scheme of cooperation of the master model and the submodels

The master model is much smaller than the submodels. Its dimensions, however, are not uniquely defined, since they are established in the working of the coordination procedure. The master model operates on the - linearized - resource efficiency functions of the submodels, thereby determining optimal resource allocations to subregions /farm type subsystems within subregions/. Because of the model dimensions the coordination procedure is not iterative, i.e. the above information exchange between levels is not repeated. It occurs just once and on approximate solution is obtained.

The master model contains descriptions of the subregional resource efficiency functions and certain constraints on regionally balanced resources, such as: infrastructural and productive investments, credits for credit schemes, and water. It is with respect to these resources that coordination is primarily performed.

Model application

SEMORA B is meant to provide information for policy construction. Directly, solutions of SEMORA B on the subregional level, specify optimal production structures and product destinations. On the master model level values od "policy variables", i.e. certain resource allocations, are determined. Thus, it is possible to construct functions relating incomes and production levels, to production and exchange structures and these to"policy variables". Evaluation of policies, can also account for other aspects, especially related to these resources, which are affected by the development. Thus, besides coordination, some post-optimal analyses are performed.

The above results and analyses obtained with SEMORA B can serve for elaboration of both internal and external policies. Internal policies are those which lie entirely within the scope of control of the regional authority /notwithstanding their possibly varying efficiency/. There are, however, also external policies, oriented at persuading other actors as to certain items of common interest. As mentioned, the main local partner considered is mining. Another important partner is the central planning body and central bugdet /finance ministry and planning commission/. With respect to these two partners the local authority may, with the help of SEMORA B, determine potential losses or gains to regional agriculture, resulting from implementation of their respective policies. Thereby optimal directions of inducing both partners can be defined.

6. Model results and policy indications

For the sake of shortness and clarity only main features of solutions and policy indications and chosen directions of analysis are presented.

One of the main objectives of analysis, in view of the changes envisaged, was establishment of adequate agricultural income conditions. Their level is decisive for the further fate of local agriculture. Several scenarios were tested, differing by assumptions as to potential water deficit, crop decrease etc. It must be emphasized that simple maintenance of the present income levels is not sufficient to effectively limit labour force diversion from agriculture to mining, since wages in new industries are, on the average, 2-3 times higher than agricultural incomes. Thus, it was shown with SEMORA B that some farm types may attain income levels comparable with those of industrial employment, while others cannot. Attainment of lower income levels does not imply, of course, that labour diversion shall occur automatically. The greater the difference, however, the more important this diversion. On the other hand, attainment of comparable incomes by some farm types is conditioned by adequate increase of capital investments in these farms, i.e. appropriate credits. For an overview of results with this respect see Table 3.

DESCRIPTION OF SCENARIOS:		CAPITAL INVESTMENTS IN FARMS		
		Present level, 100%	150%	200%
WATER DEFICIT CROP DECREASE	NONE	2	2	4
	A.	1	2	4
	B.	0	1	2
	C.	0	0	1
	D.	0	0	0

Table 3. Numbers of farm types, out of the total of 5, in which incomes comparable to those in industry jobs can be obtained under optimum conditions.
A: water cost increase with no deficit and crop decrease,
B: cost increase and water supply cut by 30%,
C: as A, with slight crop decrease, esp. in permanent grasslands,
D: as B, with slight crop decrease, esp. in permanent grasslands.

The counterport of the income situation is the labour force situation. Analysis of this aspect of the regional agricultural system is insofar important as the labour force diversion, already mentioned, is positively evaluated by some agricultural economists. The reasoning behind: agricultural employments are inefficient and unprofitable and there is too much labour force in agriculture. These opinions are formulated on the basis of a global assessment od labour force number, its theoretical productivity and actual produce. The SEMORA B model applied the same parameters as those used in global assessments. Since, however, the model solutions represent optimal rather than average conditions, it could be justly suspected that the "idle manpower" would come out in these solutions even greater than in the global economic assessment. This would provide arguments for the mining side, which claims that labour diversion helps in rationalization of agricultural production. Actual results are schematically outlined in Fig.6.

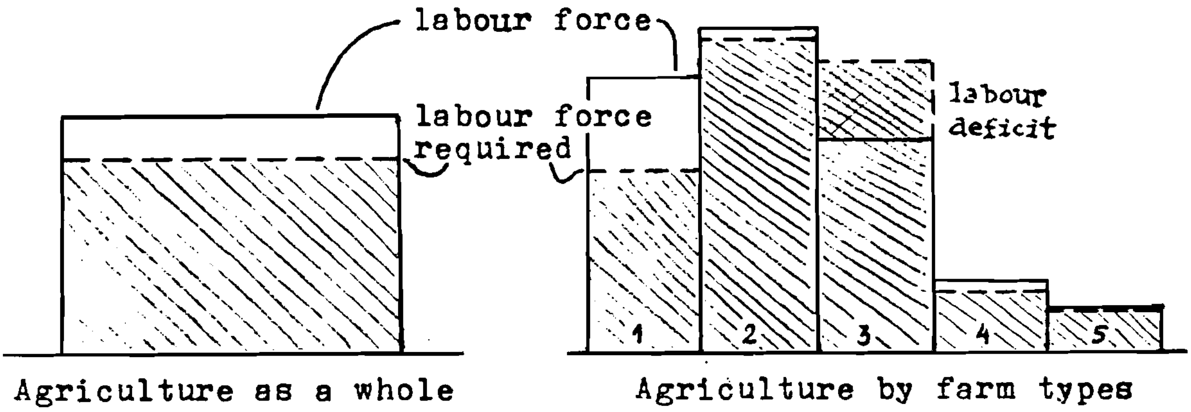

Fig.6. Relation of actual manpower to manpower requirements in the regional agriculture, according to the SEMORA B results.
Farm types: 1. private farms ⩽ 5 hectares,
2. private farms 5 to 10 hectares,
3. private farms > 10 hectares,
4. cooperative farms,
5. state farms.

The diagram shows that virtually the whole labour margin comes out of one farm type, i.e. small private farms, while the most promising farm type /No. 3 in the diagram/ is already suffering from the important lack of manpower. Furthermore, it should be emphasized that quite a share of manpower from the farm type 1 are so called double-professionals, i.e. are also employed outside agriculture, which is caused by income shortages in small farms. Thus, even the margin indicated may in reality be lesser.

Hence, while it seems almost sure that certain diversion will occur over the years to come, unless appropriate policies are undertaken, this diversion would have a negative effect on local agriculture.

As already indicated, appropriate infrastructural investments and credits for productive investments may help in limiting and controlling the flow of labour from agriculture to industry. Simultaneously, such durable investments will make it easier in the future to make an agricultural come-back, if wished. Third, these investments will make it possible for fewer people to operate on the same agricultural area. Thus, there is a synergic policy action of infrastructural and productive investments to be performed in the process.

This direction has been taken, at least partially, by local authorities. These are, however, some obstacles, stemming from the same ground as the agricultural difficulties, like e.g. lock of manpower. Because of that mainly land reclamation and water supply works are well underway. It seems that the policies adopted should be applied to themselves in order to make them applicable.

Naturally, capital investments is not the only direction to go. Fig.6 implies another way, i.e. that of labour force shifts among farm types within agriculture. Such shifts can be performed in two manners: first by land, or even better, farm buying or renting, and second, by labour selling. Both these processes occur now, but not in volumes sufficient for off-setting labour diversion and land abandonment. First of these processes looks more promissing, its enhancement, though, would require an action which is outside of the local authority power scope. Efficiency of an optimal policy of this kind is illustrated in Fig. 7.

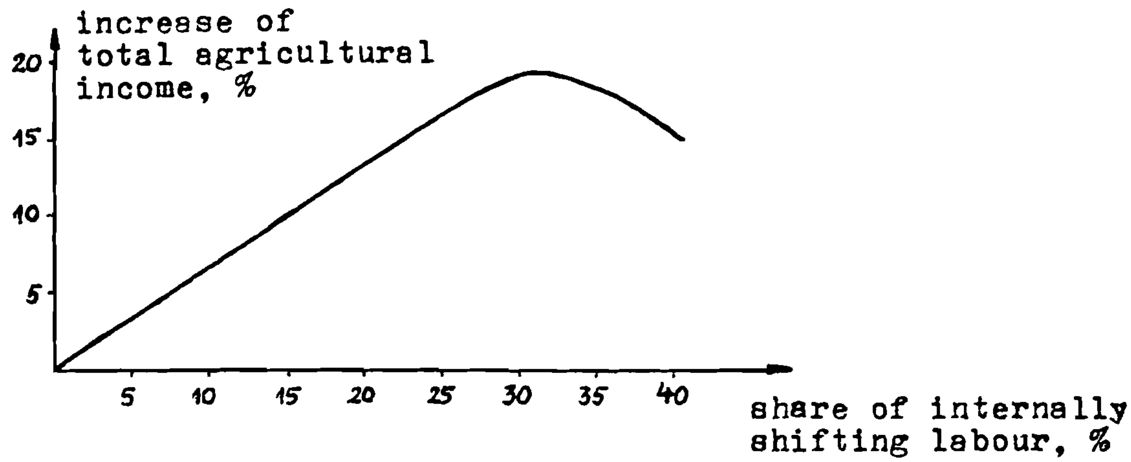

Fig. 7. Effects of an optimal labour shift policy within the regional agriculture

Thus, further managerial policy action would be needed in order to ensure a smooth transition period and secure and open return option.

There is, though, another question, which was not addressed in this modelling study, related to the effect No. 8 of the development, i.e. crop quality decrease. Namely, in view of increased loads of pollutants their contents in some crops may cause a decrease in price or even inhibit their selling for human consumption. This question was not treated in detail, primarily because of lack of data and of specification in the contract. Some preparatory work has been done, however, indicating that in conditions of low efficiency of reforestation and forest-oriented economy, a change in crop specialization towards more industrial crops and products is feasible. This alternative, though, would have to be explored in more detail.

7. Concluding remarks

It is natural that a large-scale undertaking, having multiple consequences, implanted in a relatively economically passive region is hard to control from the regional level. Because, however, of magnitudes of possible losses and gains, and attempt at making and implementation of appropriate regional policies has to be made, both in terms of own, internal, policies and external ones-oriented at other actors.

A modelling study, even if modest in scope, like the one outlined here, can provide help in problem analysis and policy formulation. The two-level LP model SEMORA B, applied here, has provided some policy indications, whose efficiency was judged to be adequate for the goals assumed. Some of these policies, though - as it could be anticipated, anyway - could not be carried out at the regional level. Further work on the subject will account therefore for both more developmental effects and for a wider range of policy levels.

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4.2 ENVIRONMENTAL IMPACT ASSESSMENT AND FOREST RESOURCE MANAGEMENT

4.2.1 SCIENCE IN ENVIRONMENTAL IMPACT ASSESSMENT AND NATURAL RESOURCE MANAGEMENT IN CANADA

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INTRODUCTION

Environmental impact assessment (EIA) and natural resource management (NRM) are both environmental decision-making processes that rely on the science of ecology and related disciplines to generate part of the supporting information base. Both are rather recent in adopting a systematic and structured form, NRM as the orchestration of the type, intensity, timing and location of local actions to meet system-level goals, and EIA as a means to ensure that natural environmental and related social concerns are given systematic consideration in economic development decision-making.

In Canada we have made very important contributions in recent years in the general direction of developing scientifically sound approaches for advising decision-makers in EIA and NRM on the responses of natural systems to human interventions. In NRM, the emphasis has been on understanding natural system dynamics in pursuit of invoking desirable resource performance, whereas in EIA the focus has been more on understanding in pursuit of preventing undesirable performance. Despite this, the logical approach to generating the scientific information base for decision-making in EIA and NRM appear exactly the same. While the institutions and procedures for EIA may be much different from those in NRM, a basic protocol is applicable to both.

To demonstrate the commonality of the scientific underpinnings of EIA and NRM, reference is made to Canadian work in developing a systematic approach to adaptive resource management (Holling, 1978; Baskerville, 1985), and to a recent study on the scientific basis of EIA in Canada (Beanlands and Duinker, 1983). First the essence of each will be described, and then the essential similarities will be shown. Finally, some recent attempts to implement portions of the basic protocol in Canadian resource decision-making will be related.

ADAPTIVE NATURAL RESOURCE MANAGEMENT

The Canadian pioneering work in adaptive NRM was centred at the University of British Columbia, in collaboration with IIASA (Holling, 1978). One of the best-known examples of application of the approach was the exercise of developing and testing strategies for dealing with the spruce budworm/forest management problem in New Brunswick (Baskerville, 1976). Baskerville has continued to champion the cause of adaptive NRM in Canada, most notably on the New Brunswick wood supply problem. The following is an extensive quote from one of his recent papers (Baskerville, 1985), summarizing the essence of adaptive NRM.

"Adaptive management is management with a built-in learning process. The design of management goals, the design of the actions, and the measurement of progress are carried out in a manner that allows the manager to learn about the system from his management of it. As the manager learns about the system, he is able to redesign (i.e., adapt) his management approach to be more efficient. Because the adaptive process forces the recognition of error, and therefore facilitates learning, it is a particularly good approach to use in initiating management in systems for which the dynamic structure is not well known, and where it is important to avoid irreversible error.

"Adaptive management is management with negative feedback control, and it can be characterized by nine steps as follows:

1. A measurable goal is chosen for management of a natural system.
2. The links among the goal, the cause-effect system dynamics, and the possible management actions are explicitly stated, usually in a model, for a system forecasting tool.
3. With the model as a forecasting tool, a set of actions are (sic) designed to regulate the system towards the measured goal. The way each member of the action set causes an effect, and the way all actions, in total, cause the system goal to unfold are quantitatively stated.
4. The action set is implemented in the natural system.
5. At specified times the progress of the system towards the goal is measured in the terms specified in step 1. The actions and their results in the

cause-effect sense are also measured in the manner of their definition in step 3.

6. The measured progress towards the goal is compared with the explicit forecast from step 1 and the deviations noted. The measured results of action in terms of cause-effect are compared with the explicit forecast in step 3, and the causes of deviations are determined.
7. Based on comparisons of the forecasts with actual system performance, adaptations are designed. The goal is reevaluated to ensure that it is attainable, and if necessary it is changed. The measure of progress towards the goal is evaluated, and if it is inadequate it is changed. Where the forecasts of system performance have been wrong, that indicates an incorrect structure of the dynamic cause-effect relationships in the forecast. In this case, change must be made in the model (hypothesis) of structure of system dynamics and new forecasts are prepared. This leads, in turn, to design of a new action set necessary to reach the goal under the new statement of cause-effect relationships.
8. The new action set is implemented in the natural system.
9. The process continues in a cycle by returning to step 5.

"...learning can only proceed by the identification of error. If error is allowed to slip by for lack of measurement, or if there is no rigorous comparison of forecast to actual performance to reveal error, then there is very little learning about system level dynamics, and very little improvement in the control achievable by management. This is a perfect setting for 'surprise' consequences...

"All decisions on resource management involve forecasts of some form. Most such forecasts have been qualitative, somewhat like those of the gypsy fortune teller. These forecasts are always 'right', because they are vague. In those rare cases where they are 'wrong', there is sufficient latitude to permit rationalization. This comfortable approach minimizes learning. Learning is not an easy process, but without learning it is impossible for management to close on a goal. The feedback loop does not really close with trivial qualitative forecasts and assessments. It is not possible to adapt management action knowledgeably if there is no feedback with respect to dynamic performance, particularly feedback that provides a quantitative comparison. Adaptive management is not easy because it requires explicit negative feedback control and explicit recognition of error. It is therefore not yet common in resource management."

SCIENCE IN EIA

In the late 1970s, scientists in Canada and the United States were becoming very concerned at the lack of scientific rigour in EIA studies (e.g., Efford, 1976; Schindler, 1976).

In response, the Canada Department of Environment launched an industry/government sponsored study to look into how to improve the scientific basis for EIA in Canada. The study lasted three years, and canvassed the opinions of selected EIA practitioners from government, industry, academe, and consulting firms across the country. The results of these extensive discussions were distilled, interpreted, and reported recently by Dr. Gordon Beanlands and myself (Beanlands and Duinker, 1983; 1984).

The findings of the study were organized into four sections: (a) basic scientific considerations important in EIA, (b) some improvements from an ecological perspective, (c) a set of "requirements" for organizing and conducting ecological impact studies, and (d) recommendations on institutional initiatives for improving the practice of ecological science in EIA. Most important in this context are the so-called requirements, which are stated here as found in Beanlands and Duinker (1984).

"An EIA should be required to:

(1) identify early an initial set of valued ecosystem components to provide a focus for subsequent activities;

(2) define a context within which the significance of changes in the valued ecosystem components can be determined;

(3) show clear temporal and spatial contexts for the study and analysis of expected changes in the valued

ecosystem components;

(4) develop an explicit strategy for investigating the interactions between the project and each valued ecosystem component, and demonstrate how the strategy is to be used to co-ordinate the individual studies undertaken;

(5) state impact predictions explicitly and accompany them with the basis upon which they were made;

(6) demonstrate and detail a commitment to a well-defined program for monitoring project effects."

THE SIMILARITIES

Let us now look at the commonalities between the requirements for organizing and conducting ecological impact studies from Beanlands and Duinker (1983; 1984) and the protocol for adaptive management put forward by Baskerville (1985).

Valued Ecosystem Components

We defined valued ecosystem components (VECs) as attributes or components of the environment for which there is public and/or professional concern, and to which an EIA should primarily be addressed (Beanlands and Duinker, 1983). These may be determined on the basis of perceived public concerns related to social, cultural, economic or aesthetic values, or they may reflect concerns of the scientific community. The reasons for defining VECs are: (a) to state impacts in terms of interest to decision-makers; and (b) to give focus to an EIA that otherwise might unsuccessfully attempt to look at all environmental attributes or components.

In other literature, VECs are referred to as endpoints (Barnthouse and Suter, 1984), indicators (Holling, 1978), and environmental performance indicators (Duinker, 1985a). They are the terms in which we want to track the performance of the system of interest in response to alternative action sets. VEC is also synonymous with the measurable goal in step 1 of Baskerville's (1985) protocol. The goal needs to be stated in terms of the identity of some attribute or component of the system of interest, and in terms of a quantitative variable that can be forecast as well as measured in the real system. In EIA as well as in NRM, there are usually several VECs or measurable goals that need to be dealt with simultaneously.

Impact Significance

This is a hotly debated subject in EIA, and we (Beanlands and Duinker, 1983) devoted considerable attention to it. From the point of view of the scientist/impact analyst, the levels of performance indicators critical to decision-makers make a difference to both forecasting and measuring impacts (Duinker, 1985a). When a decision-maker wants to be sure a critical level is not exceeded, and an analyst's first-approximation forecasts suggest that a particular action set produces a level for that indicator close to the critical level, then (a) the decision-maker may want to explore alternative action sets that might otherwise not be explored, and (b) the analyst may want to pay more attention to the structure of the forecasting model and/or the impact measurement design.

Baskerville's (1985) protocol for adaptive NRM does not deal explicitly with significance levels of indicators, but the concept is implicit in steps 6 and 7. In step 6, deviations between forecast performance and actual performance are noted, and if these are "significant", adaptations to the action set are explored and designed. If the deviations are not substantial or "significant", then presumably the action set as first implemented would be continued.

Time and Space Bounding

In the EIA study, we also devoted considerable attention to the temporal and spatial horizons of impact analysis. The temporal horizon specifies how far into the future we forecast impacts, and the spatial horizon how far afield we search for them. Time and space beyond these horizons are explicitly left out of the analysis. We offerred four categories of considerations in setting these bounds: (a) administrative considerations (time and space limits associated with political, institutional and corporate jurisdictions); (b) development considerations (time and space limits associated with the action sets proposed); (c) ecological considerations (time and space scales over which natural systems operate); and (d) technical considerations (time and space limitations imposed by our capability to forecast or measure performance indicators.

We did not deal, but should have, with the concept of time and space resolution, or "inner limits". These refer to the lower limits of explicit consideration of temporal and spatial variability. Variability within units is thus ignored and average values assigned to the variables of interest. Resolution is as, if not more, important a concept to be dealt with rigorously in EIA and NRM as is outer bounding. Although Baskerville's (1985) protocol does not mention bounding specifically, his paper deals at some length with the importance of geographic location in the design and implementation of action sets in NRM. As well, more lengthy documentations of the adaptive approach to NRM (e.g., Holling, 1978) demonstrate that the analysts involved pay special attention to such bounding when they construct forecasting models or design data collection programs. Thus, in implementing the adaptive NRM protocol, bounding is dealt with mainly in steps 2 and 5.

Study Strategy

EIA field studies, like those of NRM, can be extremely time- and cost-consuming. In North America, impact analysts have had a penchant for collecting reams of expensive environmental inventory data without having gone through a systematic exercise of determining precisely which data they need to make forecasts for environmental performance indicators. For analysts in EIA, we (Beanlands and Duinker, 1983) proposed that regulators, developers, and impact analysts get together early and often in an EIA to (a) focus the EIA on a few important environmental components (indicators), (b) engage in "ecological scoping" where the parties systematically explore the possible linkages between an action set and the chosen indicators, and (c) agree on a mutually acceptable plan for field investigations which should provide the best set of data for the needs and resources at hand.

The approach to forecasting used in adaptive NRM is most appropriate for undertaking an ecological scoping exercise and for developing a study strategy. The approach rests on the premise that the best way to find out what one needs to know to answer a question is to construct a solution path and attempt to answer it with the information at hand. Then, as in a jigsaw puzzle, the identity and nature of the missing pieces becomes clear and they can be custom-built and fitted into the solution structure. Adaptive management forecasting does just this. Forecasting models are built early in the process (step 2 of Baskerville's protocol), and the exercise is used to identify and design new research to strengthen understanding of system dynamics. In fact, the techniques of adaptive NRM are reported to be especially well suited to the task of research planning (ESSA Ltd, 1982).

Forecasting

In our EIA study, we heard consistent opinion that it would be best if ecology could produce quantitative impact forecasts for decision-makers, but conflicting opinions as to whether this was possible with any useful degree of precision and/or accuracy. In the end we called for explicit, unambiguous forecasts accompanied with the basis upon which they were made (this really can be interpreted as a call for quantitative forecasts!). It is better in impact forecasting to be quantitative and wrong than qualitative and untestable (Duinker, 1985b), principally so that (a) a "real" seat can be obtained for environmental concerns at the EIA decision table, and (b) we might engage in error recognition and learning, as so well stated by Baskerville (1985).

Ecology, despite its youth as a scientific discipline, can provide the means for building quantitative forecasting models for both EIA and NRM. The keys are (a) to build dynamic system models using state-dependent rules for change and internal feedback loops (e.g., Walters et al., 1974), and (b) to have healthy skepticism for the actual forecasts, but also healthy inquisition into the new understanding of system dynamics that forecast model building might bring.

Monitoring

The message was unanimous in our EIA study and the literature agrees - measuring impacts as they occur is critical to improved decision-making and to improved impact forecasting. Adaptation, the essential element of adaptive NRM, requires measurement of the performance of the system being managed, and comparison of those measurements with forecasts. Little more needs emphasizing here except to say that monitoring programs (a) need to be considered explicitly in the study strategy building stage of EIA, and (b) should not be designed as general, all-purpose schemes but should focus on specific indicators and adhere to rigorous design principles (Duinker, 1985c).

SOME RECENT CANADIAN EXAMPLES

In Canada, the attention devoted to science-supported, systematic EIA and NRM decision-making is increasing. Partly in response to our recent efforts to initiate improvement in the scientific basis of NRM (e.g., Holling, 1978) and of EIA (e.g., Beanlands and Duinker, 1983), we are making headway at actually improving that scientific basis. Below are reports on three areas where these improvements are evident: (a) in scoping exercises in EIA; (b) in quantitative forecasting in NRM; and (c) in monitoring in EIA.

Scoping in EIA

The exercise of identifying VECs and bounds in EIA is now commonly known as scoping. Early EIAs in Canada attempted to cover all conceivable aspects of the environment, and thus could only be superficial about everything covered. Recent EIAs, especially those undertaken under federal government procedures, have attempted to reverse this hopeless situation. For example, new techniques used in the EIA for a second nuclear power reactor at Lepreau Generating Station in New Brunswick included (a) open-house sessions, where interested parties could come to learn about the proposed development and to express any concerns about it, and (b) scoping meetings, where, before guidelines for an environmental impact statement were drawn up, interested parties could formally air their concerns and raise issues they felt the EIA should pursue. In addition, a science advisory committee was struck by the Environmental Assessment Panel (i.e., the Panel charged with conducting the government review of the EIA and the proposed development) to ensure that the studies proposed by the developer were defensible and well-directed at the issues raised in scoping.

The provision of physical mechanisms is necessary but insufficient to ensure the success of scoping exercises. Also necessary is understanding by the many participants in the process of what the exercises are trying to accomplish, and a willingness to make them work. In the case mentioned above, the limited success of the scoping exercises was probably a function of some misunderstanding and some unwillingness to participate.

Forecasting in NRM

Until recently, the forest industry in New Brunswick has been able to obtain harvests wherever and in whatever manner was considered economically efficient. In the mid to late 1970s, quantitative analyses of the future wood supply situation showed that wood supply to sawmills and pulpmills would become critically low if past and current harvesting and silvicultural practices continued.

These wood supply analyses were exercises in quantitative model building where proposed action sets (specified by type, amount, timing, and location of treatments in individual forest stands) were linked to quantitative measures of overall forest performance (i.e., wood volume supplied to mills) through dynamic relationships involving types and ages of stands and patterns of stand growth over time (Baskerville, 1985). It was only through the use of such analyses that the impending wood shortage problem could be quantitatively recognized, and that shifting towards adaptive NRM is becoming possible. Those making decisions about the forest and the industry have access to quantitative forecasts (i.e., hypotheses) about future development of the whole forest, can obtain measurements of the key dynamic variables as the future unfolds, can compare forecast performance with measured performance, and can modify the action set (i.e., adapt) if the foregoing difference warrants. All this is prevented when forecasts are qualitative and based on intuitive feelings.

As Baskerville (1985) noted, the same principles as used in quantitative wood supply analysis can be applied to wildlife supply problems. While some of the forest system dynamics are not as well understood for wildlife, such as the relationships between habitat supply and wildlife abundance and distribution, this should not prevent us from building the quantitative forecasting models (actually linked sets of hypotheses) and generating wildlife forecasts (actually more hypotheses) for alternative sets of forest harvest and silvicultural treatments. In fact, one could argue that this is precisely why we should use adaptive NRM tools (as noted above, they are so appropriate for research planning). Indeed, in New Brunswick we are just beginning to make headway here. My own work at present involves building a forecasting model that links forest operations with deer populations through habitat supply. It soon may be possible to use such a model to advise decision-makers on the design of forest action sets for the production of more deer, should deer become a forest system indicator for which the decision-makers wish to set and pursue specific measurable goals.

In summary, NRM has seen and is seeing much more extensive use of dynamic simulation models to prepare quantitative forecasts of system outcome in response to specific sets of actions. My work on deer is part of an attempt to encourage analysts in EIA to engage in similar explicit impact forecasting.

Monitoring Impacts in EIA

In Canada we are finally beginning to see some real efforts at actual measurement of impacts once large resource developments are constructed and operating. A notable example is the Newfoundland and Labrador Hydro utility which, over the past ten years, has proposed, environmentally assessed, constructed, and followed-up on three hydroelectric developments in that province (Kiell et al., 1985). At the first of these installations a study aimed at detecting elevated mercury levels in fish and sediments was initiated and is still ongoing. The study is addressing a testable hypothesis, it has spatial and temporal controls, and sample sizes are statistically adequate. The second of these developments is located within the range of one of Newfoundland's largest caribou herds. In return for early approval of the project, Hydro and the Newfoundland Wildlife Division jointly sponsored a study of the project's effects on the herd. The study began two years prior to construction of the facility, continued through the two years of construction and ended three years after completion of construction.

Finally, at the last of the three projects, Hydro has undertaken extensive monitoring of fish populations in the new reservoir with the hope of establishing a new sport fishery. The study revealed that this was not feasible. However, Hydro is continuing a study in the reservoir on primary production, zooplankton grazing pressure and water quality, expecting the results to be of considerable value for forecasting effects of new proposed hydroelectric developments in Newfoundland.

CONCLUSION

The foregoing discussions suggest strongly that the scientific basis of NRM and EIA is precisely the same, and that we are beginning to see better science practiced in support of these decision-making processes. The barriers I envisage to practicing creative and productive science in <u>regional</u> NRM problems include: (a) the difficulties of visualizing or imagining system dynamics when time and space scales are broadened, and (b) the reluctance of many so-called "resource" scientists to engage in quantitative forecasting for regional-scale system indicators. However, these problems pale beside those of an institutional and jurisdictional nature. At regional scales (i.e., spanning provinces or states in North America, and countries in Europe) our ability to study systems and propose solutions to environmental problems is probably much ahead of our ability to implement solutions, primarily because the set of decision-makers has enlarged to uncomfortable proportions.

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4.2.2 MONITORING OF FOREST RESOURCES AND FOREST DAMAGES IN AUSTRIA

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ABSTRACT

There are three monitoring systems assessing forest condition and development in Austria, which are based on the concept of permanent sampling all over the country. Samples are taken along grids of different width, sample trees are selected by objective processes. Due to their special goals, data assessment, methods of evaluation and results are of different standards. Objectives, methods and some results are briefly outlined in the paper.

Forest Inventory from which the third decade is running at the moment, makes available a wide range of data-based information upon natural resources, damages, structural, silvicultural and site conditions for the whole country as well as for special regions.

Forest Condition Monitoring's objectives are to determine visible injuries of tree crowns (defoliation) and their trends during a rather short period (5 years). Informations will accumulate from year to year, at the moment only partial results from 1984 are available.

Bio Indicator Grid is a specific investigation program related to air pollution and its influence on forest injury. Chemical needle-analysis of identical trees will be carried out over a period of ten years. Actual parameters of the latest situation, trends and regional distribution of air pollution are to be gathered.

PREFACE

All information given in this paper is gathered from literature citied below. In order to present an overview as objectivly as possible, the author tried to avoid his personal interpretation. Friendly thanks for collaboration and useful hints are expressed to my collegues M. Neumann, J. Haszprunar, J. Pollanschütz and K. Stefan.

1. INTRODUCTION

State and development of forests in Austria as well as the occurrence of damages have been registered in different ways by forest owners, administrations and scientific institutions for a long time. Also today a lot of statistics, surveys and inventories on local or regional, private or public level are realized. Putting these particular statistics together on a country-wide level doubtlessly would lead to misfitting results because of the diversity of goals, methods and accuracy.

At the Forest Research Station, Vienna, three inventoring (monitoring) systems have been installed, which - in principle - are based on a country-wide, uniform and systemmatic sampling design. Sample points are taken along special grids, data are assessed from single trees (not from stands) which are selected by objective criteria. To minimize standard error as well as sampling percent every effort is made to get very exact data from the single tree. Methodological differences between the systems depend on their special goals. In the following objectives, methods and some results will briefly be pointed out.

2. AUSTRIAN FOREST INVENTORY

2.1 OBJECTIVES

The main objective of Austrian Forest Inventory is the permanent monitoring of stock volume, volume increment, cutting quantity and reafforestation. Additional information about timber quality, silvicultural management, visible damages, site quality, frequency of forest roads and others are demanded. Forest owner's normal silvicultural and economical management is to be assessed without influencing it by realizing the inventory. For this reason sample plots or trees are not marked visibly. On the other hand, trees of the other monitoring systems have to be easy to find and are marked. That is one of the reasons, why the grids of the systems cannot be identical in parts or in total.

2.2 METHOD

The Austrian Forest Inventory is strictly based on statistical sampling methods. Every inventory takes one decade. Annually 4.400 sample plots are assessed all over the country. This way one year's results represent the whole on the basis of 1/10 of the total of 44.000 sample points. Sample plots are taken along a grid. To minimize time and costs the plots are clustered in form of rectangular tracts. Since 1981 50% of the plots are established as permanent plots. Tree diameters at different tree heights and the height itself are the main data to be collected. Additionally, there is a sample marking of necessary silvicultural management as thinning, weeding, afforestation and others. There are, of course, many interesting details of methodology, which cannot be discussed in this context.

But at least one special fact shall be brought to your attention: Even if only 0.02%, that is 1/5000 part of the Austrian forest is assessed by Forest Inventory it is possible to calculate the accuracy and probability of each result on a predefined level of significance. According to the high standard of single tree measurement and the strictly statistical design of sampling and evaluation, results for units of area down to 10 000 - 5000 ha are of fairly high level of significance.

2.3 RESULTS

2.3.1 Management Classes, Owners, Tree Species

In Austria 45% of the area is covered by forest. As a result of Forest Inventory 1971-1980 we know, that 74% of the total forest area is characterized as Commercial High Forest, which is the main basis of forest resources. More than 20% of total area is classified as "Protection Forest", 8% within, 12 % without commercial production.

Rather 88% of Commercial High Forest is owned by private persons or communities, 12% is National Forest (Figure 1). Pure or mixed stands of coniferous trees remarkably predominate all other species (Figure 2). Norway spruce as the most dominant species, covers 60% of area, represents 62% of stock volume and participates with 68% in the volume increment. From the economical point of view, Norway spruce doubtlessly is the most important species in Austria. Ecological considerations certainly limit the area to be covered by spruce. Efforts are made to reduce this species to suitable sites.

2.3.2. Age-Classes

Age-class distribution of Commercial High Forest (Figure 3) over-represents the classes 1-20 and 21-40 years with extremely high percentages. 41-80 year old stands are represented with average portions, while there is a gap of older stands. The surplus of younger stands is to be interpreted as a result of post World War II reafforestations, when huge clear cuttings had to be recovered and marginal agrarian areas were converted into forests. Taking this aspect into account the age-class distribution can be classified as adequate. From this point of view there will be no lack of mature stands in the next decades.

It is another problem that a high percentage of the post-war afforestations have been executed with pure spruce only and frequently in extremely high density. As a consequence, snow damage and other injuries will be the main problems for Austrian forestry over the years.

2.3.3. Deficiencies

This leads to the deficiencies stated by Forest Inventory (Figure 4). 26%, which is more than 700 000 ha of Commercial High Forest area are found not to be in optimal silvicultural condition. 24% of this amount is alloted to necessary weeding, precomercial or commercial thinning. In order to reduce the lack of thinnings, more than 2 million cubic meters annually have to be logged in addition to normal cut.

On the other hand 25% of the total stock volume is damaged, more or less. Besides the depreciation of timber most of these defects will cause instability of stands and secondarly increase injuries. In particulary bark-peeling of red deer will cause progressing decay as well as snow-breakage. Damage by game in total (browsing, bark-peeling etc.) is assumed to cause financial losses in order of magnitude of 3 - 4 milliards of Austrian Schilling annually (KASTNER, 1985). 3.7% of volume bark-peeled may not seem to be very much, but it means, that 6.3% of all trees (BHD > 10.5 cm), or, in absolute terms 106 million trees, representing 26 million cubic meters, are concerned. Bearing theese facts in mind, damage by game, especially bark-peeling, must be considered as one of the most serious problems of forestry in Austria.

2.3.4 Volume and Increment

Comparing the results of the 1961-1970 and 1971-1980 inventories (Figure 5) under the aspect of available natural resources, a satisfying increase of stock volume as well as volume increment is evident. The increase of volume is 20 cubic meters per ha or 51 millions cubic meters in total.The increase of increment is 0.6 cubic meters per hectar and year or 1.5 million cbm in total annually. The differences are significant on a 99% level of confidence .

Overviewing the results on a country-wide level we can identify some serious problems such as increasing percentage of Norway spruce, damage by deer or snow and others. On the other hand 75% of Commercial High forest has been found without faults, stock volume and volume increment are still increasing.

3. FOREST CONDITION MONITORING

3.1 OBJECTIVES

During the last years symptoms of crown - injuries were found in Austria as well as in other countries. In 1984 Forest Condition Monitoring was installed to investigate crown habit of selected trees and its change during a period of at least 5 years. A final evaluation and interpretation will not be possible until 1988/89. Preliminary results of single years have to be handled with care. Forest Condition Monitoring has not to find out the origin of defoliation or other crown injuries. Its goal is only realizing conditions and trends.

3.2 METHOD

Forest Condition Monitoring is concentrated on the main tree species of Austria. Stands older than 60 years are selected along a grid of 4 km distance. 30 or 50 trees of dominant or predominant social range are numbered and durably marked. Their crown should be visible from at least two sides. Defoliation and some other crown parameters are assessed by specially trained forest engineers every year in July or August. The crown classification is based on a catalogue of objective, verbally described criteria and is supported by hand-drawn typical pictures. Figure 6 (top) gives a short summary of the defoliation classes. It should be noted that this figure does not list the written criteria of classification but only their result!

For each sample plot the mean defoliation class can be calculated, which is called "Defoliation Index". The average Defoliation Index of all sample plots of a region is called "Mean Defoliation Index". In contrary to this the "Defoliation Categories" are a theoretical classification of seriousness of a special injury. Depending on its Defoliation Index each sample plot can be classified into Defoliation Categories, which may give some preliminary hints on the present state of crown habits and defoliations.

3.3 RESULTS

In 1984 Forest Condition Monitoring was carried out in only five counties of Austria. One of the most significant results is the correlation between age classes of plots and their Mean Defoliation Indices (Figure 7). This phenomenon is known as to be normal. Defoliation of older stands can more or less be caused by special site quality, dryness during the vegetation period, lack of nutrients or air pollution. A combination of two or more factors is possible. In figure 7 the indices of the lower age-classes indicate increasing Mean Defoliation Indices from the west of Austria to the east. In the same direction mean annual precipitation is decreasing!

Figure 8 presents the distribution of Defoliation Classes. In Tirol 9%, in Niederösterreich 6.4% of the trees were alloted to class 3 or 4, indicating moderate or severe defoliation. No or slight defoliation was found at more than 90% of spruce trees. Classifying the plots into Defoliation Categories, 70% of all plots are found in the categories 1 or 2, which indicates defoliation inside "natural" limits. Slight defoliation caused by biotical or abiotical factors was found in 24% of sample plots. Category 4 or 5, indicating moderate or severe injuries are found in 6% of plots. Interpreting this result, POLLANSCHÜTZ (1985) concludes, that 30% of the area represented is supposed to be influenced by biotical or abiotical factors, from which one might be air pollution. Forest Condition Monitoring's results should be combined with other investigations to give more detailed information.

4.0 BIO-INDICATOR-GRID

4.1 OBJECTIVES

Up to now there is no complete system of air analysis all over Austria; monitoring air quality is restricted to special areas. On the other hand, the problem of forest injuries by air pollution has to be monitored by law (Forest Law of 1975 and additional regulations). Since plant analysis, normally an analysis of needles, has been carried out in Austria for nearly 20 years with good results, it was decided by government to use this method for air pollution monitoring in forest on a country-wide level. In 1983 a special investigation scheme was started which is based on plant analysis as well as on systematical sampling. Branches from the top of identical trees will be analysed annually for a period of 10 years. The main goal of this investigation is the determination of accumulated sulphur, fluorine and nutrient components. The lack of nutrients might give some hints on the influence of photo-oxidants. Annual informations about the latest situation, regional, local, and temporal trends are demanded.

4.2 METHODS

The basic grid of this investigation is 16 x 16 km, which is completed in areas of special interest to 8 x 16 or 8 x 8 km . In 1983 1100 plots were installed, 1700 in 1984. Norway spruce was dedicated to be the main indicator tree species. Close to the grid points two dominant trees were selected and marked. Branches from the top are taken in autumn by special tree climbers, one- and two-year-old needles are analysed chemically.

4.3 RESULTS

Results of 1983 and 1984 are available. Representative informations can be gathered from the 16 x 16 km grid samples only (317 double samples). Forest Law and the two regulations mentioned above define the limits of sulphur concentrations, which indicate the significance of air pollution influence. Due to these regulations 10.4% of 1983 samples were found to exceed these limits, representing 425 000 ha of forest area under the influence of air pollution. 1984 only 5% exceeded the given limits, which might be a consequence of the reduction of sulphur emission as well as a more convenient climate during the vegetation period. As long as no further results will be available, the 1983 results are the indicators of air pollution influence. Air pollution influence is not only found in well-known pollution areas but also in some new regions of north-eastern Austria. Furthermore, analysis and its interpretation brought to mind a decreasing pollution with increasing altitude and cumulation of polluted areas around well-known local sources. It is assumed, that short-range transport is the dominant cause of air pollution in Austria, of which 80% is assumed to be "home-made".

5. SUMMARY

Fairly high stock volume and volume increment as well as 75% of Commercial High Forest without damages and/or silvicultural faults indicate a satisfying condition of Austria's forest resources. The composition of tree species is characterisized by a predominance of Norway spruce. This might be without ecological problems in a wide range of sites, but there are some hundred thousand hectars, where, at least, admixture of other species is desirable.

Damages, especially bark-peeling and browsing cause financial losses as well as instability and uniformity of stands. The influence of air pollution has been identified on more than 10% of forest area; on 30% of the forest area air pollution influence cannot be excluded.

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Abbreviation: MFBVA = Mitteilungen der Forstlichen Bundesversuchsanstalt Wien.

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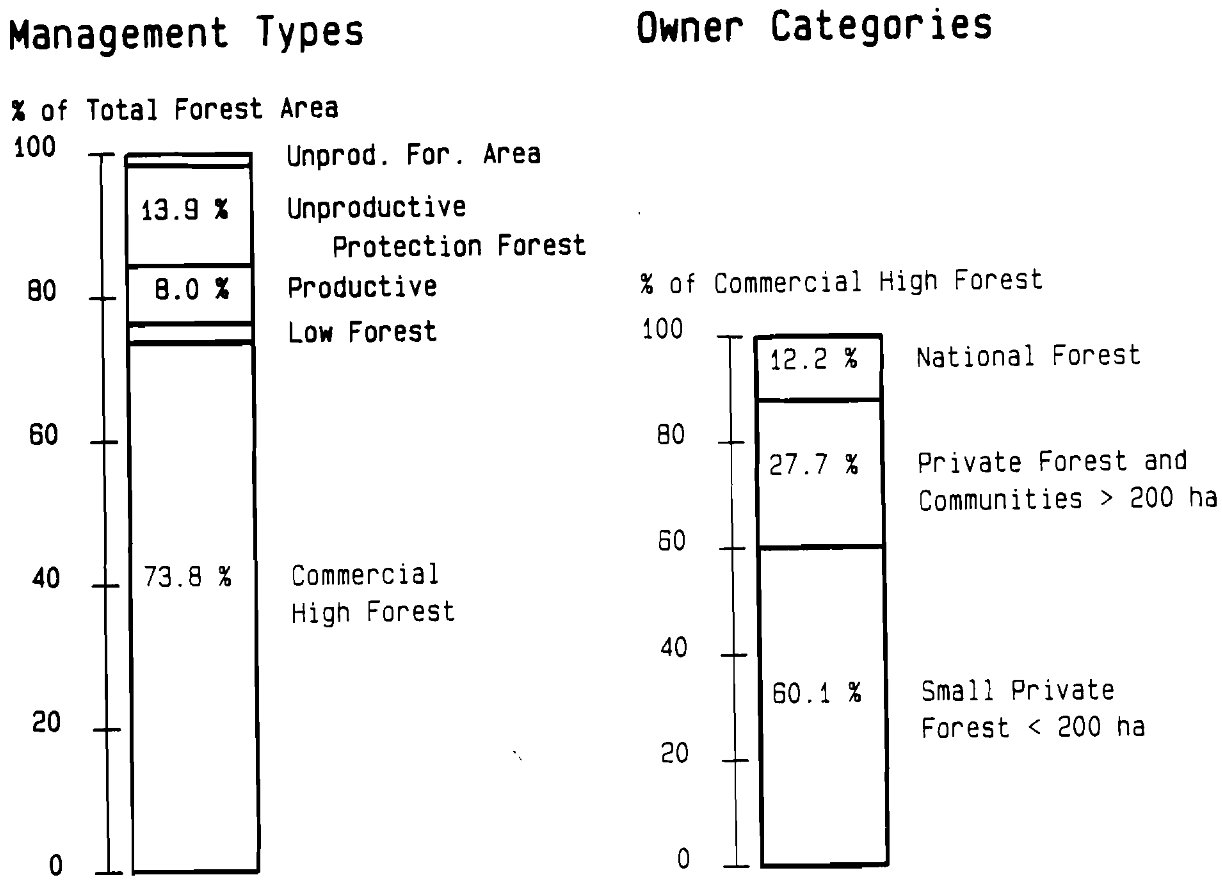

From: Mitt. FBVA, 1985, Volume 154/I

Figure 1

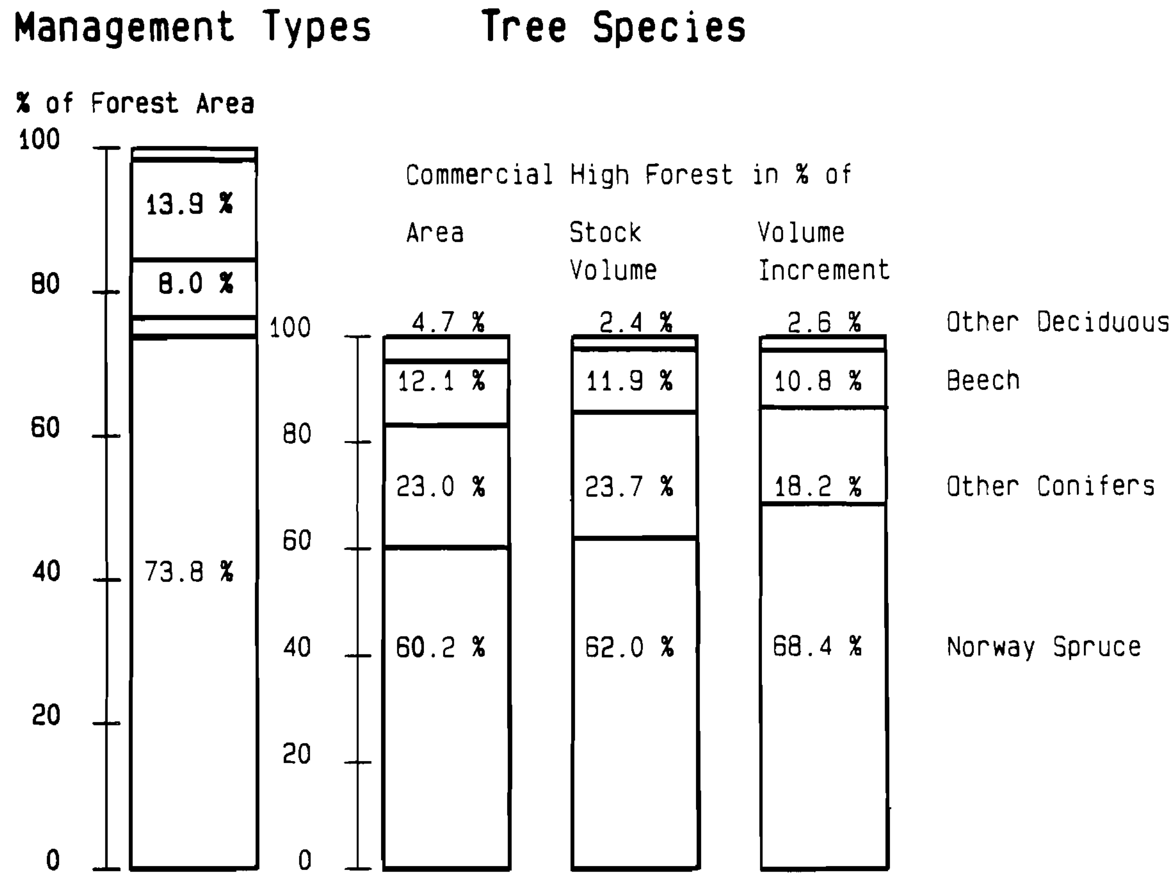

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Figure 2

Distribution of Age Classes
Commercial High Forest

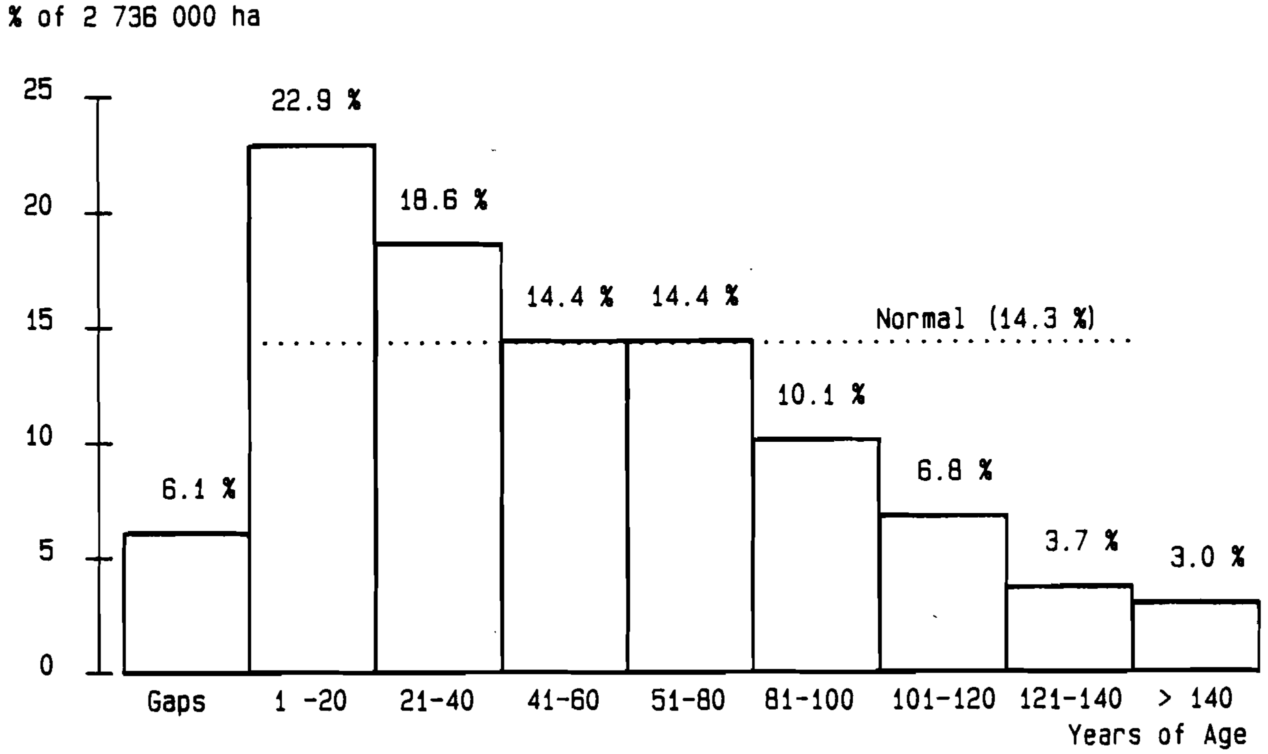

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Figure 3

Commercial High Forest

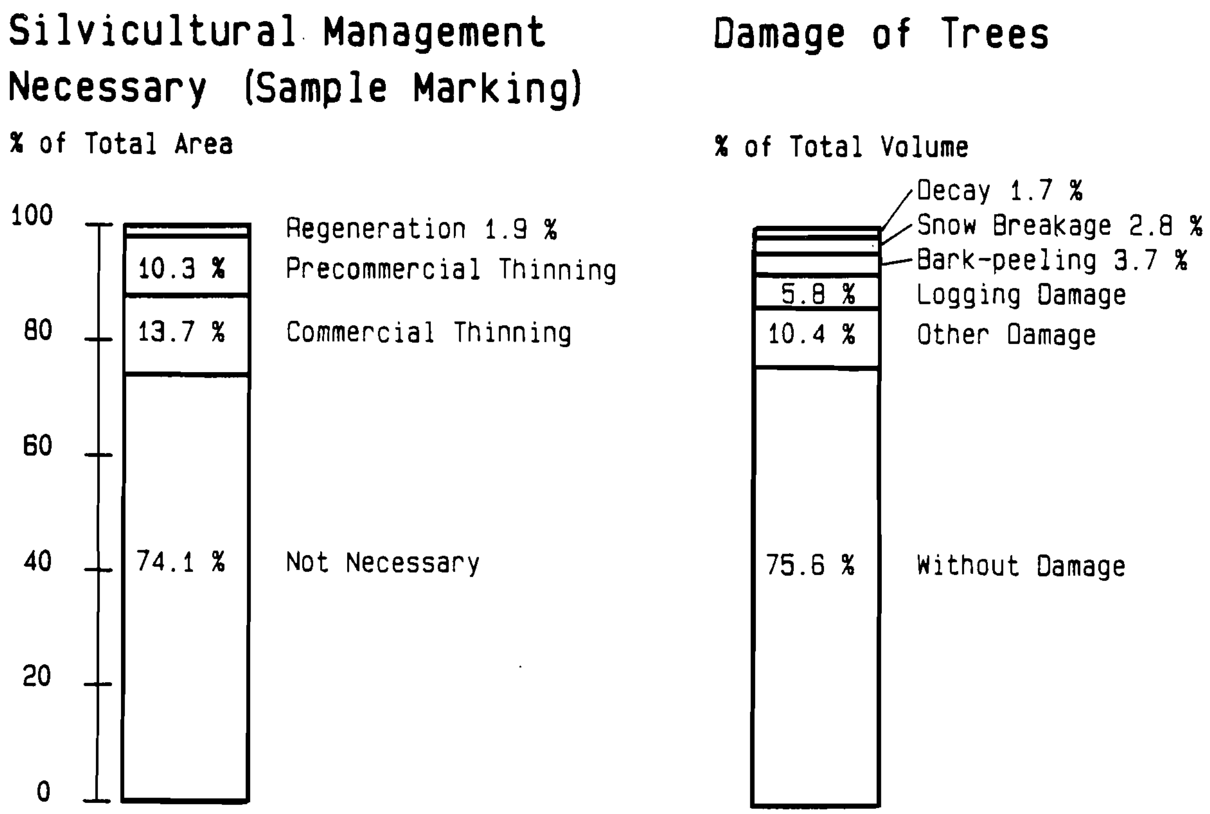

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Figure 4

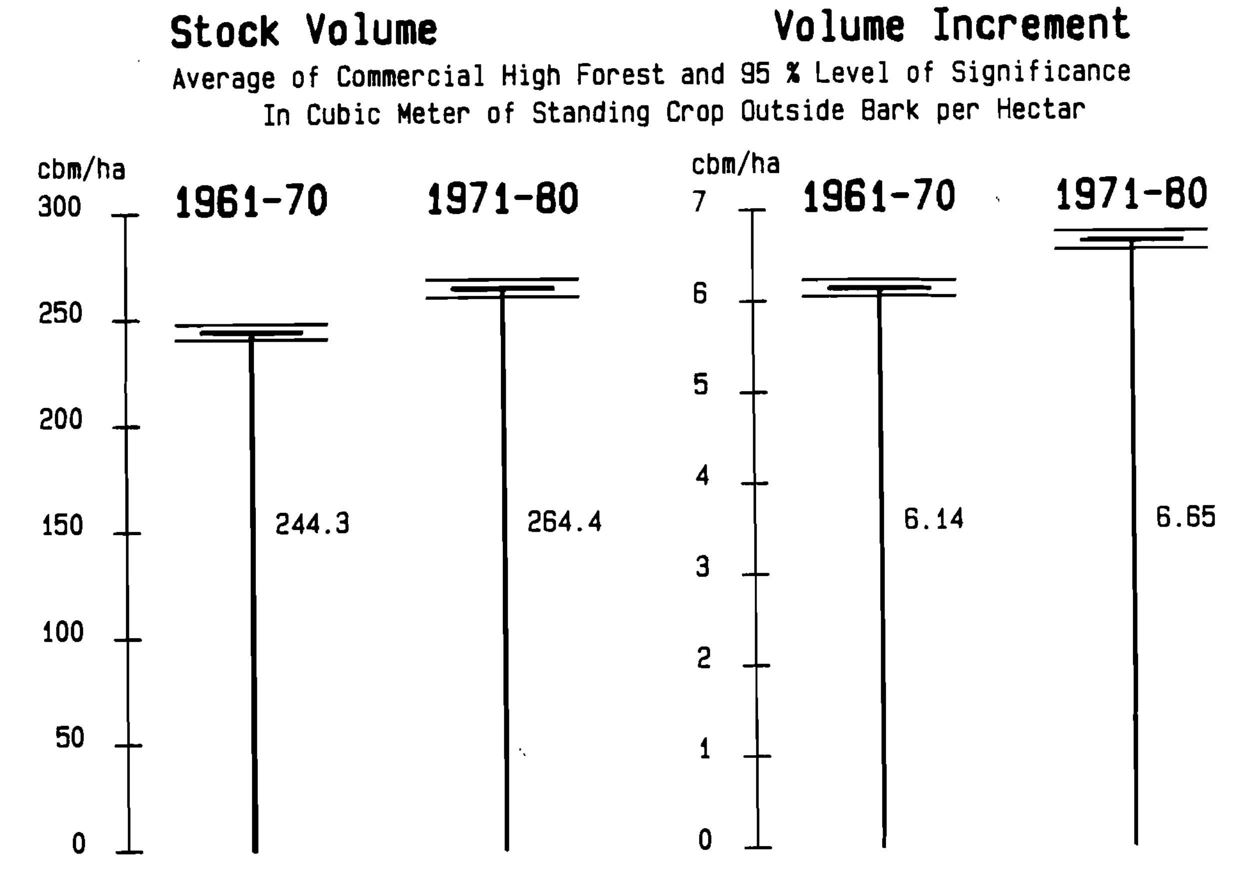

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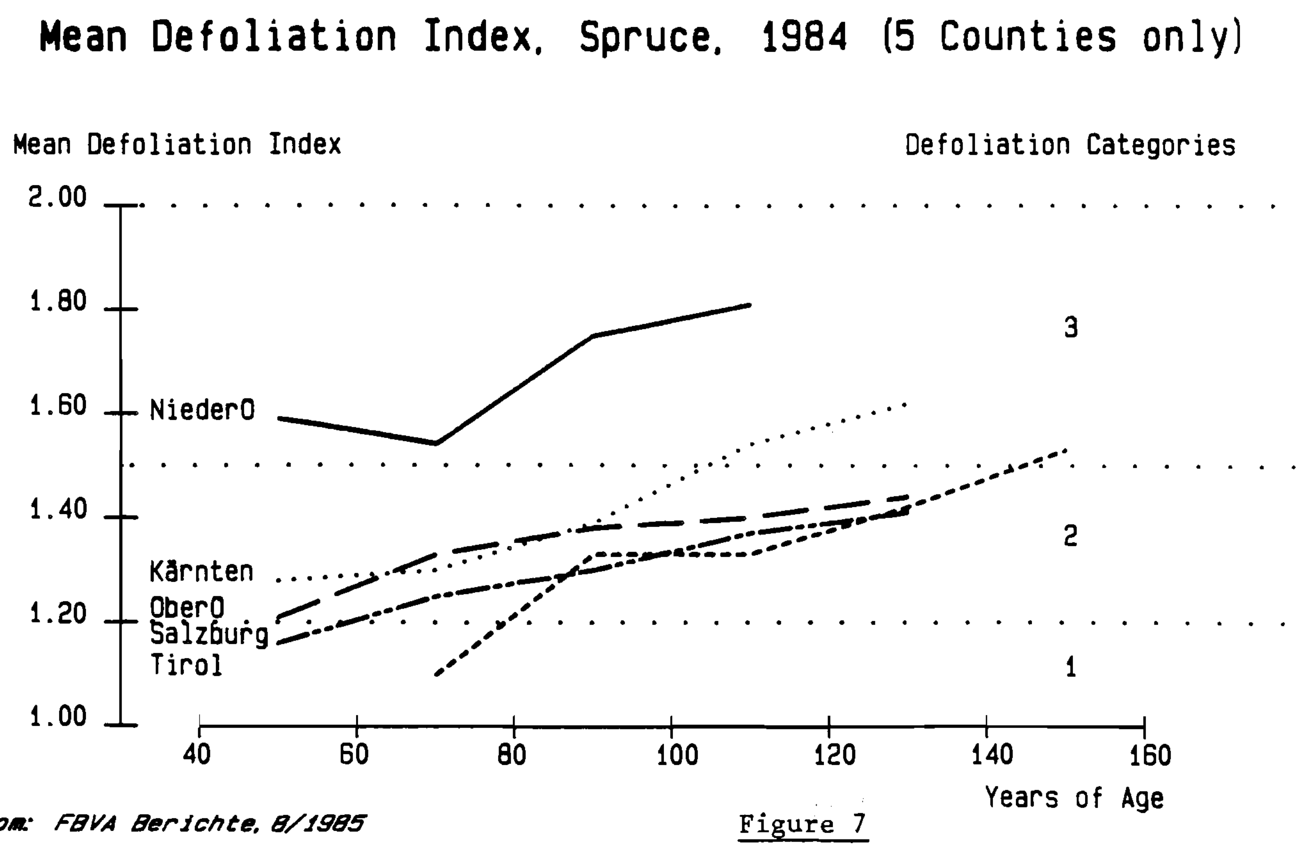
Figure 5



From: FBVA Berichte, 8/1985

Figure 7

Defoliation Classes

Class	Degree of Defoliation
1	Not defoliated
2	Slightly defoliated
3	Moderately defoliated
4	Severely defoliated
5	Dead

Defoliation Index

Mean Defoliation Class of 30 (50) Sample Trees per Plot

Mean Defoliation Index

Mean Defoliation Index of All Plots per Region

Defoliation Categories

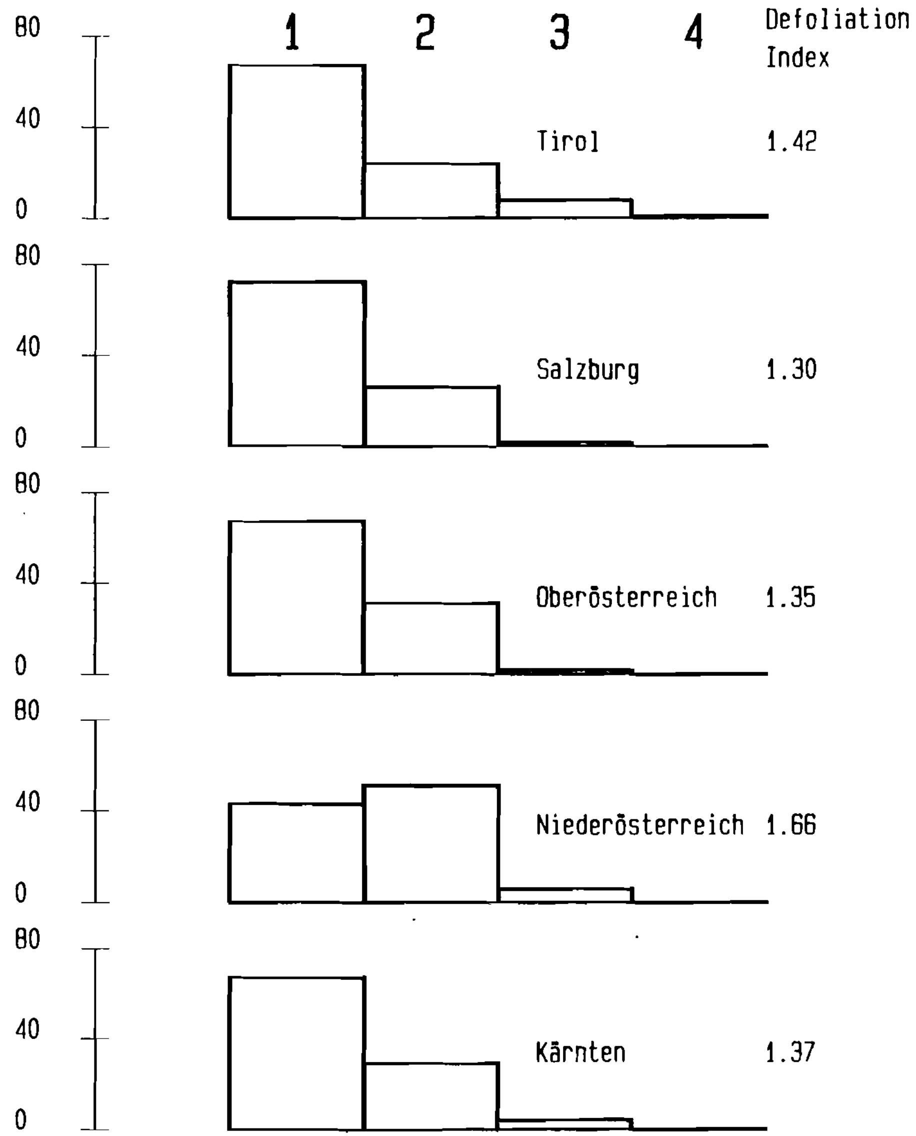
Significance Classes of Damage Caused by Defoliation

Category	Limits of Mean Index	Classification and Possible Interpretation
1	1.00-1.20	No Defoliation or Inside Natural Limits
2	1.21-1.50	Natural Transition Stage, Still Normal
3	1.51-2.00	Slight Defoliation caused by Biotical or Abiotical Factors
4	2.01-2.80	Moderate Defoliation caused by Biotical or Abiotical Factors
5	2.81-3.90	Severe Defoliation caused by Biotical or Abiotical Factors
6	3.91-5.00	Total Defoliation, Practically Dead

From: FBVA Berichte, 8/1985

Figure 6

Norway Spruce, 1984, Distribution of Defoliation Classes



From: FBVA Berichte, 8/1985

Figure 8

4.2.3 DYNAMIC GEOGRAPHICAL MAPS APPLIED TO FOREST DIE-OFF

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ABSTRACT

In many parts of the world, forest damage of a new type is affecting ever wider areas, causing ever more severe damage. Its causes are not really known; about 200 serious hypotheses exist. Most of the likely causes, e.g. pollutants, vary considerably over space and time; as do the soils, climate, tree-species and age of trees. A Geographical Information System is used to depict the spatial distribution of these factors, and several dynamic models are used to evaluate the dynamic development of this process. The result of the combination of both approaches are time series of geographical maps ("maps over time" or "dynamic maps"). This method of maps over time can be applied to many more problems in ecosystems research and management.

1. Situation

In the year 1984, forest damage of a new type had affected 50% of all forest area in West Germany, 25% in Austria and 35% in Switzerland. Nobody had noticed such damage at around 1980. There is a nearly general agreement that air pollutants play a major role to cause the problem. About 1000 air pollutants are listed in some "Plans for the Preservation of the Cleanliness of the Air" e.g. Luftreinhalteplan Rheinschiene Süd 1983. Several hundred air pollutants are known poisons to trees. There is usually a heated discussion, which concentration is sufficient to cause damage, and how long it must last.

The combined impact of these substances on forests may be additive, synergistic (more than additive) or antagonistic (counterbalancing each other). The concentrations of the substances vary over space and time. Their impact also depends on the species and age of trees, on orographic factors such as elevation, exposure or steepness and may depend on climate factors such as amount and frequency of fog and rain and amount and intensity of sunshine or characteristics of the soil.

The whole situation is becoming even more opaque from more or less frequent, more or less natural catastrophes such as pest outbreaks, diseases, large-scale windthrow and snowbreak (the whole tree may be split from the top to the root). Which catastrophe is natural, which one is due to a combination of man-made and natural factors? How do these different factors interact?

2. Problem

A new methodology is needed that can fulfil two requirements:

1. deal adequately with the many detailed factors in their spatial distribution
2. depict the linkages between the most important factors as well as the dynamic behavior resulting from these linkages including the changes that these factors cause to each other.

The direct approach usually has failed of developing an interdisciplinary feedback model to fulfil requirement 2. *and* load it with details as to fulfill requirement 1 (Lee 1973, Jeffers 1976,1979, 1981 HOLCOMB 1976, Holling 1978). An additional problem is the occurence of structural changes of the real life-system, often unpredictable, that can make obsolete the structures in a model (here Bossel's (1977) orientor approach is one of those appropriate here).

3. Method

A small aggregated and holistic feedback model is used to give dynamic behaviors and also feedback reactions to modeled management actions.

The spatial details are put into a Geographical Information System (GIS), where they can be stored, processed, combined, updated and represented (Schaller 1983). The limits and merits of dynamic feedback models are well known from applications and discussions of the last 25 years (although there is still wide disagreement regarding the usefulness of such models). Famous applications are the "System Dynamics" models (e.g. Forrester 1961, 1969, 1971, 1975, or Meadows et al. "Limits to Growth"). A different application is the "Adaptive Environmental Assessment and Management" method (Holling 1978, ESSA 1982).

The development of GIS' has now led to tools with wide applicability (e.g. city rezoning, regional planning, forest management, watershed problems) but seems to be limited by two factors

1. *Large-scale* GIS have nearly generally failed (e.g. Haber et al. 1984— as have many other large-scale MIS (Management Information System) and large-scale DB (Data-Bank) approaches)
2. There are problems in the updating of extensive spatial information (Dangermond 1983) due to costs and lack of staff. Satellite and aerial imagery may improve this situation, but there are problems in the understanding and classification of this information (e.g. Omatsu 1983).

In the method of "maps over time" (or "dynamic maps") the dynamics from the feedback models are combined with the spatial information, held in the GIS, to give time-series of geographical maps, figure 1.

This technique was first developed in a prototype-application to the problem of forest damage. A hierarchical approach is underlying this technique, outlined in more detail in Grossmann 1983 and Okosystemforschung 1983. The development of related hierarchies has a long history, e.g. Anthony 1965. The reactions to the new technique were funny: A few experts

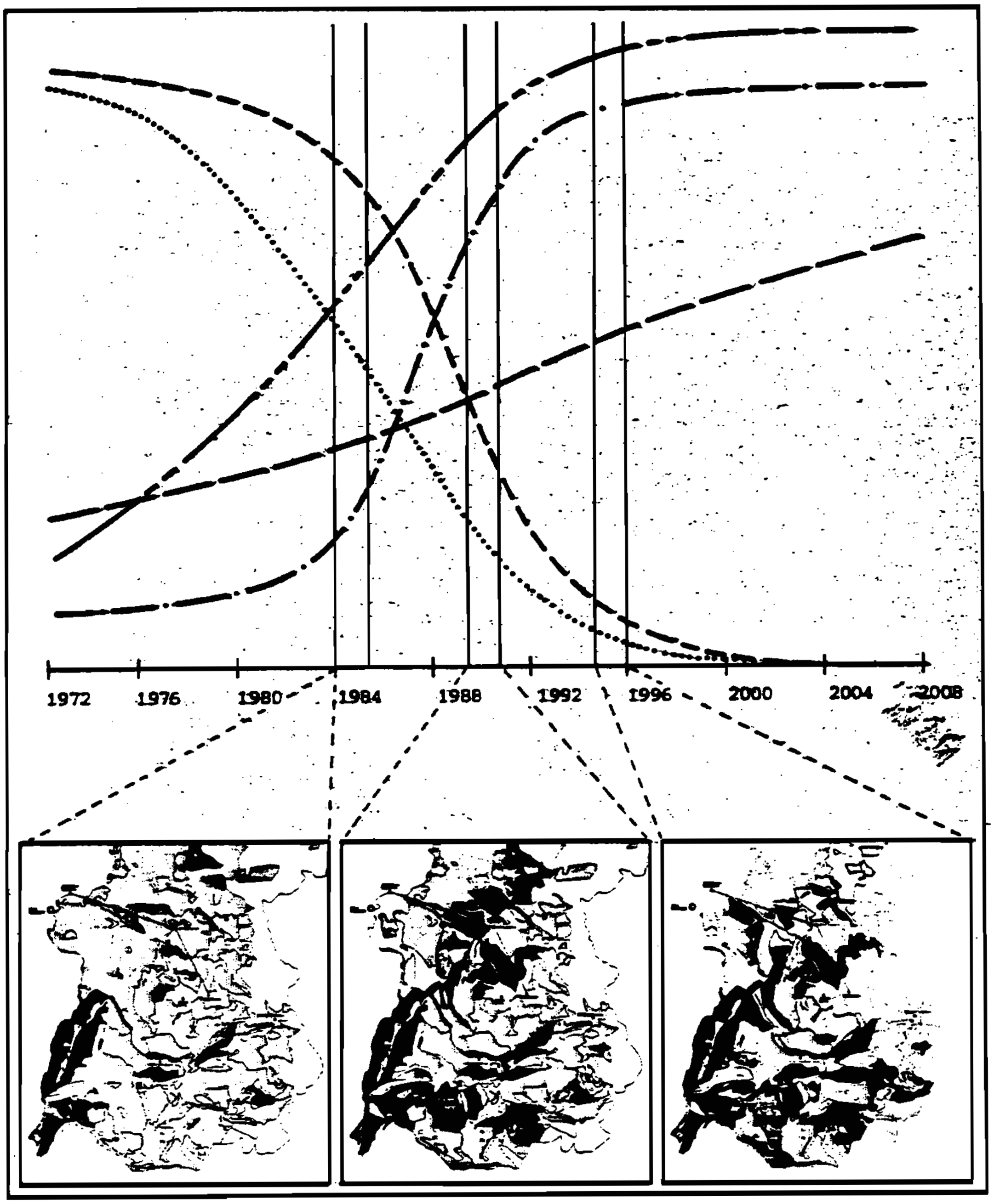

Figure 1. Spatial information on detailed factors is kept in a Geographic Information System and is made dynamic with a model to produce "maps over time"

realized its potential, whereas usually the details of the models, data and so on attracted most attention, often strong criticism.

These maps (figure 1) can be made to depict the past development which allows comparisons with old false-color infrared photographs or old records. They can be made to "predict" the expected present state of the real-life sytem as well as its expected development subject to different management actions. Deviations between expected and actual developments can be very revealing and can give early warnings for the management.

It turned out that the potential of GIS and of dynamic models can be considerably extended. New software is becoming necessary as well as new methods in the use of GIS and dynamic models.

4. Applications

There exist several major hypotheses to explain forest die-off, e.g.

1. The "Acid Rain" hypothesis, explaining forest damage as a consequence of soil acidification by acid deposition (Ulrich 1983,1984). Until about 1983 this hypothesis was generally preferred.
2. Direct impact by flue-gases, in particular by (peak- values) of SO_2. This is a very important hypothesis, because such damage was already reported by the ancient Greeks.

Other hypotheses relate the damage to oxidants, to fertilization by airborne man-made nitrates, to NH_4 chemistry and so on. A major hypothesis (Prinz et al. 1982, 1983) depicts a synergistic impact:

3. Oxidants destroy the surface of the leaves or needles such that rain and fog can leach vital nutrients from the plant, in particular calcium and magnesium. Polluted, e.g. acidified rain, seems to cause increased leaching (Krause et al. 1983, Prinz et al. 1984).

The nearly general acceptance of the "acid rain" hypothesis and the popularity of its name turned out to be the major problems of this ozone-synergism hypothesis. Naturally, the fight between different hypotheses is also about research money, power and scientific recognition. Not only facts are relevant. Prinz or Salzwedel Haber et al. 1983 needed years to make it known that the most severe forest damage in West Germany is in clean-air areas where sulfur may be a deficit substance *even as a nutrient* (e.g. Prinz et al. 1983, Salzwedel, Haber et al. 1983). Maps over time are patterns. The human being is uniquely capable of evaluating and understanding patterns. Perhaps maps can help in situations such as this to come to a faster acceptance of some important scientific results.

A dynamic model ("POLLAPSE") was developed that depicts the major interactions between the most widely discussed factors related to forest damage: trees (total biomass in a large area, e.g. a federal state or nation state), leaves and needles (total biomass), primary pollutants, secondary pollutants, topsoil, buffering capacity of the soil and soil organisms.

A typical feedback relationship between such factors is depicted in figure 2. Forest area, due to the foliage (leaves and needles), causes about five times as much deposition of air pollutants as does non-forested area. This filtering decreases if the air pollutants cause damage and subsequently decrease of foliage.

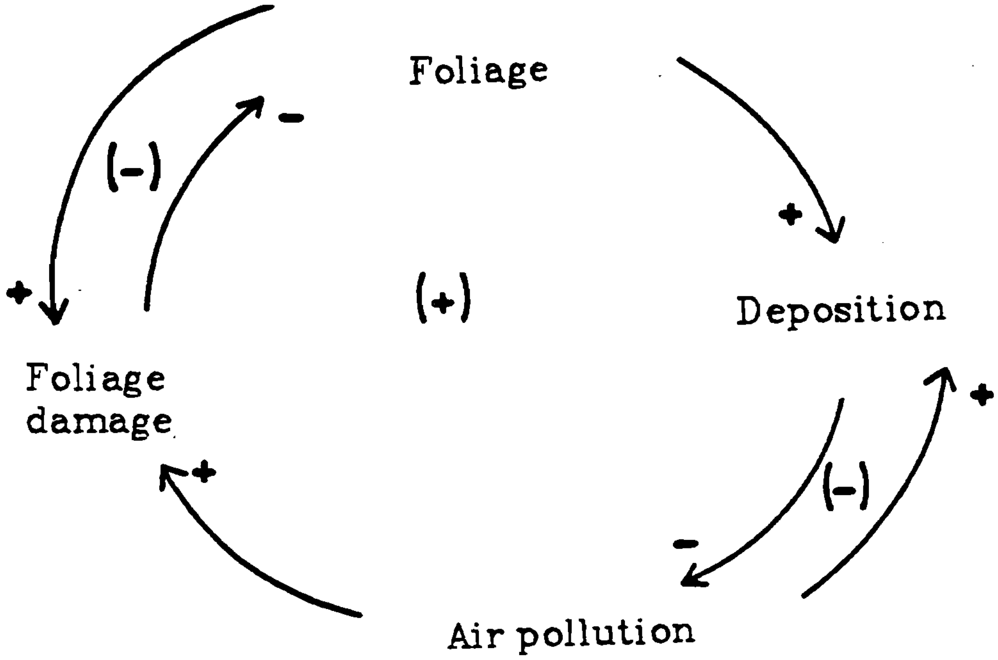

Figure 2. If air pollutants decrease the amount of foliage, the filtering by forests goes down allowing it for pollutants to remain in the air for a longer time. Concentrations in the air could increase leading to even more damage.

Hence the pollutants remain in the air for a longer period of time. The consequence is a higher concentration of pollutants in the air, if emissions remain constant. Higher concentrations will cause even more damage leading possibly to an increasingly faster defoliation. Such an acceleration is indeed observed.

Many such feedback processes interact. If all are put together, a fairly complex model will result even at this high level of aggregation. However, this complex model should only be used explanatory. If a specific hypothesis is evaluated, e.g. the soil-acidification hypothesis, many areas in this model can be taken out leading to a very small and transparent model.

It must be possible for such a model to depict the major hypotheses on the cause of forest damage. POLLAPSE can do this. Different hypotheses usually lead to different dynamic behaviors. Also the reaction to counter-policies to forest die-off changes according to the hypothesis. For example, the model in its version for the synergistic hypothesis 3 of an interaction between oxidants and polluted rain and fog does not react to liming of the soil; whereas the model reacts strongly to this neutralization of soil-acidity, if the soil-acidification hypothesis is depicted.

These different dynamics are translated into geographical maps with a combination of appropriate factors kept in the GIS in their spatial distribution, figure 3. For different hypotheses, different factors are evaluated with different relative importance. Some results are shown in the next figures. All are based on the prediction derived from POLLAPSE (in 1983) that 60% forest damage should occur in Bavaria in 1984.

Figure 4 shows the actual damage in 1984 in 462 different forest areas in the surrounding of the city of Pfaffenhofen/Ilm (Bavaria). The black areas are the city of Pfaffenhofen and other settlement areas. The hatched areas are forest areas. The density of the hatching indicates the severeness of the damage.

Figure 5 depicts the damage according to the soil-acidification hypothesis, based on soil pH-values and tree-species and -age. The soil properties were digitized from Wittmann's soil maps; the best available. In addition, results from a previous research project were available. This resulting distribution of damage was negatively correlated with the actual pattern of damage. This result corresponds with old reports that growth of trees *may* be impeded by alcalinity of the soil. Forest damage is reported from all types of soils: alcaline, acidic and neutral (Guderian 1984, Guderian et al. 1984). Much more complex criteria can be used to produce this particular map.

Figure 6 is to some extent the mirror-image of figure 5. Here, a *higher* pH- value is regarded as unfavorable for trees causing increased risk for forest damage. This map is better than figure 5, both in the statistical evaluation and in the pattern.

The next figure 7 is based on the afore-mentioned synergistic hypothesis. The pattern looks better than the one in the preceeding figure but the statistical evaluation indicates the same fit to the real situation. This is an interesting case demonstrating that the two different approaches of statistics and of pattern may have different advantages and disadvantages.

The latter figure was published in Grossmann et al. 1984. Several months after this publication our research team was informed that a wrong wind distribution had been used for figure 7 (personal communication by Dr. Hofmann, German Meteorological Service. Our research team: Chair for Landscape Ecology/ Weihenstephan: Haber, Bachhuber, Spandau. ESRI (Environmental Systems Research Institute)/ Schönbichl:Schaller, Sittard. IIASA/Laxenburg: the present author).

Figure 8 is the evaluation of the synergistic hypothesis for this different wind distribution. The correspondence to the real situation, both statistically and in the pattern, is fairly good. The difference between the three last figures shows that *patterns* of difference can be very revealing.

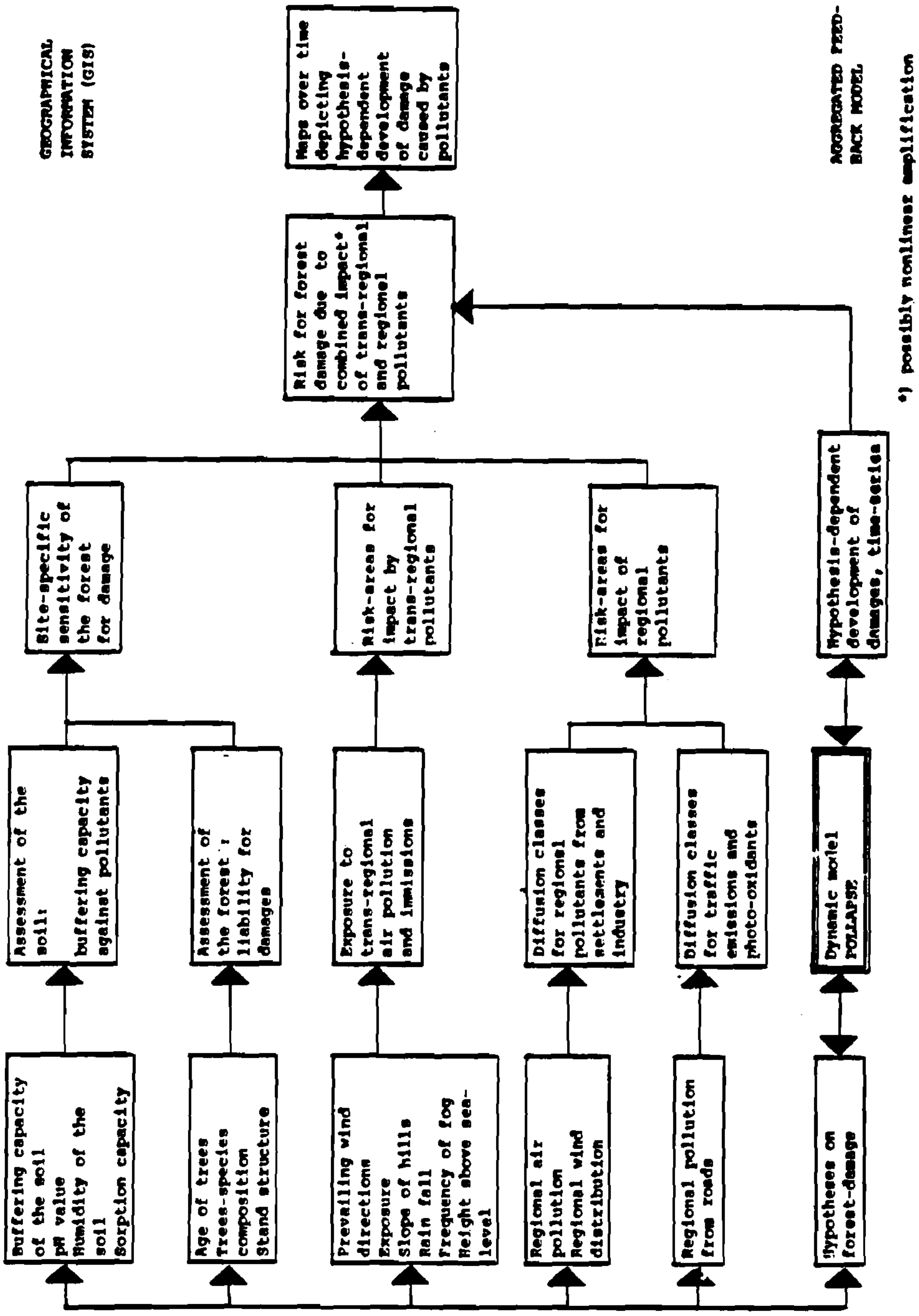

Figure 3. Detailed variables that are used to translate dynamics into detailed geographic maps on the location and amount of forest damage. The resulting maps are hypothesis-dependent, as is the selection of the detailed variables to be used in the translation process.

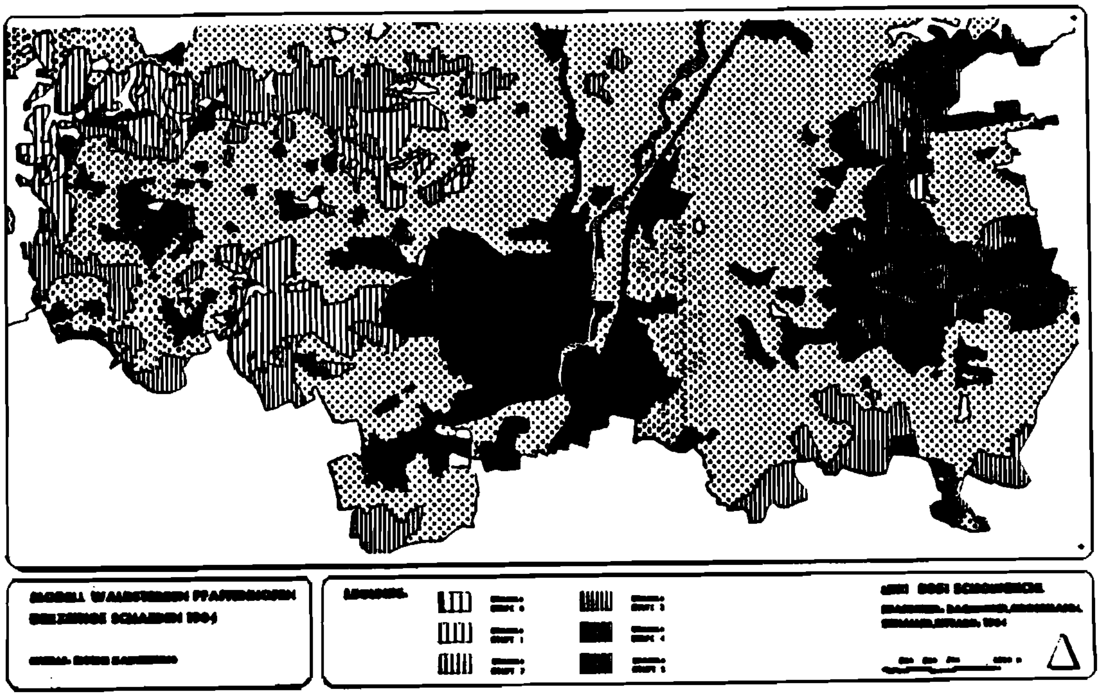

Figure 4. Actual forest damage in 1984 in 462 forest areas in the surrounding of the city of Pfaffenhofen/Ilm. Black areas are settlement areas; hatched areas are forests. The density of the hatching indicates the degree of forest damage.

Afterwards a new application of the method of maps over time was done. The initial damage function for the synergistic hypothesis was changed systematically to produce the best fit to the observed damage d with the simplest function. As the damage is in five classes, the result has to be one of the numbers 0 to 5. The resulting function is indeed simple: predicted damage d_p =a**v*b + c, where a is the concentration of oxidants (in units of 60 micro-gram per cubic metre), b is the concentration of all primary pollutants, v is an appropriate exponent. From the literature v=1.5 to 2 was expected (e.g. Jacobson 1977, Heck et al. 1977, Smidt 1978, Smith 1981, Guderian et al. 1984, Salzwedel et al. 1983). However, for v=1 the fit was best. c takes into account age and species of the trees and was adapted such as to make the difference d - d_p (sum over all 462 forest areas) equal to zero. This function d_p takes into account that no damage to plants is caused by levels of ozone below a threshold value of 60 micro-grams per cubic metre, because such values are automatically rounded to damage class zero (no damage), if the level of primary pollutants is also low. Values of d_p greater than five were set to five, because this by definition is the most severe damage possible (severely damaged to dying). However, this function can only be so simple, because the past development and all feedback reactions are contributed by a different layer, e.g. by a dynamic model.

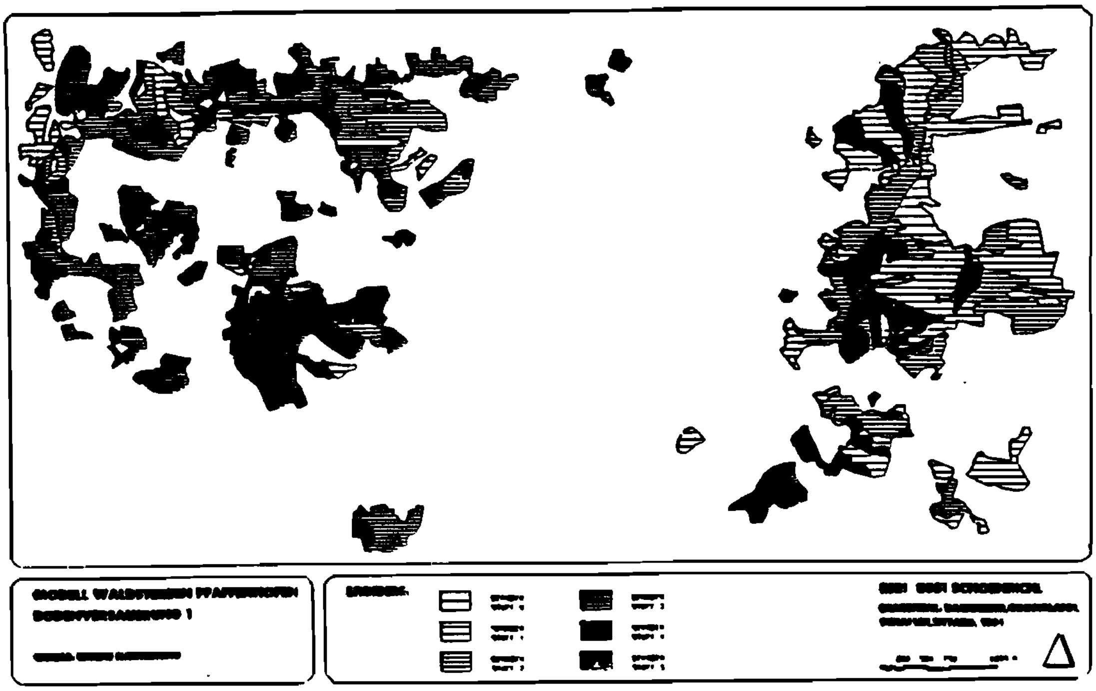

Figure 5: The percentage of damage to be shown in this map is prescribed by the dynamic model and distributed among the 462 forest areas according to soil pH-values, and species and age of the trees. The deviation to the real situation (figure 4) is striking.

This result (Grossmann et al. 1984) was a new formulation of Prinz's results. It was confirmed by laboratory measurements by several US groups, Rawlings 1985. He reported exactly the same linear increase with the level of these two pollutants and a multiplicative increase of damage for the combined impact.

Again it must be underlined that all work so far was a prototype application and a feasibility study to prepare research projects based on the method of maps over time. It seems exiting, however, if in addition to laboratory work a method for the evaluation of field work becomes available that can deal with much of the complexity of the real-life situation.

The statistical comparison of the different maps was done with the sum over all 462 forest areas of the absolute values of the differences (abs(actual damage-predicted damage)) and with the corresponding sum of the squares of these differences. This simple statistics was used to avoid difficulties inherent in the combination of more sophisticated approaches and dynamic models as already reported by Senge 1975 and confirmed by e.g. Fox 1982.

This simple hypothesis gives a good fit both statistically and with respect to the pattern. It was subsequently used to improve the dynamic model allowing a feedback process between different layers. With this improved version, different counter- policies to forest die-off were

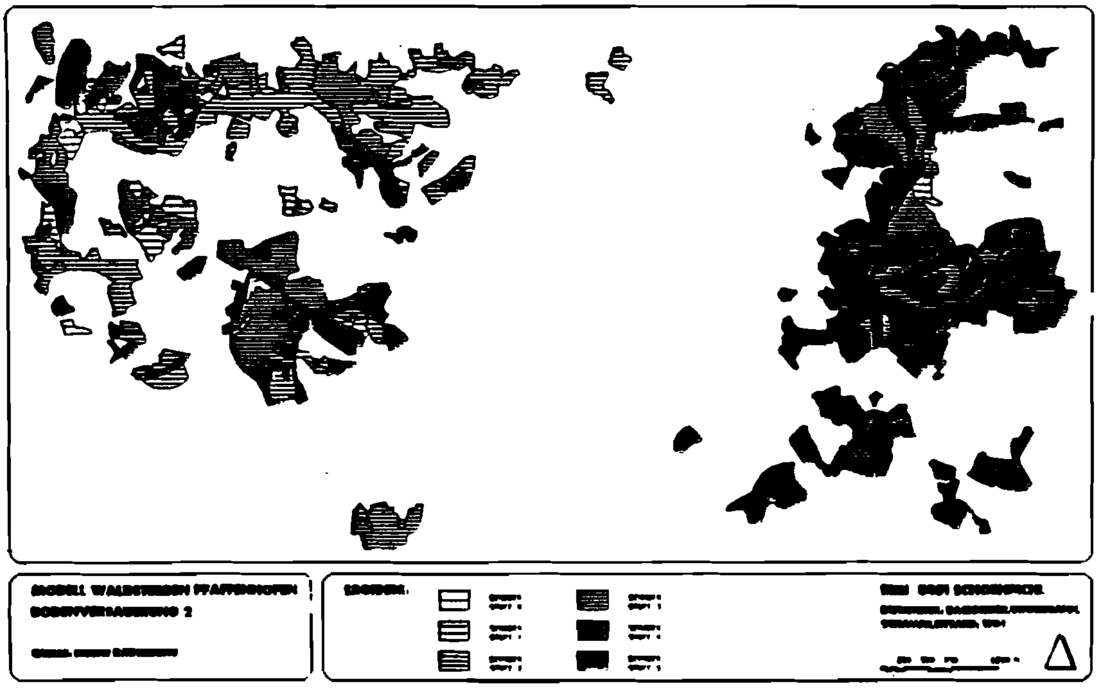

Figure 6. Here, a higher pH- value is regarded as unfavorable for trees causing increased risk for forest damage. This map is better than its counterpart, figure 5.

evaluated, figure 9. Again, these results were translated into maps that can be compared with the actual ongoing development.

The assumptions regarding the effects of the counter-policies can be measured. Everywhere in the real-life system actions are taken that should have predictable outcomes: Filters are installed in power-plants. "Autobahnen" are closed temporarily for repair work, new super highways are becoming available. The resulting local changes in pollutants can be measured and used to produce maps on the expected outcome. These maps can be compared with the actual development to allow an early warning if a counter-policy fails and in general to find out, how the different counter-policies work.

This last example indicates that maps over time can also be produced without models. Essentially the same maps should result from the following four procedures (here applied to forest damage):

1. map of the *actual* damage
2. map using local concentrations of the pollutants *measured* in the forests
3. map using local concentrations of pollutants *calculated* with short-distance transport models and regional emissions, added to the regional measured background levels of pollutants

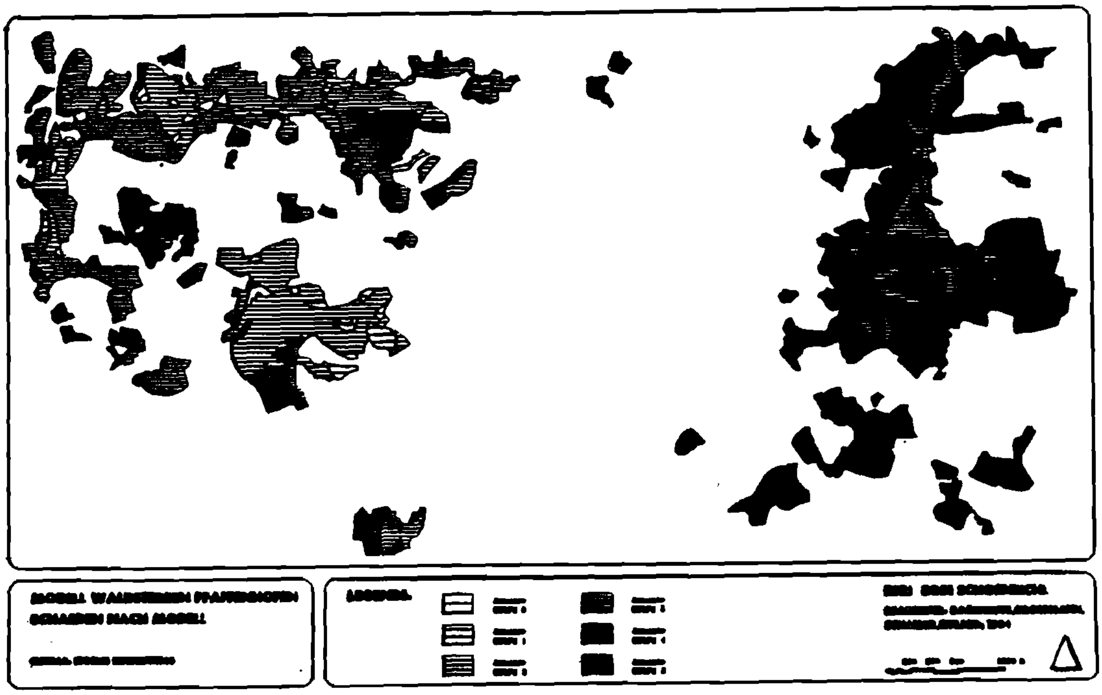

Figure 7. Forest damage according to a hypothesis depicting a synergism between oxidants and primary pollutants.

4. map based on local concentration of pollutants computed with aggregated models depicting very large areas (say a federal state).

To derive the final maps for 2. to 4., all of these informations are always overlaid with detailed spatial information such as exposure, age and species of trees.

The possibility of parallel use of redundant information is important as each of the above procedures 1 to 4 has merits and disadvantages of its own:

1. on-site inspections often produce errors, even systematic ones. The result of false-color infrared photographs depends on the emulsion of the film, the shade, and the evaluating person.
2. problems exist in the calibration and in the smoothing of the data- is an extreme peak value of a pollutant of five seconds or of 10 minutes important?
3. several models on transport of pollutants and their transformation during the transport exist that give very different results
4. the one aggregated model used (POLLAPSE) produces very different results depending on the hypothesis used and on the special choice of parameters.

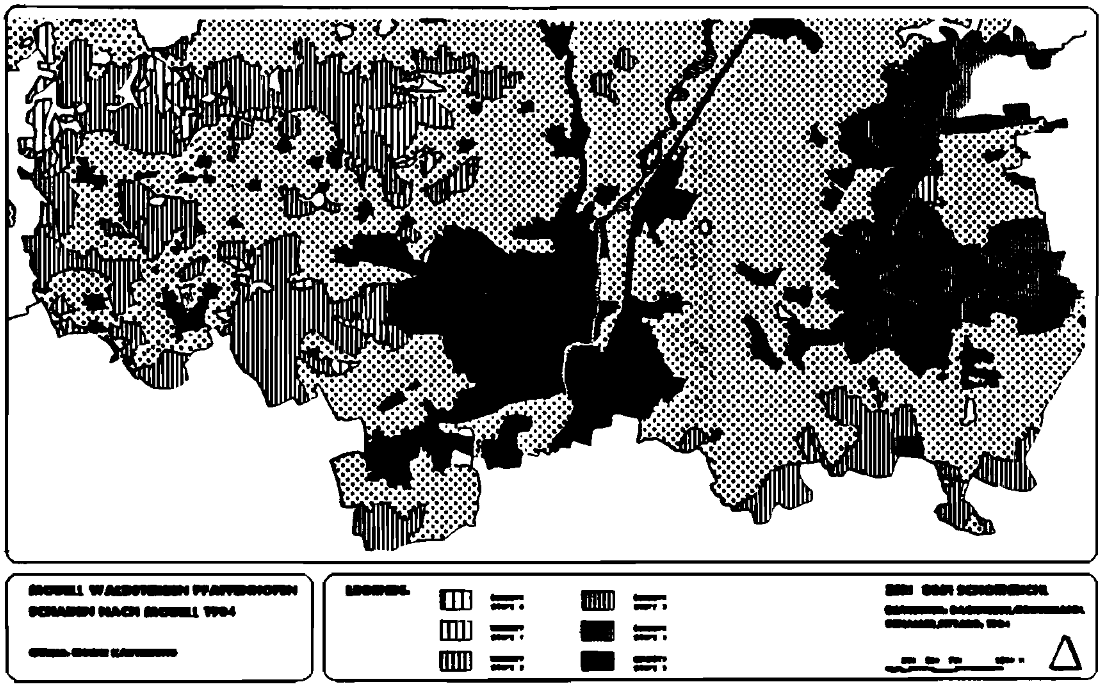

Figure 8. Same hypothesis as in figure 7. However, the wind distribution was corrected. The pattern of deviation between figures 7 and 4 is revealing a systematic error (in this case the wrong wind distribution).

Approach 4 gets most criticism but may be the most appropriate. First, it takes into account the feedback reactions in the real system. But much more important is that it is in correspondence with the most striking observed fact of forest damage.

Forest damage started historically nearly simultaneously in very different countries in nearly all types of forest stands and is affecting all types of species. The present average concentration of the most important primary pollutants in Austria was surpassed in West Germany already in 1965. But still in 1970, no forest damage occured that is comparable with present damage in Austria. Hence Schütt 1983 is postulating the existence of a "factor x" that causes the damage and is not varying as much as the "classical" factors of forest damage. If factor x exists, it must be possible to describe it with a model that is fairly homogeneous for large areas. This is the basic idea of approach 4 and of the POLLAPSE model. This "factor x" assumption has subsequently been adopted by the Ministery subsidizing most West German research (BMFT 1985).

The approach of maps over time was afterwards applied to the socio-economic-ecological impacts of Olympic Winter Games in Berchtesgaden in 1992. The usual different options were evaluated (Soft Olympics- no changes of the ecology, no construction. Hard Olympics- much construction. No Olympics. Optimal Olympics. Alternatives). The maps help considerably in the evaluation and presentation of the results.

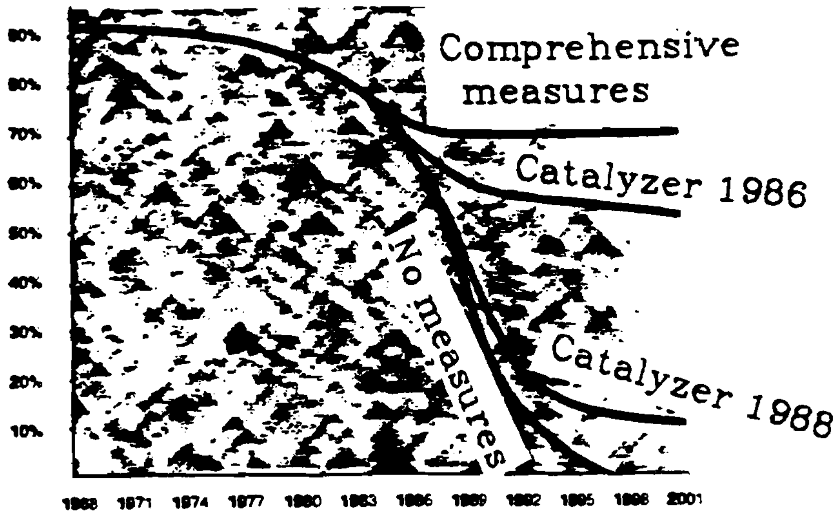

Figure 9. Reaction of the synergistic version of POLLAPSE to different counter-policies.

5. Summary

The method of maps over time combines spatial and dynamic approaches. It combines use of patterns and of statistics. It can contrast redundant information of quite different type. If the maps over time (based on confirmed topographic information) are overlaid with the (also dynamic) aerial and satellite imagery, difficulties in understanding and classification of the latter information might be overcome. The maps over time can be used for the evaluation of different assumptions, for the integrated environmental monitoring of the effects of management-actions, and for decision support in (human) ecosystem management. They may become a quite effective tool for many of these tasks.

The author is grateful for discussions with and critics by many colleagues. Besides the research team mentioned in the text, important remarks also came from D. Costello, C.S. Holling, C. Walters and at IIASA from W. Clark, T. Munn and L. Hordijk.

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4.2.4 STRUCTURAL CHANGE OF THE FOREST SECTOR AS A CONSEQUENCE OF FOREST DIE BACK – ILLUSTRATED WITH A SWEDISH EXAMPLE

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ABSTRACT

One recent estimate is that 7.0 million hectares of forest area in Central Europe have been affected by air pollution. This can have quite an effect on domestic forest sectors and international trade. For example 20 per cent of the total Swedish export value comes from forest industrial products. The main part of this export goes to Europe and the EEC. Every 15'th Swedish employee, a quarter of one million people, earns his living from the sector.

In Sweden loss of needles is limited and can be found above all in mature forest. Data from earlier years is missing and thus it is difficult to specify a reference value. Futhermore it is impossible to equate air pollution and loss of needles.

As an example of how models could be used for illustrating possible effects of forest damage on the structural change of national forest sectors two scenarios are presented. The base scenario assumes "business-as-usual". Against this background a scenario is presented where forest damage causes a substantial increase of forced cuttings in Europe. As an indirect effect the Swedish saw mills must in the scenario reduce their export with 3-4 million m^3 i e with about 50 per cent. This will seriously affect the interest groups of the forst sector: forest industry, forest owners, workers, communities and eventually the whole society.

At the end of the paper it is stressed that the interest groups must find international and domestic strategies for stopping and avoiding the negative effects of air pollution and forest damage. Suggested policies are (1) reduction of emissions, (2) silvicultural activities and (3) research and development.

FOREWORD

The purpose of this paper is to warn of the effects air pollution and forest damage may have on domestic forest sectors and international trade. This will partly be done by utilizing model produced scenarios. My own experience when working at IIASA as a scholar gave me opportunity to follow the Forest Sector Project and the development of the Global Trade Model, and the Forest Sector Model respectively. These models can be used for showing possible effects on international trade of forest industrial products and structural changes of national forest sectors as a consequence of forest die back.

A forest die back scenario illustrates how necessary it is to find international and domestic strategies for stopping and avoiding the negative effects of forest die back. But before strategic decisions are taken a better understanding is needed of a) the new situation, b) the policy options and c) the likely consequences of the alternative policies in a given set of conditions.

Director general Lennart Schotte, professor Folke Andersson, professor Sten Nilsson and Dr. Göran Lönner have given me valuable comments. I am most grateful to all of them.

1 THREAT OF FOREST DAMAGE

1.1 Europe

Every year the European air is the recipient for about 30 million tons of sulphur - the main part coming from coal and oil burning (Figure 1). Some forest areas of the Federal Republic of Germany (FRG) has received 100 kilos sulphur or more per hectare and year for half a century. From time to time we can read alarm reports. For example an article signed by Johansson (1983) said: "Half of the FRG forest will die within 20 years, if not the enormous emissions of sulphur from the industry are reduced... Already now the forest die back has affected one tenth of the FRG forest".

Quantitative estimates about forest damage are uncertain and must be treated cautiously. One recent estimate made for the Timber Committe by a group of specialists on possible market problems of air pollution damage to forest is that 7.0 million hectares of the European forest area have been affected by air pollution (Schotte, 1985). Of this area at least 5.5 million hectares are located in seven geographically closely related countries - Austria, the FRG, the Netherlands, Luxemburg, Poland, Switzerland and Czeckoslovakia. However, it is known that damaged forests also exist in the German Democratic Republic (GDR). Of the above mentioned area about 1.3 million hectares are estimated to have damaged, dying, or dead forest.

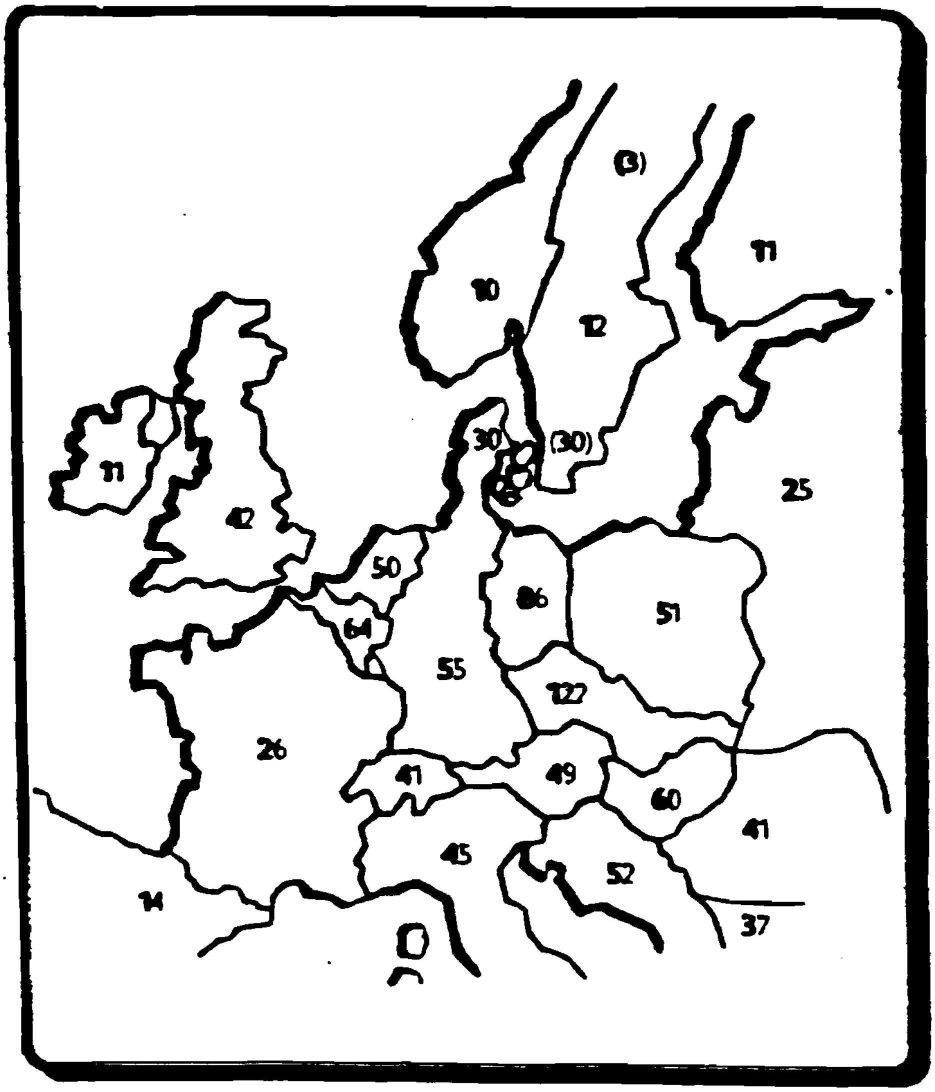

Figure 1. Sulphar deposition, kilo per hectar and year.
Source: Schotte (1985).

One of the first approaches about acid rain goes back to a biochemist from the FRG, professor Bernhard Ulrich, who claimed that the slow dying back of the forest can be devided into three steps: (1) In the first step positive nitrogen effects dominate. The forest is fertilized, which causes the trees to grow faster. This could be observed earlier in the FRG and is still the case in Scandinavia where the damage still is not that bad. (2) In the second step most of the ground in Europe has a natural ability to neutralize the acid rain and can also compensate the leached miniral nutrients from underlying layers. However, as in the FRG this ability is now decreasing. First acidification increases in the upper soil layers. Nutrients leach and their availability decrease. This can be noticed through yellowing needles and localey decreased tree growth. (3) The third and last step, which may come very quickly, is caused by acid rain dissolving toxic metals in the soil, above all aluminium. The effect will be gradually impacted root systems and soil microorganisms. After some time the trees will die due to a combined influence from different factors such as starvation and poisoning. Professor Ulrich estimates that about two million hectares of the FRG forest are very close to the third step.

However, this hypothesis does not explain the forest die back on limy areas or on grounds with high buffering capacity. Nowadays we know more about the long chain of causes and effects behind forest die back even if not all details is known. The scientific approach is wider and air pollution in general is studied and not only acid rain. Other hypotheses about causes of forest die back are (Effects of air pollution on forest land, 1984):(1) One is that the damage to the trees is caused by gases as nitrogenoxid, sulphur dioxide and ozone as well as hydrocarbons. The joint effect of these gases is sometimes extremely serious. High concentrations of ozone is disastrous. (2) Another hypothesis is that more nitrogen than a tree can assimilate is brought into the ecological system. Leaching of nitrogen and other important elements to the ground and surface water may take place. (3) Still another hypothesis, in addition to the described negative effects, deals with climate changes. Strong wind, drought, extreme fall of the temperature are some examples.

1.2 Sweden

In 1984 the National Forest Survey carried out the first total survey concerning loss of needles by Norway spruce and Scots pine (Bengtsson, 1985). Figure 2 shows the loss of needles among mature forest - mature forst in order to consider the influence of varying age structure within different regions. The most wide spread loss of needles could be found in the inner of Norrland and in the Southwest of Sweden. Because of sample errors it is important to look at regional tendences and not at the result for individual counties.

It should be born in mind that Sweden extends from lat. 56 to 68 N, and that even Stockholm is not much further north than latitute 59 N. In fact most of Sweden lies well to the north of the British Isles, and parts of it even further north than Iceland. Northern Swedèn lies in the lee of the Norvegian mountains, and southerly winds have a tendency to veer off to the east before they reach Northern Sweden.

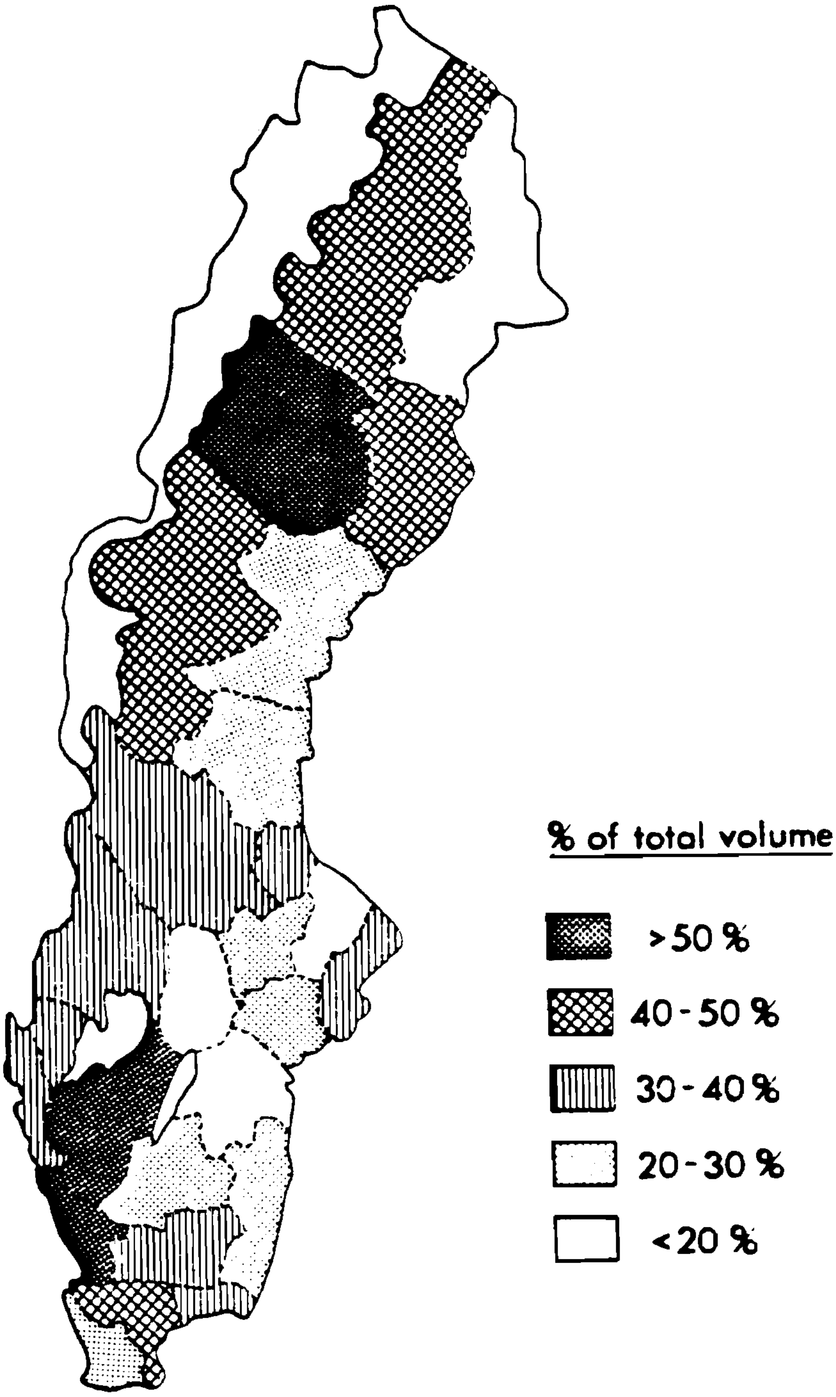

Figure 2. Proportion of the growing stock of spruce consisting of trees with defoliation >20% by counties/parts of counties. Old stands and stands in the upper middle age. - Values for single counties are in many cases uncertain, e g due to sampling errors. Source: Bengtsson (1985).

It could be that needle loss in Southern and Northern Sweden does not indicate the same thing. Thus until more knowledge is gained one ought to study the situation within regions with the same climate impact instead of comparing Southern and Northern Sweden. But it is quite clear that all over the country the needle loss for Norway spruce increases when the tree grows older. Perhaps needle loss is not an adequate indicator of the vitality of young forest? Another result is the increase of needle loss with higher altitutes above the see level.

When it comes to Scots pine the result shows that loss of needles rises with increasing age although not at the same extent as for Norway spruce. No clear difference has been found between Southern and Northern Sweden. But the result for Scots pine is much more uncertain than for Norway spruce. It could be that needle loss is not a good indicator of the pine vitality. Because of this no detailed result is presented.

The result can be summerized as follows:

- The Norway spruce growing in Southern Sweden shows a considerable loss of needles, above all mature forest in the southern and southwestern counties. However, as an average severely damaged trees (more than 60% loss of needles) are only to be found among 0.5-1% of the Norway spruce in forest to be thinned or clear cut.

- Spruce in big parts of Northern Sweden (Norrland) shows the same loss of needles as in Southern and Sothwestern Sweden. One explanation could be the hard climate on higher altitudes above the see level. Another could be a big share of old trees.

-It seems as if trees with loss of needles could be found everywhere but are more frequent on dry and thin soils at exposed sites, for example at edges of woods.

Bengtsson points out that the interpretation of the result is difficult:

(1) Needle loss has always existed but it has not been measured. Thus no time series exist. This survey gives a reference value for future studies.

(2) The relationship between air pollution and needle loss is not clear. Other explanations exist probably in combination with air pollution.

(3) The classification for a damaged tree is not clear. Probably the loss of needles ought to be much higher than 20%; for instance it is quite natural that the old Norway spruce in special locations has a high needle loss.

More research is needed. The survey will be repeated.

2 THE SWEDISH FOREST SECTOR

The total Swedish land area is 41 million hectares of which 56% is classified as forest area (Statistical Yearbook of Forestry, 1984). The inventory of standing timber is estimated at 2 200 million m^3 s. The main part (82%) consists of conifers. 44 per cent of the inventory of standing timber consists of Norway spruce. The mean annual recorded growth of standing timber 1975-1979 is estimated at 68 million m^3s. The conifer share is 32 per cent and the spruce share 49 per cent.

The forest sector is an important part of the Swedish economy (Table 1) (Skogsindustrins betydelse för Sverige, 1984):

Table 1. Some key figures regarding the importance of the Swedish forest sector for the economy.

Production value	7.3 billion USD
Value added	2.8 billion USD
Export value	4.8 billion USD
Working force	130 000

- Value added

In 1982 the total production value of the forest industry (pulp, paper, paper articles, sawn wood and board) was in total about 7.3 billion USD[1]. This corresponds to 18 per cent of the market value of the manufacturing industry.

The value added of the forest industry in 1982 was 2.8 billion USD, which corresponds to about 4 per cent of the Swedish gross national production.

The value added per employee is higher for the forest sector than the average value for the manufacturing industry. This means that the sector generates a more valuable production to society.

1) The calculation is made with an exchange rate of 8,25 SEK per USD.

The dominating part of the market value of the forest industry, about 65 per cent, is purchase of goods and services from different parts of industry and commerce. In comparison with other parts of the manufacturing industry it is a high percentage figure. This explains, as will be seen below, the high indirect employment of the forest industry.

More than 30 per cent of the purchases were made from forestry (wood raw material). Other important suppliers are to be found inside such sectors as manufacturing of goods, chemical industry and private services (for example transports and repair).

- Trade

About three fourth of the forest industrial production is exported. In 1983 the value of this export was almost 4.8 billion USD, which corresponds to 20 per cent of the total Swedish export value. Calculated as a net value, i e with reduction for import, the contribution is much higher. The explanation is that the forest industry is based on domestic wood raw material. Only a smaller amount of goods such as oil, chemicals and machines are necessary to import.

The European Economic Community is most important for the Swedish forest industry. More than one fourth of the Swedish export to the EEC concists of forest industry products. Three fourth of the Swedish paper export and two thirds of the pulp export go to the EEC. In 1983 one fifth of the total EEC import of pulp comes from Sweden. The Swedish share of the EEC import of paper was about one third. Three forth of the Swedish sawn wood production is exported to the EEC. The FRG and Great Britain are the dominating receivers of the Swedish forest industry export - about 35 per cent of the export goes to those countries.

- Employment

More than 130 000 people are directly employed within the forest industry. Forestry gives work to 50 000. Together this corresponds to 6.5 per cent of those employed by commerce and industry. About 70 000 people are employed by suppliers and thus indirectly by the forest sector. In total the forest sector directly and indirectly employs a quarter of a million people. This means that every 15'th Swedish employee earns his living from the sector.

Contributing to the importance of the forest sector as employer is that many of the jobs are to be found in areas with a weak industrial sector. This is especially true for the northern parts and the inner parts of Southern Sweden. For example in Lycksele, a community in northern Sweden, every fourth employee are dependent on the forest sector.

3 TWO SCENARIOS

As an illustration of the usefullness of models when showing possible effects of forest damage on structural change of national forest sectors and trade patterns two scenarios are presented[1]. The scenarios reflect at different

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[1] A scenario is in this paper defined as a description of the future development of key variables such as consumption, production and export.

sets of assumptions two ways in which the European and the Swedish forest sector may develop. The first scenario assumes business-as-usual, while the second scenario assumes that the sector is affected by forest damage. The first scenario is based on model runs, while the second one has added human judgements. Other assumptions will generate another development and another scenario.

3.1 Business-as-usual

The scenario extends over the period 1980-2030 and covers western Europe excl Finland and Sweden (Dykstra and Kallio, 1985). Some of the main assumptions made by IIASA's Forest Sector Project after consultation with collaborators are: a) moderate economic growth rates, b) population growth rates stabilize or decline beginning in 1995, c) a fall of the US Dollar with about 30 per cent in 1990, d) tariffs drop to "Tokyo round" levels in 1987, and e) USSR timber removals increase by 20 per cent in 1990 while removals of eastern European countries are unaffected.

In the scenario the total production of roundwood for industrial use increases all the time due to increased demand of forest industrial products (Table 2). The following description will concentrate on the saw milling development.

The total world production of conifer sawn wood increases from about 315 million m^3 in 1980 to 390 million m^3 in 2000. During the first three decades of the next century a weak consumption development and increased competition from other materials causes the increase to level off and production as a consequence starts to decline. But availability of saw timber and tradition causes another development of demand in Europe.

Western Europe

The production excluding Finland and Sweden increases from 30 million m^3 in 1980 to 45 million m^3 in 2000 and 50 million m^3 in 2030. The implication of this development is a reduction of import that drops with 50 per cent between 1980 and 2000 and in 2030 more or less has disappeared.

In the scenario real prices of conifer logs in Western Europe increases, specially between 2000 and 2030 the increase is substantial (Table 2). The real price of conifer sawn wood is for the decades to come more or less stable due to a quick technological development. During the next century an increase takes place.

Sweden

The Swedish scenario extends over the period 1970-2000 (Lönnstedt, 1983). The model is initialized to show the production capacity and the production costs of the Swedish forest sector and its competitors respectively. The first decades of the model run is a test on how well the model succeeds in recreating the history. Some of the main assumptions are as follows:

Table 2. Some key figures for Western Europe from a "business-as-usual"-scenario.

	1980	2000	2030	1980-2000 (Average annual per cent change)	2000-2030
Industrial roundwood production (million m^3/year)	1300	1800	2600	1.6	1.2
Conifer sawn wood production (million m^3/year)					
World	315	390	390	1.1	0
Western Europe	30	45	50	2.0	0.4
Conifer sawn wood import to (million m^3/year)					
Western Europe	25	10	0	-4.6	15
Price of conifer log (USD/m^3)	80	105	230	1.4	2.6
Price of conifer sawn wood (USD/m^3)	200	200	275	0	1.1

- Demand of forest industrial products will increase in Western Europe (including Finland and Sweden) but with different rates. For example the estimate is that the consumption of sawn wood in the year of 2000 will be about 78 million m^3 compared with about 70 million m^3 in 1980. The sources of the forecasts are Data Resources Inc. and Jaakko Pöyry International.

- The exchange rate between the Swedish Crown (SEK) and the US Dollar (USD) is expected to continue to fall during 1985 and stabilize in 1986 at a value of 6.5 SEK per USD.

- As an annual average the wage cost, i e salary and social costs, is expected to increase by 10 per cent per year in Sweden and competing countries. (This is the historical average.)

- As an annual average technological improvements will make it possible to increase the productivity with 4 per cent. (This is the historical average.)

The description of the scenario will concentrate on the saw milling side of the forest sector. In the model run the Swedish saw milling capacity increases after a decrease during the end of the 1970's and the beginning of the 1980's (Figure 3). The capacity increase levels off at the beginning of next decade and a new downward trend starts. At the end of this century the capacity is almost at the same level as in 1970, i e about 13 million m^3.

Figure 3. A "business-as-usual"-scenario for the Swedish saw mills.

The causes for the capacity development are to be looked for in the development of demand, prices and costs. Gross profit can be said to summarize the development of those factors. Explanations for the capacity expansion during the 1980's are thus the expected consumption increase and a relatively high profit level of the Swedish saw mills in the beginning of the 1980's.

Starting from the middle of 1980's production costs relative competitors and profit level gradually get worse and worse. During the end of the 1990's the consumption increase levels off. The result in the model run is a decrease of the Swedish sawmilling capacity. Capacity development (production) is reflected in the cuttings of saw timber.

3.2 Forest die back

This scenario is a very depressing one. The forest damage causes a substantial increase of forced cuttings which have quite an effect on the European forest sector (Nilsson, 1984). The assumptions behind the scenario are as follows:

- Sites with more than 25 per cent loss of needles in 1983 will be cut within five years
- 65 per cent of the standing volume in those sites will be cut
- No cuttings due to noxious insects are supposed to take place
- In mature but undamaged sites the cutting volume is reduced by 50 per cent compared with a normal cutting volume
- Labour and machinary is assumed to be available for cuttings and industrial processing.

The consequence of those assumptions are that the cuttings within five years will be more than 100 million m^3. Compared with the cuttings of 1981 it is an increase with more than 30%. And this is just for softwood!

If the increase of the cuttings is used by the saw milling industry its production will be increased by about 10 million m^3. Compared with 1981 this means an increase with about 50%. Existing capacity can easily produce this through introducing more than one shift.

It would be possible to increase the pulp production with 1.4 million tons. This could be done within existing capacity. An alternative to pulp production is to use wood as fuel. This is already said to take place in Poland.

In this scenario the assumption is that the main part of the increased cuttings will be used by the saw mills. The governments will support this development. But, increased supply of wood raw material and increased production of forest industrial products will cause a reduction of the prices in Europe. In the short run the forest products will increase its market share at the expense of substitutes. The low roundwood prices will cause economic difficults for the private forest owners. The governments will therefore subsidice cuttings of damaged forest and planting.

The EEC will introduce import restrictions in order to protect the forest sector. Some countries will stimulate export. Western Europe will introduce laws against price dumping from Eastern Europe.

The traditional trade pattern will be changed. The Scandinavian countries must look for new markets. The same is true for Canada and the USA. The price decrease will make it very difficult to compete on the European market.

The Swedish saw milling industry has to decrease its production with 3-4 million m^3. The profit level will decline dramatically . Many sawmills will become bankrupt. At least one quarter of the sawmilling capacity will disappear within one decade. Due to low European roundwood prices some saw mills and above all the pulp industry increase their import. The domestic cuttings and prices will be reduced due to this and decreased production. Thinnings will be neglected. The inventory of standing timber will increase and get more and more mature.

In Europe new forests will be planted after the die back period. However, the structure of the future forests will be different from what we are used to. More broad leaf trees will be found and the non industrial production will increase. This implies in the long run a second phase of industrial changes with new processing technology.

4 CONCERNED INTEREST GROUPS

Dying forests will create a number of problems in the Swedish forest sector:

- The forest product industry

Increased supply in Central Europe of wood raw material due to dying forests will probably cause a price drop. Supply will become more and more inelastic in the short run, and on a medium term basis this will give the continental forest industry a competitive advantage compared with Scandinavia. The continental production capacity will increase while the Scandinavian capacity utilization will be low. Bankrupts will follow. The shareholders will lose their money.

For those companies surviving limited investment possibilities compared with the competitors will cause difficulties to introduce new technology. This will gradually affect efficiency and production costs. The disadvantage of limited investment possibilities will be more and more obvious the quicker the technological development. A slower technological development will reverse the picture. The same is true if the consumption of forest industrial products stagnate.

However, if big parts of the European forest dies while Scandinavia is affected only to a limited extent the prices of forest industrial products can in the long run be expected to increase substantially and also the profit for the surviving part of the Scandinavian forest sector.

- Workers

Increased forest die back in Central Europe followed by increased production capacity will quite certainly affect employment of the Swedish forest sector on a medium term basis. On the other hand intensive Swedish forest management activities for avoiding the negative effects of air polution will create some jobs.

- Communities

Rural communities will be affected by the forest die back because the number of production units will decline.

- Society

The latest Swedish governmental long term plan puts its hopes to the exporting sectors. To a large extent the expected increase of the production capacity is supposed to be based on exports. Engineering, forest and chemical industry are together estimated to contribute with 70 per cent of the expected export growth. It is necessary that export of forest industry products increase with at least 2.1 per cent per year if the aim, balance of payments at the end of the 1990's, is to be achived. As a comparison it can be mentioned that the forest industrial export increased by 1.7 per cent as an average during the 1970's.

In view of the difficulties which the four interest groups of the forest sector mentioned above are facing they have a common interest in avoiding the possible negative effects of air pollution and increased forest die back. The solution for the interest groups is to find international and domestic strategies for stopping and avoiding the negative effects of forest die back.

5 POLICIES FOR REDUCING AIR POLLUTION AND FOREST DAMAGE

When talking about forest damage it is important to include air pollution in general and not only acid rain. The system is very complex. Knowledge is lacking and uncertainty exists about how quickly the system is changing. However, in the long run the system cannot for sure stand changes in the biological base. It is necessary for governments and interest groups of the forest sector to decide what policies to follow (Table 3) (Schotte, 1985).
(1) It is essential to require intense counter measures at the emission sources. International cooperation is needed. (2) But it is also important to adapt the silvicultural methods to the situation. Adaption of site activities will be a key word. The silvicultural activities must be characterized by high quality forest management, forest hygiene and soil treatment. (3) More research about the biological system and the forest damage is needed.

(1) Reduction of the emissions

With high international priority it is important to continue the worldwide

Table 3. Policies for reducing air pollution and forest damage.

REDUCTION OF OUTLET
- Adjustment of industrial processes
- Use of fuel with low contents of sulphur and nitrogen
- Cleaning
- Lead free gasoline
- International cooperation
- East-west contacts

SILVICULTURAL ACTIVITIES
- Leave needles and branches
- Liming
- Fertilization
- Selection of type of tree
- Genetics

RESEARCH AND DEVELOPMENT
- Support to ongoing research about air pollution and forest damage
- Research about quality of damaged trees
- Research about the whole ecological-economical system
- Data collection and supervision
- International cooperation

ongoing work to reduce the emissions. The convention about remote sources of air pollution crossing borders under the protection of the ECE (Economic Commission for Europe) has been signed by 33 countries and the EEC as an organisation (op cit). 20 countries have promised to reduce the sulphur emissions by 30 per cent before 1993. Some countries are prepared to go even further.

One most important question is to reduce the nitroc oxide emissions. Formation of ozone is caused by nitroc oxide emissions. The EEC commission suggested at the turn of the year 1983/1984 a program for substantial reduction of sulphur dioxide and nitroc oxides emissions from incinerators. This could be done through an adjustment of the process of combustion. Oil refineries could use so called hydrotreatment. Another possibility is to use fuel with low contents of sulphur and nitrogen. In addition several methods exist to clear flue gas from nitroc oxide. Also the emissions from the industrial processes must be reduced. This is particularly true for the forest, chemical and metallurgic industries. The industries could adjust their processes and introduce the measures mentioned above.

Suggestions about leadfree gasoline and a certain tightening up of the requirements on exhaust cleaning have also been presented - however, up till now without any definite decisions. From this point of view exhausts from cars are of great importance. The FRG gives high attention to this type of pollution. It is uncertain how far it is possible to reach in the convention mentioned above. Thus it is important to establish international cooperation about exhausts from cars. Sufficient scientific base exists for judging exhausts from cars as being the perhaps most serious emissions source.

Cleaning technique already exists! It is possible to produce leadfree gasoline! A delay is irresponsible!

It is important with a broad and covering international support of actions against air pollution. It is important that the Eastern European countries constitute a part of this international cooperation, because the emissions in some of those countries are quite substantial. An east-west cooperation is important. Scientific academies and international research organisations play an important role when aiming at reaching the correct scientific level and crucial links to influential decision makers.

The FAO (Food and Agricultural Organization of the United Nations) European Forestry Commission has continously devoted attention to the forest damage question through its working party "Impact of Air Pollution on Forests" since a discussion in Innsbruch in March 1982 (op cit). The FRG and Sweden strongly supported a treatment of the question.

(2) Silvicultural activities

Silvicultural activities as policies for reducing forest damage are of importance as complement to reduction of the emissions. When utilizing a whole tree system it is important to separate the needles and leave them on the ground. If branches and needles are taken away the soil lose important minirals and organic matter which causes a reduction of resistance against air pollution. But it is also possible to compensate for this through liming and fertilization.

Selection of tree species is also of importance. The birch litter has higher nutrient contents and quicker decay. But, it is important to realize that it is not realistic to change the share of broad leaf trees generally because of the high economic value of the conifer production. But broad leaf trees could be planted in delicate areas, exposed sites, edges of woods or as protection. Even if the effect is a long term one genetics could be used as a complement to selection of tree species for developing resistant trees.

Moreover, as mentioned, it is important to adapt the fertilization. In areas with much nitrogen, a combination with liming and reduced fertilization could be used.

(3) Research and development

Research and development concerning the biological system and air pollution goes on in many countries. Research groups in different countries collaborate - the problem is, as has been stated, of international nature.

Furthermore, contacts are developed between and within international organizations. International organizations concerned with air pollution and forest damage are IIASA (International Institute for Applied Systems Analyses), IUFRO (International Union of Forestry Research Organization) and UNESCO (United Nations Conference, Scientific and Cultural Organization).

However, missing today is projects showing possible consequences in the short and long term of the forest damage on economy, competition, market and production capacity. The short run situation can be increased air pollution, forest damage and forced cuttings, while the long run situation hopefully will be decreased pollution and damage but also decreased possibilities of cuttings because of limited wood resources. ECE Timber Committee has during the spring established a special group with the purpose of studying the effects of forest damage on supply of wood raw material and the markets of forest industrial products, specially saw timber. Twelve countries have up till now announced their willingness to participate in the work of the group. This group as well as IIASA would benefit if IIASA would establish a project dealing with the consequences of forest die back on international trade and structural changes of national forest sectors. IIASA has knowledge about the topic through the Forest Sector Project and the Environmental Program.

Projects exist concerning the quality of damaged wood and its suitability as raw material for the industry. Possible qualitative changes are of importance concerning the usefulness of wood for the industrial processes. The preserved degree of moisture of damaged wood seems to be of determining importance.

Another important area is data collection and supervision of the situation. Statistics are needed about the development of air pollution (above all nitroc oxide and ozone) and forest damage.

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4.2.5 MODELLING RESOURCE DYNAMICS AND FOREST DIE-OFF

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A characteristic feature of the forests in Bulgaria is the great variety in site conditions, structures, productivity and stand management methods.

The forestry in this country has strongly suffered from human activity for many years. After the Second World War the fully deforested and eroded forest areas covered about 800 000 ha /21,0%/ and the destroyed forests with reduced wood-producing and special functions have spread over 30 300 000 ha /8,0%/. The area of the coniferous forests has be been reduced to 11,3% and about 60% of the broadleaved forests have been coppice woods in a bad condition and with secondary forest species in composition. The average growing stock of the forests amounted about 70m^3/ha and the mean annual increment - about 2m^3/ha.

During the period after World War Two substantial structure changes occured in forestry along with the whole development of the country. In 1942 the forest area was distributed according to property to state forests-26%, community forests-55,0%, school forest 0,6%, monastery forests-1,0%, co-operative forests - 0,7% and private forests - 16,7% In 1975 the distribution of the forest area changed as follows: state forests 97,3%, forests belonging to the Agro-Industrial complexes 2,4% and forests belonging to other owners - 0,3%. The main task of forestry within this period was the increase of forest productivity and the improvement of their protective and water conservation functions. Afforestation and forest tending measures have been carried out on a large scale. The state forest condition in 1980 can be assessed after the values shown on Table 1.

Table 1. Indices values characterizing the forest condition 1980.

Indices	Values
1. Total forest area	3 743 123 ha
2. Afforested area	3 199 936 ha
incl:	
- coniferous forests	1058085 ha-33% Scotch pine 17% black pine 9%, Spruce 4% etc./
- broadleaved high forests	641 911 ha - 20%, beech 10% Oak 4% etc./
- reconstruction forests	650 092 ha -20%, Oak 8% oriental hornbeam 5% etc./
- coppice forests for conversion in seed woods	727 910 ha - 23%
- coppice forests /acacia/	96 751 ha - 3%
- poplar	251187 ha - 1%
3. Rated correlation of areas after age classesI:II:III:IV:V/VI-VII	39,6:28,5:10,0:8,1:6,0:7,8%
4. Mean age of forests	38 years
5.Mean density of forests	0,75%
6.Forests with special destination	25,9
7.Total growing stock	296 830thm^3
8.Growing stock per ha	92,8 m^3/ha
9.mean annual increment	7 620 thm^3
10.Mean annual increment per ha	2,38^3/ha
11. Total yield standing volume	5 907 thm^3
12.Yield volume per ha	1,85 m^3
13.Rate of yield from growing stock	2,20 %

Forest state improvement, productivity increase and effective use of the forest resources are the basic tasks in the future management of forests too.

The application of up-to-date methods of forestry management, the introduction of economic-mathematical optimation and other models, the wide use of computers have a great significance for the solving of these tasks. In this connection a a team of experts under Acad. Mako Dakov has been founded and has been working for several years on the elaboration of a overall forestry management model.

The work of this team has been considerably helped by using the results of the International Institute for Applied Systems Analysis /IIASA/. The systematical approach in creating the prototype models in IIASA, the opportunities they supply for the study of the forestry relations with other economy-branches are used in this country both in methodological aspect and for the determination of the strategy of the Bulgarian forestry policy.

The Model of the Forest Resources Dynamics appears as a base model elaborated in the frames of a complete forestry management model.

The Model of the Forest Resources Dynamics (MFRD) represents an automated method for processing a multiaspect information about the forest with the aim to characterize its states in future instances as related to the present conditions, the natural processes which take place in it and the policy of its future management. The model is realized in a dialogue regime by means of the APL programme language. As a basic calculating unit of the model appear the thre types distributed according to their characteristics in age classes.

I. Input of MFRD

Ia. Information Sources

Statistical account forms, models, information systems etc. serve as information sources for the determination of th e values of the input data for the model.

In the statistical account forms for the forest fund data are included for the distribution of areas and growing stocks of tree species, densities of tree vegetation and other data used immediately or after processing in the model.

In this year began the creation of a data bank for the state of the forest fund according to stands on hand of an automated system for processing forest management information. After introduction into practice of the data bank the information in it will be used in the model on the place of the data from the statistical account forms for the forest fund.

The directions of the strategic development of the forest sector are taken into account and above all the assesment of the kind and volume of future economic impacts on the forest. These directions have been determined after the analysis of the results from the models, as follows:

- models for the perfection of the organization and management structure of the branch, directed to the problems of concentration and specialization of production, territorial distribution of the production forces, improvement of the organization and management structure;

- the global model for an international trade with intermediate fellings;

- for the determination of the expected yeilds distribution by assortments;

-for the forest's social functions

The models for the impact of environmental pollution o n the forest give information about the degree and character of the damages on forest ecosystems caused by environmental pollution and forecast the development of this process. Besides these models elaborated for this purpose in our country it is also envisaged to use the IIASA works of the "Acid Rain Project".

IB Input Data

The input data of the model can be unified in the following directions:

- inventory - these are data for areas, growing stocks per ha and densities of forest trees by age classes in the initial moment of the prognosis period;

- for the future management impacts on the forest;

- the regeneration table ensures the passing of areas set free after final cutting or reconstruction from one tree species to another by biologic, ecologic and economic reasons;

- with the help of the afforestation vector the tree composition at the afforestation bare lands is determined;

- the part of the reconstruction forests, which has to be reconstructed is determined;

- the tables for the percentage of intermediate fellings by age classes are elaborated for three intervals of mean densities of the age classes /0,76-0,85; 0,86-0,95;0,96-1,00/;

timber and timber products has been elaborated in IIASA in co-operation with this country. The results received with this model orientate above all about the volumes and prices of import and export of timber products;

- the models for the consuming of timber and timber p products are multi-factor regression prognosis models, describing the amount of use of the separate forest products as a function of different factors, as amount of the national income etc.

-the models for the improvement of the production structure cover the object of the forestry activities, nomenclature and structure of the final production, structure changes in the sector etc.

- at studying interbranch relations use is made of results obtained both from models elaborated in Bulgaria and from the prototype model for the forest sector and its social economic and ecologic conditions, elaborated in IIASA.

The level of present and future security of the sector in the material, technical raw material, financial and personal aspect represent limiting conditions at the choice of one or other alternative in forest management.

The forest models describe the forest development caused by the natural processes going out of it. Some of these models are:

- for the growth and productivity of stands;

- echological models / choice of tree composition in conformity with nature, studies of the site conditions etc.

- for the optimal base area and the intensity of

- for calculating the final cutting are in the model are given seven alternatives.

- for the natural loosening of the forest - the data in the respective table are differentiated according to tree species relation to light;

- assortment structure of expected yeilds - it is determined by the percentage of large, middle-sized and small timber, fire and waste eood conten according to age and assortment class of the standing volume of the tree species envisaged to be felled;

- organization data;
- number of species
- number of age classes
- years in the age class
- initial year of prognosis
- years in the prognosis cycle
- number of prognosis cycles
- number of afforestation cycles
- number of cycles at performing of reconstruction

- for the losses caused by environmental pollution - they are expressed in percentages by tree species and classes. With the aid of these percentages the respective growing stocks per ha are reduced.

II. Processing of information in MFRD

The processing of input data is realized with a model which reflects the aging of the forest /passing of areas, resp. growing stocks from one age class to another/, the growth trend of the forest /the increase of growing stocks with the increase of age/ and the management impacts on the forest.

The actualization of areas and growing stocks per ha of tree species by age classes at the end of every prognosis cycle are the basic moments in the model.

The actualization of areas occurs by removing the areas of all age classes in the next classes on the right. Before the removal the area of final fellings /reconstructions/, which are included in the first class of age along with the afforestation areas is reduced.

The actual growing stocks per ha for the age classes are calculated as a product of normal growing stocks of the respective age classes /at density 1,0/ with their actual density. The normal growing stock per ha are the product of the growing stocks per ha with their present density. The actual density is the density of the preceeding class of age reduced by the percentage of the natural loosening of the forest.

A great number of other processings, which contribute to receive information characterizing in many aspects the state of forest fund both in the separate prognosis cycle and for the whole prognosis period, are performed through the model.

III. Output of MFRD

III.A. Output Documents.

The output documents as a result of the model operation show the indices and their values characterizing the state of the forest fund.

Fifteen documents for every prognosis cycle can be received by choice through MFRD:

- distributions /tables/ by tree species and age classes
- afforested area
- age structure
- growing stock
- growing stock per ha
- densities
- mean increment
- area for final fellings
- yield volume from final fellings
- yield volume from intermediate fellings
- total yield volume
- current increment
- analytic characteristics by tree species
- share percentage of tree species by area and growing stock
- mean age
- mean annual increment per ha and % from the growing stock
- percentages of yield volume from the growing stock and from the current increment
- assortment structure of yield by tree species
- yield from final fellings
- yield from intermediate fellings
- for the total yield volume

Output documents can be received for the change of values during the whole prognosis period of all indices, which give an information for every prognosis cycle.

IIIB.Application Field of Model Results

The application field of model results is large.

Various policies of forest resource management can be simulated through the model. The expedience of policies can be determined after the analysis of the forest state caused by the same policies.

In 1986 an actual prognosis for the development of the forest resources in Bulgaria shall be elaborated depending on specified concepts for forest management and after analysis of a great number of scenarios studied through the model.

Data for the development of the forest resources and for the expected raw wood materials are received through the model. The forecast of wood yields has a great information significance by the planning both of the forest industrial production and of the activity of the remaining timber and timber products consumers.

Information for different aggregates of stands can be processed by the model. It is envisaged for the model to be introduced separately for the forests of fifteen territorially differentiated forest industrial combinates in this country. This will help at the determination of the territorial distribution of the production forces both in the sector and in the country.

4.2.6 SUCCESSION, PRODUCTIVITY AND STABILITY OF NATURAL AND ARTIFICIAL FOREST ECOSYSTEMS

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1. Introduction

All forest ecosystems, natural as well as artificial, are subjected to a steady dynamics, which results from changes in the environment caused by reactions of the biocoenosis on the site and different growth strategies of the various tree species. Besides change of the species spectrum and species richness this dynamics is obvious above all in the extent of the net primary productivity quantity of dead organic matter being currently eliminated from the life process, balance between these two counteracting processes, accumulation of living and dead organic matter as well as decomposition of detritus.

The knowledge of these processes is of interest not only theoretically for forest ecology but also practically for silviculture, in order to utilize these natural processes in forestry. In view of the dwindling of fossil energy carriers this point of view wins more and more in importance. Therefore, one of the main tasks of modern silviculture is to practice forest production in forested ecosystems, which demand a minimum of additional energy.

During the past decades much work has been done dealing with the dynamics of forested ecosystems not only in Europe but also in Northern America. In this connection let us remind above all the primeval forest research the voluminous work dealing with organic matter production of forested ecosystems, and the investigations research on forest succession (see WEST, SHUGART and BOTKIN 1981).

These papers gave impetus to analyze the organic matter production in the Central European forests in the course of their succession. However, on behalf of the lack of data on the total biomass production numerous assumptions had to be made. For this reason the following considerations were confined to the above-ground wood substance, for which corresponding tables are available.

2. Modelling

The normal case of a forest succession takes place, if the firs forest generation consists of one or several pioneer tree species, which are later followed by climax tree species (fig. 1). This is attributed to considerable differences with regard to site requirements and growth strategy of these two groups of tree species, between which there are transitions, of course.[1)]

The pioneer tree species distinguish themselves by:

a) ecological demands
   - resistance against extreme meteorological influences in open space (frost and heat, wetness and dryness)
   - low demands to soil (capability of colonizing virgin soils)
   - high light requirements

b) ontogenesis and growth strategy
   - rapid juvenile growth, early culmination of increment and afterwards rapid decline in growth
   - early, frequent and rich fructification, often anemochory
   - short life expectancy.

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1) In figure 1 the viewpoints explained in this paper have already been taken into consideration.

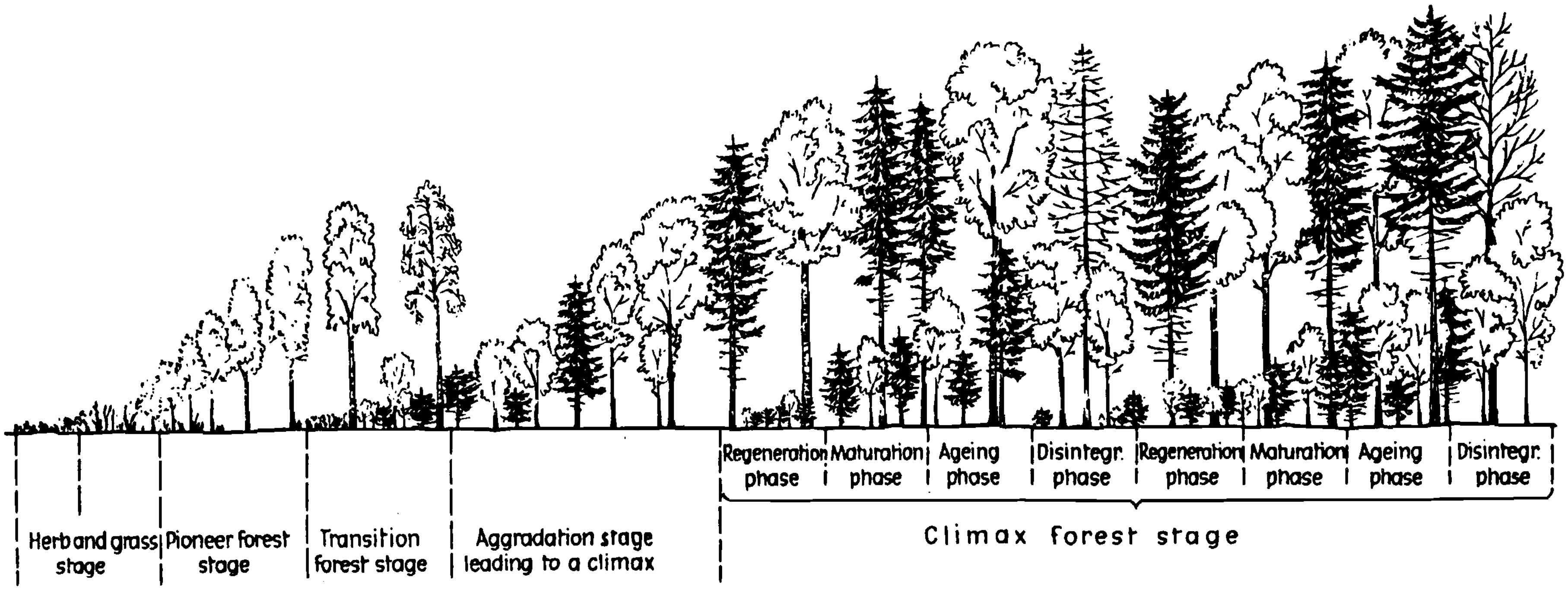

Fig. 1 Proccess of development of a secondary succession (a modivied version of ODUM 1980 and BURSCHEL 1982)

In the contrast climax tree species distinguish themselves by:

a) ecological demands
   - susceptibility to extreme meteorological influences in open space
   - higher demands to soil condition (humous forest soils)

b) ontogenesis and growth strategy
   - slow juvenile growth, late culmination of the current increment and long-lasting increment afterwards
   - late, less frequent and mostly also less fructifikation, often zoochory
   - greater life expectancy.

These two ecological and ontogenetical tree species groups are well represented by birch (Betula verrucosa EHRH., fig. 2) and beech (Fagus silvatica L., fig. 3).

In figure 2 a the current annual increment P'(t) of the above-ground wood substance of birch is presented. This curve is based upon values taken from the yield table by TJURIN (1956), first site class, which were supplemented and equalized up to 100 years with the aid of the growth function by RICHARDS (1959).[1]

From the increment values P'(t) one has to deduct the dead wood substance E'(t), which is annually eliminated from the life process. As no grounded values are available for this, an estimate had to be made, which is based upon the following hypotheses:

- If there are no anthropogenous influences, then the living biomass produced by the generation of pioneer trees until their end of life must be equal to the biomass eliminated during the entire life process, i. e. $P \approx E$.

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1) $P = P_{max} (1-c_1 \exp(-c_2 t))^{c_3}$

$P' = P_{max} c_1 c_2 c_3 \exp(-c_2 t) \cdot (1-c_1 \exp(-c_2 t))^{c_3-1}$

with $P_{max} = 7.15\ m^3/ha$ $c_1 = 0,999$
$c_2 = 0,258$
$c_3 = 1,594$

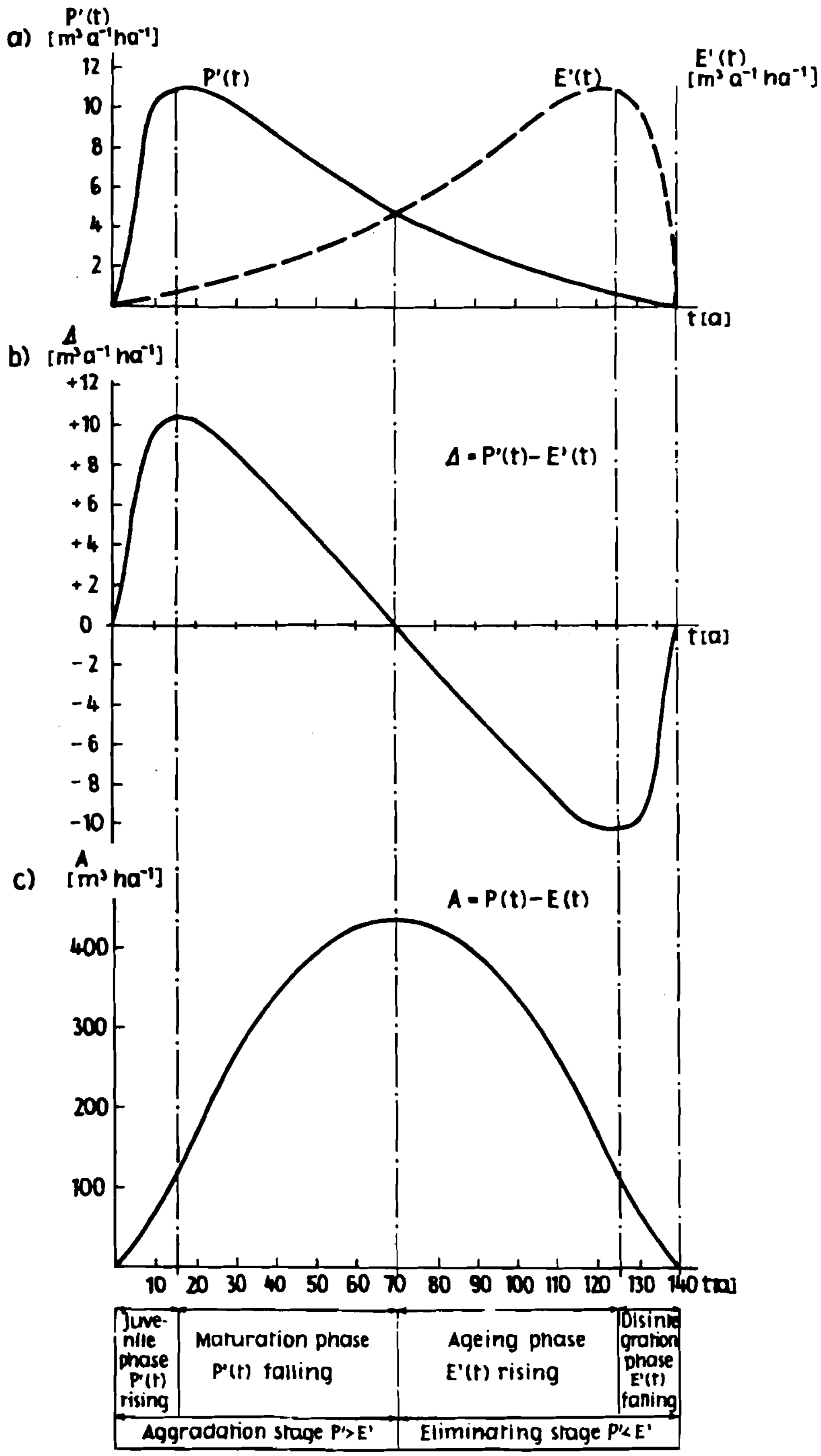

FIG. 2 Full tree increment P'(t), dendromass (full tree) eliminated during the crop development, balance Δ = P'(t) - E'(t) and accumulation of dendromass (full tree) A = P(t) - E(t) with birch (Betula verrucosa EHRH.) The curves are based upon the values

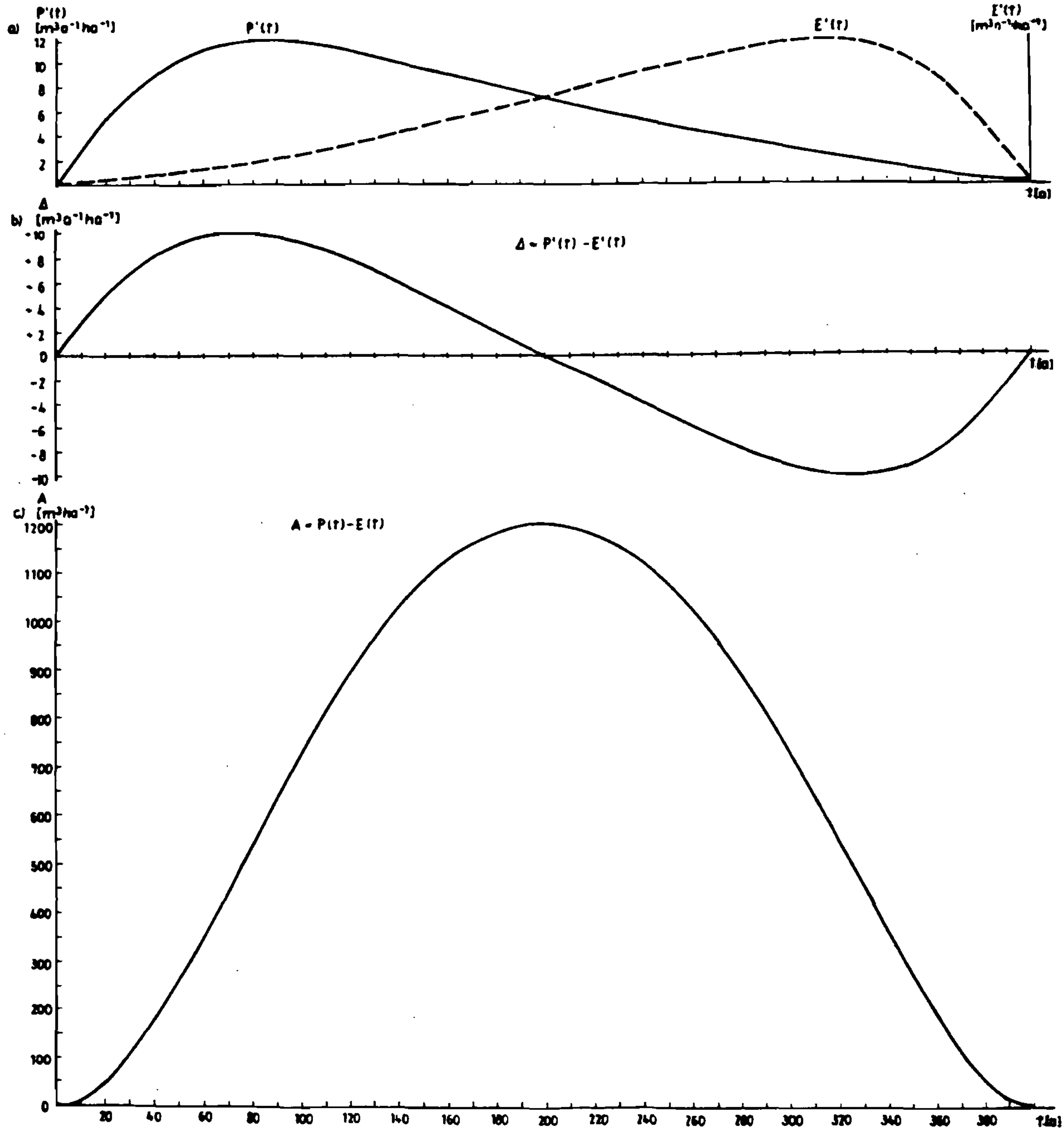

Fig. 3 Full tree increment P'(t), dendromass full tree eliminated during crop development, balance $\Delta = P'(t) - E'(t)$ and accumulation of dendromass $A = P(t) - E(t)$ with beech *Fagus silvatica* L. The curves are based upon values of a yield table constructed by the Eberswalde Institute for Forest Sciences in 1983, mean site index $H6_{100} = 28$ metres, which has been supplemented and equialized with the aid of the growth function by RICHARDS.
As life expectancy $t_m = 400$ years was stipulated

- Between the producing $P'(t)$ and eliminating processes $E'(t)$ there is a certain counteraction: The rapid increment increase in the juvenile phase and slow increment decline at high age is opposed to low elimination of living substance in the juvenile phase and high elimination at old age.
- Taking these two hypotheses into consideration it is assumed that the curve for elimination $E'(t)$ runs nearly as a reflected image to that of the production $P'(t)$, i. e. $E'(t) \approx P'(t_m - t)$, whereby $t_m = 140$ a designates the life expectancy of the pioneer tree species generation.

With the aid of this assumption one receives the curve shown in figure 2 a.

The balance Δ between $P'(t)$ and $E'(t)$ is depicted in figure 2 b. After integration one receives the curve for accumulation of living above-ground wood substance $A = P(t) - E(t)$ (fig. 2 c.).

When considering the curves for organic matter production of a pioneer forest generation alone, it is possible to subdivide this process into several developmental phases. Before the culmination point of the accumulation curve one can speak of an aggrading stage, afterwards of an eliminating stage. Within the aggrading stage a difference must be made between a juvenile or initial phase and a maturation or maturity phase. Accordingly, the eliminating phase should be differentiated into a ageing and elimination phase. However, both play scarcely any role, because at this time already immigration of climax tree species occurs.

In an analogous manner the growth process of a beech generation is shown in figure 3. In this connection, however, it should be borne in mind that the juvenile development of this climax tree species normally takes place under the canopy of a pioneer forest or an older beech forest generation. The values of the curve $P'(t)$ drawn in figure 3 a are based on the yield table constructed by the Eberswalde Institute for Forest Sciences with the height of the mean basal area $H_G = 28$ m at an age of 400 years. They were supplemented and also equalized up to 250 years with the growth function by RICHARDS (1959) according to the following parameter values:

$$P_{max} = 2712 \quad m^3/ha$$
$$c_1 = 1,0$$
$$c_2 = 0,08945$$
$$c_3 = 2,1681 \; .$$

In estimating the eliminated living above-ground wood substance $E'(t)$ the procedure was that as applied in the case of birch, t_m being stipulated with 400 years. The balance $\Delta = P'(t) - E'(t)$ is shown in figure 3 b and the accumulation $A = P(t) - E(t)$ in figure 3 c.

The different growth strategy of the pioneer and climax tree species can clearly be seen in the figures 2 and 3. Between these two representatives larch, pine and spruce have to be arranged as transitions. However, they little change the here discussed principle of modelling or simulating forest successions.

The next step in our modelling consists in side-by-side arrangment and superposition of growth processes of pioneer and climax tree species. Here, first of all the question arises at which time the pioneer forest generation will be imbued with the following generation. In good approximation one can apply the intersection point of the curves $P'(t)$ and $E'(t)$ for this, because together with the progressing elimination of trees gaps develop in the canopy, light reaches the ground and thus the prerequisites for emergence and continued life of the regeneration are provided. This applies particulary to climax tree species, which distinguish themselves by low light requirements in the juvenile phase. It is a matter of course that one has to reckon here with a wide variation, because not only the site quality but also the compensation point of the tree species give impetus to modifications.

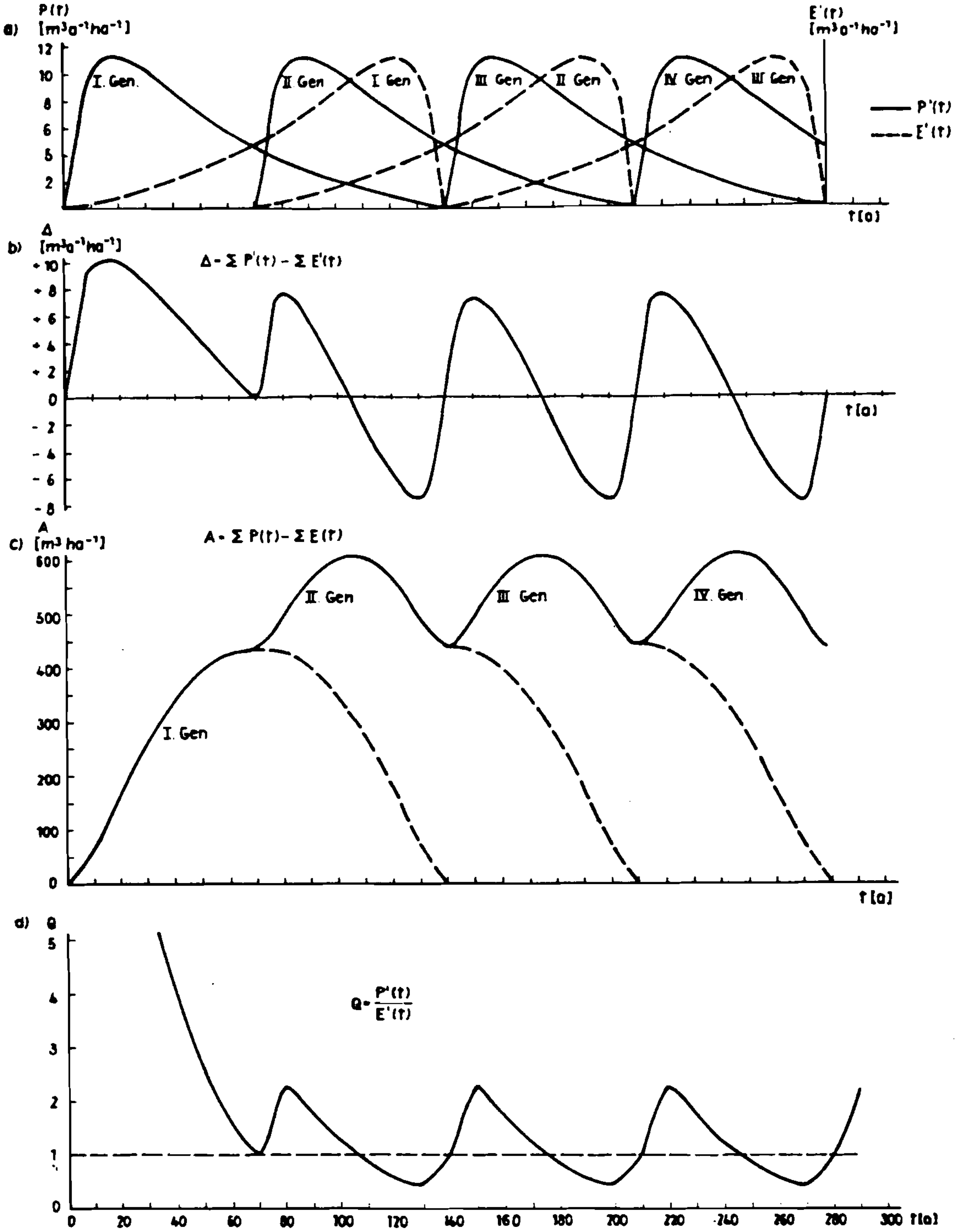

Fig. 4 Simulation of the succession on an extreme site, where birch is simultaneously a pioneer and climax tree species (P-P succession)
a) overlapping of the increment and elimination curves of several birch forest generations
b) balance Δ between increment P'(t) and elimination E'(t)
c) accumulation of dendromass (full tree) $A = \Sigma P(t) - \Sigma E(t)$
d) ratio of increment and elimination $Q = P'(t) / E'(t)$

For the sake of simplicity it is intended first to arrange one above the other several generations of the pioneer tree species birch. This case of a P-P-succession is also relevant in practice, as this tree species can be a pioneer species just as a climax tree species on extreme climatic and edaphic sites, for instance on poor wet and peat soils. In this case one receives the succession course shown in figure 4. In figure 4 a the opposing curves of $P'(t)$ and $E'(t)$ are represented. The commencement of regeneration being given with $P'(t) = E'(t)$. In figure 4 b the balance $\Delta = \sum P'(t) - \sum E'(t)$ and in figure 4 c the accumulation $A = \sum P(t) - \sum E(t)$ are represented. The course of the ratio $P'(t)/E'(t)$ considered above all by ODUM (1980) as an indicator of the maturity of an ecosystem is depicted in figure 4 d.

From these simulations we conclude that in forest successions, in which the stages following the pioneer forest stage also consist of pioneer tree species, relatively large fluctuations of the organic matter balance and organic matter accumulation occur so that only restrictedly one can speak of a state of equilibrium. This applies also to cases, in which the time of regeneration is supposed for a later term.

The typical case for Central Europe is the replacement of an pioneer tree species, for instance replacement of birch by climax tree species, such as beech, fir or spruce. We simulate such a P-K-succession in figure 5. In this connection the regeneration start of beech is assumed for the 70-year-old pioneer forest proceeding from the aggradation to the disintegration phase. In our example regeneration of the second beech generation (K-K-succession) starts after 200 years under the canopy of the first beech generation at a time when the latter proceeds from the aggradation to the disintegration phase.

Figure 5 a shows the curves of $P'(t)$ and $E'(t)$ of the various overlapping forest generations. In figure 5 b the balance $\Delta = \sum P'(t) - \sum E'(t)$ and in figure 5 c the accumulation

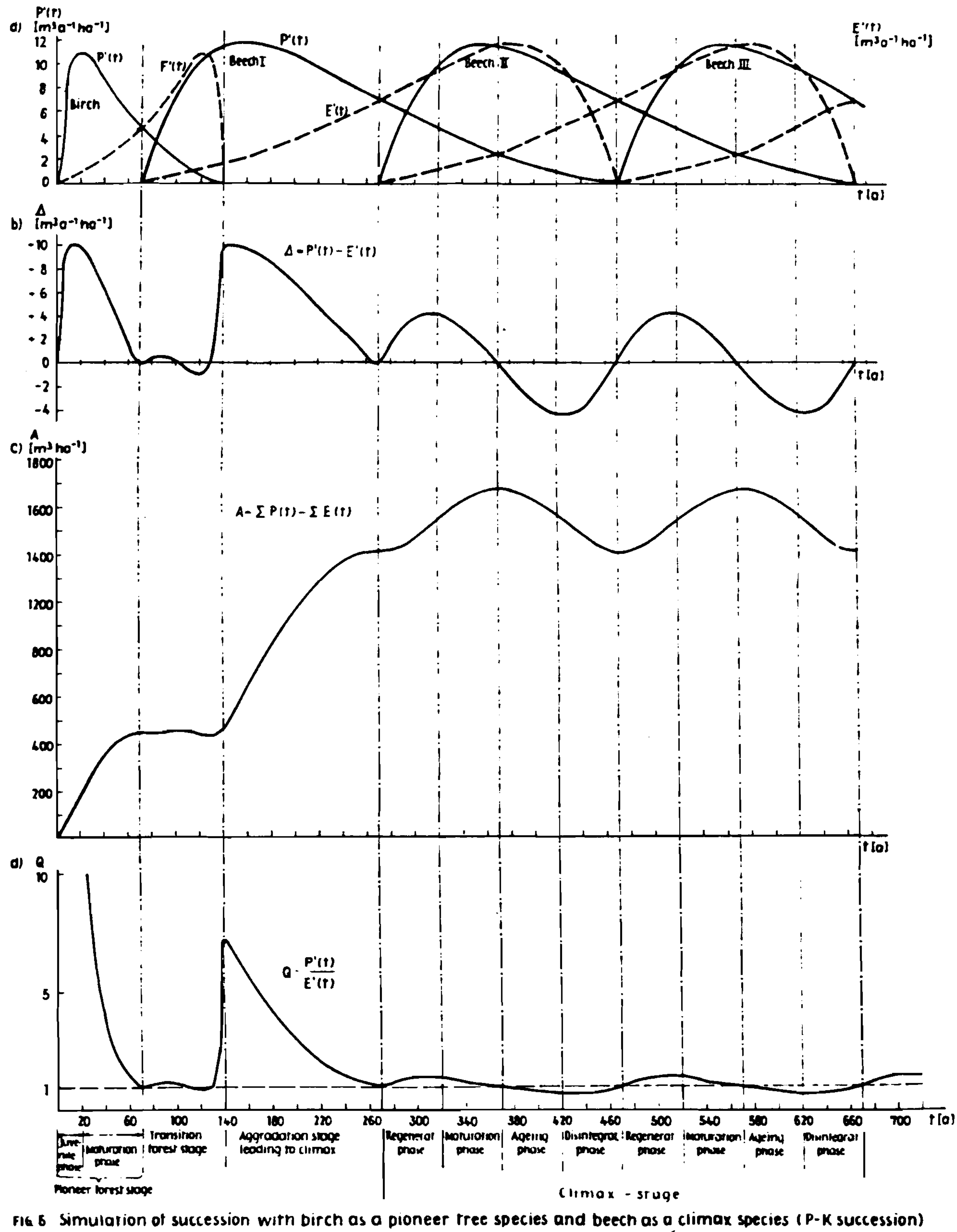

FIG. 6 Simulation of succession with birch as a pioneer tree species and beech as a climax species (P-K succession)

$A = \sum P(t) - \sum E(t)$ are represented. In this context it becomes obvious that this P-K-succession takes place over a pioneer forest stage, a transition forest stage and an aggradation stage up to climax.

One can speak of a climax stage only, if a corresponding accumulation level is reached and a dynamic state of equilibrium has been atteined. In the given example this is achieved only after the regeneration start of the second climax generation.

Within the climax the production and accumulation values oscillate around a mean value. This oscillation permits to differentiate the climax into regeneration, maturation, ageing and disintegration phases.

Generally based on the demonstrated normal model of a P-K-succession the following intervals can be distinguished (fig. 6):

1. Pioneer forest stage
   forest is formed only by pioneer tree species

1.1. Juvenile phase
   - organic matter balance $\Delta = P'(t) - E'(t)$ is positive and rising
   - accumulation $A = P(t) - E(t)$ of living dendromass is positive and rising

1.2. Maturation phase
   - organic matter balance is positive and falling
   - accumulation of living dendromass is positive and rising

2. Transition forest stage
   the upper tree layer consists of pioneer tree species, the lower of climax tree species
   - organic matter balance can be positive or negative and rising or falling
   - accumulation can be positive or negative and rising or falling

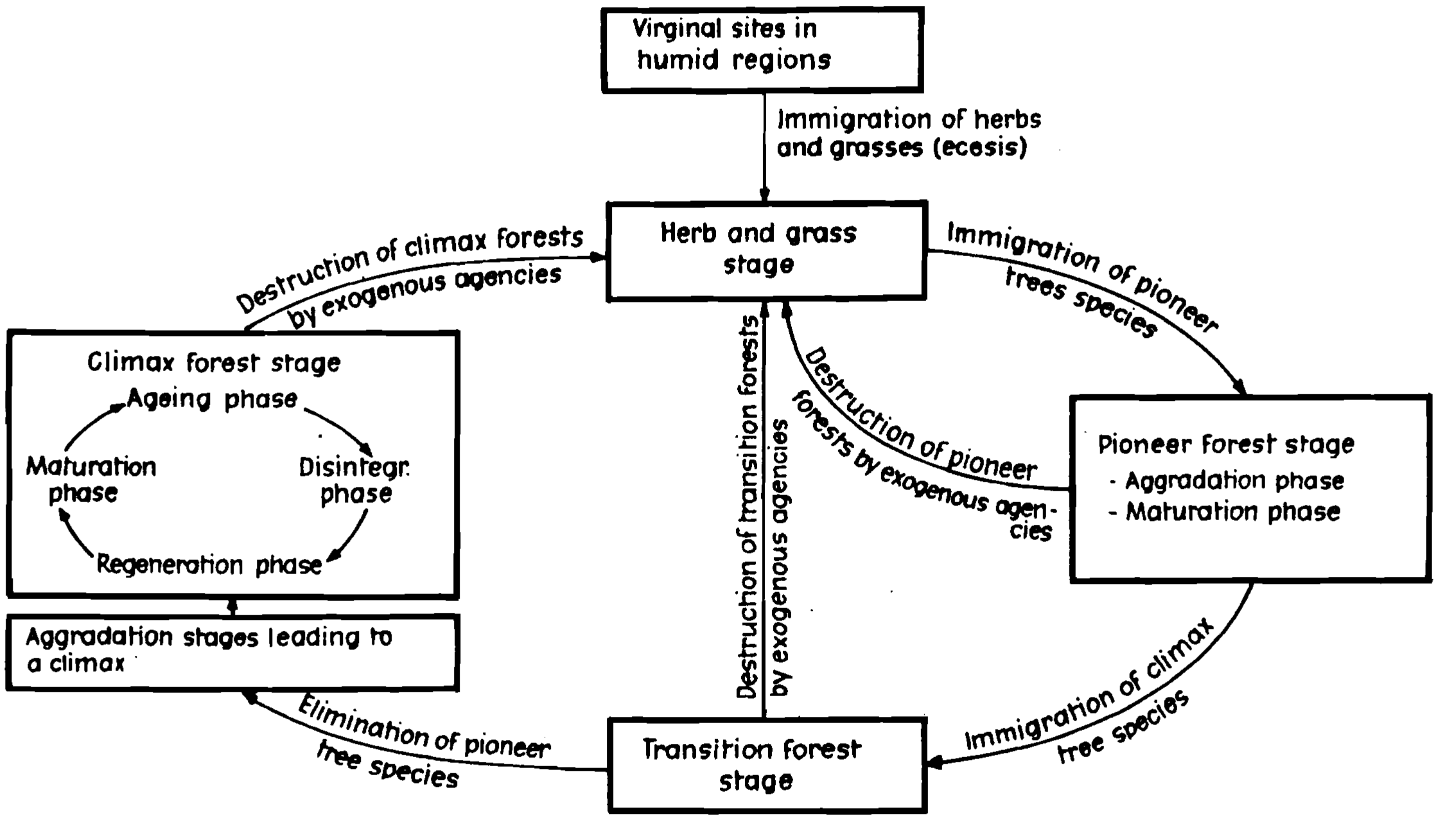

Fig. 6 Stages and phases in the succession of forested ecosystems

3. Aggradation stage leading to climax
nearly one-storied forest consisting of climax tree species, the age of trees is little differentiated
- organic matter balance is positive, at first rising, later falling
- accumulation is rising

4. Climax stage
multi-storied, uneven-aged forest consisting of climax tree species

4.1. Regeneration phase
- beginning regeneration of the second or higher climax generation in gaps, which are the result of the elimination of older trees of the preceding generations
- organic matter balance is positiv and rising
- accumulation is rising

4.2. Maturation phase
- regeneration of the second or higher climax generation enters the high-increment phase after having received more light in consequence of the elimination of older trees of the preceding generation
- organic matter balance is positive, but falling
- accumulation is rising to the absolute maximum

4.3. Ageing phase
The increment of the older generation strongly decreases
- organic matter balance is negative and falling
- accumulation is falling

4.4. Disintegration phase
- the trees of the older generation die off
- organic matter balance is negativ and falling
- accumulation falls to the lowest value.

The here described normal model of forest succession is in good conformity with the observations made in nature. Modification occur, if regeneration sets in earlier or later. The former can happen, if the site is very fertile and/or the light requirements of the regenerating tree species are very low, the latter can happen, if the site is unfavourable and/or light requirements of the tree species in question are high.

Further modifications are caused by the occurrence of several tree species. This leads more and more to an obliteration of the differences in time and space, which are still obvious in the presented model, and finally to a "shifting mosaic steady state" as in detail described by BORMANN and LIKENS (1979). After these model analyses one can say that depending on site and tree species the forest succession can take a very different course. However, in spite of all diversity it is possible to record and describe them with the aid of methods of system analysis.

3. Dynamics of development in managed forests

After the hitherto made observations on the dynamics of natural forest ecosystems the question arises how to make use of these natural processes in managed forests and which dynamics lies at the bottom of man-made forests.

In the case of close-to-nature managed forests, which have in part developed from natural forest ecosystems, but partly also by long-term selection cuttings the ageing process of indivual trees and the development of an ageing phase are anticipated by corresponding single-tree logging. In this way a state is reached oscillating between the regeneration and maturation phase of the climax forest. Due to this elimination of the ageing and disintegration phase the stock of dendromass is reduced to a lower level, the regeneration cycle shortened (fig. 7) and the rotation frequency raised.

Quite another situation occurs in artificial forest ecosystems, which need a by far larger quantity of additional energy for their establishment, tending and protection. This is demonstrated exemplfied by an evenaged spruce model stand of mean productivity (second quality class according to ASSMANN and FRANZ (1963)), managed in a system of cutting by compartments (THOMASIUS, FIEDLER and PRIEN 1984) (fig. 8).

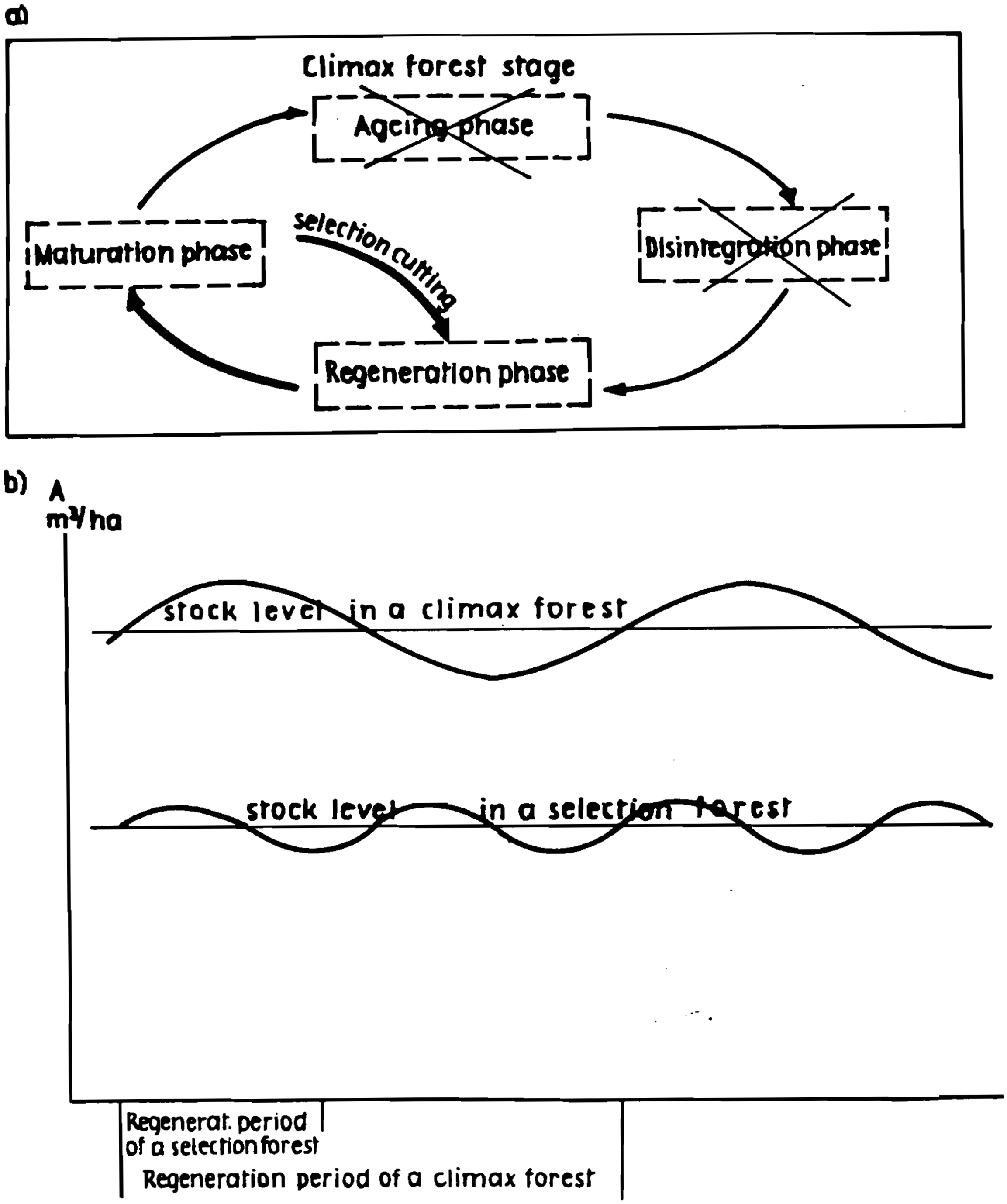

FIG. 7 Modification of the natural dynamics as a result of selection cutting
a) elimination of the ageing and disintegration phases
b) decline of the stock level and shortening of the regeneration period

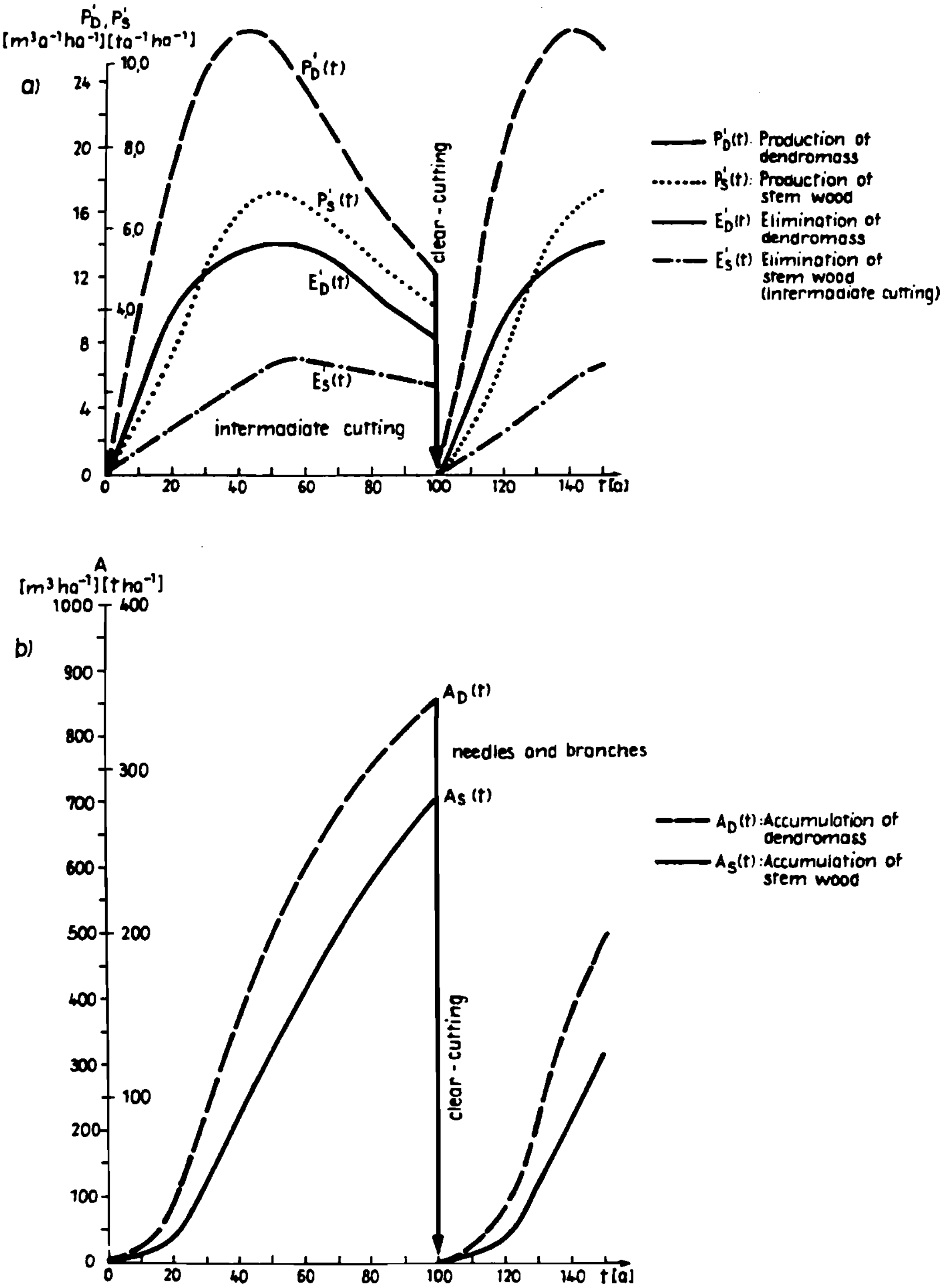

FIG.8: Production, elimination and accumulation of the above-ground dendromass and stem wood of even-aged spruce stands with mean productivity
(in support of the data by ASSMANN and FRANZ 1963, spruce M32 as well as BLOSSFELD, FIEDLER, NEBE, WIENHAUS 1978)
a) production and elimination of above-ground dendromass ($P'_D(t)$, $E'_D(t)$ and stem wood ($P_S(t)$, $E'_S(t)$)
b) accumulation of above-ground dendromass and stem wood ($A_D(t)$, $A_S(t)$)

Figure 8 a shows the production $P'_D(t)$ as well as elimination $E'(t)$ of above-ground dendromass and stem wood S as well as the striking reduction by clear-cutting at an age of 100 years. In figure 8 b the accumulation of dendromass $A_D(t)$ and stem wood $A_S(t)$ is shown.

From the integration of full-tree and stem wood increment $P'_D(t)$ and $P'_S(t)$ and their difference to full-tree and stem wood accumulation $A_D(t)$ and $A_S(t)$ one can infer on self-thinning dendromass $E_D(t)$ and $E_S(t)$. In this connection the stem wood is cut in thinnings, while the residual dendromass remains in the forest just as in the conventional felling methods. It serves as the most importent source of energy supply for the edaphon.

The further transformation of this dead organic matter is shown in figure 9. In the upper part of the drawing (fig. 9 a) the full line describes the supply of detritus. In addition to this there is the organic matter annually produced by herbs and grasses (dotted line). These assets are contrasted with the decomposition of detritus by decomposers (dashed line).

In figure 9 b the quantity of dead organic matter accumulated above ground during stand development is shown.

From these figures one can see that in the clear-cutting system the organic matter balance is to a large extent non-equalized and there is no component permitting to speak of a state of equilibrium. In this connection the following remarks to be underlined:

1. By cutting the old stand the living dendromass and together with it also dendromass production is at one stroke reduced to zero.
2. The stem wood is almost completely removed from the dendromass and the latter thus becomes deprived of the possibility of being decomposed in situ. Due to the relatively low mineral content of wood only small quantities of minerals are removed.

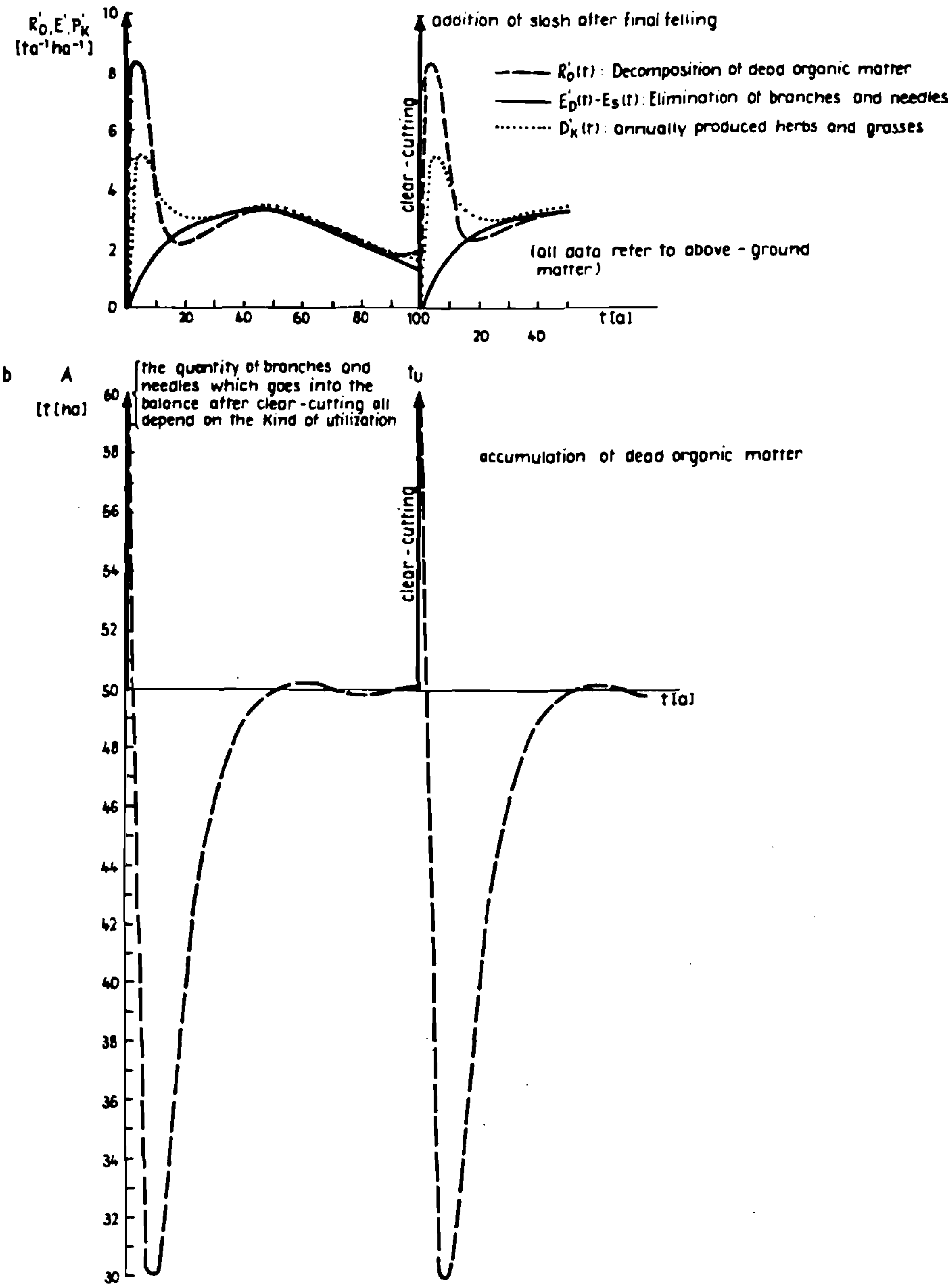

FIG. 9 Detritus production, detritus decomposition and accumulation of organic matter (above-ground) during the life course of a spruce stand with mean productivity and managed in the clear-cutting system (in support of the values by ASSMANN / FRANZ 1963, BLOSSFELD, FIEDLER and NEBE 1978)

a) supply of dead organic matter stemming from branchwood and needles (full line) as well as grasses and herbs (dotted line) and decline of the dead organic matter by decomposition (dashed line)

b) above-ground accumulation of dead organic matter

3. In the conventional types of felling a high proportion of the residual dendromass, which distinguishes itself by far larger content of minerals, remains on the site. The height of the peaks resulting from the supply of slash depends on the type of felling. In spruce stands it can amount from 5 to 50 t/ha, In the here demonstrated example 10 t/ha were assumed corresponding to a supply of two thirds of the residual dendromass for utilization purposes.
4. In the case of whole-tree utilization the energy source for the decomposers is strongly throttled due to the removal of the entire dendromass and consequently the feeding process of biogeochemical cycles is inhibited. It must be clarified to which extent this removal can be practised on the different sites without essentially lowering soil fertility.
5. In consequence of the unshelteredness of the soil surface the decomposition process of the dead organic matter is considerably accelerated. As a result, the stock of litter and humus strongly decreases.
   This process is connected with an big loss of nutrients. These are the more subject to washing out the weaker the sorption power of soil is and the less mineral substances can be taken up by the ground plants. The washed-out mineral substances pass into groundwater and can lead to eutrophication problems in water management.
6. The nutrient losses are made good by the secondary succession with herbs, grasses and pioneer tree species, which take up larger quantities of mineral substances. This process should be regarded as an act of self-regulation important for maintaining soil fertility.
7. Contrary to the quickly efficient secondary succession the subsequent crop artificially established in the open space becomes effective very slowly and only after stand closure. Connected with this are a gradual suppression of the ground cover developed in the course of the secondary succession and a decrease in the humus decomposition process. The latter seems to be particularly well pronounced, if the edaphon has to shift from herb and grass nutrition to conifer litter.

8. The balance of organic matter decomposition and organic matter production by primary producers is settled again only after 10 to 20 years depending on the productivity of the felled area vegetation and subsequent.
9. Depending on the quantities of residual slash, productivity of felled-area vegetation and subsequent stocking as well as intensity of the process of organic matter decomposition the original level of accumulating dead organic matter is reached only at an age of 40 to 50 years.
10. Quantity and quality of the forest floor are of decisive importance for soil fertility of forestry production. Litter and roots constitute the life basis for soil organisms, the activity of which causes transformation of the above-ground organic matter, incorporation into the upper soil and infiltration of nutrients into the biogeochemical cycle. This permanent activity of organisms exerts an influence on the chemical and physical properties of the soil as a plant site and renders a contribution by saving energy and material in soil utilization. Therefore, the task consists in providing the biological (litter), chemical (nutrients, acidity) and physical (structure, temperature) conditions permitting optimum efficiency of the soil-biological processes in the ecosystem causing the transformation of energy and organic matter (THOMASIUS, FIEDLER and PRIEN 1984/1986).

4. Stability of natural and artificial forest ecosystems

Under stability one first of all understands the capability of a dynamic system to maintain the equilibrium in the case of outer factors influencing (stress range) or after fading of these outer factors to return to the temporarily lost state of equilibrium. In the case of permanent outer factors, i. e. industry emissions or lowering of the groundwater level stability means capability of the corresponding system to acquire a new state of equilibrium, which is adequate with these permanent environmental changes (THOMASIUS, PRIEN and TESCHE 1982).

This definition needs to be explained and supplemented:

1. One can speak of a state of equilibrium only, if a forest ecosystem is at its climax stage, where the ratio $Q = P'(t)/E'(t)$ oscillates around a mean value (cyclic recurrence).
   In all other developmental stages of forest ecosystems the definition of stability based on the equilibrium postulate has to be modified.
2. In the case of forest ecosystems, which are not in a state of equilibrium as for instance the younger succession stages of natural forest ecosystems and all evenaged man-made forests, the conception stability has to be modified to the extent that it designates the capability of an unbalanced forest ecosystem to maintain the age-dependent process of growth and development regardless of adverse outer factors or to adapt oneself again after fading away of these adverse outer factors.
3. In evenaged forest ecosystems, as represented by the majority of man-made-forests, there is neither a state of equilibrium nor will such come into being.

For evaluating the risk of these commercial forests it is important to know the probability, with which a definite forest stand will reach a certain age with full productivity. The input value for evaluating this probability is the relative frequency $p'(t)$ of the occurrence of system-destroying outer factors at the different developmental stages of such forest ecosystems (fig. 10 a). The integral over time then gives the course of the instability $p(t)$ inherend in the system.

The probability of the occurrence of system-destroying adverse influences is in artificial forest ecosystems during the first years of life rather great, as the small plants growing close to the soil surface are exposed to considerable dangers by extreme meteorological influences and competition by felled-area vegetation. Having grown out of the close-to soil zone this juvenile instability diminishes. By taking plant-protec-

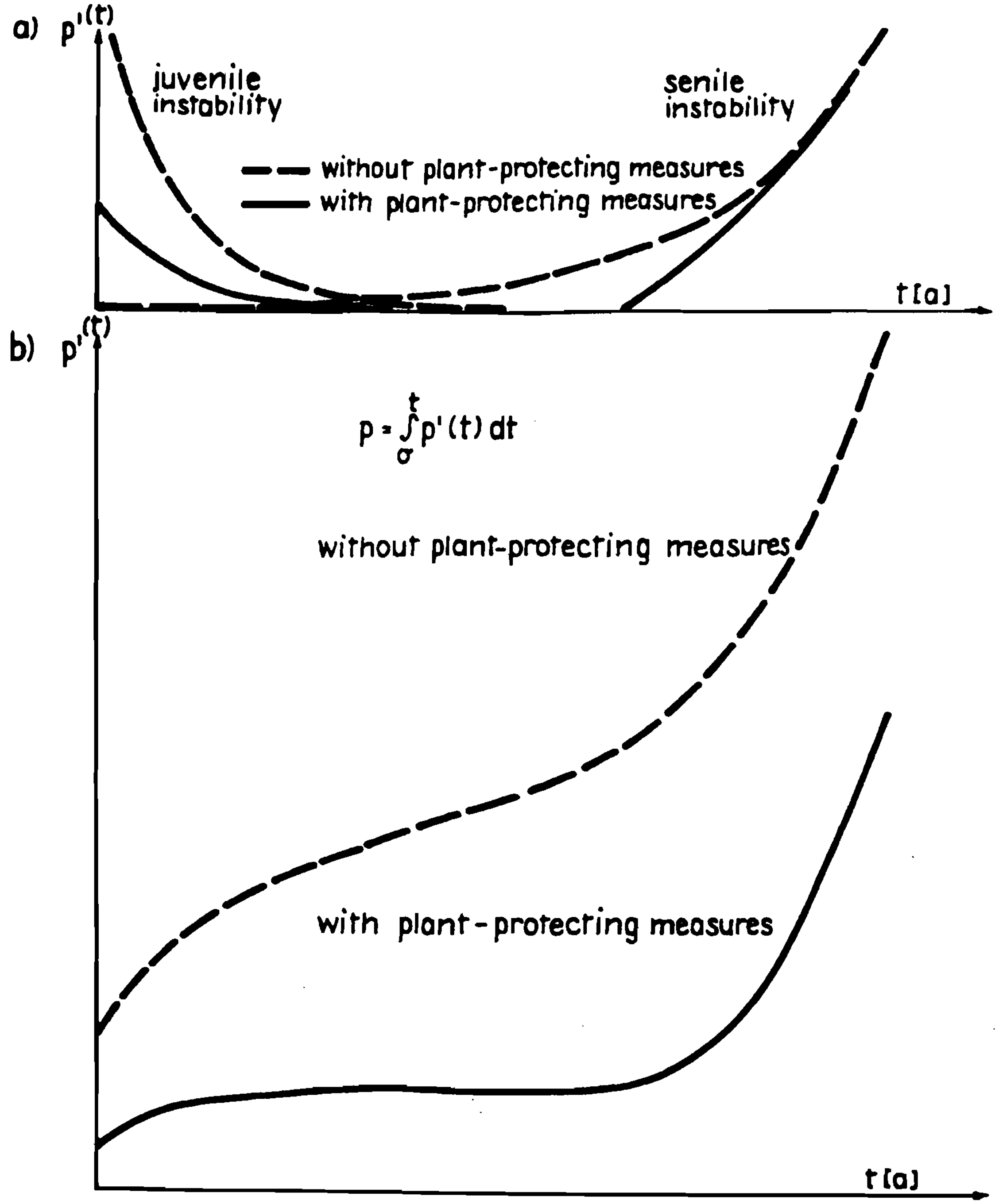

FIG.10 Scheme of the course of instability of even-aged man-made forests

a) relative frequency p'(t) of the occurrence of system-destroying environmental influences

b) sum frequency p(t) for desctruction of an even-aged forest stand prior to reaching a definite age ting measures it is to a certain degree possible to reduce this system-inherent instability to a relatively small residual instability.

The juvenile instability is confronted with a senile instability. It is primarily caused by the physical ageing on the trees. To this influences must be added, for instance storm danger, which increases with stand height. It is true, this senile instability can be retarded by tending measures, for instance by well-timed removal of sick and dying trees, but it is principally impossible to stop this process (fig. 10). In figure 10 b it is shown how to obtain curves of the relative frequency of system distruction by outer factors.

The curves giving an information about the probability p, with which an evenaged stand will be destroyed by adverse outer factors up to a definite moment. Here, again, one has to differ between the system-inherent instability and the residual instability remaining when plant-protecting measures are taken. From this we conclude that the stability of artificial forest ecosystems is a factor dependent on age. For this reason a reference age has to be stipulated, for which the normal rotation period is best suited.

When investigating the instability behaviour of forest ecosystems one cannot plainly speak of stability or instability, but one has always to bear in mind stability or instability against certain, quite concrete adverse factors. These often overlap or occur subsequently. The sum of these individual effects, which should be regarded as partial probabilities then gives the total instability. An example for it is shown in figure 11. Here, it deals with normal pure spruce stands of poorer sites at an altitude of 500 to 800 meters above sea-level (THOMASIUS and BUTTER 1985).

From this figure it is obvious that in the juvenile phase these stands are endangered by a complex of pests doing harm to young plantations. In the thicket and pole stage these stands are endangered by snow and in the tree stage storm damage dominates.

Thus, the probability that the investigated spruce stands reach the stage of small-sized pole (height 5 metres) amounts to about 97 %, that they grow up to the tree stage (height 20 metres) is approximately 80 % and that for reaching the normal rotation period about 70 %. Such curves to be established for each stand type x on the corresponding site types y are obtained by analyzing management documents and statistical data collected in the forest protection registration centre.

It is clear that the very different causes of damage, which depend on the developmental stage, require the application of special techniques of treatment, which cannot be explained here in greater detail.

5. Conclusions

For practical silviculture the development of natural and artificial forested ecosystems is of great importance, because on this basis techniques designed for managing forests may be derived which envisage comprehensive utilization of the natural powers, require little additional energy and ensure high productivity and stability of the forests. The basic principles of such a treatment of forests have been empirically found in the last 150 years. With the aid of modern techniques applied in ecology these principles can to-day be theoretically fathomed and improved. In this connection simulation models play a great role, because many data necessary for analyzing the complicated total situation are lacking and it is difficult to provide them on account of the long-term character of forest-ecological processes. The to-day in great numbers available data obtained in the field of forest ecology must be theoretically processed and utilized with the purpose of improving these models and the conclusions drawn from them.

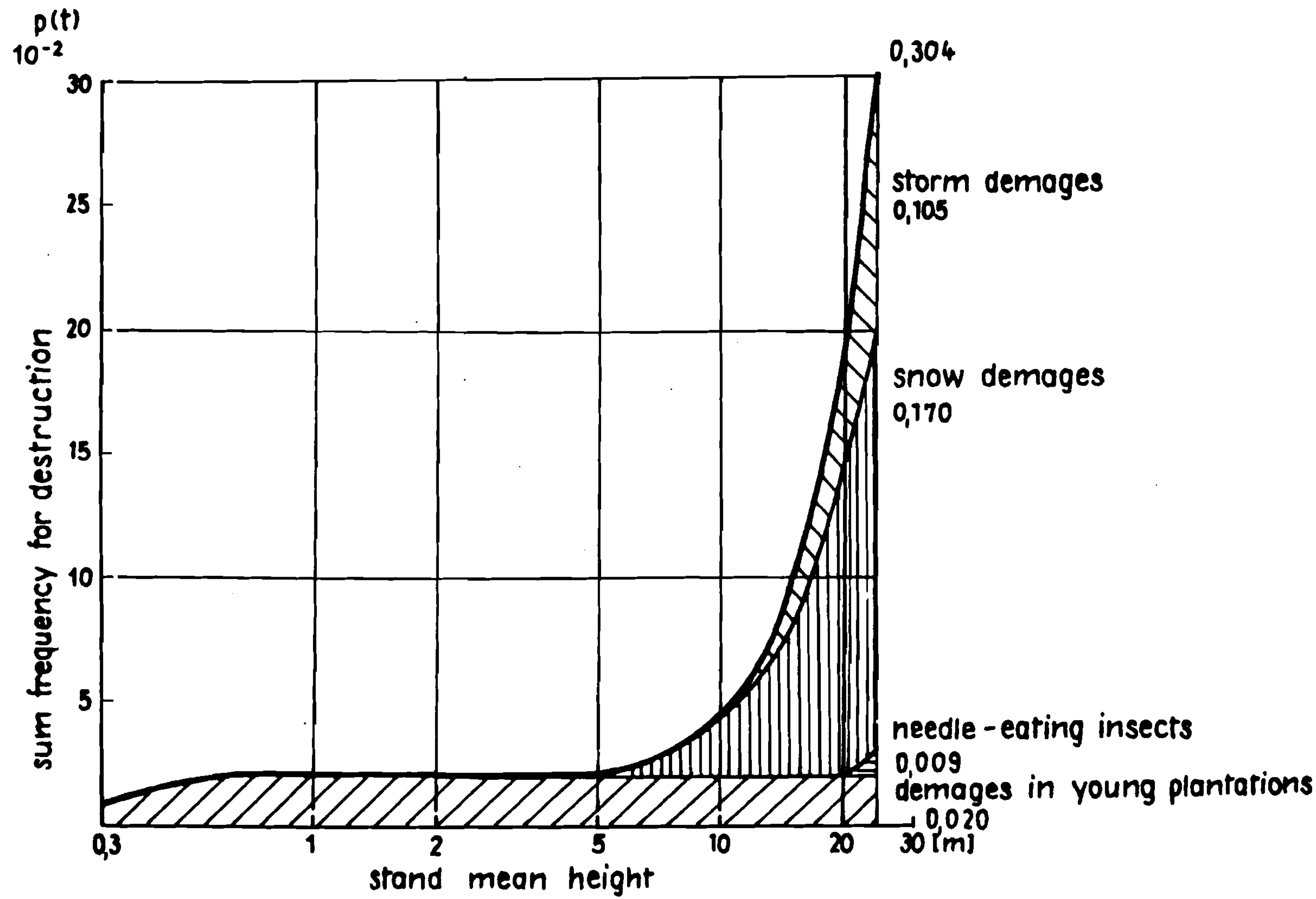

FIG.11 Instability probability p(t) of even-aged spruce stands on poor sites at an altitude of 500 - 800 m above sea-level.

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4.2.7 UTILIZATION OF FOREST RESOURCES AND ENVIRONMENTAL MANAGEMENT STRATEGIES IN THE LITHUANIAN SSR

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1. INTRODUCTION

Lithuania SSR is characterized as a region of intensive development of industry and agriculture. The economical development has caused negative consequences for the environment (air, water and soil pollution). The main task nowadays is to achieve the equilibrium between development of economy and sustainability of ecological systems. To solve such a problem one must know the behaviour of the economic-ecological systems under different conditions. The ecological systems are huge and complicated. There are no possibilities for the experiments on a large scale. The system analysis and simulation has to be the most acceptable approach for those systems study.

Methodological approach for such studies can be described as follows. When exploiting natural resources and creating the gross national product economy has impact on the structure of the resources and quality of the environment. As a result the deriorated environment causes the changes in the productivity of soil, grassland, crops, forests and finally causes in the people health etc. The main scheme of relations between economy and ecology depicts the fig.1. The changes of these relations are aggravated by natural climatic-background (ecological) fluctuations, which affect the regeneration of forest resources, populations of animals and socio-economic development of a region itself. Hence the impact on global biosphere is noted too.

Traying to use the forest resources for achieving more or les equilibrium between economic and environmental development in regional level we are going to create the so called goal-forest for a region which should give a compromised meeting of all society demands for forest resources, ensure an optimal multiple use and serve for sustainability of ecological systems. The approach to such a goal-forest is not the exclusive preserve of foresters. There are two levels to carry out all the activities needed - an interbranch level and a single branch level. The area forested, the distribution of forest tracts, the harmony between the forest growing and the environmental pollution in a region depend on the land-use planning authorities combining the needs and resources for the best reproduction of the gross national product.

To achieve our goals we are going two ways: working out the new simulation models and adopting the old, already known models. An important role in modelling is aloted to the forest sector. Polyfunctional nature of the forest, utilization of the forest resources by the human society on a very broad sca-

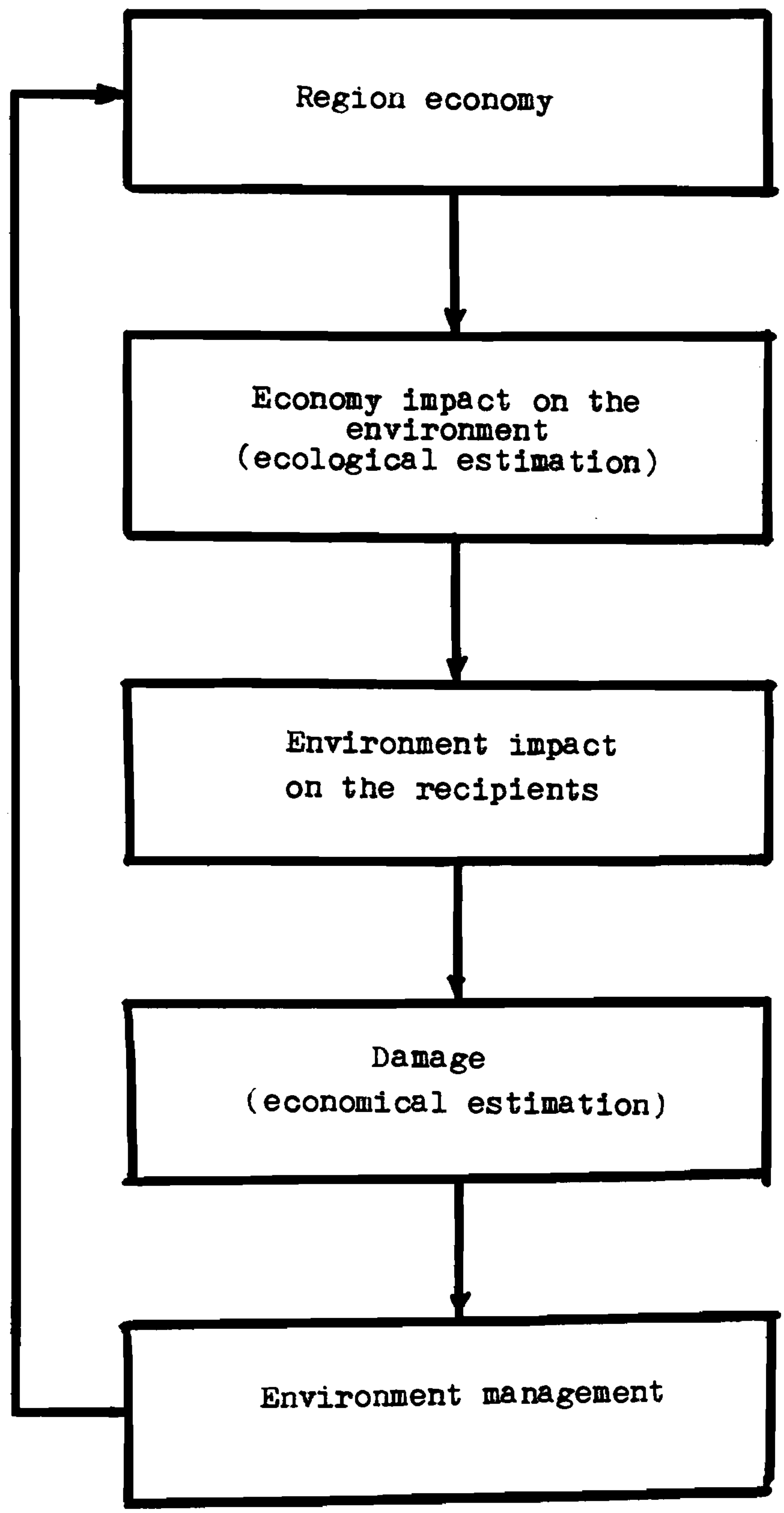

Fig.1. Relations between economy and environment

le, requires the thorough scientific approach to the forecast of the forest sector development in the environment management system.

2. PRINCIPLES OF THE FOREST SECTOR MODELLING

To describe the forest sector a great quantity of the diverse information is needed, that's why the problem is divided into separate blocks. Such an approach gives us the possibility of exposing the structure of the object under investigation more distinct. The climatic back-ground fluctuations as natural conditions and other economy branches can be determined as a forest sector environment. The forest sector optimization scheme schows, that every model of lower level serves like means to achieve the goal of the more high level (fig.2). As a territorial object for a model of the highest level serves a region (union republic) and for that of the lowest one serves a stand.

On the way to the optimized Lithuanian forest sector the protection, preservation and improvement of the environment as well as meeting the economy demands for the forest resources must be taken into consideration. As a first step in this direction the development and allocation of the productive forces should be improved in conformity with rational use of forest resources. The forestry development and the forest resources reproduction to improve ecological equilibrium and nature preservation should follow as a second step. To estimate the impact of the ecological and anthropogenic changes on the forest through simulation of behaviour of the single trees - forest elementary systems should become an object of study too.

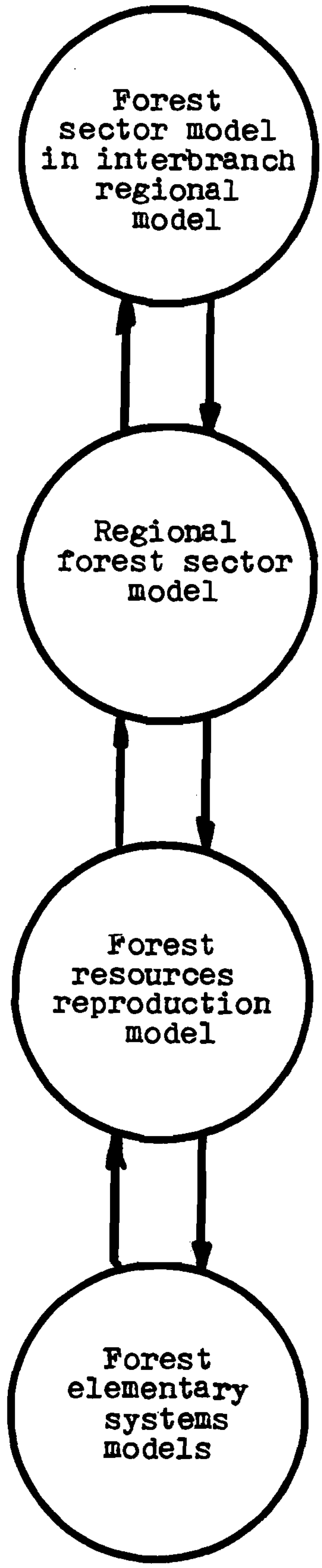

Fig.2. Hierarchic structure of the forest sector modelling

The whole system of the models for the forest sector simulation is generalized in the fig.2.

3. FOREST SECTOR IN THE INTERBRANCH MODEL

For the top level in the forest sector hierarchy the model of the republic gross national product can be considered as a proper tool (Rutkauskas, 1978). In general the model describes the process of creating the product as a balance:

$$X_t + I_t - M_t - Z_t - K_t - A_t - R_t - V_t - E_t = 0$$

where $X_t = (X_{t1}, X_{t2}, \ldots X_{ti} \ldots X_{tn})$ - gross national product vector;

X_{ti} - gross national product of i branch;

$I_t = (I_{t1}, I_{t2}, \ldots I_{ti} \ldots I_{tn})$ - vector of imported products;

I_{ti} - volume of i imported products for industry, accumulation and unindustrial consumption;

$M_t = (M_{t1}, M_{t2}, \ldots M_{ti} \ldots M_{tn})$ - vector of total interbranch flows;

M_{ti} - production of i branch used for industrial consumption by all branches;

$Z_t = (Z_{t1}, Z_{t2}, \ldots Z_{ti} \ldots Z_{tn})$ - total investment vector;

Z_{ti} - production of i branch used for investment in all branches;

$K_t = (K_{t1}, K_{t2}, \ldots K_{ti} \ldots K_{tn})$ - total unindustrial investment vector;

K_{ti} - production of i branch used for unindustrial investment in all branches;

$A_t = (A_{t1}, A_{t2}, \ldots A_{ti} \ldots A_{tn})$ - total increment of circulating funds;

A_{ti} - production of i branch used for increment of circulating funds in all branches;

$R_t = (R_{t1}, R_{t2}, \ldots R_{ti} \ldots R_{tn})$ - vector of total costs for extensive repair;

R_{ti} - production of i branch for extensive repairs in all branches;

$V_t = (V_{t1}, V_{t2}, \ldots V_{ti} \ldots V_{tn})$ - unindustrial consumption vector;

V_{ti} - production of i branch used for unindustrial consumption by all branches;

$E_t = (E_{t1}, E_{t2}, \ldots E_{ti} \ldots E_{tn})$ - vector of exported production;

E_{ti} - export of i production.

Optimality criterion of the model - maximum unindustrial consumption when the structure of the consumption is given. The model simulates:

a) perspective demand structure and quantities for the forest sector products;

b) resources reserve and structure to ensure rational activities of the sector branches;

c) impacts of alternative forest sector development versions on the general economy development and vice versa impact of the general economy development on the forest sector activities.

4. REGIONAL MODELLING OF THE FOREST SECTOR

The data delivered by the interbranch model serve as the limitations for the further detailed determination of the forest sector branches. There are two main tasks to be solved on this stage: 1) optimal forest sector products transport to the consumers; 2) forest resources evaluation for the multiple use planning.

The timber transport was optimized by the following model:

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} \longrightarrow \min$$

$$\sum_{j=1}^{n} X_{ij} = B_i, \qquad i = \overline{1,m}$$

$$\sum_{i=1}^{m} X_{ij} = A_j, \qquad j = \overline{1,n}$$

$$X_{ij} \geqslant 0$$

where C_{ij} - distance between forest enterprise (producer) i and consumer j ;

B_i - timber volume produced by the i forest enterprise;

A_j - timber volume received by the j consumer;

X_{ij} - timber volume transported from the i forest enterprise to the j consumer.

5. MODEL OF THE FOREST RESOURCES REPRODUCTION

The models of the third hierarchic level mentioned above contribute to analysis of the separate branches in the forest sector. the main tasks to be solved on this level shows fig.3.

5.1. Data required

All the data needed for the modelling process are taken from the forest stands survey. During forest inventory every stand is described by 63 charasteristics. A computer having all those charasteristics written on a magnetic band enables us to get data needed to any degree of agregation. For the descrip-

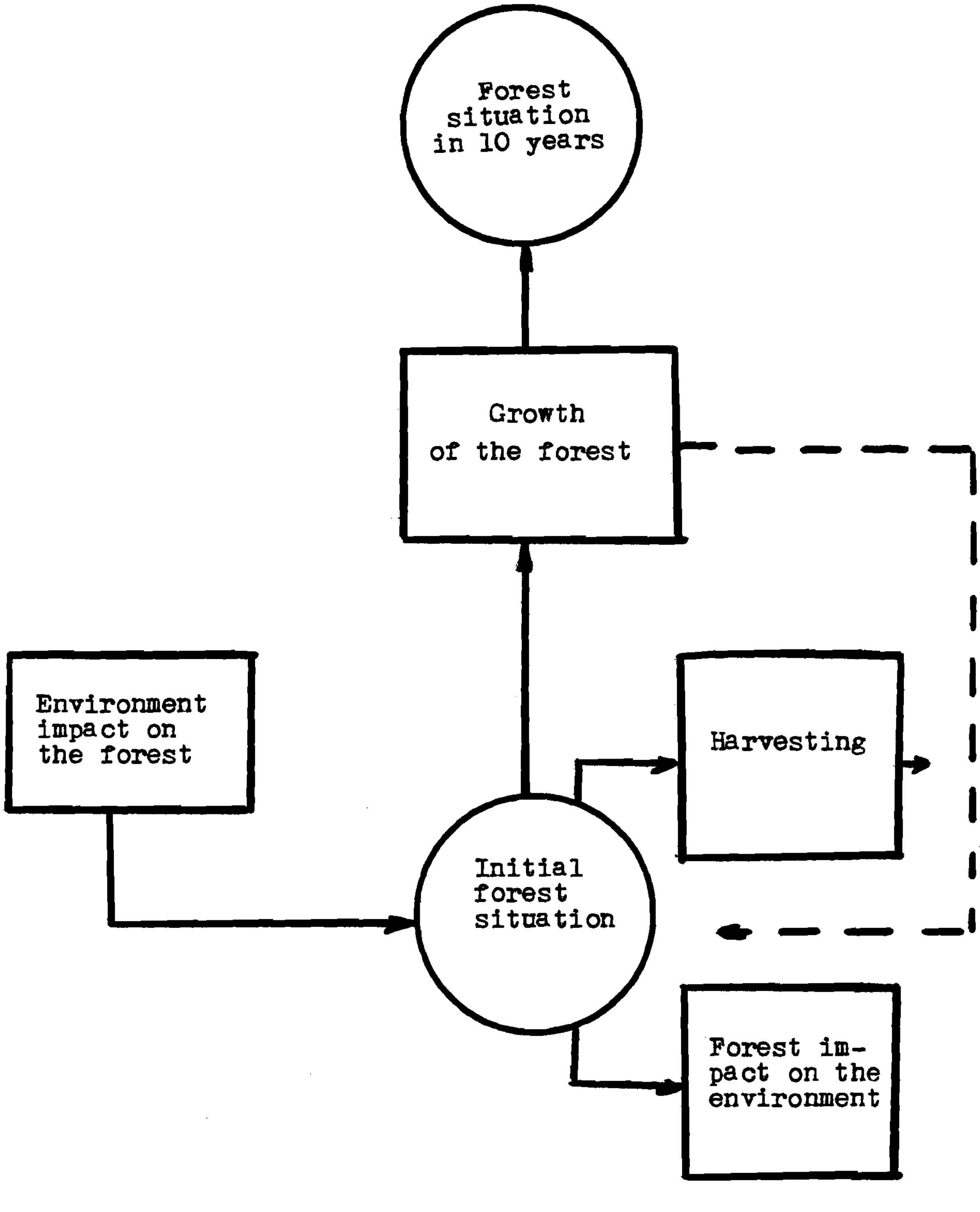

Fig.3. Reproduction of the forest resources

tion of the republic's forests age class tables are used as a best degree of agregation. They can be considered as a four-dimensional matrixes C(k,i,j,n), where k is an index of a specialized use forest territory (timber production, outdoor recreation, water and soil protection etc.), i - is that of a tree specie, j - is that of a site and n - is that of an age class. Description sequence of the forest situation corresponds to the scheme given in fig.4.

5.2. Determination of the allowable cut

For the final yield regulation we have developed an area method OPTINA (Deltuvas, 1982), based on a growth rotation and the age class distribution of the management classes. In the Soviet Union the management classes are combined on the level of a forest enterprise after the stand inventory has been carried out and they are characterized by the dominant tree specie, it's rotation and areas of age classes in ten-year intervals (there are 8 main tree species in Lithuania). When estimating the allowable cut for such a management class we seek a normal (regular) age-class areas distribution in it to ensure a sustained yield. The area yield for a ten-year period can be calculated by following formula:

$$L_r^k = \frac{1}{r}\left(\sum_{i=1}^{r} f_i^k + f_{i+1}^k \right), \quad r = 1 \div T_k - 1,$$

where L_r^k - possible area yield of k tree species management class for ten-year planning period;

f_i^k - area of i age class (beginning from the mature stand);

T_k - number of ten-year age-class in the k tree specie rotation;

α - coefficient, $\alpha \leq 0{,}9$. This coefficient is based on

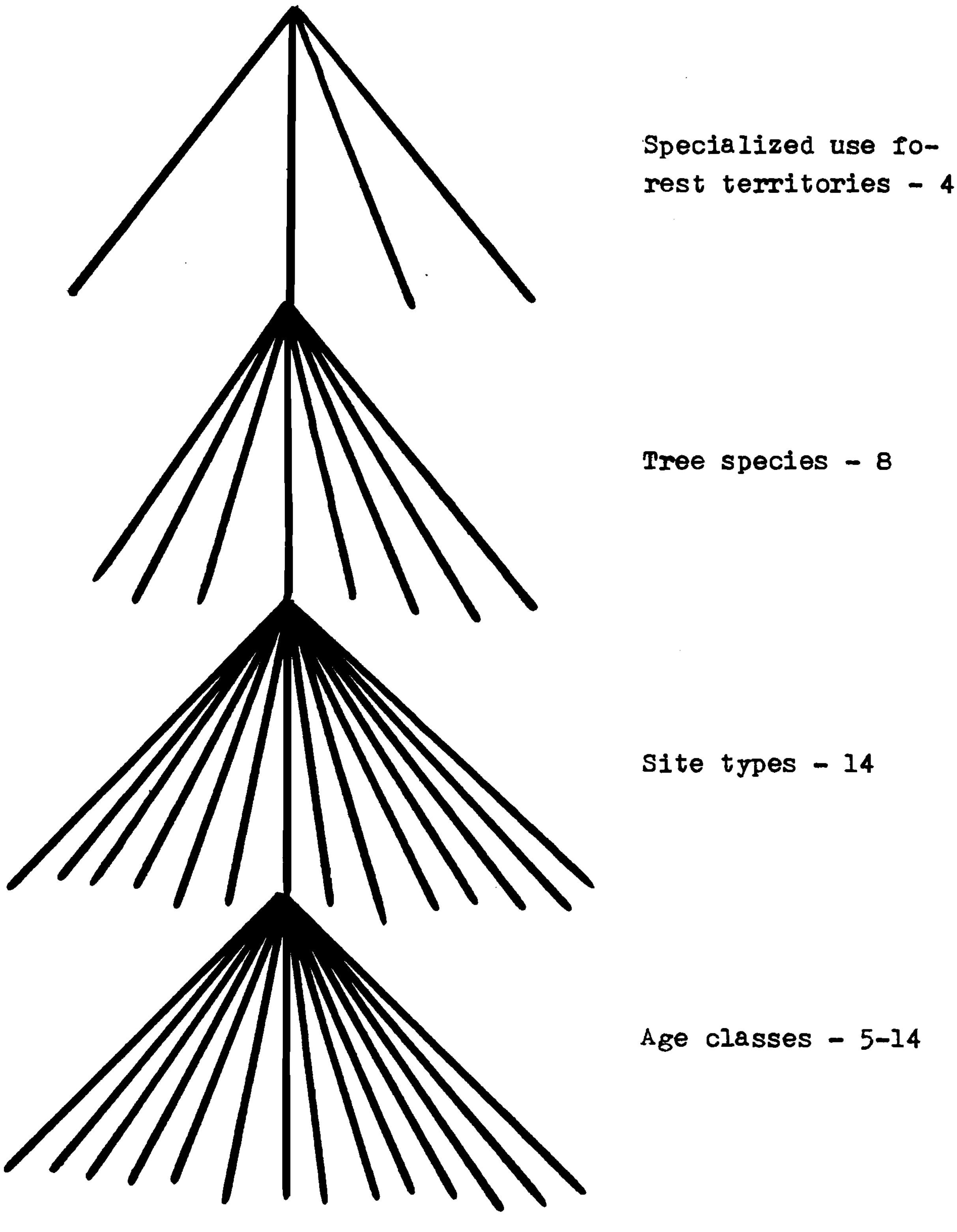

Fig.4. Description of the forest situation

the theoretical presumtion that the stands of every year in an age-class are occupying equal areas and gradually moving up to the next age class. The value of α depends on the limitation β , requiring certain mature stands area at the beginning of every planning period to be ensured. As a rule this area must ensure equal final yield for the first five years (β = 0,5) which should be not less than that during previous five years. To determin the allowable cut the following limitations must be taken into consideration:

$$L_n^k = \min_{r=1 \div T_k - 1} \left\{ L_r \right\}, \qquad (1)$$

$$L_n^k \leqslant N^k , \qquad (2)$$

$$f_{T_k}^k \geqslant \beta L , \qquad (3)$$

$$L_n^k \leqslant L_{n+1}^k , \qquad (4)$$

N^k - normal final yield area:

$$N^k = \frac{F^k}{T_k} ,$$

F^k - management class area;

$f_{T_k}^k$ - nature stands area;

β - coefficient;

L_n^k - allowable cut determined for ten-year planning period, n = 1,2,3,...

The volume cut would be the average volume per unit of area multiplied by the area cut.

The OPTINA model enables us to controll the allowable cut and the optimization of the tree species composition of a forest area simultaneously. When changing the coefficient β there is the possibility to simulate different scenarios of the allowable cut dynamics (fig.5). The determination of the allowable cut by OPTINA contributes to sequence flattenning of the age class areas distribution id est it leads to the normal management class structure (fig.6).

To determin the volume of intermediate cut actual stands volumes are compared with those of goal-stands. The difference between two figures is a basis for intermediate cut intensity determination. The timber volume should be eliminated from a stand by sanitation cut can be determined having known the mortality and intermediate cut.

5.3. Forest impact on environment

Forest impact on soil can be described as follows:

$$D = k \cdot a \cdot d \cdot A$$

$$E_1 = m \cdot A$$

$$E_2 = n \cdot A$$

where D - area to be protected from wind erosion, ha;

k - coefficient of the forest edge length, km/ha;

a - area of the light arable land, protected by 1 km of the forest edge, ha;

d - share of the light arable soils at the forest edge;

A - forest area, ha;

E_1 - reduction of the sweeping out dissolved chemical substances, kg;

E_2 - reduction of the solid particles removal, kg;

m - reduction of the sweeping out dissolved chemical substances from the arable lands by 1 ha forest; kg;

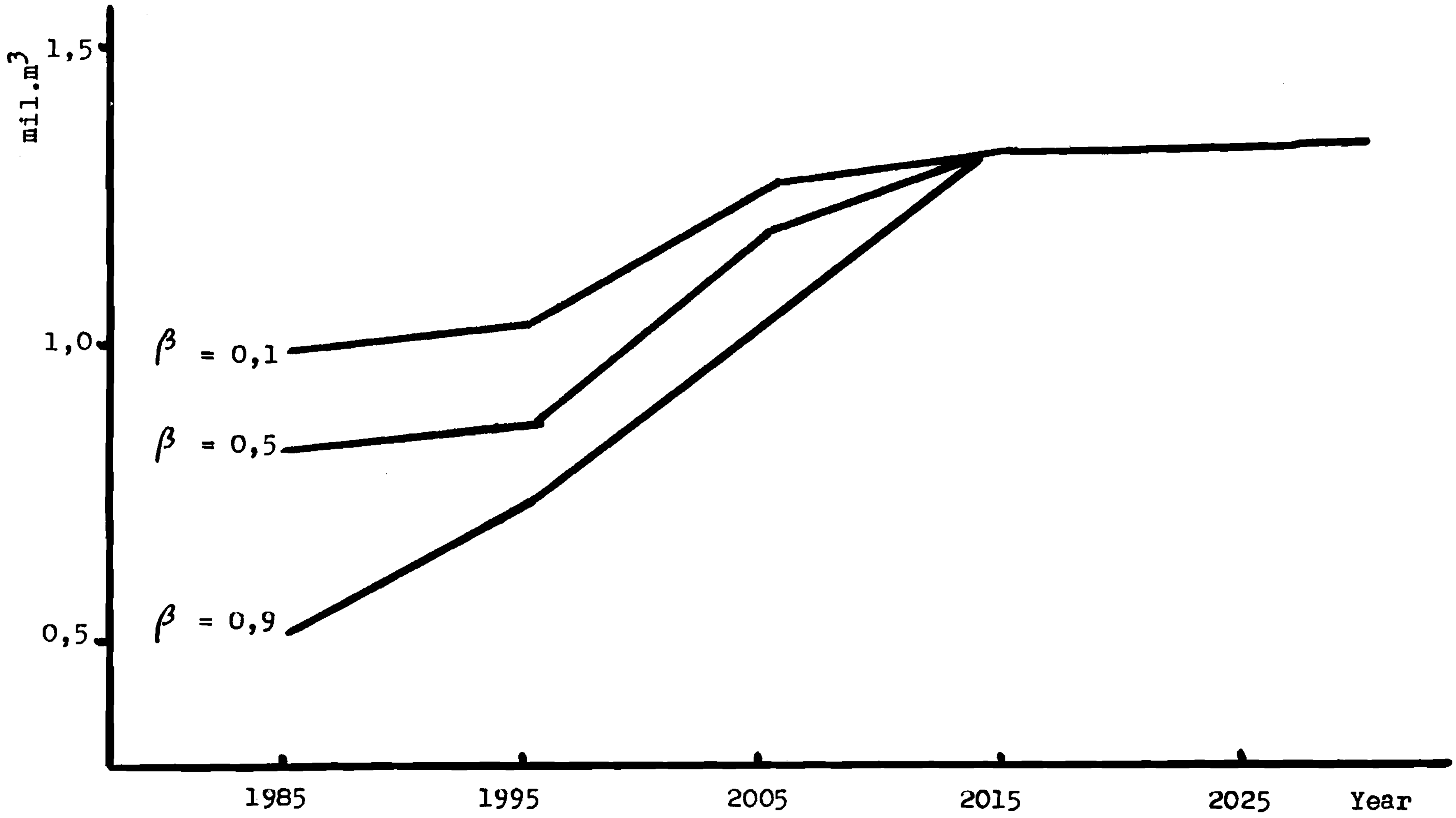

Fig.5. Allowable cut scenarios

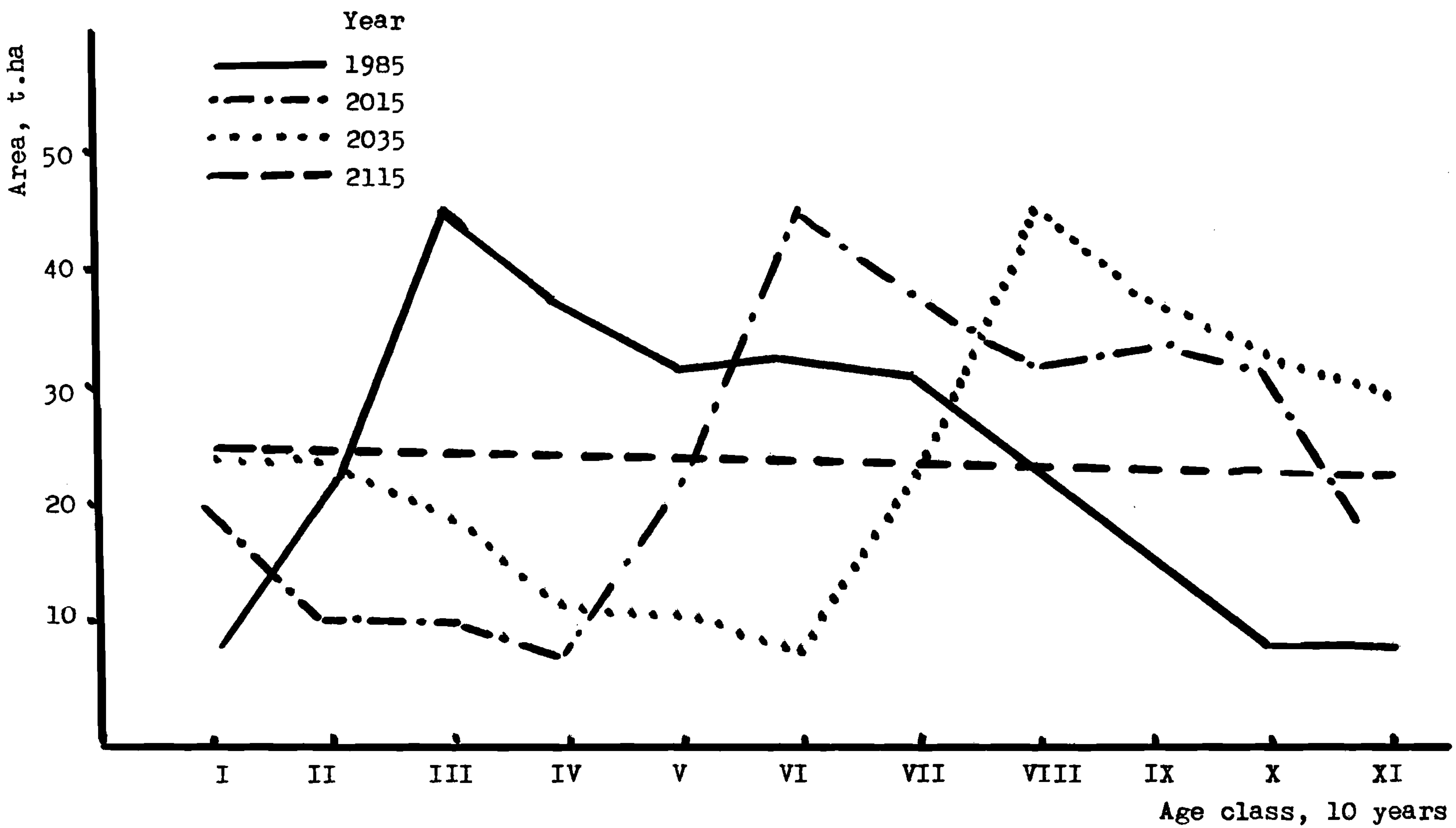

Fig.6. Flattening of the age class distribution in a management class

n - reduction of the solid particles removal from the arable lands by 1 ha forest, kg.

Forest impact on water can be described as follows:

$$V_1 = a_1A_1 + a_2A_2 + a_3A_3$$

$$V_2 = b \cdot A$$

where V_1 - water flow increased by the forest, m^3;

a_1, a_2, a_3 - water flow increased correspondingly by pine, fire and other tree species stands, m^3/ha;

A_1, A_2, A_3 - area of the pine, fire and other tree species stands correspondingly, ha;

V_2 - pure water flow from forest, m^3;

b - water flow from forest, m^3/ha.

Quantity of the oxygen discharged by the pine forests can be estimated in a next way:

$$O = f(Z)$$

$$f_1(Z) = 0,5955 + 0,5718\ Z + 3,1794\ \ln Z\ ,$$

and that of the carcon dioxide

$$CO = f'(Z)$$

$$f_1'(Z) = 1,1365 + 0,9967\ Z + 3,0385\ \ln Z.$$

Forest impact on the fields protection from dust and other technological immissions:

$$S = p \cdot k \cdot A$$

where O - oxygen discharged by the forest in a year, m^3/ha;

Z - timber increment, m^3/ha;

CO - carbon dioxide discharged by the forest in a year, m^3/ha;

S - fields area protected from dust, ha;

p - fields area protected from dust by 1 km forest edge, ha.

5.4. Volume development of the stands

The volume development of the stands can be simulated on the basis of timber increment regularities in consideration of main environmental impacts on the forest:

$$M_{t+1} = M_t + \sum_{i}^{7} M_i$$

where M_{t+1} - timber volume forecasted;

M_t - initial volume;

M_i - volume change as a result of:

M_1 - natural increment;

M_2 - silvicultural activities;

M_3 - air pollution;

M_4 - mortality, left in the forest;

M_5 - intermediate cut;

M_6 - final cutting;

M_7 - accidental factors.

The climatic fluctuations belong to the accindental factors. Since the forest is a natural phenomenon, it has a strong reaction to the changes of the climatic medium (Kairiukstis, 1981). The ecological-climatic changes influence the stability and efficiency of the forest ecosystems either strengthening or weakening then to a considerable extent.

The timber volume of the stands (V_t) in consideration of climatic fluctuations can be determined by such a formula:

$$V_t = M \left(1 + \frac{Ky(t)}{100}\right)$$

where M - average volume in many years;

Ky(t) - increment percent;

K - proportion coefficient.

$$y(t) = \sum_{j=1}^{n} A_j \cos\left(\frac{2\pi t}{T_j} + \varphi_j\right)$$

where $y(t)$ - dendroclimatological index (relative forest productivity deviation from an average) in a year t;

j - climatic cycle;

n - number of cycles;

A_j - amplitude of the fluctuation during a cycle j;

φ_j - phase of the fluctuation in a cycle j;

T_j - duration of cycle j.

6. SIMULATION OF THE FOREST ELEMENTARY AND MEZOSYSTEMS

On the level of smallsystems models simulating a single tree growth, most productive stands growth etc. should be worked out. For instance we have a model to simulate the most productive stands. The main task is to determin an optimal number of trees in 1 ha (N) and an optimal crown closure in a stand to every site type:

$$N = \frac{Q}{q\left(1 - \frac{P}{100}\right)}$$

where Q - total crown projection area of a storey, m^2;

q - optimal projection area of a crown, m^2;

P - optimal percent of crown overlapping in a storey.

After that an optimal basal area and an optimal volume per ha can be estimated easily. An optimal diameter and height of a stand can be estimated in relation with optimal crown projection too.

7. SUMMARY

Lithuanian SSR is characterized by intensive industry and agriculture. To analyse relations between economy and natural environment and to study their mutual impacts the system of models is being used. As a component of such a system the model of the forest sector has been singled out. The forest sector of an optimal structure can be built on the basis of a goal forest, producing raw materials necessary and playing a balancing role in the environment regulation. The models of the forest sector must work on an interbranch, on a single branch and on territorial level. The model of the forest resources reproduction including data acquisition, determination of the cut, forest impact on environment and volume development of the stands has been discussed. As an example of the smallsystems simulation the determination of the most productive stands on the basis of crown closure and number of the trees has been given.

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5. SUMMARY

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1. INTRODUCTION

Industrial agricultural and social development usually leads to negative consequences for the environment such as the exhaustion of natural resources, the destruction of forests, increased soil erosion, water and atmospheric pollution, etc. In some regions, this process is rapidly approaching a level which is dangerous not only for the regions in question, but also for the biosphere as a whole. At the same time, resource utilization and landscape transformation processes have been, still are, and will continue to be inevitable preconditions and consequences of the further development of society. It offers an opportunity to create productive industrial agriculture, to develop industry, transportation, and to create a sound economic basis for higher material, cultural and social welfare of the human population. It is therefore important that resource utilization and all environmental changes are well-balanced in regional and national development and do not break the ecosystem balance on a large scale.

Taking into consideration the above, and within the framework of the Environment Program at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, the methodological theme "Ecological Sustainable/Unsustainable Regional Development in an Historical Perspective" was initiated in 1985. This methodological theme spans across the on-going research projects *Ecologically Sustainable Development of the Biosphere, Acid Rain*, and *Climate Impacts* and aims to achieve some integration of results on ecological impacts of industrial agricultural development on the environment on a regional level.

Using a network of collaborative organizations established in Europe, Asia and North America, as a first step the Workshop on "REGIONAL RESOURCE MANAGEMENT" was held in Albena, Bulgaria.

The Workshop was designed to achieve the following results:

- to develop an approach to regional (national) renewable resource management which is best for long-range socio-economic and environmental development and for the sustainability of the biosphere.

- to focus its debates on the *region* itself, thus making the region the system of concern.
- to glimpse at the current level of knowledge on eco-climatic background fluctuations as these appear from dendro-indications;
- to look at the current level of knowledge on regional and trans-regional pollutant distribution, especially of acid rain in Europe and in the USA;
- to make a survey of regional economic environmental models and to facilitate their implementation and adjustment within the network of collaborators;
- to glimpse at the experience patterns in regional (national) physical planning and management of renewable resources; and
- to revise IIASA's Environment Program approach to ecological sustainability/ unsustainability of regional development with reference to local situations and to the sustainability of the global biosphere.

2. CONTENTS OF THE DISCUSSIONS

The following issues were discussed during the Workshop:

- methodological approaches to sustainability of biospheric subsystems: definition, boundaries, organization and management of the regional system, the relevance of models;
- long-range eco-climatic background fluctuations as these appear from dendro-indications: modeling long-term regional and zonal situations (prognoses) using master chronologies; adaptive policies for forestry, etc.;
- long distance transportation of air pollutants: modeling the distribution of pollutants and acid rain at the trans-regional (continental) level, assessment of the impact on forests, water and agriculture; counteractive policies;
- resource management, utilization and regeneration of renewable resources (forest, soil) under the conditions of eco-climatic background fluctuations and anthropogenic (trans-regional/regional) pollution, modeling possible trends; management systems; and
- multiple land-use, regional (national) physical and environmental planning and management strategies: adaptivity to global and local changes.

Particular attention was given to multidisciplinary and multidimensional approach to the regional system. With this background, eco-climatic changes, environmental pollution and forest resources as these interact in regional systems and impact on their sustainability and management of renewable resources was discussed.

2.1 Why We Looked At Tree-ring Chronologies

Trees are sensitive indicators of environmental conditions. During the growth process, tree rings accumulate information on environmental (eco-climatic background) phenomena and store it for a long unlimited time. In dendrochronology (the science of dating events and variations in the environment by a comparative study of tree rings) much information has been collected. Thus, the existing grids of tree-ring chronologies for separate regions and the Northern Hemisphere as a whole contain valuable information on eco-climatic fluctuations for many centuries, where instrumental observations of the climate do not extend. Tree-chronologies give actual baselines of forest growth which closely correlate with the productivity of agricultural crops and carrying capacity of other ecological systems. They also provide early indications of forest die-back and help in evaluating ecological sustainability of biospheric subsystems. Finally, there is the common belief that an evaluation of the past eco-climatic conditions and present trends in the eco-climatic fluctuations by applying a dendrochronological date will be possible to forecast probable future outcomes. Hence, tree rings can help regional managers to answer questions as to what eco-climatic conditions for the restoration and productivity of renewable resources were prevalent in the past and what the probably extent of change will show in the future. It was for this reason that we discussed the tree-ring chronologies with regional specialists.

2.2 Why We Looked at Acid Rain

Today's Industrial Revolution has brought negative effects of air pollution (SO_x, NO_x, Q_3, etc.) and this is becoming a common phenomenon in most regions. Some emissions may remain airborne for several days and can travel over a distance of a thousand kilometers. Acid compounds, for example, may have a direct or indirect effect on regional resources (soil, forest, water, etc.) reproduction, as well as on the sustainability of the regional system as a whole. This means that air pollution requires a regional response both on how to adapt regional resources policies to the growing impact of trans-regional pollutants and how to decrease emissions of pollutants from that particular region as far as resource utilization policies are concerned.

2.3 Why We Looked at the Forest

Forestry is most representative as an example of a regional resource and as an indicator of environmental quality. Forestry formations provide goods as regional output and services which contribute to environmental conservation of rural and industrial development and to food security. Nevertheless forest ecosystems are degrading in many cases due to loss of germ plasm, exctinction of species, decline in productivity, insufficient renewal and poor utilization of resources. This has caused a danger of adverse changes in ecology, hydrology and climatology, soil depletion and may cause many troubles for future humanity as a whole. Hence, regional responses to forest resources are urgently required. This was why the subject of forest resources was selected for discussion on regional resource management.

3. SUMMARY OF THE DISCUSSIONS

Some 50 scientists, planners and managers from 15 countries representing East and West approaches and international organizations participated in discussions concerned with methodological aspects of regional systems studies as well as factors bearing an impact on regional resources management and regional development itself.

3.1 Methodological Aspects

The group of participants was charged with contributing to methodological debates relevant to the study of "sustainable regional development". Papers presented by Kairiukstis, Nedialkov and Buracas prove a headline for an approach to the sustainability of the biosphere subsystems by properly managed complex regional systems. Espejo's contribution provides a framework for organizational design based on a discussion about the management of complexity. The paper by Kurnossov puts the emphasis on the process of planning and suggests that the selection of strategies should take into account not only limited resources but also the need to minimize the impact of production activities in the environment.

The paper by Braat and van Lierop gives an overvies of models to study environmental issues from economic, ecological and economic-ecological viewpoints. In their view the economic models try to maximize the production of goods and services at minimum cost and the ecological models aim at minimizing the exploitation and damage of natural systems, the economic-ecological models have as an objective "the maximum sustainable use of resources and environmental services". The authors make the point that the objective of these latter models is neither well-known nor common.

Discussions on the above permits one to relate models to managerial processes. The emphasis and therefore its methodological contribution, is in aiding the study of management processes (as they take place in the regional system) and not in supporting the modeling processes (as triggered by the activities of a modeling team).

3.2 Factors Bearing Impacts on Regional Resources Management

It was generally agreed that in regional renewable resources management two most important factors bearing an impact on their carrying capacity must be considered: 1) natural eco-climatic fluctuations and 2) environmental pollutants.

Eckstein and Schweingruber clearly showed that tree-ring growth as well as wood density sequences provide excellent material for restoration of climatic and ecological situations of the past. The pattern of summer temperatures during the Holocene has been determined from tree-ring width and density chronologies for many regions (Shiyatov, Becker, Baillie and Eronen). Abrupt growth reductions in trees during the last decades indicate an extensive threat to the environment. The geographical distribution of such abrupt changes in tree growth varies greatly. It is to be assumed that there is some additional (local) stress factor which orignates the damage quota of resources and must be considered.

Bitvinskas, Kairiukstis and Shiyatov discuss the models, the prediction of eco-climatic background fluctuations by using dendrochronological scales (DS) of short (100-150 years) and long (200-1250 years) duration. Using DS from different sites, an eco-climatic background prognosis was obtained for many regions. This concerns the prediction of agricultural crops, carrying capacity of forests, etc. The practical applications of eco-climatic prognoses in resource management were also discussed.

Among the environmental pollutants as a factor-bearing impact on regional resources management, acid rain was discussed. As was made clear (Hordijk, Rubin, Argirova and others), though the phenomenon of acid rain has been known since 1890, it is only recently that the effects of acid deposition have become visible. For regions like Central Europe and north-eastern USA, acid rain promotes a strong disturbance in renewable resource management simulation models and scenarios of adaptive policy have been demonstrated.

3.3 Management of Regional Resources

The main subject of discussions was focused on the subject of regional resources itself and its management strategies. Lönnstedt, Dakov, Johann and Thomasius discussed forest resource dynamics: the state-of-the-art of resources, the methods of monitoring and management policies (Kochetkov). Models for long-term prognoses of resources assessment (Grossmann) and their utilization strategies (Kairiukstis, Mizaras and Deltuvas) were also discussed. With regard to environmental impact assessment and natural resources management, it was generally agreed that both approaches are essentially underpinned by the same scientific basis (Duinker). In this discussion, it became apparent that the models used for decision-making have to be constantly updated as a result of comparing the actual performance of the regional system with the earlier forecasts made by these models. This was offered as an important mechanism for adaptive planning and management. The paper by Ikeda on sustainable resource and environmental management in the Seto Inland Sea and coast region provides an illustration of precisely this type of model. Ikeda explains a method to develop and highlights the advantage of using a systems approach to avoid well-known methodological difficulties in the use of mathematical optimization techniques.

The practical experience of management of regional systems in Sweden was illustrated by Sviden, in Estonian SSR by Luik, and in Poland by Owsinski, to mention by a few.

4. WORKSHOP CONTRIBUTIONS TO THE STUDY OF REGIONAL SYSTEMS

The Workshop focused on the economic-environmental regional system. This system has to take into account a longer-term perspective and recognize more interconnections. The term sustainable regional development has emerged in this context.

4.1 Definition of the Regional System

The logic for the regional system stems from the need to tackle economic-environmental problems at different levels of resolution. The perceived connectivity of issues and problems has made it necessary to think in terms of the following for the levels of aggregation:

- environmental systems on the landscape (local) level;
- economic-environmental systems on the regional or national level;
- macro-systems on the transregional, zonal or continental level; and
- the biosphere system on a global scale.

While it may not be easy to offer clear cut distinctions between these levels, in general, we can say that the regional level emerges from a concern with the effective survival of micro-populations in particular geographical areas. In contrast, the local level appears to emerge from a concern with the prosperity of, and services for, particular individuals in a community. Today, the syndrome of the "global village" is too apparent as to dismiss the need to deal with the higher levels of aggregation.

Indeed, it is apparent that the complexity of environmental issues is growing and wants new and more comprehensive approaches/methods to tackle them. This complexity stems both from a larger demand for limited resources and higher levels of social awareness about aspects like the quality of the environment, the wastes produced by an indiscriminate use of resources, the need to have a sustainable use of some key resources, and a more clear perception of environmental capabilities. The following are, in more detail, some of the issues which add to the perceived complexity of the sustainable use of natural resources:

- Dynamic interdependence of multi-species ecosystems. This issue relates to the limited understanding of the ecological principles underlying the stability and resilience in the dynamic interaction among many species sharing the same habitat. As usual, a decision based on inadequate knowledge, opens a chain of downstream effects that alters the balance of other resources and affects economic stability.
- Multiple use of resources (water, land, air and biota), for different purposes and by different groups with multiple and conflicting objectives. Particular uses of a resource may benefit some groups or victimize others in a competitive situation.
- Intergeneration equity in resource economics. The growing concern, on ethical as well as practical grounds, for the preservation of environmental goods or services for future generations adds to the complexity of the regional issues by making necessary a longer-term perspective in decision-making.
- Spatial and temporal externalities in environmental pollution. There is increasing concern about the environmental impact of wastes in general, about the impact of the activities of one area on the activities of resources of other (e.g., acid rain), and about the transformation of pollutants into other types of materials that may prove hazardous in the future.

Seldom are these issues focused on particular communities or localities. In general, they affect a number of social groups in a geographical area beyond that of a specific community, suggesting the need to consider a higher level of social-geographical aggregation; we call this level the regional system. Thus, we offer the following definition for the regional system:

> "A regional system is a human activity system producing economic, environmental, demographic and other transformations that are perceived as relevant to the survival of a specific (micro) population, within a defined geographical space (the region)."

If the transformations maintain the ecological stability and the sustainable use of specific resources, then the regional system is achieving a sustainable use of these resources.

The participants in this human activity system are those affected, favorably or unfavorably, by the named transformations, those producing them and those regulating these transformations.

4.2 The Boundaries of the Regional System

We see a ***regional system*** as a human activity system intertwined with a natural system. In this sense its boundaries, for the purpose of systems analysis, are defined both by the purposes ascribed to the situation by individuals and by natural (geographic, ecological) factors.

The increasing concern for both the sustainability of ecological resources and the environmental constraints limiting the spatial and temporal use of resources, suggests that the boundaries of the regional system are constantly being enlarged to take into account a longer time horizon and more interdependencies. This change in boundaries is an expression of the perceived larger complexity in social activities. Indeed, in practical terms, this is an extension from an economic system, concerned with exploiting resources at a minimum cost, to an economic-ecological system, concerned with sustainable development.

In the end, the boundaries of a system, from a viewpoint of a system analysis, are defined by the variables that the analysts choose to study. The choosing of these variables needs very careful attention in order to make the individual studies both efficient (in terms of bounding a manageable regional system analysis), and effective (in terms of having a reasonable possibility of influencing development policies in regions where ecological sustainability of an economy appears to be in jeopardy). These variables are likely to be instances of the dimensions that are shown graphically in Figure 1 and are discussed below.

A. Spatial Boundaries (Geographic Regions)

This dimension is a rather obvious bounding requirement when planning a set of systems analyses. If any study is to have a substantial chance of influencing development policy on the basis of ecological sustainability, the geographic bounds would need to be very carefully placed. Thus, the more political decision-making centres (especially national governments) included within a region under study, the more difficult it would be to obtain consensus in development-environmental policy throughout the region. This would be an acute situation when the region included diverse orientations of government, a frequent problem encountered in continents like Europe.

B. Basic Ecosystem Components

Ecological sustainability is concerned with the capacity of the biophysical environment to support or permit specified levels of social and economic activity. It is clear that the concept of ecological sustainability must embrace all major facets of nature, which can conveniently be classified as land (soil), water, air, and biota. While it is not possible to consider ***all*** detailed components of natural ecosystems in a systems analysis of regional development/environmental interactions, it appears necessary at least to take a synoptic view of the environment and to examine its past and future conditions in a region in terms of specific measures relating to major physical media (i.e., land, water, forest and air) and the organisms which inhabit the region.

C. Economic Sectors

Economies are commonly subdivided for analysis purposes into activity or market sectors, e.g., agricultural sector, forest sector, manufacturing sector.

D. Exogenous Disturbance of Ecological Sustainability

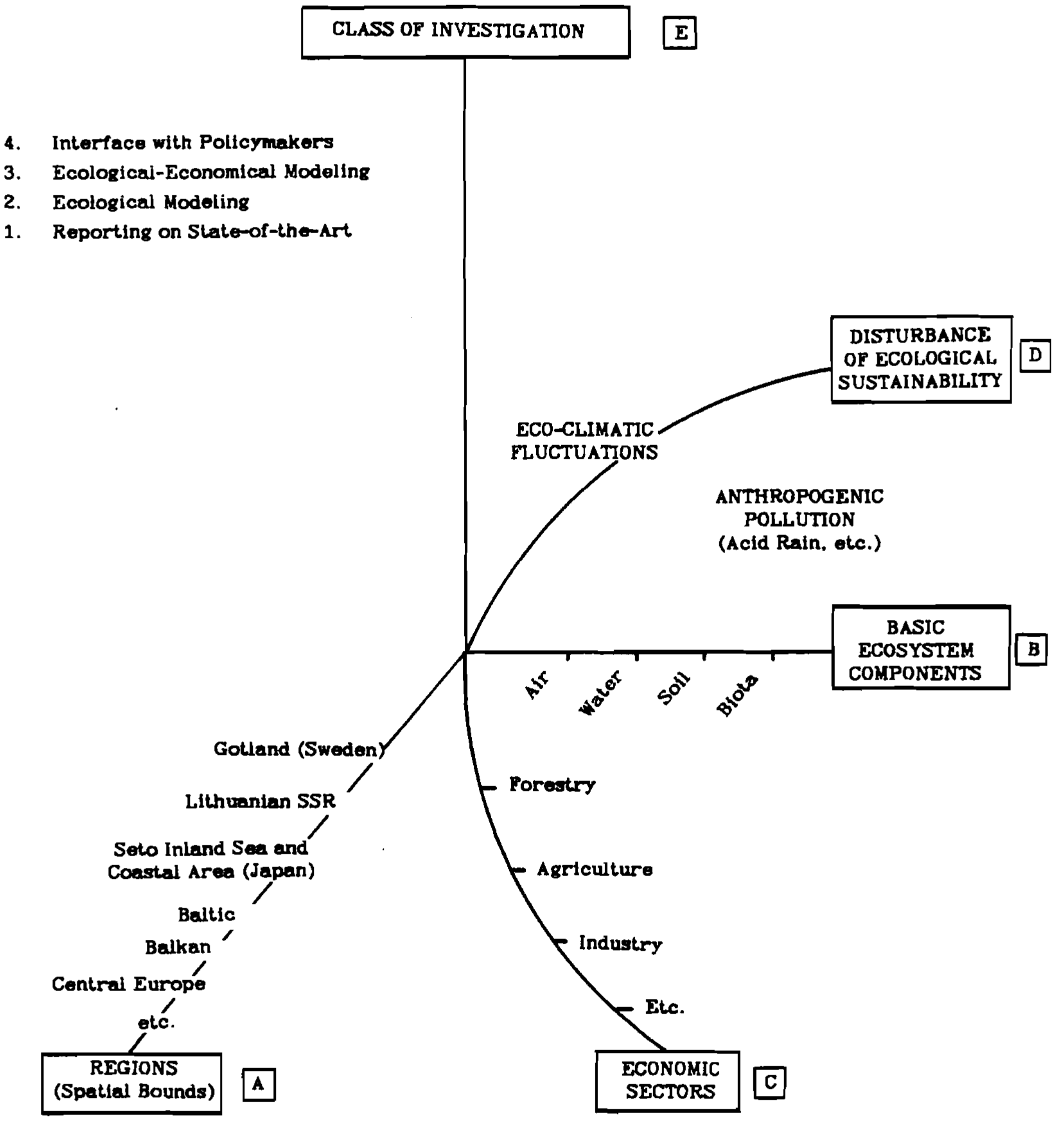

Figure 1. The dimensions required in defining the boundaries of regional systems and their sustainability.

General concensus was reached that the problems faced by some economic sectors, as for example, forestry, agriculture, aquaculture, etc., are both a matter from within the sector as well as exogenous to the sector (e.g., air pollution from industrial activity or changes of eco-climatic background as a natural phenomena). Both factors reduce the growth rate and carrying capacity of biological systems and have great negative consequences on the environment and sustainability of regional systems. Therefore, factors of environmental pollution (e.g., acid rain, etc.) and eco-climatic fluctuations which are exposed through tree-ring chronologies must be considered when analyzing the sustainability of regional systems.

E. Class of Investigation of Regional Systems

Whatever the objects of regional studies might be (simple report on the state-of-the-art, ecological modeling, ecological-economical modeling, or interaction with policy-makers) the above variables must be taken into consideration. Thus, within the framework of the above definition, at a higher level of resolution, the regional system can be defined from multiple perspectives; it can be focussed in any geographical area, or climatic zone, it can encompass any ecosystem component(s) or economic sector(s) with exogenous and endogenous factors bearing an influence on them.

Finally, any study needs to pay special attention to the bounding of economic sectors, based largely on the specific kinds of problems deemed most acute by specialists in each region.

4.3 The Organization of the Regional System

Given the flexibility that is necessary in the specific definition of a regional system, it is quite natural that ecological regions will not necessarily coincide with the economic and administrative regions. This most likely will create managerial problems; the management of the ecological region may imply the coordination of multiple institutions perhaps operating under different institutional systems. We may expect that systems analysts in these circumstances will have difficulties in producing useful definitions of the regional system.

Yet, however the regional system is defined, as long as we are referring to a human activity system, it will be embodied in a set of institutions and/or institutional parts concerned with the transformation of some inputs into some kind of outputs. If the purposes of a particular system analysis are to understand the transformations actually taking place in the regional system, then these institutions will be a "black box" with resources and "disturbances" as inputs and products and/or services and "externalities" as outputs. On the other hand, if the purposes of the study are to change, in one form or another, these transformations and then these institutions cannot remain as a "black box"; they have to be made, to a larger or lesser degree, transparent.

While it is clear that the management of these transformations can be distributed, not only between many different institutions, but also between several structural levels within each institution, it is suggested that there be a set of managerial instances, and mechanisms of coordination, concerned with the management of the region as a whole. If this were not the case then the region would not have a recognizable identity (of course, for analytical purposes it may well be that studies make reference to regions which do not possess cohesion in the world at all; however, if this is the case, the "regions" would only be creations of the analysts and not organizations in the world). In other terms the organizational boundaries of any ***existing*** regional system are defined by the highest structural level at which cohesion exists with reference to the particular purposes ascribed to the region. Indeed, these boundaries may not overlap with the geographic boundaries of the defined system.

In conclusion, the above views suggest an important methodological problem: the boundaries of the regional system are seldom those of existing administrative divisions. In general, the boundaries of the regional system are defined by the purposes ascribed to them by relevant viewpoints. However, the regulation of the transformations implied by these purposes is unlikely to fall precisely within the regulatory capacity of a single or cohesive set of existing administrative units. For instance, a "river basin space", or a "coastal space", is likely to encompass a number of administrative units, as implied by the named "space". An adequate definition of the regional system is a necessary first stage to make further studies possible.

5. CONCLUDING REMARKS

Clearly the economic-ecological regional system is an area of human activity that requires foresight, planning and integrated efforts. Intra-and inter-regional connectivity, based on natural phenomena, makes inadequate any arbitrary break down of regional activities, yet there is a whole range of institutional factors that make it difficult to handle these problems holistically. This fact poses an interesting challenge to the development of methodological aids for applied systems analysis.

This Workshop has recognized a set of important methodological problems that need attention to improve the management of regional resources. These problems involve not only how to improve modeling activities, but also and more importantly, how to link models more effectively to management processes.

The general mood of the Workshop was that regional case studies were very timely and useful, and that IIASA was an appropriate forum for coordinating the individual studies and providing the synthetic framework for the comparability of results.

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