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INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION
POLISH ACADEMY OF SCIENCES

CONFERENCE PAPERS 19

CLIMATE AND ATMOSPHERIC DEPOSITION STUDIES IN FORESTS

Edited by

Jerzy Solon
Ewa Roo-Zielińska
Andrzej Bytnerowicz

INTERNATIONAL CONFERENCE
NIEBORÓW OCTOBER 6-9 1992

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Preface

This volume contains a collection of articles presented during the international conference "Climate and Atmospheric Deposition Studies in Forests" held in Nieborów, Poland, on October 6-9, 1992. These articles describe methods used in the United States and several Central and East European countries for monitoring forest health and dynamics of selected biological processes in forests.

The first article (Breymeyer and Noble) gives a history and perspectives of scientific cooperation between Poland and the USA in research on effects of climatic changes and increasing levels of environmental pollution on forest ecosystems.

The remaining articles are divided into four subject groups:

— forest monitoring systems (4 papers)
— forest gradient studies (5 papers)
— forest pollution (6 papers)
— special methods for forest monitoring (6 papers).

This division is not self-excluding — most of the articles in this volume are multi-topical; however, each of them is focused on one basic subject.

We hope that the current volume of the Conference Papers will be of interest to the individuals directly involved in various international projects addressing "Forest Health Monitoring". We also hope that articles from this book will be of importance for those interested in analysis of forest reactions to environmental pollution and climatic changes in different parts of the world.

Andrzej Bytnerowicz
Ewa Roo-Zielińska
Jerzy Solon

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
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HISTORY AND PERSPECTIVES OF THE US-EEC COOPERATION IN THE FOREST ECOSYSTEM RESEARCH AND MONITORING

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BRIEF HISTORY OF THE US-POLISH PROJECT

The Nieborów Conference on Climate and Atmospheric Deposition Studies in Forest Ecosystems in Central and Eastern Europe was held in Nieborów, Poland, October 6-9, 1992. It represented a major step in the advancement of the goals of the cooperative project between the US and Poland entitled "Status and Long-term Trends in Forest Ecosystems: Climate, Pollution and Forest Health" that was begun in 1991.

Historically this project had its beginnings at a workshop held in Key Biscayne, Florida in March 1991. This workshop was made possible with the assistance of a number of American scientists. Key among them were Dave Shriner, Ann Bartuska and Mike Slimak; as well as Roger Blair, Keith Jensen, Dave Reed and the other nine Americans who joined us in this initial meeting. The workshop was held for the purpose of exploring the need for, and benefits of developing a US-Poland cooperative research program in the area of Atmospheric Deposition and Forest Health Monitoring Studies. It was held under the sponsorship of the US EPA — Poland MOSZNL Agreement (for Polish visitors) and the US EPA. The Polish side was represented by a four-member delegation which was headed by Dr. Alicja Breymeyer, and which included her colleagues Drs Krystyna Grodzińska, Lech Ryszkowski and Michał Zaremba-Czereyski. Dr. Breymeyer had been a participant in a workshop on Ecological Risks and Environmental Protection held in 1987 in Mogilany, Poland under the sponsorship of the Polish Academy of Sciences and the US National Academy of Science. Papers and recommendations from this and a subsequent meeting in Washington in 1988 were printed in a book entitled "Ecological Risks. Perspectives from Poland and the United States", which was edited by Grodziński, Cowling and Breymeyer, 1990. The authors proposed joint work on the effects of air pollutants on forest ecosystems and further suggested inclusion of a broad scale gradient study coupled with more intensive case studies at specific locations; however, due to political changes in Poland and changes in research directions in the US, there was no follow up to these recommendations.

Discussions at the February '91 meeting in Florida clearly demonstrated that both sides recognized the need for, and interest in development of collaboration as a means of furthering the goals of their respective countries. After agreeing that a joint endeavor was desirable the following specific objectives were identified for consideration in future planning:

— to evaluate data comparability and availability for monitoring sites in Poland and at EMAP and IFS sites in the US (also to test the power of the sampling frame);

— to conduct on-site evaluation of specific monitoring/research projects in both countries (1991) prior to finalizing research design and quality assurance protocols for the 1992 field season;

— to apply US models to Polish data where atmospheric loads are considerably higher;

— to compare deposition fate, and the impact of air toxics, on the terrestrial and aquatic systems of the two countries.

It was also agreed that a Polish delegation should return to the US in July, 1991, to visit gradient study sites in Michigan and Tennessee.

Thus in July, a five-member team of Polish specialists spent one week with their US hosts from Michigan Technological University reviewing the Michigan gradient study project. From there they went to the Great Smoky Mountains National Park, where discussions were held on further development of a plan for cooperative work. At these meetings discussions focused on the development of research protocols for five projects to be undertaken in the 1992 field season; logistics and costs; and the naming of the project. Projects identified to be undertaken in 1992 included:

— litter fall decomposition and herb layer diversity in forests along the transcountry climatic and pollution transects;

— the Niepołomice forest case study as it relates to an atmospheric deposition gradient and groundwater level changes;

— the development of a network for the assessment of regional forest health monitoring.

Cost estimates were developed for each project along with the identification of instrumentation and personnel needs. The two sides agreed that the project should be called the "US-Poland Cooperative Project on Status and Long Term Trends in Forest Ecosystems: Climate, Pollution and Forest Health". In September, 1991, a five-member US team visited research laboratories and field sites at various locations along the proposed atmospheric deposition gradient in Poland. Ideas were exchanged on many aspects of the work including site selection criteria, methods of data collection and methods for the incorporation of existing data into the gradient work. The two sides reaffirmed their commitment to the projects identified in July and expanded on plans for the 1992 field season. In January, 1992, key US project participants met with representatives from the USDA FS in Fort Collins, Colorado, for the purpose of considering the development of an expanded effort that would incorporate components of a proposal for cooperation that they had composed independently. It was agreed at this meeting that it would be desirable for US cooperators to join forces and to expand the project by incorporating projects from the USDA FS proposal as well as others as deemed desirable. It was further agreed that Dr. Andrzej Bytnerowicz, USDA FS, Riverside, California, should join the project as a co-project leader on the US side. These agreed upon changes were subject to concurrence by the Polish side. In May, 1992, a four-member team visited Poland for the purpose of reviewing the changes in the project, finalizing plans for the upcoming field season, exchanging data sets, delivering research materials related to the decomposition study, evaluating allocation of existing funding and considering new funding sources. This meeting was next followed by the Nieborów Conference.

NIEBORÓW CONFERENCE

The Nieborów Conference was subdivided into two components. The first component was run as a symposium that allowed invited participants to present papers on their recent work connected with, or relevant to, this project. These papers are published in this volume, except for those which are being published in other reviewed journals. The second component was conducted as a series of working sessions dealing with the review and planning of work already underway, and deliberations on new areas of endeavour.

The Symposium provided a forum for all participants to introduce the research goals/activities/needs in their respective countries as well as ideas for modifying the project, and some more general considerations. Opening remarks were made by project founders Professors Alicja Breymeyer and Reginald Noble; and by Dr. Ann Bartuska, whose efforts to promote cooperation in US-Poland forest research go back far beyond the inception of this project. After opening remarks, Dr Andrzej Bytnerowicz reviewed an expanded version of the document entitled “Effects of Atmospheric Deposition and Climate Change on Forest Ecosystems in Central and Eastern Europe” that had been presented at the January meeting in Fort Collins. Discussion centered on how the proposed additions to the project added breadth and strength, as well as a focus on expansion into other Central and Eastern European countries. Following these discussions, individual paper presentations began. In all twenty papers were presented during the four sessions that extended over a two-day period.

The Working Sessions, which followed the symposium, offered an opportunity for participants to exchange ideas and to gain a better insight into the needs and capabilities of current and prospective cooperators. They were divided into two concurrent sessions entitled:

1. Intensive Studies, and
2. Regional Monitoring.

The session on Intensive Studies was chaired by Breymeyer and Bytnerowicz. Here participants focused on fine tuning current work as well as on expansion of the effort into other Central and Eastern European countries.

The session on Regional Monitoring, chaired by Stolte and Noble, brought to the project a possible new initiative for consideration. Discussion focused on developing a regional-scale approach to forest health monitoring in Central and Eastern Europe which might parallel the US-FHM (Forest Health Monitoring) Program (a component of the US EMAP initiative). Participants from the nine countries represented at the meeting expressed strong support for developing a transboundary approach to forest health monitoring, which could provide a broad framework for cooperation, while allowing for the preservation of the integrity of the monitoring efforts of individual countries.

NEW PERSPECTIVES

The contemporary political division of Central and Eastern Europe is illustrated in the enclosed map (Fig. 1). Many of the states presented came into being 2-3 years ago, and previously existed as parts of another large state organism. They are now determining their own strategies in various areas, including environmental protection. Is it for this reason, or maybe in spite of it, that they have given a positive response to our invitation, with the institutions responsible for environmental protection deciding to send representatives to Nieborów? Regardless of the motives involved, the conference in Nieborów represents a major contribution to advancement of international cooperation between foresters and ecologists. It should also be noted here that international cooperation among foresters has a long and excellent tradition in Europe. Monitoring the condition of the forests is carried out in many countries using programs which have been agreed upon jointly. Information accumulates in joint databanks, and it is thanks to this that it is even more interesting to compare European monitoring with the technically advanced, probability based Forest Health Monitoring Program in America.

Let us pause to consider the geographical range of our programme; the countries participating at Nieborów lie in the zone of mixed or coniferous forest (Russia, which embraces almost all climatic zones, cannot be included in this classification). Ideal transects may be marked out in both the east-west and north-south cross section. These cut across clear climatic gradients and can be studied to consider the dependence of various forest charac-

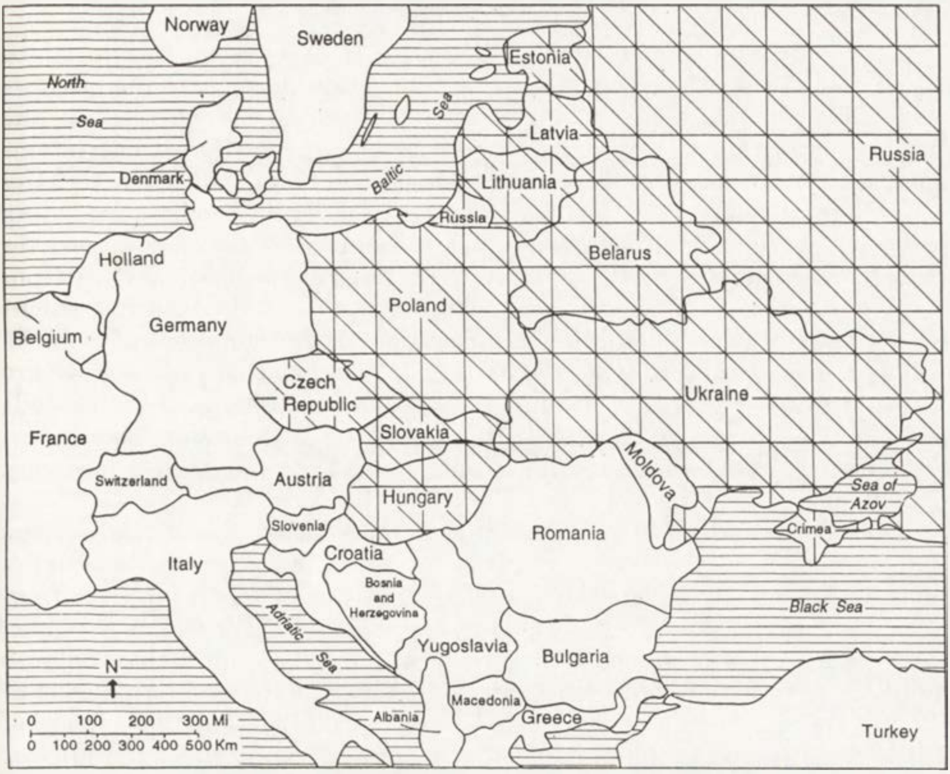

Fig. 1. Central and Eastern Europe in 1993. Representatives of shadowed countries presented in Nieborów their monitoring systems and declared eventual cooperation in FHM program

teristics on climate. The gradient of continentality runs along the east-west axis, with the greatest influence of the Atlantic in the west, and the greatest influence of the Asian landmass in the east. The north-south axis in characterized by cooling as one moves north (distance of approximately 2000 kilometers divides the south of Hungary from Estonia).

Another aspect giving a special flavour and significance to our programme is the fact that the patterns of land use in participating countries are experiencing a period of intence changes. In this part of Europe, great changes in afforestation, and in the ways of using forests, are likely to accompany changes in forms of ownership, and the clear prospect of a reduction in the amount of land designated for food production. In this period of transition it is particularly important to possess good and precise information about the structure and function of forest ecosystems in a critical area. It is also very important to produce modern maps of the area. We hope that we will be able to take a step forward in both of these fields.

And now to the last question over which we should pause for a while. At the same time as forests in Central and Eastern Europe are studied and monitored, selected similar studies will be carried out in the United States.

Will these studies be comparable? Of course it depends on the questions asked, but it will certainly be extremely interesting to compare the answers concerning the influence of anthropogenic stresses and climate on the functioning of forest ecosystems on both continents. All forest ecosystems have a certain number of identical structural and functional characteristics which permit comparison. However, the many different conditions existing between the Old and New Worlds rose a challenging set of questions for ecosystem ecologists. Similarly exciting for foresters will be questions concerning the reaction of forests to changing climate — along both the gradient of continentality and the thermal gradient, and in the conditions of both the Old and New Worlds. Thus, summarizing, it should be said that — if we are just able to ask good questions and to address them using modern methods and quality assurance criteria — there will be little cause for concern regarding the comparability of these ecosystems even though they are very distant geographically.

The significance of the Nieborów conference goes beyond the obvious contributions to furtherance of the goals of scientific cooperation and assistance in Poland. By incorporating the participation of representatives from other Central and East European countries, including: the Czech Republic, the Slovak Republic, Hungary, Ukraine, Estonia, Latvia, Lithuania, Belarus and Russia, this conference represented the first major step in expansion of the project to a truly regional scale where the unifying, applied theme of Forest Health Monitoring amplifies basic research problems of the project. The uniqueness of the forests of the individual countries, coupled with the vastness of the region under consideration, and some comparable points on the North American continent offer a valuable opportunity to develop long-term collaborative work of parallel importance to policy makers as well as to the scientific community. We are pleased that the Nieborów Conference opened up this window of opportunity and thank our many American and Polish colleagues for helping to make it happen.

REFERENCES

Grodziński W., Cowling E.B., Breymeyer A.I. eds., 1990, *Ecological Risks. Perspectives from Poland and the United States*, National Academy Press, Washington D.C. 415 p.

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More than one year later, the authors are pleased to report that many of the objectives started at the Nieborów Conference have now been achieved; including establishment of a FHM network in the three new Baltic countries, e.g., Estonia, Latvia and Lithuania, and plans for similar work to begin in Poland, Ukraine and Belarus in Summer 1994.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:13-64, IGSO PAS, Warszawa

FOREST HEALTH MONITORING PROGRAM IN THE UNITED STATES

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Abstract: The United States Department of Agriculture's Forest Service and the U.S. Environmental Protection Agency have initiated a multiagency Forest Health Monitoring program. This program has 4 main components — Detection Monitoring, Evaluation Monitoring, Intensive Site Ecosystem Monitoring, and Research on Monitoring Techniques. The focus of the program is to evaluate forest ecosystems for condition, changes, trends, causal agents, and mechanisms, thereby to assess the health of the U.S. forests. One goal of Forest Health Monitoring is to statistically estimate the current extent, status, changes, and trends in indicators of the condition of the nation's forest ecosystems, on a regional and a national basis, with known statistical confidence in the estimates. The FHM program also wants to monitor indicators of pollutant exposures and habitat condition, and seek associations between human-induced stresses and the ecological condition of the forests. Finally, the FHM program wants to be able to provide yearly statistical summaries and periodic interpretive assessments on the ecological status and trends to resource managers and the public. The evaluation of the condition of forest health is performed in Detection Monitoring through monitoring ecological indicators of forest condition that address ecosystem inputs, components, processes, and outputs. These indicators primarily focus on the soil, vegetation, plant, pathogens, and faunal components, and some processes, of the forest ecosystem. A probability based sample in Detection Monitoring allows determination of population response through cumulative distribution function analysis. Annual statistical summary of 12 eastern States in 1991, indicated 628 of 925 plots were forested, containing over 45,000 trees and seedlings of 100 species belonging to 10 forest types.

Key words: Forest Health Monitoring, forest ecosystems, indicators, pathogens, statistical evaluation, quality assurance, USA.

INTRODUCTION

This document is an overview of the cooperative, multi-agency national Forest Health Monitoring (FHM) program. The FHM program is headed by the United States Department of Agriculture's Forest Service, and the United States Environmental Protection Agency's (EPA) Environmental

Monitoring and Assessment Program (EMAP). This document is a compilation of many facets of the FHM program, which are in various stages of evolution in the program. It contains two primary sections; an overview of the FHM program, and some results from the 1991 Statistical Summary (Forest Health Monitoring 1992). It is intended to contribute to the technological exchange of information between the U.S. and Central and East European (CEE) countries, for monitoring the health of forest ecosystems.

Forests are an important part of the American culture, ecology, and economy. Currently about one-third (296 million hectares) of the United States is forested. Of this total, about 200 million hectares help to support forest products-related industries that employ over 18 million people and contribute over 5% of the gross national product (Forest Health Monitoring 1992). Forests everywhere provide important wildlife habitat, watershed protection, and recreational opportunities. These amenities are difficult to evaluate in economic terms, but their value is substantial, and in some cases priceless. Forests occur in a variety of environments ranging from near-deserts to wetlands, and they are a part of many national parks, wilderness areas, community parks, and greenways. Some forests are virtually untouched, while others are completely artificial. Forest lands are owned by the public, by businesses, and by private individuals. Nearly everyone has a personal experience with forests that helps to shape their expectations, and therefore perceptions, of what constitutes “good forest health”. American forests are an integral part of a global ecosystem that bestows and sustains the richness and productivity of life on our planet.

The health of the world forest ecosystems has gained increased public and political attention with current concerns about acid rain, global change, and a variety of insect, disease, and pollution problems. Monitoring of forests to describe their condition and identify changes that may be occurring, due to any causal agent, is needed to provide the factual information base upon which public policy and private ownership decisions can be made. Providing this information is the goal of the U.S. Forest Health Monitoring program.

The FHM program addresses the needs of the EPA’s Environmental Monitoring and Assessment Program for forest ecosystems (EMAP Forests). Participants in FHM include the National Association of State Foresters, Bureau of Land Management, Tennessee Valley Authority, Soil Conservation Service, Fish and Wildlife Service, and National Park Service (Fig. 1a). Although FHM is not yet established in all parts of the nation, it has already provided valuable information about forest health in some areas. Today, as more Federal and State organizations are joining the program, FHM is becoming a focal point for many efforts to understand forest health and to assess the impacts of natural and man-made stresses. In response to the diverse and growing public concerns about human impacts on our environment, FHM will provide a many-sided view of forest health, through diverse Indicators of forest condition, that will assist the public in setting priorities and making informed choices aimed at reducing the environmental risks of human activities.

The Forest Health Monitoring program is designed to provide information to help protect, manage, and use forest resources wisely. But monitoring alone can only provide information about the status and trends of forest health. The FHM program also supports more intensive monitoring that is intended to discover specific causal agents of change (Evaluation Monitoring), intensive site-specific long-term monitoring of processes to understand the mechanisms of forest ecosystems (Intensive Site Ecosystem Monitoring), and research to improve monitoring techniques (Research on Monitoring Techniques) (Fig. 1b). When the multiple aspects of forest ecosystems functions are well-understood, specific actions can be proposed to mitigate or prevent impacts. Detection Monitoring then can again be used to measure the effectiveness of any subsequent management actions.

Forest health monitoring is concerned with identifying early indications of systematic damage, by determining the current status of forest resources and tracking any changes in that status over time. This can be accomplished in Detection Monitoring by monitoring indicators of ecosystem structure and function, so that any widespread, fundamental changes in forest ecosystems can be identified in the early stages of development. Localized damage to forest ecosystems is intensely monitored in Evaluation Monitoring, to determine the causal agent(s) responsible for the damage. Intensive Site Ecosystem monitoring is designed to understand the fundamental mechanisms underlying the structure and function of forest ecosystems, so that predictive modeling of forest ecosystems can indicate the consequences of management actions. Research on Monitoring Techniques Activity supports the other three primary program components improving monitoring activities. This paper will primarily address Detection Monitoring, which at present is the most intensely developed component of the program.

DESIGN AND METHODS

SAMPLING APPROACH

Forest ecosystems in the United States cover approximately 1/3 of the land area, and range from subtropical forests in Florida to the boreal forests of Alaska (Fig. 2a). To monitor these forest ecosystems over large geographical areas, the FHM program has used the EMAP grid that consists of one large hexagon that covers the North American continent (Fig. 2b). Within this large hexagon are approximately 12,000 smaller (64,000 ha) hexagons, which contain 4000 ha (40 km^2) offset sampling hexagons, located 27 kilometres apart. There are approximately 4,200 sampling hexagons that are estimated to contain forest ecosystems (Fig. 2c). This basic EMAP grid

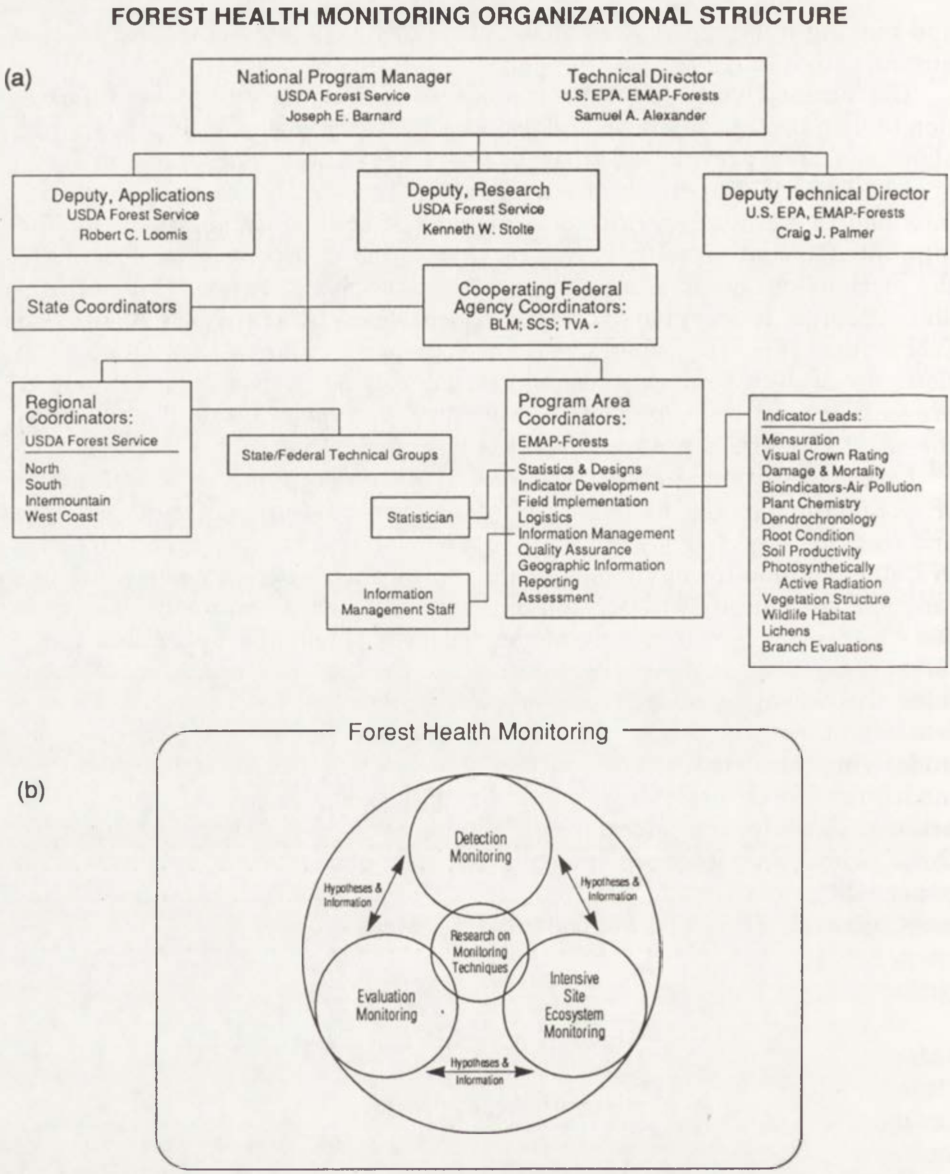


Fig. 1. (a) Organizational structure of the Forest Health Monitoring program, showing principal federal and state participants and program areas. (b) The four major interrelated components of the Forest Monitoring program

design can be intensified or detensified according to program goals, using multiples (intensify) or inverses (detensify) of 3, 4, 7, 9, and 11. The design is focused on regional, not plot-level, assessments of Indicators by using cumulative distribution frequencies (CDFs) analysis. The design allows for partial sampling of a proportion of the plots, commonly 1/3, 1/4, or 1/7, in a spatially robust design, while making inferences for the whole population. The nesting of the FHM sampling plots can be seen in Figure 3. The primary sampling hexagon (A), 4,000 ha (40 km^2) in size, contains smaller areas where aerial photography (1:12,000 and 1:6,000, respectively) samples the smaller 400 ha plot (B) and 100 ha plot (C) (Fig. 3a and 3b). Within these aerial plots is nested the 1 hectare ground sampling plot (D) (Fig. 3b and 3c). The nearest U.S. Forest Service's Forest Inventory and Analyses (FIA) photo-point plot to the random hexagon point becomes the Detecting Monitoring (DM) plot for that hexagon. A 1 hectare circle containing four smaller subplots (1/24 acre each) arranged in an inverted "Y" configuration become the DM plot at this point (Fig. 3c). Non-invasive (non-destructive) Indicators are sampled within the 4 subplots and nested 4 microplots, and invasive Indicators are sampled in the annular plot. A 2-6 person crew, depending on the number of Indicators, performs the sampling in a single day. Data is recorded on personal data recorders (PDRs), and samples are mailed each evening to appropriate laboratories for species identification and/or elemental analyses.

The ecological indicators are based on a conceptual model of forest ecosystem structure and function. These indicators are tested rigorously before becoming "core" indicators in the FHM program. The indicators must address criteria (Indicat or Development Criteria) relevant to overall program objectives and sound statistical sampling considerations. The Indicator Development Criteria are currently being addressed by all indicators in the FHM program. To date 4 Indicators, plot establishment/mensuration, crown assessments, biotic/abiotic damage, and biodiversity of overstory trees, have been deployed in 12 eastern and 2 western States.

The major elements of Detection Monitoring are:

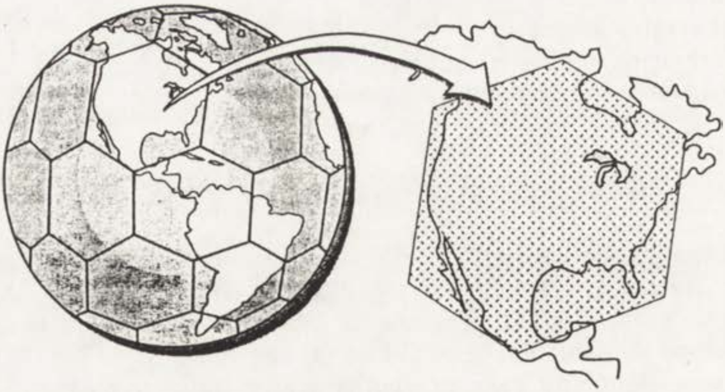
— development of policy goals
— assessment endpoints to meet policy goals
— quality assurance and control
— logistics
— training
— indicator development and testing
— plot establishment
— information management
— data analysis, reporting, and assessments.

STATISTICAL DESIGN

The statistical design for the FHM program presented here is taken from the 1991 Statistical Summary (Cassell 1992). Specific design criteria are essential to achieve FHM program objectives, and were realized in the design chosen by EMAP Forests/FHM (Overton et al. 1990). The design requires consistent and realistic representation of all ecological resources

(a.)

(b.)



(c.)

Fig. 2. (a) Areas in the United States containing forested ecosystems. (b) The global approach of EMAP, with one of the large hexagons covering most of the North American continent. (c) The basic EMAP triangular grid density of 27 km delineates approximately 4200 samples sites in U.S. forests

and environmental entities through the use of probability samples. The design is flexible to accommodate post-stratification and aggregation for many alternative subpopulations such as specific ecological units (e.g. forest types) or specific states (e.g. Maine), or other areas of special interest. It provides a mechanism to respond quickly to new questions or issues. The spatial distribution of the sample of any resource is arranged according to the population distribution of the resource. Periodic revisiting of all sampling sites is necessary. This design is periodically reviewed by a panel of the American Statistical Association, and is continually being researched and reviewed by EPA-EMAP, U.S. Forest Service, and other Federal, State, and private entities.

THE MONITORING GRID

The design uses a triangular grid so that the nation is tesselated (tiled) with hexagons, each covering approximately 635 km^2 (Cassell 1992). Within each 635 km^2 hexagon (a “635-hex”), another hexagon of approximately 40 km^2 (a “40-hex”) (Fig. 3a and 3b) represents a 1-in-16 sample of the resource. Each 40-hex represents a sample that will be characterized using remote-sensing techniques. Each 40-hex is uniformly offset from the center of the larger hexagon. Within a 40- hex, a point can be located on the ground where one plot, or a constellation of plots, can be physically established. On these plots, measurements are made to gauge the selected forest condition and stress indicators.

The national design provides for measurements at four-year intervals.

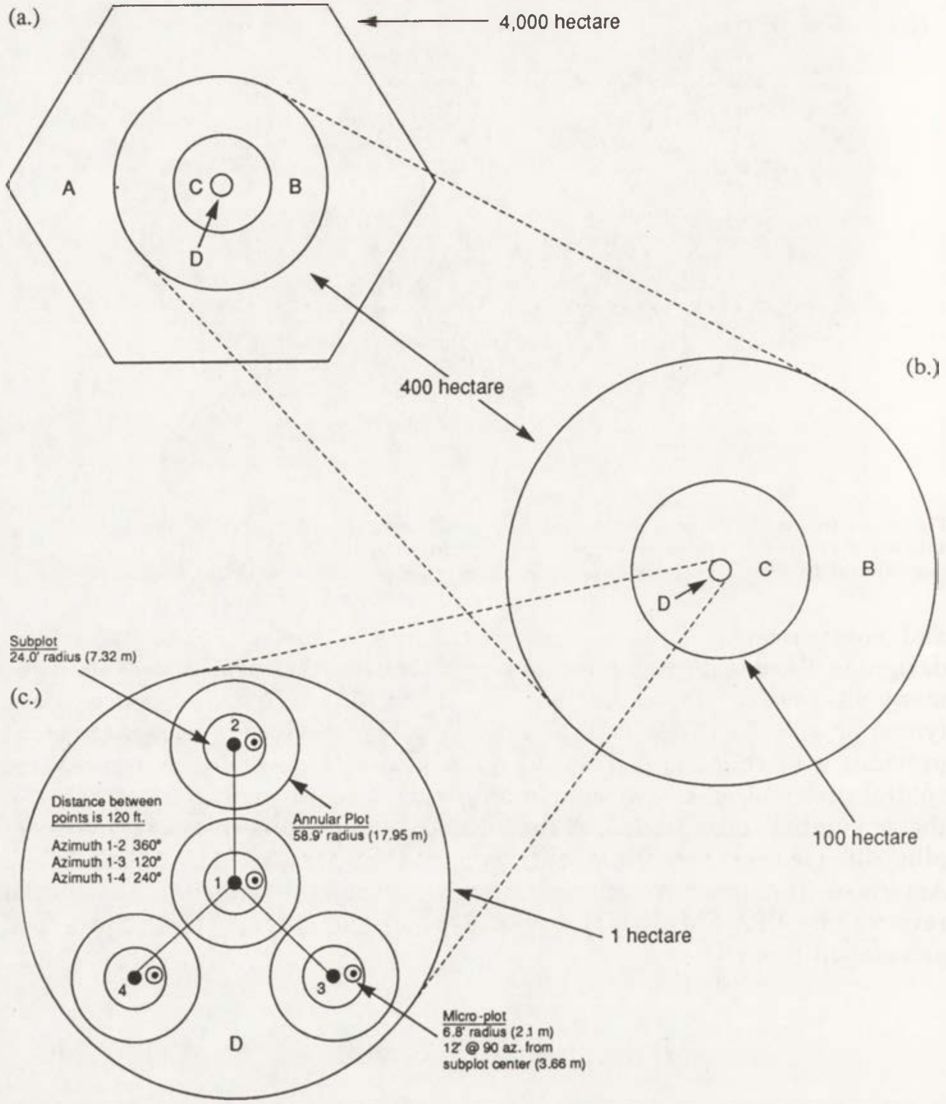


Fig. 3. (c) FHM 1 hectare Detection Monitoring plot. Non-replacement sampling of vegetation > 12.5 cm occurs within the 4-7.3 m radius acre subplots, and sampling of vegetation < 12.5 cm occurs in small 2.1 m radius microplots. Replacement sampling occurs in the larger 18.0 m radius annular plot

The plots measured in any one year are selected so that the spatial structure of the plots is preserved; in other words, so that the samples are spread uniformly over time and space. This arrangement of sites across space and time is often referred to as an “interpenetrating” design, or a rotating panel design. The design permits analysis using traditional Horvitz-Thompson procedures (Horvitz and Thompson 1952; Overton et al. 1990).

BENEFITS OF THE TRIANGULAR GRID

The triangular grid is systematic with a random start (Cassell 1992). The centers of the larger 635-hexagons have been randomly located by selecting a single random point in space, and moving the entire pattern so that an arbitrary hexagon center is on that point. A random point is then located within that hexagon, and the entire systematic grid of smaller 40-hexes is fixed by centering one of them on that point. The triangular grid is spatially compact, provides uniform spatial coverage, and is very flexible. The grid density can be altered easily, without destroying the overall temporal and spatial structure of the measurements. In addition, a triangular grid is less likely than a square grid to coincide with artificially linear features such as state boundaries.

In forestry, regular spacing of sample points generally leads to population estimates with smaller sampling variances than simple random sampling. The uniform spatial coverage means that for a given density, resources in the landscape are sampled in proportion to their abundance, area, and spatial pattern. Use of an interpenetrating sample and a fixed remeasurement cycle also means that this is achieved every year. The triangular grid allows a wide variety of grid magnifications and reductions, and it can handle special cases of subpopulations of special interest (e.g., forest ecosystems surrounding sources of air pollution).

EVALUATING STATUS AND CHANGE

There are several key issues in monitoring across both time and space (Cassell 1992). Current status is best estimated by including as many population units as possible, because greater coverage enhances the identification of subtle subpopulation differences. But detection of trends is best done with repeated observations of the same units over time, with the interval between observations chosen on the basis of the signal-to-noise ratio of the measurements. Observer effects can be important; too long a time between visits may mean that field measurements cannot be properly calibrated, while too short a time may lead to unwanted impacts such as trampling of the understory.

To answer questions about the condition of forest ecosystems, it is necessary to specify explicitly what set of forests will be analyzed. This set becomes the target subpopulation, the areal extent of forested ecosystem about which estimates of conditions will be made. Target subpopulations can be defined for any region or attribute. They serve two main purposes: 1) to increase the precision of condition and trend estimates by controlling extraneous variation, and 2) targeting specific sets of resources for reporting and assessment. The focus of the sampling design is regional assessments of forest health, focused on aggregating subplot-level data into a single plot-level datum point for analyses in cumulative distribution functions.

STRATIFICATION

The sample design currently used does not employ stratification (Cassell 1992). This topic continues to be debated because stratification is usually very useful for reducing sample variances, but no clear choice of stratification method has emerged from the debate. One argument against stratification is that if it is based on current resources, then distinctly non-optimal sample designs would be forced upon any future study of the same forest resource because forests normally change over time. In many cases, insufficient data are available to perform the proposed stratifications at the desired scale, and classification errors as small as 20 percent would erase any potential gains in precision. It is still an open question whether stratification can be applied effectively at larger scales in the immediate vicinity of ground plots.

SELECTION OF GROUND PLOTS

The field sampling involves the collection of FHM Detection Monitoring measurements that will be used to calculate values for forest condition indicators (Cassell 1992). One key feature is the statistical selection of ground plots so that the data represent a probability sample. In comparison with current and widely-used U.S. Forest Service Forest Inventory and Analysis (FIA) procedures, the FHM method of Detection Monitoring site selection is equivalent to selection of a single FIA photo point (i.e., stage one of the FIA multi-stage sample). This permits a linkage to the FIA statistical design. The FIA photo point grid for a region is overlaid on a 40-hex. Then the closest FIA photo point is selected. In cases where the selected photo point is already an FIA plot, the FHM plot will be offset from the photo point. This procedure was used in all but one of the states implemented in 1991.

Because the selected photo point is the one closest to the center of the 40-hex, and because the photo point grid is statistically independent of the EMAP/FHM hexagon grid, the probability of selecting that particular photo point is proportional to the area that photo point represents in the FIA sample design. To estimate this probability, the coordinates of the photo points around each hex center are entered into a data base and plotted on an equal-area projection map. Then, for the selected photo point, a geographic analysis system computes the area of all land closer to this point than any other photo point. The larger this area, the more likely it is that the hex center would fall in this area. The inclusion probabilities are calculated as a constant multiple of this area. Thus, inclusion probabilities are proportional to the area that the FIA photo point represents in the photo point grid. This means that the inclusion probabilities can be used to provide population estimates for all of our variables of interest.

Another approach is needed for the regions where FIA photo points are not available. In these regions, the ground plot can be located at a random offset and azimuth from the center of the 40-hex. These points are then added to the list of photo points that are interpreted by the FIA process. This "reversed" procedure was used in the one state that did not start with the FIA photo points as a sampling basis. Since the same probabilistic procedure was performed within each 40-hex, all ground plots in that state have the same inclusion probability.

GROUND PLOT STRUCTURE

Another key feature of the Detection Plot measurements is the flexible design of ground plots for multiple categories of measurements (Cassell 1992). The plot designs used in EMAP/FHM have been developed jointly by the U.S. Forest Service and the EPA, based on an optimally cost-effective plot design for FIA mensuration measurements (Scott 1991). A circular, one-hectare plot contains four fixed-radius (7.32 meters) subplots for field measurements. The subplots are arranged in an equilateral triangle with an additional subplot at the center of the triangle. The centers of the outer subplots are 36.6 meters from the center of the central subplot (Fig. 3c). This basic plot design has been evaluated for many indicators (Ritters et al. 1991) using sampling theory (Cochran 1977) to estimate optimal numbers of plots, subplots, and observations within subplots. The results suggested that the plot design was adequate for current FHM indicators, in the areas where FHM has been implemented. Furthermore, the indicators evaluated on the FHM plots are thus implicitly defined as being sampled over a specific area of forested land.

Fixed-radius plots have several advantages over the variable-radius plots that are used often in forest inventory. Variable-radius plots are more efficient for measuring the current status of characteristics that are correlated with tree size. But fixed-radius plots are generally more efficient for measuring quantities that are not correlated with tree size, which is the case for most FHM indicators. Another advantage is that change over time is more easily estimated by using fixed-area plots.

A subset of the total ground plot was sometimes used for a given measurement. In those cases, a factor was calculated to show what proportion of the plot was used in the analysis. This provided an expansion factor so that all variables could be summarized on an equal-area basis. Since only areal estimates were computed, this was combined with the inclusion probability for the plot to give an inclusion probability for the subset. Another alternative is to use multiple-stage sampling procedures.

For all estimates computed over the forested portion of the plot, the expansion factor was the inverse of the proportion of plot in forested conditions. For estimates computed over specific forest type groupings or crown groups, the expansion factor was the inverse of the proportion of the plot in that classification. For estimates based on individual tree species, the expansion factor was the inverse of the proportion of plot in forested conditions, multiplied by the inverse of the proportion of the plot's basal area covered by the specified species.

PROCEDURES FOR ANNUAL STATISTICAL SUMMARIES

Annual statistical summaries are produced each year, reporting on the analysis of data collected each summer from the Detection Monitoring plots. Detection Monitoring was conducted in 14 states in 1992, using 4 fundamental indicator groups; mensuration (structure, growth, mortality, and regeneration), crowns (dieback, transparency, and VCR structure), damage (biotic and abiotic), and biodiversity (richness, evenness, diversity). Twelve of the states are in the eastern United States, with Colorado and California being the only western states. Data from the 12 eastern states was subjected to analysis for the 1991 Statistical Summary (Forest Health Monitoring 1992). There were insufficient number of plots established in the western states in 1991 for any relevant analysis in that region.

Cumulative distribution functions (CDFs) were generated for plot-level Indicators aggregated from measurements collected at the ground plot locations (Fig. 4a). The estimated CDF at a value (x), equals the estimated proportion of the areal extent of the real resource being examined that has values less than or equal to x. The Horvitz-Thompson estimate of the CDF at x is then computed (details in Cassell 1992).

The approximate 90% confidence bounds about each CDF are calculated by assuming that the CDF estimates approximated normal distributions. The confidence regions are obtained as the estimated CDF value, plus or minus 1.645 times the estimated standard error of the CDF value. The standard error was computed as the square root of the estimated variance of the CDF value. In application, the variance estimates assumed a fixed sample size within each analyzed subset. The analyzed subset may have been the region as a whole, the area of a major forest type grouping within a region, or the area within a region covered by a particular tree species. For such subsets, the sample size is a random variable depending on the position of the sampling grid and the selection of the data stratification (major forest type, crown group, or tree species). This variance component has not been incorporated into the estimation procedures.

Additional analysis of populations organized by CDF analysis was obtained for the crown variables by setting thresholds, or cutpoints, at specific values of the Indicator (Stolte et al. 1992a). These thresholds are the points or ranges in an Indicator where current understanding of forest condition, and human valuations of those conditions, are used to categorize the forest ecosystem populations into nominal and subnominal proportions. Additional analysis of each of these two major population groups is accomplished by set-

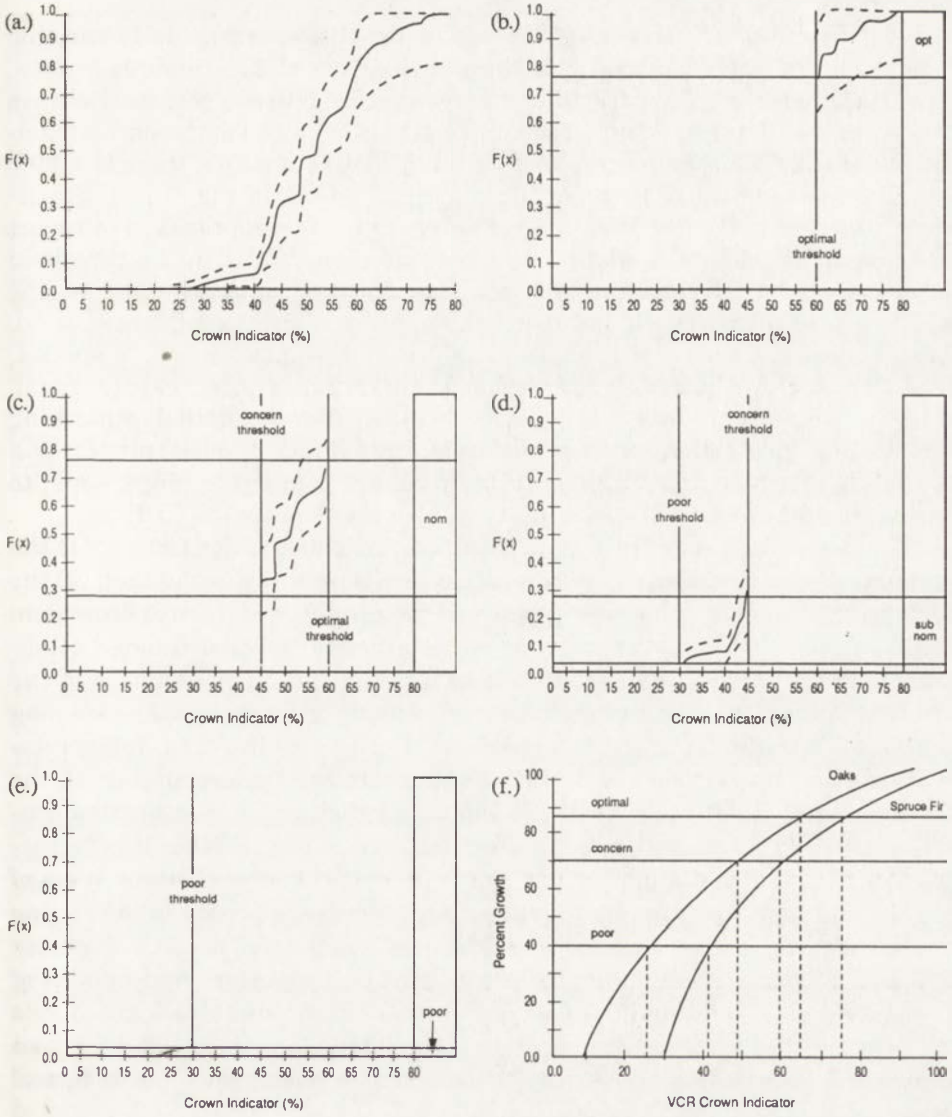


Fig. 4. Cumulative distribution function analysis of plot-level Indicators. (a) A representative CDF for any crown Indicator. (b) Setting a concern threshold that separates population into nominal and subnominal segments; bar indicates 90% confidence range for estimates (same for nominal and subnominal segments). (c) Nominal segment of population delineated. (d) Subnominal segment of population delineated. (e) Optimal threshold delineates and optimal proportion of the nominal population, with 90% confidence range bar. (f) Poor threshold delineates a poor proportion of the subnominal population, with 90% confidence range bar

ting an optimal threshold within the nominal proportion to delineate an optimal group, and a setting of a poor threshold in the subnominal group to delineate a poor condition proportion. The breakpoint between population proportions occurs at the point where the threshold intersects the CDF curve. The exact value or range of values for these thresholds is variable within an Indicator, according to the stratification of the resource groups, i.e., thresholds may differ for different tree species, forest types, etc. Because the threshold intersects the estimated position of the population distribution, and the 90% confidence bounds around that estimation, there is a 90% confidence bound range for any population proportion. In the Annual Statistical Summaries (Forest Health Monitoring 1992), the approach is to report the proportion of the population as the value observed when the threshold intersects the CDF, and the 90% confidence range as determined by the points where the threshold intersects the upper and lower confidence bound. For analysis of crown condition, the analysis of a population (e.g., a species, forest type, crown group) is accomplished by setting 3 thresholds (optimal, concern, poor) to produce 4 proportions of populations (nominal, containing an optimal proportion; and subnominal, containing a poor proportion). Separating each population proportion was a 90% confidence range, equal to the width of the 90% confidence intervals above and below the CDF.

The determination of health or condition has three major factors: (1) the estimate of the condition of the resource at the time of the evaluation; (2) the interpretation of the relationship between the condition and forest ecosystem function; and (3) the anthropogenic values ascribed to the estimated condition, based on the working definition of forest health. The estimate of the condition of forest ecosystems is determined by the efficiency of the sampling approach, and the accuracy and precision of collecting the data. Interpretation of any condition is controlled by the current understanding of the functioning of forest ecosystems. The human valuation of an estimated condition is based primarily on human use of the resource, whether it is recreation, aesthetics, or commodity use that's intended. In the CDF analyses of crown condition, we attempted to take a conservative approach in the setting of CDF thresholds, recognizing that "healthy" values for density, diameter and the other crown variables are dependent on the nature and habitat of the individual species and the past and present, biotic and abiotic conditions at a site. Within a species we recognized that individual trees will differ in a realistic determination of "healthy" based on size class, crown position, and other habitat characteristics of a stand.

The CDF thresholds set for crown assessments were the best estimations of values for species, forest types, and crown groups, within the open-grown, dominant, and codominant crown position classes. Additional refining of thresholds will occur in subsequent years, as information accumulates on the relationship between crown condition and growth and/or aesthetic appearance of trees. For most crown variables, the CDF thresholds set were consistent with the general trends of the VCR model (Anderson et al. 1992b). The CDF thresholds differed from the VCR model values in two ways:

The CDF concern threshold divided the population into two major classes (nominal and subnominal). Proportions of these 2 major categories were then delineated by 2 additional thresholds: optimal proportion defined by an optimal threshold set within the nominal proportion of the population; and a "poor" proportion defined by a "poor" threshold set within the subnominal proportion of the population. The VCR model contains three classes or proportions, defined by two breakpoints.

The CDF thresholds were generally more conservative. In most cases the CDF concern threshold, dividing the population into nominal and subnominal proportions, was set in the range of average and good classes in the VCR model. That is, some of the values in the subnominal class in the CDFs would fall in the average class in the VCR. The plot level Indicator averages in the CDFs generally had a more narrow range than the tree level values used in the VCR model. Tree level values were more broadly distributed (e.g., 10-100 for crown density) than plot-level averages (range 20-80 for crown density); consequently few plots were optimal for crown density.

MENSURATION

The data from the 12 states was divided into Northeast and Southeast states (Droessler 1992), for an Annual Statistical Summary (1992). The Northeast states were Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut. The Southeast states were New Jersey, Delaware, Maryland, Virginia, Georgia, and Alabama.

The Northeast and Southeast data sets were divided into major forest groups. The major forest groups were partitioned as follows: the pine group consisted of the white, red, and jack, longleaf-slash, and loblolly-shortleaf pine groups; the spruce-fir group consisted of spruce and fir; and the hardwoods/miscellaneous group took in the remaining categories. The species groups were originally further subdivided (e.g., the longleaf-slash pine group), but the sample sizes were too small to be meaningful.

Only forested land use portions of subplots (wholly or partially) were included in the calculations. Each subplot was considered a sampling unit. Basal area by forest group was first calculated by subplot and then expanded to a hectare basis before calculating the mean for the plot. If basal area of a particular forest group was present on only one of the four subplots, the basal area values for that forest group on the other three subplots were included as zeros in the calculation of the mean basal area. The calculations were conducted as follows.

First the basal area (m^2) was calculated by forest group for each subplot. The condition number was used for subsetting to a forest group. Next the forest group basal area was expanded to a per hectare value by multiplying by the subplot per hectare expansion factor (approximately 59.48). A weighted mean basal area (m^2/ha) was then calculated by forest group over the four subplots. The weight used in the numerator was the fractional area of each forest group for each subplot calculated by summing the fractional area percents (area percent divided by 100) by condition number. A weight of

1.0 was used if the whole subplot had a forested land use and was of a particular forest group. It was possible for a plot to have zero basal area if it was classified as a forested land use with a forest type identified, but there were no trees greater than 12.7 cm DBH present.

The denominator in the weighted mean was the total area over the four subplots classified as forested land use (maximum of 4.0). The sum of the weights in the numerator for a particular forest group equalled the denominator only if all forested area on all subplots was of a particular forest group. The mean basal area for a forest group represented an observation for calculating a CDF. The CDFs can be used to determine the cumulative probability of the relevant forested population that has a basal area equal to or less than a specified level. Additional details can be found in Droessler (1992).

BIODIVERSITY OF OVERSTORY TREES

A series of diversity measures were selected for evaluation of open-grown, dominant, and codominant trees (Cline 1992). The series consists of diversity measures based on the number of species present (S), the exponent of Shannon's index ($e^{H'}$, Shannon and Wiener 1949), and the reciprocal of Simpson's index (1/D, Simpson 1949), and represents various symbolic measures of the number of species present based on different levels of analysis of their rarities (Hill 1973). The highest diversity values are measured using S, because it includes species presence without regard to rarity. The lowest diversity values are derived from 1/D because it weighs the abundant species more heavily than rarer species. Intermediate diversity values are obtained using $e^{H'}$ because it weighs rarer species more heavily than 1/D. Additional details can be found in Cline (1992).

Overstory tree species diversity values based upon S, $e^{H'}$, and 1/D were calculated for each plot. Species richness (S) was expressed as species density, the number of tree species >12.7 cm DBH per 672 m^2 (the total area of a plot). The Shannon (H') and Simpson (D) indices were calculated from the relative abundance (pi) of each tree species >12.7 cm DBH on the plot. In this analysis, the pi values were the weighted mean basal area in m^2/ha. First the basal area of each tree >12.7 cm DBH was calculated in m^2, which was then multiplied by an expansion factor (ca 59.48) to estimate basal area in m^2/ha. Next, basal area of each tree was summed by species on each subplot and multiplied by a weighting factor based on the percent subplot area forested. Then the weighted basal areas of each tree species were summed across subplots, and divided by the total percent area forested. Finally, each species-specific mean weighted basal area was divided by the mean weighted basal area of all trees on the plot. When trees >12.7 cm DBH were absent on the plot (i.e., basal area was zero), S, $e^{H'}$, and 1/D were all set to zero.

Both $e^{H'}$ and D are sensitive to changes in species richness (S) and to the evenness of the distribution values among species. H' increases with species richness from a minimum value of 0 when only one species is present. For a given number of species, the maximum value of $^{H'}$ is obtained when all species are equally abundant; $^{H'}{}_{max}$ equals ln(S). The value $e^{H'}$ is the number of equally abundant species equivalent to the sample diversity $^{H'}$. In contrast, D increases as species richness decreases. The maximum value of D = 1.0 is obtained when one species is present. Similarly, the value 1/D is the number of equally abundant species in a sample with a dominance of D, and is comparable to $e^{H'}$. In comparison to $^{H'}$, D is less sensitive to changes in the abundance of rare species of the community.

The baseline status of overstory tree species diversity in NE and SE regions was expressed using cumulative distribution functions. A CDF characterized the regional variation in overstory tree species diversity in 1991. In each region a CDF was constructed based upon the diversity values using S, $e^{H'}$, and 1/D. The CDFs were analyzed for intra- and inter-regional patterns.

While a statistical summary cannot be used to infer cause and effect relationships, associations among variables can be explored. For example, what are the predominant characteristics of the forest population with relatively high overstory tree species diversity values? How do these features contrast with conditions associated with low diversity values? Consequently, an exploratory analysis of the association of $e^{H'}$ diversity values and forest type group, stand origin, stand size class, disturbance history, and condition code was conducted in each region. First the range of $e^{H'}$ diversity values was divided into five categories (range in $e^{H'}$ values): none (0), very low (> 0-1), low (> 1-3), medium (> 3-5), high (> 5). Then for each variable, the proportion of sample plots within each diversity and forest condition category were determined. The trends based upon $e^{H'}$ diversity as representative of trends based upon S and 1/D diversity values.

CROWN AND BOLE DAMAGE

Summaries of significant pest activity observed in the eastern United States in 1991 was compiled by forest type and specific agents (Anderson et al. 1992b). The data was organized by major forest type group, and by native or introduced pest within forest types. Detailed information was provided for hemlock woolly adelgid, hemlock loopers, eastern spruce budworm, fusiform rust, southern pine beetle, littleleaf disease, gypsy moth, oak decline, beech bark disease, and dogwood anthracnose. Brief summaries were given for other pests. The information was compiled from state forestry and agriculture agency reports, from Forest Service research, inventory, and Forest Pest Management data bases such as the Southern Pine Beetle Information System and Forest Inventory and Analysis, and from Forest Health Protection information.

CROWN ASSESSMENTS

In 1991 the Forest Health Monitoring (FHM) program directed the evaluation of the crown condition of all forest species trees found on the 4 subplots within the 1 hectare Detection Monitoring Plot. Morphological determinations of crown and bole condition were made on all forest trees with diameters at breast height greater than 12.7 cm, that occurred within the bounds of these 4 subplots. Measurement and estimation of variables to describe the condition of a tree crown have provided reliable information on the growth characteristics of trees. In the eastern U.S., crown diameter has been related to the size of hardwood trees (Francis 1986; Sprinz & Burkhart 1987), and crown density related to the growth of loblolly pines (Grano 1957; Anderson & Belanger 1987; Anderson et al. 1992b; Belanger & Anderson 1991). In the western U.S., crown ratio and crown density have been related to growth and survivorship of conifers (Dolph 1988). Other crown variables, like dieback, transparency, and density, can be related to insect defoliation and subsequent growth and survivorship effects on both conifers and hardwoods (Kulman 1971; Schmitt et al. 1984). As part of the 1991 FHM field activities, tree crowns and boles were evaluated in 12 eastern States by recording the crown position, crown ratio, crown density, crown transparency, crown dieback, crown diameter, damage (crown, bole, and exposed roots), and bole growth at breast height.

Crown position refers to the relative position of the tree crown in a stand of trees. The five crown positions often utilized to stratify crowns are: open grown (crown exposed to sunlight on all sides); dominant (tree crown above the general height of the stand; some of the sides of the crown in direct sunlight); codominant (tree crown about the same height as the general height of the stand; top of crown exposed to direct sunlight); intermediate (tree crown generally below height of the stand; very top of crown may see some direct sunlight); suppressed (tree crown far below the general height of the stand; tree crown may never be exposed to direct sunlight). Crown position can be used to stratify analyses, i.e., the crown condition of healthy, open grown, dominant, and codominant trees can be expected to be very different from the crown condition of healthy intermediate and suppressed trees. In this section, all plot-level cumulative distribution function analyses are done on open grown, dominant, and codominant trees because more is known about the relationship between crown condition and health of this group. CDF thresholds have not been set for intermediate and suppressed trees at this time. Intermediate and suppressed trees typically grow poorly under normal forest conditions, except for the more shade-tolerant understory species, and often die sooner than other trees in a cohort, unless released from competition by death of the overstory trees. The fastest growing trees are most often limited to the open-grown, dominant, or codominant crown positions.

Crown ratio is the percentage of the entire tree bole, from the ground to the top of the tree, that supports living foliated canopy that is contributing to the vigor and growth of the tree. It is length of the bole that is foliated (X), divided by the total length of the bole (Y). It also forms part of the basis for crown density. Crown ratio (X/Y) can be measured with a clinometer, but in FHM it is estimated. Crown ratio is estimated in 5% classes, with a range of 0-100%. Crown ratio in some western conifers is reduced as a result of chronic exposure to ambient ozone (Stolte et al. 1992b). A high live crown ratio score increases the potential for carbon fixation and nutrient storage.

Crown density is the 2-dimensional appearance of fullness of the crown when ideally viewed against the sky. It basically estimates how much of the sky is blocked from view by the upper tree bole, branches, foliage, and any reproductive structures (e.g., cones). It is the area bounded at the top and bottom by the live crown (X). The sides of the crown are defined by a line connecting the branch tips on the widest, fullest side of the crown. The other side of the crown is then mentally constructed by projecting a mirror image of the widest, fullest side of the crown (a symmetrical crown is constructed). In this way crown density is based on the potential of the crown to be symmetrical in outline, as can often be observed on open-grown trees. The symmetrical crown is defined by the shape of the widest, fullest side of the crown when the evaluation is performed. This approach is taken based on studies by Anderson and Belanger (1987) that have shown that trees with less than full crowns (e.g., half the crown missing on one side due to competition from a neighbouring tree) have reduced growth rates compared to trees with full, more symmetrical crowns. Using this method a tree crown that is 100% dense on one side (no sky can be seen through the crown) and has the other side of the crown missing due to shading from an adjacent tree, would only score 50% for crown density. Consequently we recognize that when we report on crown density we are evaluating the effects of normal tree competition on this variable, in addition to any other factors that may be causing reduction in branches, foliage, and/or cones. Crown density is estimated in 5% classes, with a range of 0-100%. Trees that have a high crown density score increase the potential for carbon fixation and nutrient storage, suggesting a lack of defoliating agents that attack new and older foliage, and generally low, random branch mortality.

Crown transparency refers to the amount of sunlight that passes through the foliated portions of the tree crown. Transparency ignores holes in the tree crown that are due to lack of branches. Transparency partially overlaps with crown density, since the foliage contributes to crown density. The difference lies in the emphasis on foliage. A tree could have only 1 branch that had thick foliage on the branch. This tree would score poorly for crown density (and live crown ratio and diameter), but would score well for crown transparency, i.e., it would have a low foliar transparency. Crown transparency is estimated in 5% classes, with a range of 0-100%. Trees that have a low crown transparency score increase the potential for carbon fixation and nutrient storage, and indicate a lack of defoliating agents that attack new and older foliage.

Crown dieback refers to the mortality of relatively new branches (less than 2.5 cm in diameter) that are in the upper, sunlight-exposed portions of the crown. The premise is that these branches have died from some stress other than the normal branch mortality that occurs from shading. In open-grown trees, crown dieback can occur on most of the crown. On codominant trees, crown dieback is confined primarily to the top and upper sides of the crown that are exposed to direct sunlight. Crown dieback is estimated in 5% classes, with a range of 0- 100%. Trees that have a low crown dieback score increase the potential for carbon fixation and nutrient storage, and indicate a lack of defoliating agents that attack new foliage.

Crown diameter is the measured average of the widest part of the crown and the 90° perpendicular axis to the widest part of the crown. It is measured by standing under the estimated drip line of the crown at the two axes described. Crown diameter is affected by stand stocking (basal area per unit area), and has been associated with tree growth. Crown diameters are measured to the nearest 25 centimetres. Crown diameters vary naturally with species; some species have wide crowns and others have narrow crowns. Diameters were analyzed in this report as a percentage of the maximum plot-level average for each species, so we evaluated the crown diameters with respect to the largest plot-level average tree crowns for the species. Trees that had a high percentage of the maximum crown width increased the potential for carbon fixation and nutrient storage.

A visual crown rating (VCR) model was developed by Anderson et al. (1992b) to describe the crown condition of individual trees as a composite of all the crown variables. The VCR was calculated at the tree level, and then averaged to a plot-level score. The VCR model placed each crown measurement, by tree, into categories or classes of good (1), average (2), or poor (3). The various crown variable classes were then aggregated, and the aggregated values were classified by a decision-tree process into an overall tree condition. There were four tree condition classes: good (1), average (2), poor (3), or very poor (4). The range of VCR values therefore was from 1-4. Trees with low VCR values have crowns that are in the best visual condition. Current crown indices under development include an additive index with variables weighted by current population estimates, that also factors in the effects of stand stocking through the use of competition indices. These indices will generally address the structure of the tree crown (diameter, ratio, and density), and the defoliation of the tree crown (density and transparency), and will consider the effects of stand stocking on crown variables that are particularly influenced by tree competition. A third crown indices will look at all 5 crown variables simultaneously, but will also be adjusted for effects of stand stocking.

The 5 crown variables, currently monitored in 12 eastern and 2 western states in the United States, are analyzed using descriptive (tables; frequency distributions) and comparative (cumulative distribution functions) statistics. All determinations are made on plot-level averages (estimated to the 1-hectare plot size), calculated by estimations of data from the four FHM subplots. The plot-level values are then evaluated for frequency distribution, and the most common species, forest types, and crown groups were analyzed using CDFs (Fig. 4a). Crown groups are aggregations of species based on similar crown characteristics (e.g., long needle pines; oaks) (Anderson & Millers 1992). Populations described by CDFs (forest types, species, crown groups) were delineated into 4 population proportions of nominal, optimal (a subset of nominal), subnominal, and poor (a subset of subnominal). These population proportions were delineated by 3 thresholds (optimal, concern, and poor), where such information was available based on the relationships between crown condition and growth, or expert opinion. Once the population was delineated into the 4 crown condition categories (optimal, nominal, subnominal, or poor), proportions of populations in each category were identified as to plot location. The population proportion of a region were then evaluated in the context of a regional condition, which can be spatially compared with numerous natural and anthropogenic influences through a geographical information system (GIS). Additional details can be found in Stolte et al. (1992).

CROWN MEASUREMENT QUALITY OBJECTIVES

To evaluate the relevance of the crown data analyses, it is necessary to understand the accuracy and precision of the crown estimates (position, density, dieback, ratio, transparency, damage) or measures (diameter), and the desired remeasurement precision. Table 1 provides an overview of those measurement quality objectives (MQOs). More detail on the QA/QC process are found in Byers and Palmer (1992).

Table 1. Measurement quality objectives (MQOs) for the five crown variables (ratio, density, transparency, dieback, diameter), crown position of trees, and bole and crown damage variables. For all crown variables, DQOs were met more than 90% of the time

Sample Tree Variable	Measure Accuracy[1]	Audit MQO[2]	MQO[3]
Ratio	5%	± 10%	90%
Diameter	30.5 cm	± 91.5 cm	90%
Density	5%	± 10%	90%
Dieback	5%	± 10%	90%
Transparency	5%	± 10%	90%
Damage	+/-	ND	ND
Position	1 class	ND	ND

[1] The minimum level of measurement or estimation for a variable.

[2] The measurement/estimation should be within these limits.

[3] The measurement/estimation should fall within the MQO at least 90% of the time.

ND = Not Determined; no MQOs for these variables in 1991.

CUMULATIVE DISTRIBUTION FUNCTIONS

Cumulative distribution functions (CDFs) are calculated to evaluate the distribution of any Indicator across the population sampled (Fig. 4a). Cumulative distribution functions are calculated for large regional expanses (e.g., eastern U.S.), or aggregated into smaller regional evaluations such as:

— Ecoregions
— States
— Forest types
— Other: research area associations like Southern Appalachian Man and Biosphere; wilderness areas; national forests and parks.

The area must be large enough to contain enough plots to calculate CDFs. Based on criteria developed for indicators (see Regional Accuracy below), 50 plots are currently the minimum for calculation of CDFs.

In the 1991 Statistical Summary, CDFs were calculated for:

— Species: based on the Society of American Foresters (SAF) species designations. Cumulative distribution function analysis was performed on species found in ≥ 50 plots.

— Forest types: based on the Society of American Foresters(SAF) grouping of species to define a forest type. Cumulative distribution function analysis was performed on forest types found in ≥ 50 plots, except for the red spruce-balsam fir forest type which was found in less than 50 plots. This was done because of the current concern for the health of this forest type.

— Crown groups: Crown groups are based on similar crown characteristics (Anderson & Millers 1992) with regard to evergreen, or deciduous habit, size of foliage, and general crown morphology. Examples are small leaf hardwoods spruce-fir, compound leaf hardwoods, long needle pines, etc. Crown groups include individual species that were found in ≥ 50 plots.

THRESHOLDS IN CDFs

A CDF threshold, or breakpoint, is defined as the value (or range in values) in the population distribution of a variable, where some significant change in response or value related to forest condition is believed to occur. A threshold can be viewed as any human-derived valuation of forest condition. These thresholds therefore are key components in assessing forest health. Thresholds set for the Crown Indicators separate the population distribution determined by CDF analysis (Fig. 4a) into acceptable (nominal; Fig. 4b and 4c.), questionable (subnominal; Fig. 4b and 4d), exceptional (optimal; Fig. 4e), and undesirable (poor; Fig. 4f) population proportions.

Thresholds should be based on reasonable and consistent criteria for all species, forest types, and crown groups within any condition class of interest. Any criteria developed for setting thresholds should address a relevant societal value. Two conceptual approaches for setting thresholds for crown variables, that relate to defined FHM societal values, that could be taken are:

(a) Tree growth/survivorship relationship to crown condition:

— Based on experimental data relating tree height or basal area growth to the condition of the tree crown;

— Based on expert opinion (>10 years experience in research/monitoring the relationships between tree crowns and tree vigor);

— Addresses productivity and biodiversity.

(b) Visual appearance of the tree:

— Expert or public opinion (perception of healthy trees);

— Addresses aesthetics.

The choice of method for delineating thresholds in CDF analysis depends on the need of the user of the information. Industry may be interested in forest productivity and, consequently, thresholds based on growth would be the most meaningful. Alternately, the public may be primarily concerned with aesthetics, and thresholds based on the visual appearance of the crown may be more meaningful. Another group, such as foresters, may be interested in both growth and the visual appearance of the tree crowns. A limitation to both approaches is the lack of data on the relationship between crown condition and growth or appearance that may be currently available from the literature. In comparing thresholds set for productivity and those set for aesthetics, we must recognize that large differences in the perception of health of a forest may occur depending on the type of threshold used. It is likely for most species and forest types, that thresholds for aesthetics will be more conservative than thresholds for growth; the visual appearance of the tree may become undesirable well in advance of any negative, discernible growth effects. In general, we can expect aesthetic determinations to be more rigorous than growth determinations. In the analysis of Annual Statistical Summaries, thresholds were based on known or suspected relationships between crown condition and tree growth and/or survival (Anderson et al. 1992b; Belanger & Anderson 1991).

Ultimately we would like to have data on the growth-crown condition relationships for all common species (identified in the frequency distribution analyses), as forest growth is probably a better estimate of productivity, sustainability, and resiliency than is visual appearance (aesthetics). The thresholds based on growth effects may be determined by:

— Specific growth studies where crown condition estimates are compared to tree growth rates;

— Existing models of crown condition and growth; values set for variables in those models;

— Published, peer-reviewed literature;

— Estimates by scientists; weighted by years experience working with the species, forest type, etc. of interest.

In the 1991 Statistical Summary (Stolte et al. 1992a), three thresholds were set in the Crown Indicator CDFs: poor, concern, and optimal. The three thresholds, and the effects on delineation of the population due to the placement of the thresholds, can be seen conceptually in Figure 4 (4b-4f). Since each threshold value intersects the confidence bounds for the CDF, each threshold also defines the range of the 90% confidence bounds, which are equal to the width of the CDF confidence intervals. It is the length of the threshold line from the top confidence bound to the bottom confidence bound, where the threshold intersects the CDF and confidence bounds (Fig. 4b-4f). A brief discussion of the purpose of each threshold and its effects on the population follows:

(a) Concern thresholds:

— The value (or range of values) where we become concerned about the plot-level averages measured or estimated for an Indicator; the threshold where we feel, based on growth data and/or expert opinion, that the species, etc. may begin to be stressed to a degree that is detrimental, e.g., beginning to stretch the resources of the tree and affect the resiliency of the tree.

— Setting concern thresholds breaks the population into nominal and subnominal portions, with a 90% confidence range for the delineation. The size of the 90% confidence range depends on the width of the confidence interval around the CDF (Fig. 4b-4f), and the range in values, if any, for the concern threshold. Both factors contribute to the width of the 90% confidence range.

(b) Optimal thresholds:

— The value (or range of values) that separates out a subset of the nominal proportion into an optimal proportion. This optimal proportion represents the segment of the population that is in superior condition, relative to plot-level values that can be expected for species, forest types, or crown groups, within a given stand condition class.

— Setting an optimal threshold delineates the optimal proportion of the population. The 90% confidence range for this delineation is based on the same factors discussed above for concern thresholds.

(c) Poor thresholds:

The value (or range of values) that separates a subset of the subnominal proportion into a poor proportion. This poor proportion represents the segment of the population that is in serious condition. These plot-level species, forest types, or crown group values are considered to indicate a high probability of mortality, either as a direct result of the causal agent, or the causal agent rendering the trees highly vulnerable to other forest stresses.

— Setting a poor threshold breaks delineates the poor proportion of the population. The 90% confidence range for this delineation is based on the same factors discussed above for concern thresholds.

The width of the 90% confidence range for all population proportions depends also on where the thresholds are placed in relation to the curve of the CDF. If a threshold occurs where the slope of the CDF curve is steepest, then the 90% confidence range will be increased, since the distance between the upper and lower confidence bounds are greatest when the slope is greatest. For example, compare the width of the 90% confidence range for the optimal and poor proportions in Figures 4e and 4f.

SETTING POOR, CONCERN, AND OPTIMAL THRESHOLDS

The values selected for CDF thresholds in this report are derived from the Visual Crown Rating (VCR) model, a classification model developed by Anderson et al. (1992b). The VCR model is based on relationships between crown condition and growth, derived from the literature and expert opinion on crown condition relationships to tree growth. The VCR model aggregates all the crown variables into a tree-level score that describes the overall crown condition. These tree-level index values are then averaged to give a plot-level value (an Indicator) for species, forest types, or crown groups. Since it is difficult to determine dieback and density once transparency reaches high levels (>50%), there is a subroutine in the VCR model to calculate crown vigor for trees that have high transparency scores. The values proposed for the VCR model were the basis for the CDF threshold values used in this report. The determination of the health of tree crowns is based on expert opinion of foresters with many years of experience working with the species found in the eastern forests, and their evaluation of crown health reflects what is "normal" for each species (i.e., they recognize that some species normally have less dense crowns, small live crown ratios, etc.). Most of the values in the VCR are based on crown condition and growth relationships and/or survival. Therefore, although the thresholds proposed for the CDFs in this report are not solely based on functional relationships between crown condition and tree growth/survival, they do broadly reflect those relationships. That is, thresholds set to delineate the subnominal proportion of the population can be reasonably expected to infer reduced growth for those population proportions of the species, forest type, or crown group under consideration. Comparison of the CDF thresholds for all crown variables in this report with the classification values used by Anderson et al. (1992b) in the VCR model can be seen in Figure 5. At this point in time we do not have sufficient data to set thresholds unique for species, forest types, or crown groups for any crown variables except crown density. The threshold values for crown density, specific for species, forest types, and crown groups in the 1991 Statistical Summary, are summarized in Figure 6. In general, the values tend to follow a gradient of lower thresholds to higher thresholds as the tree species, forest types, and crown groups change from those with naturally dense crowns (e.g., spruce and fir) to species with naturally thinner crowns (hardwoods with compound leaves).

Although there are known relationships between crown diameter and bole growth (Francis 1986), we are confronted with the same difficulty in setting thresholds for crown diameters that we would be with setting thresholds for DBH. It is difficult to say what constitutes a nominal or subnominal crown diameter or bole diameter. Small bole diameters or crown diameters means there are small trees, which may be very normal depending on the successional stage of the stand, or the intended landuse for the stand. Currently, tree-level crown diameters are compared to the cumulative distribution (CDF analysis) of tree-level crown diameters in the population. The percentage of population that corresponds to the tree-level value, becomes the scaled, tree-level value for that tree. In this way tree diameters are evaluated over a 0-100 percent range. Tree level scores are then estimated up to a plot-level average for CDF analysis.

We decided to use a single value for each threshold since these values are intended to represent a range of values for a range of species. We did not feel we had sufficient data to calculate any “confidence bounds” for the threshold values, and question the appropriateness of confidence bounds when these values are intended to be generic and represent a wide range of species. It may be more appropriate to calculate uncertainty around a threshold value when those values are based on growth responses and appropriate data are available to make such a calculation feasible. The threshold values in this report were slightly adjusted relative to the VCR values (Fig. 5 and 6), taking a more conservative approach to setting thresholds, since we recognize that the VCR values were set for individual trees, and in the 1991 Statistical Summary CDF threshold values were based on plot-level means. We recognize the need to obtain much more information on the relationship between tree crown condition and tree growth (shoots and roots) and survivability. By setting thresholds, we were able to make inferences concerning the status of the forests in 12 eastern states based on the 1991 data, and will be able to track changes in the stat us of the forest over time.

PLOT-LEVEL DATA AND GIS

The proportion of the population for each crown variable was characterized as nominal (includes optimal subset) and subnominal (includes poor subset). These population proportions were then illustrated by making the size of the proportion symbol (“weight”), representative of the plot-level estimate, i.e., the representativeness of the species, forest type, or crown group at a plot was dependent on how common the species was in the plot, the inclusion probability for the plot, and the expansion factor for the species found at the plot. As such the size of the symbol represents the relative confidence in the estimate of the proportion of the population assigned to each of two categories (nominal and subnominal). Relative population proportion values were then mapped into a GIS, and spatial comparison of plot locations and crown condition classifications were made. In future Annual Statistical Summaries, any region will be spatially evaluated by shading based on the composite information of all plots found within that region.

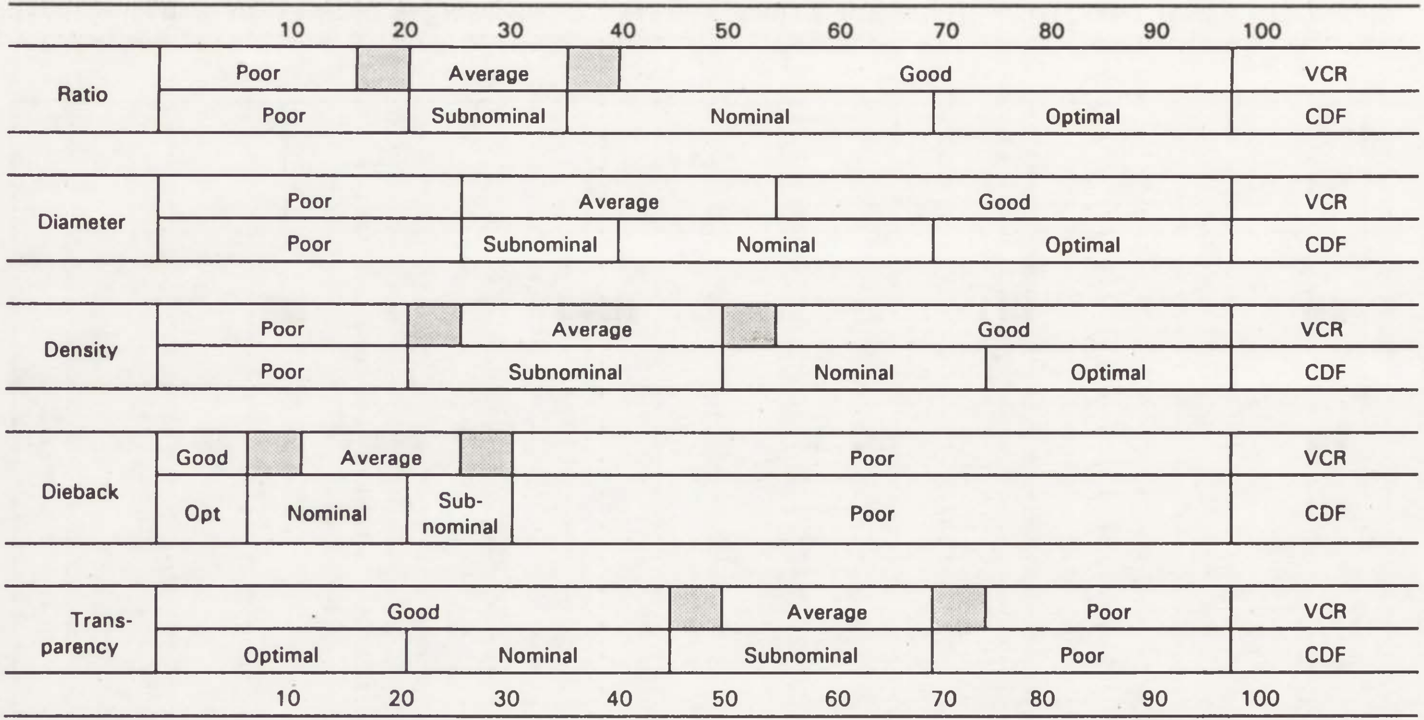


Fig. 5. Schematic representation of population zones for each crown variable (ratio, diameter, density, dieback, and transparency). Zones are defined by placement of values to define poor (A), concern (B), and optimal (C) thresholds for each variable. Thresholds based on visual crown rating (VCR) based on crown apperance, that is related to known or potential growth effects (Anderson et al., 1992)

	CDF THRESHOLDS				Species-Individual			Crown Group			Forest Type	
	0 10 20 30 40 50 60 70 80 90				Common Names	SAF #	# Plots	Names	#	# Plots	Names (SAF #)	# Plots
VCR	Poor	Average		Good	All Species	–	–	–	–			
CDF THRESHOLDS	Poor	Subnominal	Nominal	Optimal	All Species	–		CDF-All Groups	–			
	Poor	Subnominal	Nominal	Optimal	Hickory Sp.	400	65	Hardwoods-Cpd. Lvs.	90	111		
	Poor	Subnominal	Nominal	Optimal	E. White Pine	129	75	Pines-Short Needles	40	49		
					Yellow Birch	371	68	Hardwoods-Small Lvs.	80	285		
					Paper Birch	375	82					
	Poor	Subnominal	Nominal	Optimal	Yellow Poplar	621	108	Hardwoods Lg. Lvs., Open Crowns	70	132		
					White Oak	802	110	Hardwoods-Oaks	100	287	White Oak-Red Oak-Hickory (530)	73
					Scarlet Oak	806	54					
					S. Red Oak	812	57					
					Water Oak	827	82					
					Chestnut Oak	832	54					
					N. Red Oak	833	77					
					Loblolly Pine	131	152	Pines-Long Needles	30	234	Loblolly (310)	74
					Short-Leaf Pine	110	64					
					Red Maple	316	224	Hardwoods-Lg. Lvs., Closed Crowns	60	358	Loblolly-Hardwood (460)	55
					Sugar Maple	318	75					
					Sweetgum	611	128					
					American Beech	531	59					
	Poor	Subnominal	Nominal	Optimal	——	—	—	Hemlock	50	41		
					——	—	—	Cedar-Juniper	30	56		
					Balsam Fir	12	75	Spruce-Fir	10	93	Spruce-Fir (130)	39
					Red Spruce	97	58					

Fig. 6. Cummulative distribution function (CDF) thresholds for individual species, species groups [1] (based on similar crown characteristics), and forest types for the crown variable density. CDF thresholds are related to the visual crown rating (VCR) method [2] used to describe crown condition based on known or suspected affects on true growth or survival

[1] Millars and Anderson, 1992, [2] Anderson et al., 1992

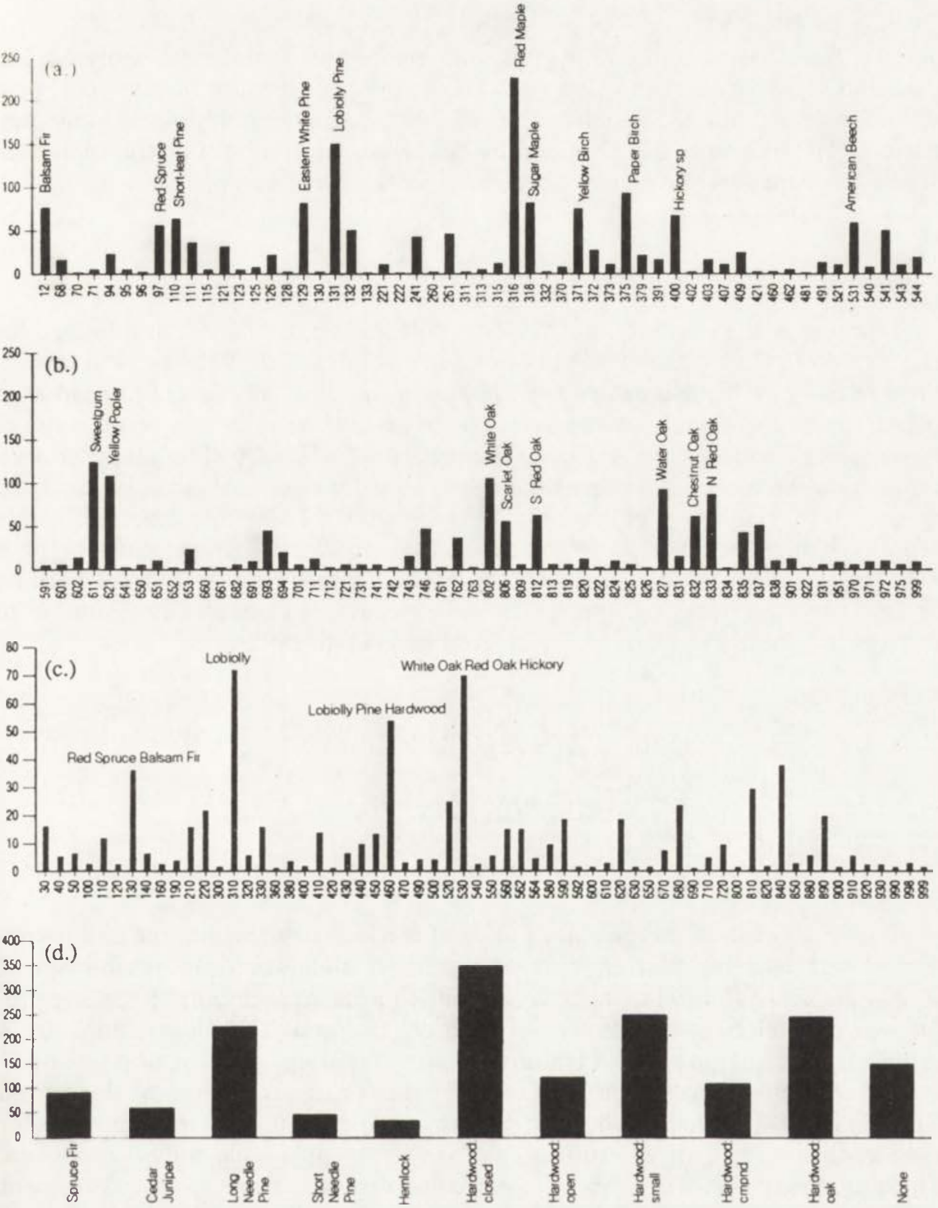


Fig. 7. Frequency of occurrence where 1 or more individual trees were found on the 606 Detection Monitoring plots in the eastern United States in 1991, for (a. and b.) Species, (c.) Forest types, and (d.) Crown Groups. Species, Forest Types, or Crown Groups that were found on 50 or more plots were subjected to CDF analysis

FREQUENCY DISTRIBUTION ANALYSIS

The frequency distribution of each species was evaluated to determine how many plots contained at least one individual of each species, forest type, or crown group (Fig. 7). These frequency distributions were used to select species, forest types, and crown groups for comparative statistical analyses, i.e., cumulative distribution function analysis. In general, species, forest types, or a crown group not found on a minimum of 50 plots were not analyzed as individual entities. The frequency distributions are shown as bar graphs of distribution classes for frequency of species, forest types, and crown groups on plots.

DAMAGE TO BOLES AND CROWNS

Damage is the evaluation of the tree bole, crown, branches, and foliage for any symptom that is believed to be serious enough to affect the growth or survival of the tree. Damages are recorded as to the type, location, and suspected causal agent. As such, damage evaluations in 1991 were a "yes or no" type of evaluation. This indicator has been changed, and in 1993 will be analyzed as a continuous variable. Up to three damages, in order of severity, can be recorded on each tree. Damage 1 is the most severe, and is the damage reported in this report. Damage is reported as the percentage of affected trees found in the 4 subplots. Trees with type Damage 1 are less likely to survive than trees with no or less severe damages. Damage variables evaluated on plot are similar to damage information collected off-plot (Anderson et al. 1992a).

RESULTS AND DISCUSSION

DETECTION MONITORING

TRAINING

Training is one of the primary duties of the logistics coordinator and is concerned with insuring that multiple crews clearly understand the establishment of the plot, indicators to be measured, field equipment, sampling handling procedures, and electronic collection of data on and near the plots. There are 4 principal components of FHM training: lecture, training, practice, and testing.

All crew members must be certified prior to the collection of data from FHM plots. This is accomplished by testing the crew members under similar field conditions on all the indicators they are responsible for on the plots. The guidelines for evaluating performance are based on the measurement quality objectives (MQOs) established for each Indicator (Byers & Palmer 1992). The purpose is to insure that multiple crews are meeting the same QA/QC objectives in data collection. This testing is done on reference plots that can be remeasured several times during the summer sampling season to obtain information on the temporal stability of the indicator over the summer, and obtain measurement error estimates on accuracy, precision, within-crew, between-crew, and laboratory error. Index Period Stability and Measurement Error are two important components of the Indicator Development Criteria discussed below.

LOGISTICS

Logistics are the facet of FHM that is concerned with training, personal data recorder programming, crew formation and schedules, transfer of samples from field to laboratory, debriefing, and scheduling of reporting. This person serves as the “control tower” for Detection Monitoring activities. The composition of the FHM field crews is an important consideration. Crews range in size from 2-6 people, depending on the number of indicators tested in each region. Generally a 2-person crew, with forest mensuration experience, is responsible with the establishment of FHM plots where tree species are the focus. This is detection monitoring that is currently established in 14 States. The detection monitoring crews are responsible for evaluation of the mensuration indicators (structure, growth, regeneration, mortality), crown assessments (ratio, diameter, density, dieback, transparency), and damage (biotic, abiotic). Larger crews are necessary when all the current FHM indicators are being evaluated in localized regional studies, i.e. the Southeastern Loblolly-Shortleaf Demonstration study. These crews are typically 4-person, with 2 foresters, 1 botanist, and 1 soil scientist. These crews are supported by local logistical support personnel who assist with downloading data, mailing samples, communication with home base, arranging lodging, etc. Even larger crews have been utilized in some States where additional crew members, like insect and disease specialists, have joined the more typical Pilot/Demonstration crew.

QUALITY ASSURANCE AND CONTROL OF DATA

The EPA’s Quality Assurance Management Staff has developed a process for establishing Data Quality Objectives (DQOs) that can be applied to the FHM QA program (Byers & Palmer 1992). Modifications to the process are expected to be developed over time. In 1991, DQOs were considered to be specific statements of the level of uncertainty a data user (presently defined as the respective indicator leaders) is willing to accept in a body of environmental data, with respect to the kind of scientific or policy question that motivated the data collection activity. Data Quality Objectives are definitive, quantitative, or qualitative statements developed jointly by data users (e.g., scientists, policy makers, interest groups) in conjunction with the QA staff.

The DQO process is an iterative approach that balances costs versus uncertainty to achieve a desired or acceptable level of quality. This information can also be used to allocate resources to specific monitoring phases in order to generate data of sufficient quality to support management decisions or answer specific scientific questions.

Data quality, and therefore DQOs, may be defined for several levels of FHM data collection. The first level is measurement-level DQOs (MQOs) for specific measurement parameters, estimated using existing or initial baseline data. These DQOs may define acceptance criteria for detectibility, precision, accuracy, representativeness, completeness, and comparability in field and laboratory measurement data (Byers & Palmer 1992). Beyond this, another criterion may be to optimize measurement uncertainty with respect to non-measurement sources of uncertainty (e.g., due to sampling design constraints or naturally-occurring spatial and temporal variability that often is confounded within environmental data).

Other levels are recognized at a higher ecosystem level but they have not yet been addressed seriously. They are Indicator-level DQOs (IQOs) derived from aggregated parameter data for ecological indicators: Resource-level DQOs (RQOs) derived from aggregated indicator data for the EMAP-Forests Resource Group, and Ecosystem-level DQOs (EQOs) from aggregated resource data for overall ecosystem assessments.

Throughout the DQO-setting process, there should be communication among program management, policy-makers, program coordinators, resource scientists, data analysts, and scientists involved in the actual data collection activities. Acceptance criteria established during the DQO development process serve as benchmarks for satisfying data user requirements. In FHM, DQOs are being established for several levels of data collection, e.g., sample measurement system, measurement parameter, or indicator level for various indicators. Included in the DQO assessment are four quantitative attributes: detectibility, precision, accuracy, and completeness. Also included are two qualitative attributes; representativeness, and comparability.

FIELD QA FOR MEASUREMENTS IMPLEMENTED IN 1991

Several QA issues were of concern for the 1991 field measurements of mensuration and visual damage. Their resolution for 1991 was based partly on logistical and budgetary constraints. The issues were:

— How to assess field crew precision, accuracy, and comparability within and between regions;

— How to assess trainer precision, accuracy, and comparability between regions;

— What are the logistical constraints using different crews on the application of QA techniques in the relatively large Forest Service regions, such as the Northeastern, Southeastern, or Western regions of the U.S;

— How beneficial and cost-effective will be the different possible QA techniques.

ACCURACY

1. Two-person field crews were provided by the Forest Service or by state forestry authorities. An adequate number of field crews were hired to ensure

that the planned 1991 measurement program was accomplished in the available time.

2. Reference plots (also called "standard" or "accuracy" plots) were established at training sites in Durham, NH, and Asheville, NC. All trainers measured the reference plots to establish "true" values. The field crews also measured the reference plots as part of the training program, and were judged under the same standard.

3. Specific test and training trees were used for training and testing the field crews' abilities to make the visual crown measurements. An expert team selected approximately 40 trees at each training site that reflected a broad range of visual damage conditions found in the forests. The field crews were trained on these trees after classroom instruction. Then the field crews were tested on another set of 20 test trees, both individually as crew members and as two-man crews.

4. Expert trainers were used to form trainer crews for each of the regions for 1991. All measurement data used as standards on the reference plots were established by these Forest Service personnel who are trained and experienced in the measurement techniques. The four trainers for the regions crossed over to each other's regions during pre-training sessions to establish the national standards for the measurements.

5. Two-person audit crews visited field plots randomly during measurements to observe protocol application and to provide real-time input to the field crews to reduce inaccuracy in the measurements. The audit crews worked with the field crew, assessed its performance, and discussed deviations from protocol when they occurred. The audit crews performed these audits about 1 to 4 weeks after the start of data collection.

PRECISION

Each field crew remeasured two plots that it had previously measured. These plots were selected about 1/3 and 2/3 through the data collection period. This permitted estimation of within-crew variability. Between-crew variability was assessed from the reference plot measurements.

COMPARABILITY

Each field crew collected data from the reference plots at training in June and also at a debriefing session in October to establish a basis for comparability among crews within a region. Inter-regional comparability is also of great concern, and a technique was developed in 1991, but it was not deemed proper (financially, logistically, and legally) for all field crews to collect data inter-regionally, nor to travel to inter-regional training sessions. However, two field crews from the northeast region were able attend the debriefing session in Asheville, NC, in October. The southeast and the northeast trainers both measured the reference plots (mensuration and visual measurements) to reestablish accuracy data for the plots that might have changed from the pretraining sessions and to compare measurements among trainers. Detailed results are not yet available due to limited QA resources, but preliminary analyses suggest acceptable within-crew and between-crew precision.

REPRESENTATIVENESS, COMPLETENESS, AND DETECTIBILITY

Representativeness criteria are established by the plot design and plot sample selection established for 1991. Completeness and detectibility criteria have been established for some of the components of the implementation indicators. Measurement parameters for some indicators were very qualitative, e.g., merely presence or absence with no detectibility criteria.

DATA VERIFICATION

Verification is the act of determining and controlling the quality of data. Verification can be accomplished manually, electronically, or through remeasurements. A systematic approach to data verification ensures that all data are subjected to basic standards of accuracy that verify the authenticity, but not necessarily the validity, of the data. Verification is accomplished by comparing data at each level of processing to established data quality criteria. Most of the data collected were entered into portable data recorders in the field. Computer programs performed real-time logic checks of most entries, automatically determining if entries were valid and logically correct.

THE 1991 FHM QUALITY ASSURANCE REPORT

A summary of quality assurance information collected during the 1991 field season is currently being prepared. The report will provide information on data quality attributes for the indicators included in this annual statistical summary as well as indicators undergoing testing in pilot and demonstration studies.

Rigorous quality data assurance and control (QA/QC) procedures will be implemented following guidelines established in the USFS/EPA Forest Health Monitoring programs (Byers & Palmer 1992). Data QA/QC procedures will particularly focus on:

— training: insuring that sundry crews are performing the right evaluations in the same way so that defined measurement quality objectives can be met;

— reference plots: plots located off the main sampling grid that are evaluated throughout the field sampling season to determine bias, within, and between crew measurement error; also evaluates stability of the Indicator over the sampling season;

— detection monitoring plots: field audits are performed to insure that field crews are collecting data in a repeatable fashion and within stated measurement objectives;

— laboratory analyses: laboratory analyses will have QA/QC checks such as splits in sample stream, NBS samples, blind samples, etc. Differences between analytical laboratories will be addressed by analyses of same samples containing known amounts of target elements.

DATA ANALYSIS AND REPORTING

Data analyses is a continually evolving aspect of the FHM program. Techniques such as development of indices, CDF analysis, and GIS approaches are common to all Indicators. The approaches for development of plot-level indices (an Indicator) may differ depending on the nature of the Indicator. Some techniques begin with descriptive statistics that are generated to provide information for various indices that may be used to aggregate associated variables, e.g., a crown structure indicator that sums crown ratio, diameter, and density, weighted by stand stocking, into an index for each tree. Frequency distribution graphs are generated to evaluate the normality of the data for each variable, and to identify resource groups, i.e., species, forest types, etc. that are commonly found on the detection monitoring plots. Correlation analyses explores associations between variables. Parametric and non-parametric analyses are conducted on the principle species to determine the optimal method of aggregation of the data at the plot level (e.g., forest type, crown position, or age class). Calculation of CDFs is done on regionally common species, forest types, etc., for the plot-level average of each indicator. Threshold levels for concern for the Indicator values in the CDFs are set so that calculation of the proportion of the population that falls into nominal and subnominal ranges can be performed. Geographical information systems (GIS) will be used to produce maps overlaying air pollution, climate, forest types, species, and response variables.

Reporting consists of annual statistical data summaries with limited interpretation and comprehensive reports every 3-5 years, with a comparison of multiple-year data and assessments of results.

ASSESSMENTS

An assessment group will be formed to insure an continuous feedback loop between indicator development and data acquisition and relevance to policy goals or societal values. The group will serve as a liaison between the scientists and the decision makers who will use the results of this program to evaluate human activities, e.g., land management practices and air pollution, in order to protect the health of U.S. forests.

INDICATORS OF FOREST CONDITION

In order to monitor the condition of U.S. forests, the FHM program had to identify ecosystem attributes that are common to many forest types. These attributes are aggregated into four main categories: inputs, components, processes, and outputs (Table 2). Indicators in the FHM program are currently being tested that can be linked to the attributes of a forest ecosystem (Fig. 8a). The FHM has identified 3 societal values (ecological integrity, aesthetics, and extent) (Fig. 8b) as the current goals for the program. These societal values are to be addressed by 5 primary assessment categories (productivity, sustainability, biodiversity, extent, and aesthetics) (Fig. 8c). These societal values and assessment questions can be thought of as a screening mechanism to determine what attributes of a forest ecosystem to monitor. The FHM program has selected a number of indicators of forest condition that can be linked to one or more of the assessment categories (Fig. 8d). FHM is now conducting research to evaluate the quantitative relationships between the indicators and the assessment questions. These indicators are aggregates of 1 or more plot level measurements, and occur in groups or a single indicators (Table 3). The FHM program tests conducts site-specific and regional studies to determine the indicators that best characterize the condition of the forest ecosystem, that can be qualitatively and quantitatively linked to the current Assessment Questions, and perform well statistically and logistically under the constraints of Detection Monitoring.

Table 2. Attributes of a forest ecosystem that are considered in the FHM program. Assessment questions and societal values determine the attributes to be addressed through the FHM indicators

Inputs
Insolation
Precipitation
Toxins
Heat
Nutrients
Surface/Ground Water
Components
Abiotic:
— water
— soil
— rock
— troposphere
Vegetation:
— woody
— fungi
— nonwoody
— mosses & lichens
Fauna:
— birds
— amphibians
— insects
— mammals
— reptiles
— invertebrates
Processes
Weathering
Element Cycling
Production
Decomposition
Succession
Hydrology
Fixation
Consumption
Phenology
Outputs
Removal
Leaching
Evaporation
Runoff
Albedo
Respiration

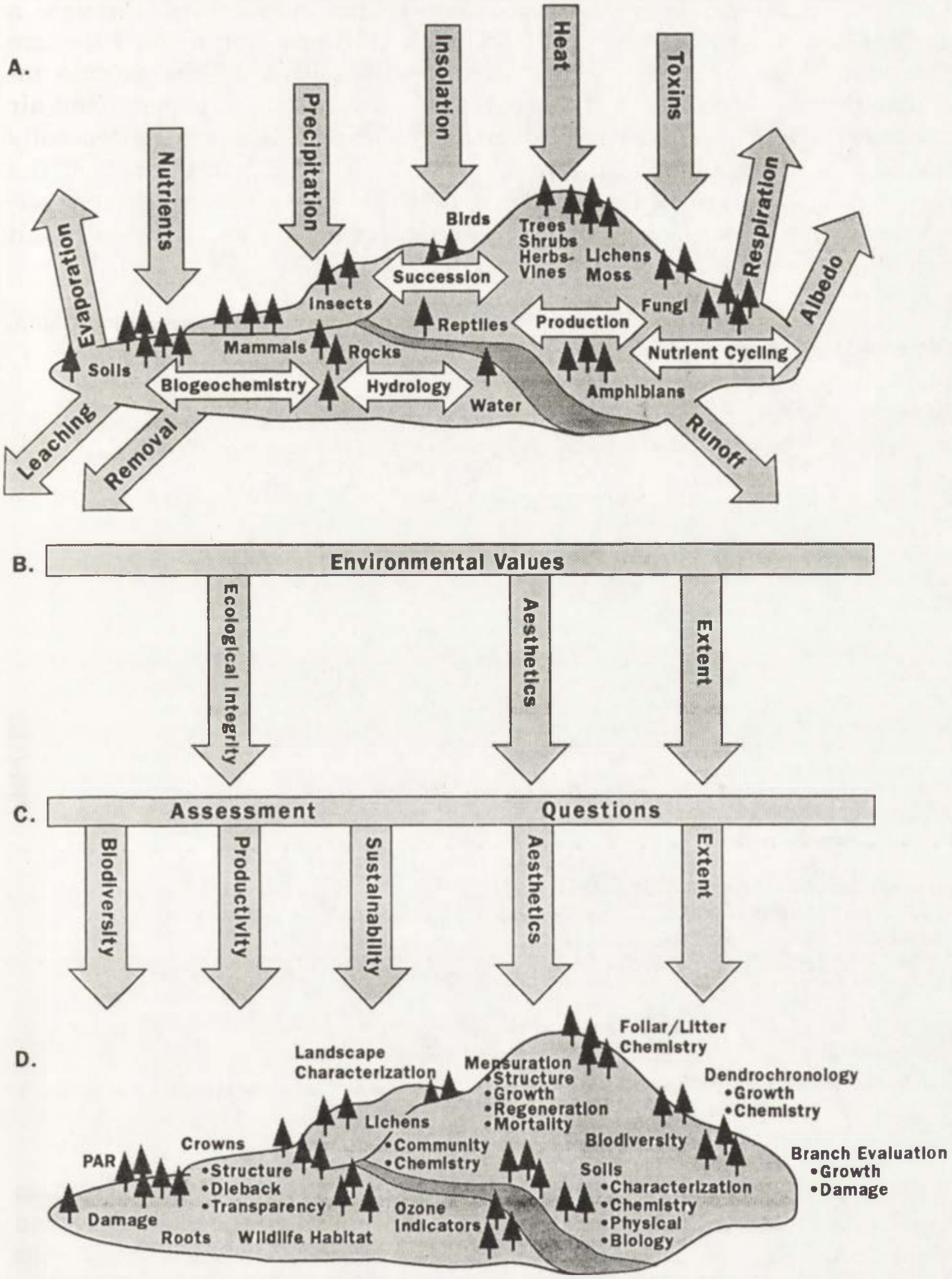


Fig. 8. (a.) Schematic of a forest ecosystem illustrating some inputs, components, processes, and outputs. (b.) Current FHM defined Environmental Values, and current FHM Assesment Qestions (c.) determine Detection Monitoring Indicators of forest ecosystem condition in FHM. (d.) Current FHM Indicators under testing in regional studies

These plot-level indicators are then spatially evaluated through a geographical information system (GIS) with off-frame (out of the 1 hectare plot) data collected by other associated agencies. This off- frame data includes regional evaluations of insect and diseases on trees, climate, and air pollution. These plot-level Indicators and off-frame data are conceptually linked to the attributes of a forest ecosystem, so that many facets of the forest ecosystem are being addressed (Fig. 9). These indicators, and off-frame ancillary data, are currently under review in the Demonstration Studies being conducted in the southeastern U.S.

Table 3. Plot-level indicators currently undergoing testing in regional demonstration studies, Detection Monitoring, and off-frame research

Plot-Level Indicators

- Mensuration Group
  - Structure
  - Regeneration
  - Growth
  - Mortality
- Damage
  - Biotic
  - Abiotic
- Crowns
  - Dieback
  - VCR93 (Structure)
  - Transparency
- Biodiversity
  - Richness
  - Diversity
  - Evenness
- Lichens
  - Community
  - Chemistry
- Tree Rings
  - Dendrochronology
  - Chemistry
- Foliar/Litter Chemistry
  - Nutrients
  - Toxins
- Soils
  - Characterization
  - Chemical
  - Physical
  - Biological
- Photosynthetically Active Radiation (PAR)
- Wildlife Habitat Structure
- Bioindicator Plants
  - Ozone species
- Roots
  - Pathology
- Branch Evaluation
  - Growth
  - Foliar/wood damage
- Landscape Characterization

INDICATOR DEVELOPMENT PROCESS

The Indicator Development Process (IDP) consists of guidelines to develop indicators of forest condition for implementation in Detection Monitoring (Fig. 10). Essentially the IDP is an iterative process that begins with the identification of forest ecosystems attributes; screens attributes, based on the current societal values and assessment questions in FHM, to identify plot-level indicators; specifies logistical and statistical performance standards for the indicators; develops a review and ranking process to evaluate the functioning of the indicators relevant to the performance stand-

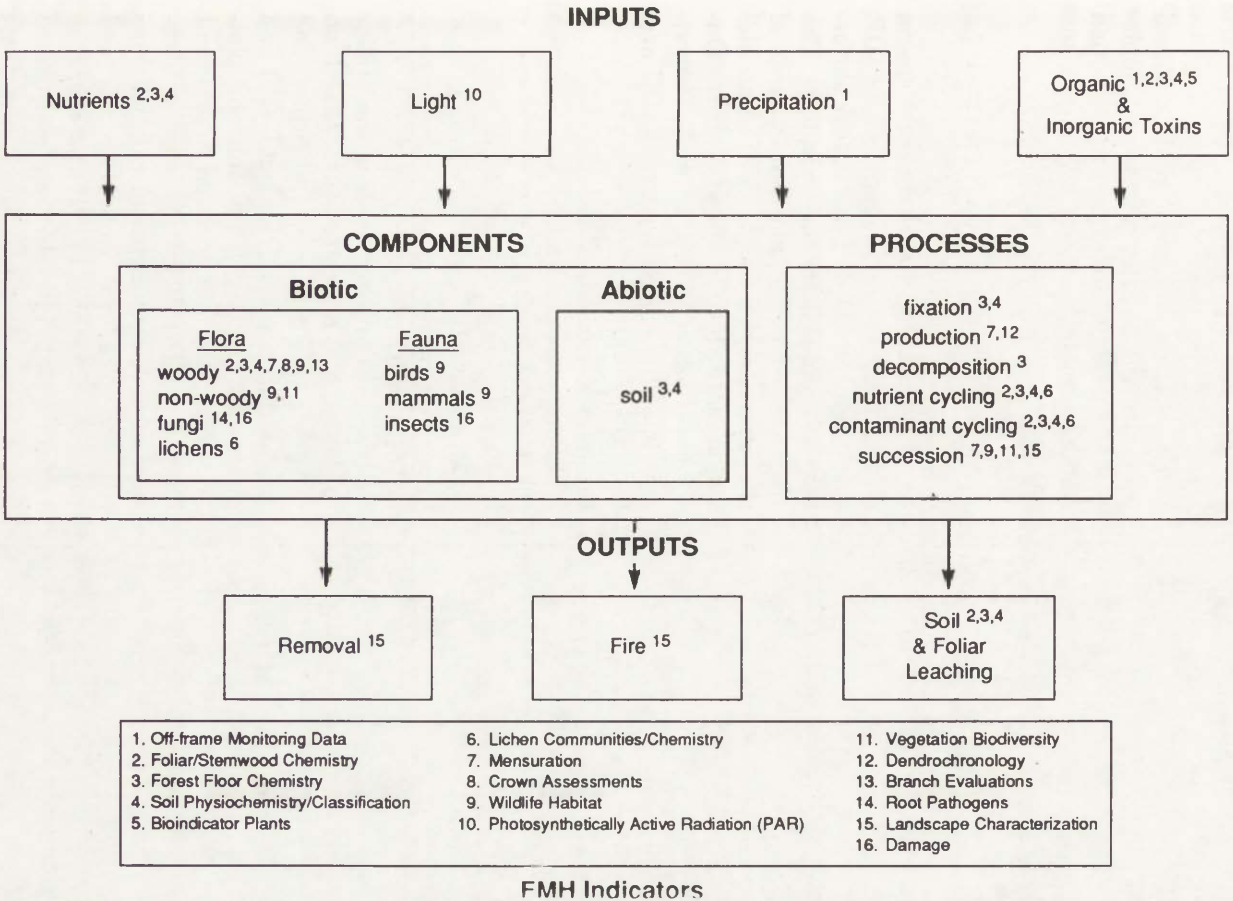


Fig. 9. The FHM forest conceptual model showing inputs, components, processes, and outputs that area currently being addressed by the FHM Indicators undergoing testing in regional studies

ards; obtains internal and external review of the entire process; and implements successful indicators in Detection Monitoring.

FOREST ECOSYSTEMS

- inputs
- components
- processes
- outputs

↓

FHM VALUES

- biotic
- abiotic
- aesthetics
- extent

↓

ASSESSMENT QUESTIONS

- biodiversity
- productivity
- sustainability
- human perception
- area

↓

INDICATORS

- status, changes, trends
  - condition
  - stressor

↓

INDICATOR CRITERIA

- interpretibility
- index period stability
- signal-to-noise ratio
- regional accuracy
- plot impact
- quantification, cost, logistics

↓

OFF-FRAME RESEARCH

- link indicators to Assessment Questions
- develop thresholds for CDFs
- plot level indices
- index period stability
- cost, impact, quantification

↓

ON-FRAME PILOTS & DEMONSTRATIONS

- logistics
- signal-to-noise ratio
- regional accuracy

↓

ON-FRAME DETECTION MONITORING

- passed most logistical/statistical criteria

↓

PEER-REVIEW

- within FHM
- external

↓

CORE

- policy
- logistics
- statistics

↓

IMPLEMENTATION

- addressing Assessment Quetions
- core in new plot establishment

Fig. 10. The FHM Indicator Development Process that illustrates the Indicator selection, performance criteria, research goals and approaches, and management considerations. Details of components of the process are discussed in other section of this document

INDICATOR DEVELOPMENT CRITERIA

The Indicator Development Criteria (IDC), a critical component of the IDP, are the logistical and statistical performance standards for the Indicators. The IDC are used to guide development of the indicators through Off-Frame Research (OFFR) studies and in On-Frame Research (Pilots and Demonstration Studies). The current IDC are:
(a) Interpretibility;
(b) Index Period Stability;
(c) Signal-to-Noise Ratio;
(d) Regional Accuracy;
(e) Plot Impact;
(f) Quantification/Cost/Logistics.

a. Interpretibility

Interpretibility addresses the ability to aggregate measurements taken on the plots into plot-level Indicators, and to qualitatively (Fig. 11a and 11b) and quantitatively (Fig. 11c) link the plot-level Indicator to associated Assessment Questions. The FHM program will obtain or develop functional relationships between plot-level Indicators (X) and response variables (Y). If the response variables (e.g., growth) are closely allied to FHM Assessment Questions (e.g., Productivity) (Fig. 11c), then the FHM program will be able to make quantitative assessments of the relationship between changes and/or trends in Indicators and changes and/or trends in Societal Values. Another important component of Interpretibility is to analyze the plot-level indicator in a cumulative distribution function analysis (Fig. 4a), and to assess forest condition by setting CDF thresholds to delineate the population into optimal, nominal, subnominal, or poor proportions (Fig. 4b-4f). The same Indicator (X), Assessment Question (Y) relationship observed in Figure 11.c., can be used as a consistent way to set CDF thresholds across species, forest types, or other resource groups (Fig. 11d). The FHM program will seek continue review of the scientific community on setting reasonable optimal, concern, and poor thresholds.

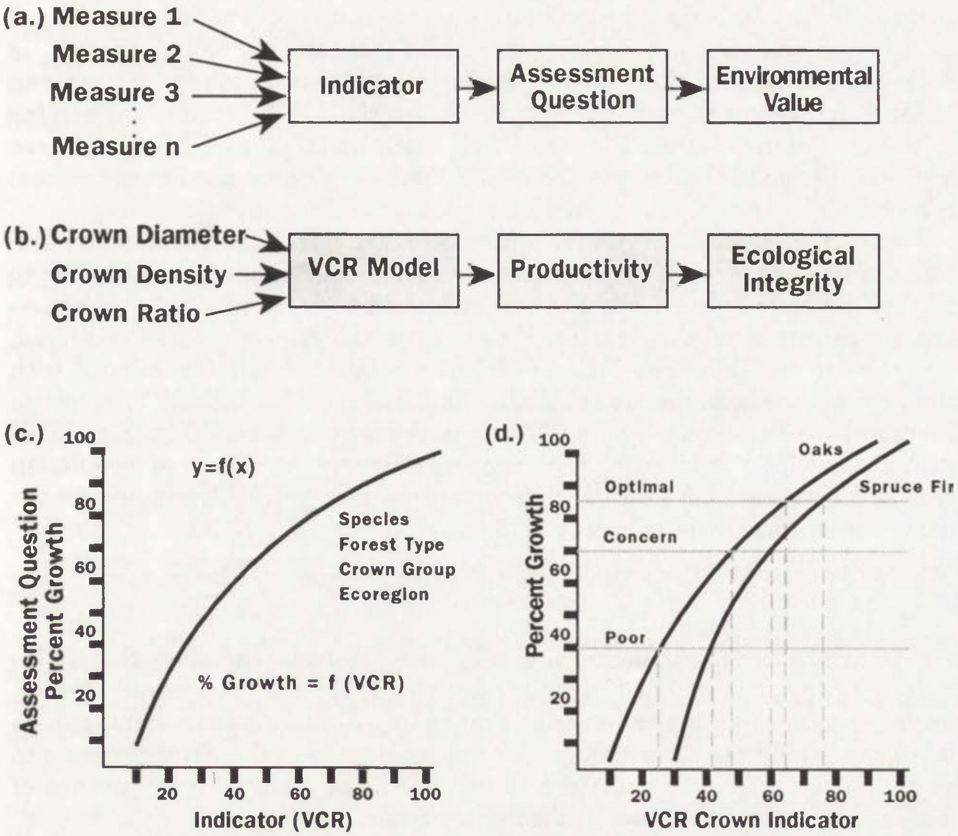


Fig. 11. Development of FHM Indicator and method for linking conceptually and quantitatively to Assessment Questions (AQ) and Environmental Values (EV). (a.) General approach for aggregating measurements into plot-level Indicators that address AQ and SV. (b.) Example of aggregation of crown variables into a plot-level Indicator that addresses Productivity and Ecological Integrity. (c.) General approach for relating an Indicator quantitatively to an Assessment Question. Hypothetical relationship between a Crown Indicator (X = VCR) and an ecological response (Y = Percent Growth) that defines a part of the AQ Productivity. (d.) The same functional relationship between an Indicator and an Assessment Question provide a consistent method to set thresholds for species, forest types, and Crown Groups

The FHM proposes the following priority for obtaining information to establish optimal, concern (nominal/subnominal split), and poor thresholds:

- evaluation of scientific literature
- evaluation of existing data
- manipulative studies
- stress gradient studies
- retrospective analyses
- expert opinion
- public opinion.

This sequence lays out an approach for developing thresholds (or cutpoints). First, we study the available literature and databases to determine where the threshold should lie. For example, if the data says that 4 is poor (subnominal) but 6 is good (nominal), then we can cite these references and suggest 5 as a legitimate concern threshold. If these data tell us that 0.1 is poor but 100 is okay, then we cannot suggest the threshold of 5, but we can at least determine the range in which the threshold falls. Expert opinion (as in the development of the Index of Biotic Integrity (IBI) used EMAP Surface Waters), or public opinion (as in the development of some aesthetics indices) can provide guidance, if done in a controlled and documented manner.

Once an appropriate range for a threshold has been established, manipulative studies, gradient studies, or retrospective studies can be performed to further define the thresholds. The research must be more than a "good site — bad site" study, since the complete shape of the X, Y response curve is desired, and not just the tails (Fig. 11c and 11d). Any studies should be designed with the goal of developing an Indicator (X) and Biological/Ecological (Y) response relationship that is closely allied to an Assessment Question (Fig. 11c.). This will enable the FHM program to demonstrate that an observed population change in an Indicator can be interpreted as a quantifiable change in the Assessment Question of relevance.

MEASUREMENT ERROR

We are concerned with the accuracy and precision variation that is inherent in any field and/or laboratory sampling process. Our goal is to minimize the total sampling variance so that changes in forest ecosystems can be more easily detected. The factors that are considered in the FHM program to be measurement error, and need to be quantified for quality assurance of data collection and in analysis of indicator criteria, are:

- bias
- within crew variability
- between crew variability
- local within-plot spatial variability
- laboratory variability.

Additionally, these factors contribute to the variability in sampling and determining indicator performance such as signal-to-noise ratio and index period stability. These factors are not the same for all indicators — some indicators have more than others. For example, some indicators have no laboratory analyses and/or local spatial sampling variability components (invasive sampling).

The general Measurement Quality Objectives (MQOs) for the overall measurement error variance is to keep all components low enough so that the total measurement error is not a significant factor in Index Period Stability and Signal-to-Noise Ratio determinations.

b. Index Period Stability

Index period stability addresses the seasonal variance that may occur in an indicator over the summer sampling season. In FHM Detection Monitoring, crews begin field sampling in early June and finish sampling in late August. Consequently, an Indicator's seasonal variance may contribute to the noise and block out the signal we are trying to obtain from the indicator (see Signal-to-Noise Ratio). The components of Index Period Stability are:

- plot-to-plot variability
- index period variability
- measurement error.

The FHM program will attain plot-to-plot data from 1992 and 1993 SE Demonstration studies; index period data from 1993 Quality Assurance (QA) pilot study (3 repeat measurements over the growing season); and the measurement error component from 1993 QA pilot study (3 crews remeasure same plots and each other's plots). The DQO for the Index Period Stability is defined as:

$$\frac{\text{index period var.} + \text{measurement error}}{\text{plot} - \text{to} - \text{plot var.}} < 10\%$$

then Index Period Stability is acceptable.

c. Signal-to-Noise Ratio

Signal-to-noise ratio refers to the ratio of the year-to-year changes (signal) in the Indicator and the measurement error (noise) that makes determination of the true signal difficult. The ultimate goal is to be able to determine real trends in forest ecosystem condition, if they occur, that can be observed from year-to-year natural changes. The components of signal-to-noise ratio are:

(i) year-to-year variability
(ii) residual error
- year × plot interaction
- Index Period Stability
- measurement error .

The FHM program will remeasure a sample of plots (x) for "t" years. We will then perform a 2-way Analysis of Variance, with time and plot as factors, according to desired post-stratification data analysis (e.g., crown group, forest type, species, etc.). The FHM program will begin this analysis, which ultimately may take 1 or more decades to yield the most relevant results, by remeasuring 7 plots common to studies in 1991, 1992, and 1993. The Data Quality Objective desired is to be able to Detect a 2% per year linear trend in Indicator response over a 10 year period, if such a linear trend were to occur.

d. Regional Accuracy

Regional accuracy reflects the utility of an indicator for a given area. Generally the indicator should be found on 50 or more plots, and consequently the post-stratification of the data will determine the frequency of an indicator at the plot level. For example, if the population strata is all trees, than the indicator will be found on all forested plots, as opposed to an individual species that may be found on only a proportion of the subplots (i.e., 1 or more trees per plot). The less frequent an indicator is found on a subplot, the wider the confidence intervals are around the CDF for that plot-level average.

The component of Regional Accuracy is primarily the occurrence of the Indicator on 50 or more plots, within the population strata of concern (e.g., forest type, species, etc.). The FHM program will analyze plot-level Indicators from the 1992 and 1993 SE and SAMAB Demonstration Studies (regional test of all Indicators), and also analyze the 1990-1993 Detection Monitoring data for Mensuration (structure, growth, regeneration, mortality) and Crown Condition (dieback, transparency, and structural VCR). The DQO for Regional Accuracy desired is to have less than a 10% difference between the upper and lower confidence bounds and the CDF, at the point where the threshold crosses the CDF (Fig 4b-4f). That is, the upper confidence bound should be less than 10% from the CDF, and so should the lower confidence bound. With finer and finer post-stratifications of the data, e.g., from crown group to forest type to species to species within a certain condition class, the tendency is to widen the confidence intervals around that point on the CDF (the resource is found only on a proportion of the subplots). If that point is where a CDF threshold falls, and the difference between either one or both of the confidence bounds and the CDF is greater than 10%, you will exceed this data quality objective.

RESEARCH ON MONITORING TECHNIQUES

Research on Monitoring Techniques (ROMT) is the fourth component of the FHM program, charged with improving the monitoring methods used in FHM through on-frame (on EMAP grid) and off-frame research. A Research on Monitoring Techniques committee, consisting of USFS and EPA FHM representatives, was formed in the Spring, 1992. In the future it will be expanded to include federal and state representatives such as EMAP Central

(EPA), USFS Regions (USDA), Bureau of Land Management (DOI), Tennessee Valley Authority (DOE), and National Association of State Foresters (multi-State). The Research on Monitoring Techniques (ROMT) committee will provide technical direction for the Research on Monitoring Techniques component of the FHM program. The primary responsibilities of the ROMT committee are to provide research coordination for policy, logistical, and statistical concerns common to all indicators. The ROMT committee will also develop guidelines for evaluating indicator performance, including the revision of grading procedures for indicators addressing the Indicator Development Criteria. They will also establish internal (within FHM) and external Review Panels to grade indicator performance. The ROMT committee will provide technical direction for administration of the ROMT operating budget, projected to be 10% of the total FHM budget. This base budget may be occasionally supplemented to address specific indicator issues. The ROMT will assist Indicator Leads by supporting, and often participating in, individual Indicator workshops. The ROMT will provide technical direction for within-FHM Request for Proposals to fund off-frame indicator development.

The immediate goals of ROMT are to identify research needs for indicators, form Review Panel and grading criteria for Off-Frame Research, and develop research approaches to link Indicators to Assessment Questions, produce scientifically defensible cdf thresholds, and test new or improvements in current indicators relevant to the Indicator Development Criteria. In general the ROMT committee will oversee activities in two major areas of research:

(a) Indicator links to Assessment Questions & CDF thresholds (X,Y relationships between Indicators and response)
 — extensive literature review
 — cooperation w/ISEMs, LTERs, Global Change
 — short and long-term gradient studies
 — short and long-term manipulative studies
 — multivariate analysis of DM data
(b) Addressing Indicator Development Criteria
 — statistical criteria partially addressed by the 92/93 Demos
 — (e.g., year-to-year variability)
 — test indicators in new ecoregions.

INDICATOR ANALYSIS

The FHM program will analyze the 1992 Detection Monitoring data using the statistical "engine" (data analysis approach and programs) initiated in 1991 that produced the 1991 Annual Statistical Summary (Forest Health Monitoring 1992). This "engine" will be continually upgraded as better understanding of forest ecosystems is obtained, and will be used to complete the 1992 Annual Statistical Summary. In addition, in late 1993 the FHM program will do an analysis of the 1992 and 1993 SE and SAMAB Demonstration studies (regional tests of Indicators), using the Indicator

Criteria as guidelines for analyzing the data. The FHM will continue to work on improving current cdf thresholds and adding thresholds to Indicators. Most of this information will come from literature reviews and Off-Frame Research.

EVALUATION MONITORING

Evaluation Monitoring (EM) is focused on determining the specific nature of detected changes and, if possible, the causes. It will provide a basis for corrective actions if warranted. Evaluation Monitoring will produce hypothesizes of causal agents that can be tested experimentally or ascertained from Intensive Site Ecosystem Monitoring (ISEM). In 1993 FHM will improve methods to develop thresholds or "triggers" to initiate Evaluation Monitoring (EM). The general approach will be to develop EM "trigger" parameters into analysis, such as subnominal or poor population proportions as triggers.

The general approach currently consists of first exploring additional computer analysis of existing data sets to see if there is any plausible explanation for the anomality observed. For example, poor crown condition of a species or forest type in a number of clustered plots could be due to a ice-storm in recent years. This relationship may show up in an Interpretative Report, but not in an Annual Statistical Summary. If computer analysis of existing data cannot produce a probable cause, then an FPM crew may be sent to the area to look for a biotic (insect/disease) or abiotic (climate/air pollution) cause of the anomality. If this does not produce a causal agent, then on-plot (on-frame) addition of indicators, at all plots where the species, forest type, etc. occurs, will attempt analysis beyond that normally not employed in Detection Monitoring, i.e. analysis of ecosystem components or processes not evaluated by the indicators used in DM. If that does not produce the causal agent, the EMAP grid can be intensified in the area of concern, and analysis of the anomalies condition will be done on the intensifies grid using the DM indicators and the additional indicators (Evaluation Monitoring indicators). In some cases FPM surveys may be conducted on the full or intensified EMAP grid, if the initial FPM survey at and around the DM anomalous plots indicates the potential for a pest-pathogen interaction with the undesirable condition. In summary the four approaches are:

(i) Intensified computer analysis
    a. multiple off-frame stressors
    b. expanded analytical approaches
(ii) Forest Pest Management survey
    a. on or near DM plots
    b. on or near intensified grid
(iii) Evaluation of additional indicators.
    a. indicators not used in Detection Monitoring
(iv) Intensified grid and additional indicators

a. enhance grid sampling in impacted area

b. broad suite of indicators.

The general approach will be to look at the species, forest type, etc. at all plots where they occur, and not only at the plots where the anomality occurs. This will statistically define the scope of the problem, and ensure that any potential or probable causal agent, determined through correlative or "weight of evidence" approach, will not erroneously be accepted because of high correlations at the site where the anomalous conditions occur. It will be important to determine that the same variable is not also highly correlated with healthier trees of the same species, etc. at other DM plots. Intensification of indicators at the DM plots, in addition to intensification of plots and indicators if necessary.

INTENSIVE SITE ECOSYSTEM MONITORING

Intensive Site Ecosystem Monitoring (ISEM) is the long-term monitoring of components and processes of forest ecosystems (Stolte & Radloff 1993). The ISEM component of FHM focuses on intensive, continuous measurement and analysis of forest ecosystem attributes and processes at selected biologically representative sites. The purpose is to provide detailed baseline information on key components and processes of selected forest ecosystems, and to further understanding of the processes and mechanisms responsible for adverse or unexpected changes in forest health.

Intensive Site Ecosystem Monitoring has five purposes:

(1) To help anticipate changes in forest health by systematically making cyclic, detailed measurements of key aspects of ecosystem structure and function on a limited number of sites over a long period of time. ISEM provides an understanding of ecosystem processes, to interpret health-related changes in forest ecosystems. The goal is further our understanding of the ecosystem processes and mechanisms responsible for changes in forest health.

(2) To increase basic understanding of causal relationships by testing hypotheses developed in Evaluation Monitoring in long-term monitoring studies.

(3) To provide the long-term, detailed measurements that will support experimental, manipulative research conducted at the ISEM sites.

(4) To provide Indicators and methods for Research on Monitoring Techniques that will increase the effectiveness in conducting Detection and Evaluation Monitoring in the future.

(5) To provide the understanding of forest ecosystem processes necessary to enable management to make informed decisions regarding adverse or unexpected changes.

In general, ISEM will provides very high quality, detailed information to support assessment of cause/effect relationships. ISEM will document processes that shape forest ecosystems, and provide a supporting framework for experimental research monitoring on a limited number of sites representing 20 important U.S. forest ecosystems.

The following concepts and broad questions are intended to guide the planning and implementation of ISEM. All monitoring activities in this component should be designed to answer these questions. The questions intergrade between two categories:

(1) Understanding the natural variability of forest ecosystems processes.

(2) Understanding the response of forest ecosystems due to human environmental influences.

Question 1. What are the key ecosystem processes that determine resilience and sustainability?

Question 2. What ecosystems processes are sensitive to change and what ecosystem components are the best indicators of those processes?

Question 3. What are the normal levels of variability in ecosystem processes?

Question 4. Are observed changes in ecosystems fundamental changes or are they manifestations of natural variation?

Question 5. How do the cumulative effects of land management practices interact with other stresses in changing ecosystem processes?

Question 6. Are ecosystems being damaged by human influences?

Question 7. Can we separate the influences of human-induced stress from natural stress on ecosystem sustainability?

Question 8. What changes in the genetic, successional, or evolutionary biology of species result from human-induced changes in ecosystem processes?

Question 9. What rates of change in ecosystem processes result from human influences?

Intensive Site Ecosystem Monitoring was initiated with the formation of the Hubbard Brook group in 1992. This group is currently composed of the primary site, Hubbard Brook, and associated satellite sites. A core set of monitoring methods within and among monitoring groups is still under review in ISEM. A potential core group of measurements that have emerged from several workshops where this was addressed include:

— site characterization
— vegetation plots
— hydrology, meteorology, deposition
— biogeochemical pools and fluxes
— soils
— aquatic biota
— fauna
— wetlands
— endemic and event diseases.

The ISEM component of FHM plans to add a second group, the Coweeta Hydrological Laboratory group in the southeastern U.S., to the program in 1994.

USE OF FHM DATA IN LAND MANAGEMENT DECISIONS

The data analysis procedure in FHM consists of aggregation by desired resource class (e.g., species, forest type, etc.), frequency analysis to select for CDF analysis, CDF analysis with thresholds, and combination with on and off-frame data in a GIS system (Fig. 12a). The results can then be forwarded

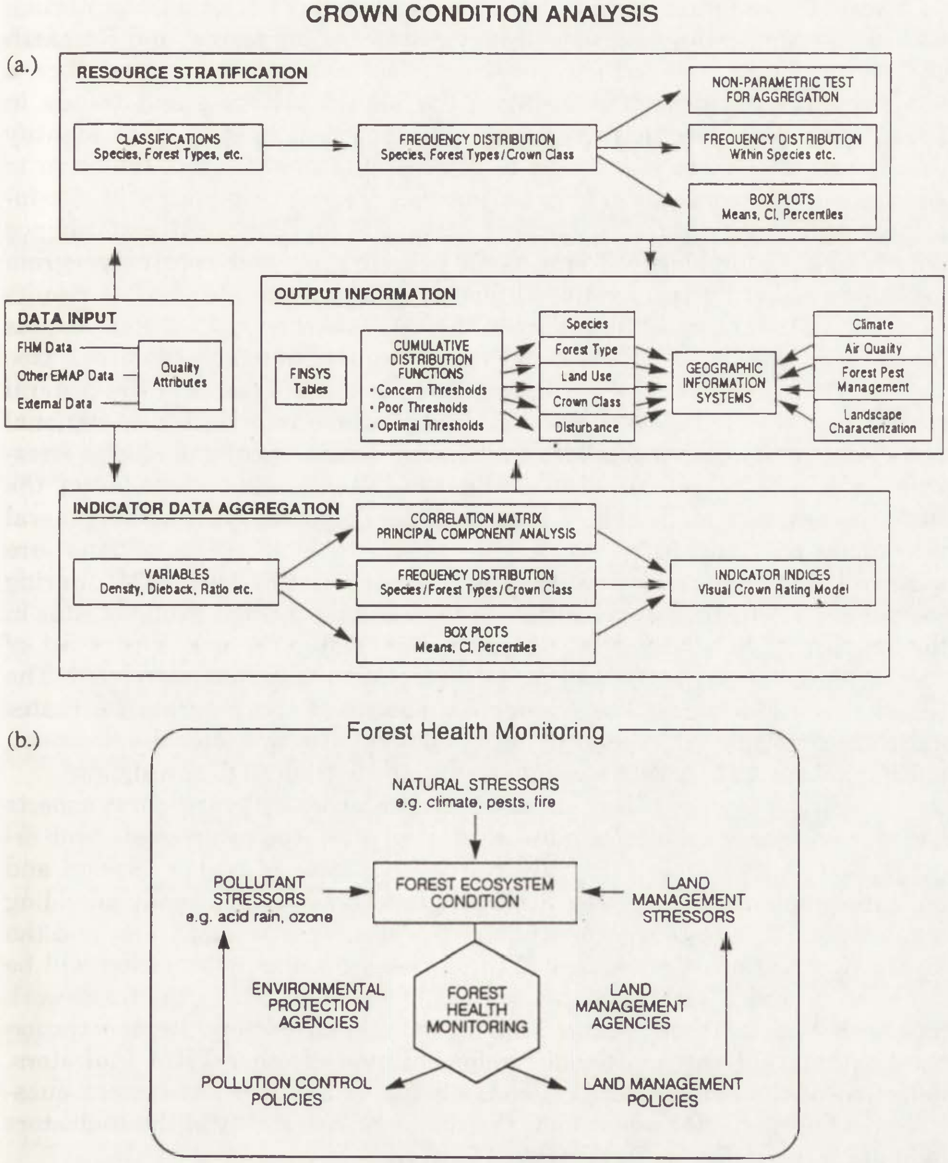


Fig. 12. (a.) The data analysis pathway for Crown assessments in the FHM program. (b.) Data analysis results are supplied to protection and land management agencies to improve and protect forest ecosystems

by FHM to protection and/or land management agencies to improve and protect the condition of forest ecosystems (Fig. 12b).

SUMMARY

The FHM program consists of four components: Detection Monitoring, Evaluation Monitoring, Intensive Site Ecosystem Monitoring, and Research on Monitoring Techniques. The Detection Monitoring component relies on a flexible statistical design to evaluate the status, changes, and trends in forest ecosystem condition over time. The approach in DM is to identify values and assessment questions to select indicators of forest condition to address societal concerns. These indicators are tested rigorously in site-intensive and regional studies to meet statistical and logistical performance criteria. A comprehensive data quality assurance and control program facilitates reporting on forest condition with known confidence. The results from the 1991 Statistical Summary of the DM activities in 12 eastern States provides information on the composition and abundance of forest tree species, the damage to the crown and boles of those trees, and the general condition of the tree crowns. Off-plot data provided information on regional pests, air quality and deposition, and climate as biological and abiotic stressors on forest ecosystems. The Evaluation Monitoring component of the FHM program is in the early stages of development, with some general directions on procedures to follow when subnominal conditions are widespread in any forest resource. The Intensive Site Ecosystem Monitoring component of FHM has been initiated in the Hubbard Brook group of sites in the northeast. Selection of 20 major forest ecosystems and a core set of measurements to be performed in each ecosystem is almost completed. The Research on Monitoring Techniques component of the program facilitates indicator development by identifying mechanisms for indicator development, linking indicators to assessment questions, and setting CDF thresholds.

The FHM program will continue to evolve for many years; some aspects will become more stable over the next few years (program goals and organization), while others may always be in a state of review (design and indicator implementation). The FHM program is, however, already providing a valuable insight into the condition of the aerial portions of trees, and the diversity of various age classes of these trees. Similar information will be analyzed for the 2 western States in early 1994. Additionally, the framework has been laid in those States, and the additional eastern Demonstration Study states, for the additional implementation of other FHM Indicators. Selection of these Indicators depends on the values and assessment questions driving the FHM program at the time, and the ability of the Indicators to address the Indicator Development Criteria.

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REFERENCES

Anderson R.L. & Belanger R.P. 1987, A crown rating method for assessing tree vigor of loblolly and shortleaf pines, (in:) Phillips D.R. (comp.), Proceedings of the fourth biennial southern silvicultural research conference, pp. 538-543. November 4-6, 1986; Atlanta, GA. General Technical Report SE-42, USDA Southeastern Forest Experiment Station, Asheville, NC.

Anderson R.L., Burkman W.G. & Hoffard W.H. 1992a, Status of major forest insects and diseases in the eastern United States, 1991, (in:) Forest Health Monitoring 1992, Forest Health Monitoring 1991 Statistical Summary, Contract 68-DO-0 106; Preprint. U.S. Environmental Protection Agency, Washington, DC. Section 7: 1-24.

Anderson R.L., Burkman W.G., Millers I. & Hoffard W.H. 1992b, Visual crown rating model for upper canopy trees in the eastern United States, USDA Forest Service, Southeastern Region, Forest Pest Management, 15 pps.

Anderson R.L. & Millers I. 1992, Tree groups based on foliage and crown characteristics, USDA Forest Service white paper, Asheville, North Carolina, 7 pp.

Belanger R.P. & Anderson R.L. 1991, A guide for visually assessing crown densities of loblolly and shortleaf pines. USDA Forest Service, Research Note SE-352. 1 p.

Byers G.E. & Palmer C.J. 1992, Quality assurance program for Forest Health Monitoring for 1991, (in:) Forest Health Monitoring 1992, Forest Health Monitoring 1991 Statistical Summary, Appendix B: 1-7. Contract 68-DO-0106; Preprint. U.S. Environmental Protection Agency, Washington, DC.

Cassell D.L. 1992, Statistical design, (in:) Forest Health Monitoring 1992, Forest Health Monitoring 1991 Statistical Summary, Appendix A: 1-4. Contract 68-DO-0106; Preprint. U.S. Environmental Protection Agency, Washington, DC.

Cline S. 1992, Characterization of regional overstory tree species diversity on FHM plots, (in:) Forest Health Monitoring 1992, Forest Health Monitoring 1991 Statistical Summary, Section 5: 1-10. Contract 68-DO-0106; Preprint. U.S. Environmental Protection Agency, Washington, DC.

Cochran W.G. 1977, Sampling Techniques, Third Edition, John Wiley and Sons, Inc., New York.

Dolph K.L. 1988, Predicting height increment of young-growth mixed conifers in the Sierra Nevada, USDA Forest Service Research Paper, PSW-191, 1-7.

Droessler T.D. 1992, Characterization of stand density and number of trees on FHM plots, Forest Health Monitoring 1992, Forest Health Monitoring 1991 Statistical Summary, Contract 68-DO-0106; Preprint, U.S. Environmental Protection Agency, Washington, DC.

Francis J.K. 1986, The relationship of bole diameters and crown widths of seven bottomland hardwood species, USDA Forest Service, Research Note, SO-328, 1-3, October, 1986.

Grano C.X. 1957, Growth of loblolly pine seed trees in relation to crown density, Journal of Forestry 55.11: 852.

Hill M.O. 1973, Diversity and evenness: a unifying notation and its consequences, Ecology 54: 427-432.

Horvitz D.G. & Thompson D.J. 1952, A generalization of sampling without replacement from a finite universe, J. American Stat. Assoc., 47: 663-685.

Kulman H.M. 1971, Effects of insect defoliation on growth and mortality of trees, Annual Review of Entomology 16: 289-324.

Overton W.S., White D. & Stevens D.L. 1990, Design report for EMAP (Environmental Monitoring and Assessment Program), EPA/600/3-91/053, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

Ritters K.H., Papp M.L., Cassell D.L. & Hazard J. (eds.) 1991, Forest Health Monitoring Plot Design and Logistics Study, EPA/600/S3-91/051, U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

Schmitt D.M., Grimble D.G. & Searcy J.L. 1984, Managing the spruce budworm in eastern North America, USDA Forest Service, Agriculture Handbook No. 620, 192 pp., October, 1984.

Scott C.T. 1991, Optimal Design of a Plot Cluster for Monitoring, (in:) Proceedings from The Optimal Design of Forest Experiments and Surveys, 1991.

Shannon C.E. & Wiener W. 1949, The mathematical theory of communication, Univ. of Illinois Press, 117 p., Urbana.

Simpson E.H. 1949, Measurement of diversity, *Nature* 163: 688.

Sprinz P.T. & Burkhart H.E. 1987, Relationships between tree crown, stem, and stand characteristics in unthinned loblolly pine plantations, *Canadian Journal of Forestry Research* 17.6: 534-538.

Stolte K.W. & Radloff D.L. 1993, Intensive Site Ecosystem Monitoring, The Third Monitoring Component of the Forest Health Monitoring Program, Draft 4, 65p.

Stolte K., Anderson R., Burkman W. & Stockton T. 1992a, Crown condition of forest trees on FHM plots, (in:) Forest Health Monitoring 1992, Forest Health Monitoring 1991 Statistical Summary, Section 4: 1-58, and Appendix E-J. Contract 68-DO-0106; Preprint. U.S. Environmental Protection Agency, Washington, DC.

Stolte K.W., Duriscoe D.M., Cook E.R. & Cline S.P. 1992b, Methods of assessing responses of trees, stands, and ecosystems to air pollution, (in:) Binkley D.B., Olson R.L. & Bohm M. (eds.), Pollution impacts on forest ecosystems in western United States, Chapter 7, 65 pp., Springer-Verlag, New York, (in press).

*J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:65-72, IGSO PAS, Warszawa*

FOREST DAMAGE SURVEYS IN HUNGARY

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Abstract: Degradation of forest ecosystems became widespread throughout the Northern hemisphere in the 1970's. Research projects were developed to clarify the role of air pollution and changes in climatic conditions by using new monitoring methods. Based on old traditions and a newborn international cooperative program, a complex monitoring and research project was developed in Hungary to better understand the rapid changes in the forest ecosystems.

Key words: forest monitoring, crown damage, permanent plots, Hungary.

INTRODUCTION

The permanent control of the health state of forest stands has been a basic task of the forestry since historical times. Every forest owner tried to collect information about the potential dangers in order to take measures to avoid damages or to minimize the harmful consequences.

In the 1970's, degradation of forest ecosystems became widespread throughout Europe, and a new name — new type forest damages — was born. Large geographical areas and different tree species were affected within a short time in Europe and in North America as well.

Many insects and fungii already known and considered secondary gained primary importance as the stability of forest ecosystems decreased.

Different factors such as air pollution, acid rain, or unusual climatic conditions were suspected to be the principal reasons for decline. New methods had to be developed to detect the rapid changes of the environmental and forest health status.

Under the Convention on Long-range Transboundary Air Pollution (1979, Geneva), the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, the ICP Forest developed an important Pan-European monitoring system to detect and better understand the changes going on in the forest ecosystems. Thirty one countries participated in the 1991 program and have a permanent information exchange with the National Acid Precipitation Assessment Program (NAPAP) in the United States and the Acid Rain Early Warning System of Canada (ARNEWS).

Hungary signed the Convention in 1985 and immediately started to work out a forest health monitoring system.

The survey methods used in Hungary can be divided into two groups. The first group consists of those surveys which were designed for large-scale information collection. These surveys are as follows:

— Forest protection monitoring network and light-trap network (Forest Research Institute);

— Forest health survey of the forest inventory (Forest Management Planning Service);

— 4 × 4 km grid for monitoring of defoliation and discolouration on the basis of the International Co-operative Programme‘s Method (Forest Management Planning Service).

In the second group, surveys are found that provide information for specific cause-effect studies. These surveys are as follows:

— Intensive studies in a 16 × 16 km grid based on the 4 × 4 km network;

— Ecological studies on permanent plots (both follow the ICP Manual);

— Specific studies for complex evaluation of the health status of certain tree-species (oak, beech, etc.).

All the surveys listed above are carried out by the Forest Research Institute.

The traditional forest protection monitoring network and light trap network are able to detect calamities or forecast insect damage based on information from district foresters.

Since the author is involved in the large-scale surveys, this paper focuses on these questions.

THE FOREST INVENTORY

The forest health survey relating to traditional forest inventory procedures was introduced in 1985. The Hungarian forest inventory covers 1/10 of the total forested area annually. One specific area is surveyed in every tenth year.

During the compartment-wise inventory, the health status of stands are also assessed. The statistically evaluated results represent an entire forested area.

The most favourable characteristic of this method is that the stand health status is classified after the detailed field work, and large numbers of trees are examined before the classification.

The method also has some disadvantages. Since the surveyed area changes year-by-year, it is difficult to make a comparison between the results of the two surveys.

Another important feature of the survey is the time horizon. The field work is carried out through the whole vegetation period as the inventory proceeds. The stands examined in spring were generally more healthy than those surveyed in autumn.

LARGE-SCALE DAMAGE SURVEY

A new survey method was introduced in 1988 to eliminate these disadvantages. This method was based on the manual from the International Co-operative Programme on Assessment and Monitoring the Air Pollution‘s Effects on Forests (ECE Manual). According to the principal characteristics of the Hungarian forests, a 4 × 4 km grid was chosen to determine the location of the sample plots.

A sample plot was established using 1,027 grid points. One sample plot consisted of four sub-plots around a sample point. The centres of the sub-plots are 25 m away from the sample point, toward the north, east, south, and west. The size of the sub-plots are determined by the distance of the sixth sample tree from the plot‘s centre.

Field work is carried out during a relatively short period, August 1- 31, before the beginning of natural defoliation and discolouration. The sample plots were constructed so that they provided opportunity for growth investigations also. Height and diameter is measured annually.

During the adaptation of the international survey method, certain modifications were necessary, but these were generally extensions of the original method.

The damage survey is based not only on the assessment of defoliation and discolouration, but also on all visible damage symptoms. Their identifiable origins are recorded, encompassing the following:

(a) Crown damage:
— Top dieback;
— Mistletoe (*Loranthus europaeus*);
— Distortion of shoots (mostly on *Pinus* spec.);
— Foliage rodent insects;
— Foliage destroying fungi;
— Browsing of shoots (if it is not caused by game);
— Foliage damage caused by emission;
— Crown break (snow, wind, rime, ice);
— Other crown damages;
(b) Stem damages:
— Stem tinders — on Turkey oak *Inonotus nidus-pici*, on oaks *Phellinus robustus*, on poplars *Phellinus tremulae*;
— Goitres and cancerous injuries;
— Ulcers (on poplars: *Dothichiza populea*);
— Bark lice;
— Shield scales;
— Wood-destroying beetles (mostly on poplars);
— Strong slime flow;
— Frost rib, frost split;
— Water shoots;
(c) Bark injuries:
— Injuries by skidding and transport;

— Other injuries (damages on shoots, branches);
(d) Root and butt root damages:
— Decayed coppice stumps;
— Coniferous roots decaying tinder (*Heterobasidion annosum*);
— Other damage;
(e) Soil damages:
— High level of underground water;
— Slack water;
— Erosion;
— Soil pollution (chemicals, oil, etc.);
— Other compaction (grazing);
(f) Damage caused by games:
— Hindering natural regeneration;
— Afforestation damage to acorns;
— Browsing, damage on buds and shoots;
— Bark stripping, browsing, fraying;
— Damages by break;
(g) Other damages:
— Fire damage;
— Damage caused by unknown reasons;
— Windbreaks;
— Drought;
— Improper forestry activity.

An accurate interpretation of the impact of environmental changes shown by tree defoliation and leaf discolouration cannot be expected without a detailed description of the sample trees.

Although Hungary is a small country, there are more than 70 tree species in the survey.

The crew must be extremely careful. They are planners who spend most of their time in the forests taking the forest inventory. As for the staff, a dipl. eng. degree is required; however, experts with special degrees in plant pathology are appreciated. National and regional training courses are organized annually.

The sample tree distribution (Fig. 1) represents the total distribution surprisingly well. The only exception is the class "other broadleaved hardwood", because normal forest inventory has records of those stand components that only exceed 5% within a compartment. There are no restrictions regarding tree-species when selecting sample trees. The distribution by age classes (Fig. 2) also represents the distribution of the total forested area well. The difference in the first-age class can be explained by the fact that assessment is postponed on those areas where the reforestation has yet to be finished.

Site conditions have a basic effect on the health status of the forests, hence a site survey had to be done on the monitoring plots.

The soil sampling was done in 1991 to 1992, and the laboratory analysis will be finished in 1993. National genetic soil classification and site description were used.

A manual for soil sampling and analysis was accepted from the 1992 Task

Force meeting of the ICP Forests. For practical reasons — a large number of plots as well as a lack of a well-trained staff with international experience — the recommendations are followed only on the 16 × 16 km plots. The archive soil samples ensure the opportunity for future investigation.

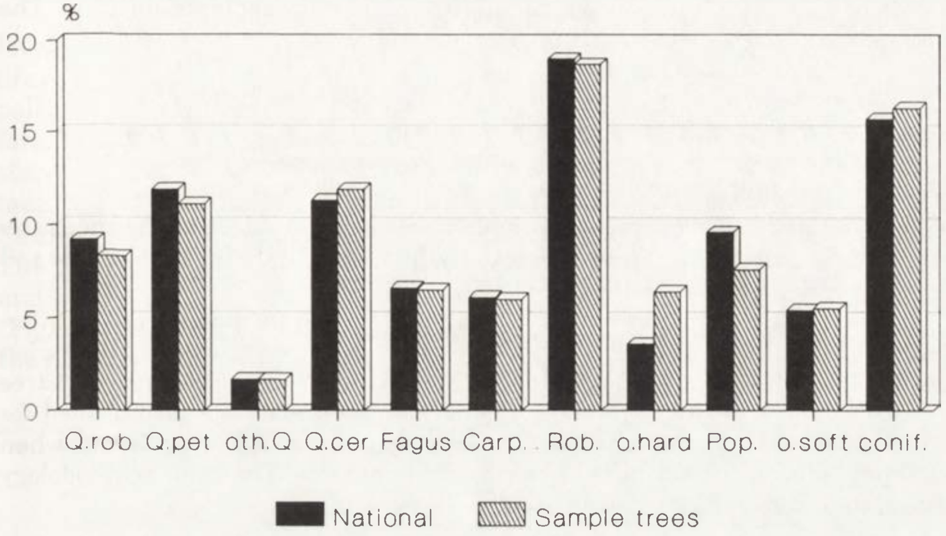

Fig. 1. Distribution of the sample by tree-species

Source: Nat. Forest Health Database and National Forestry Database

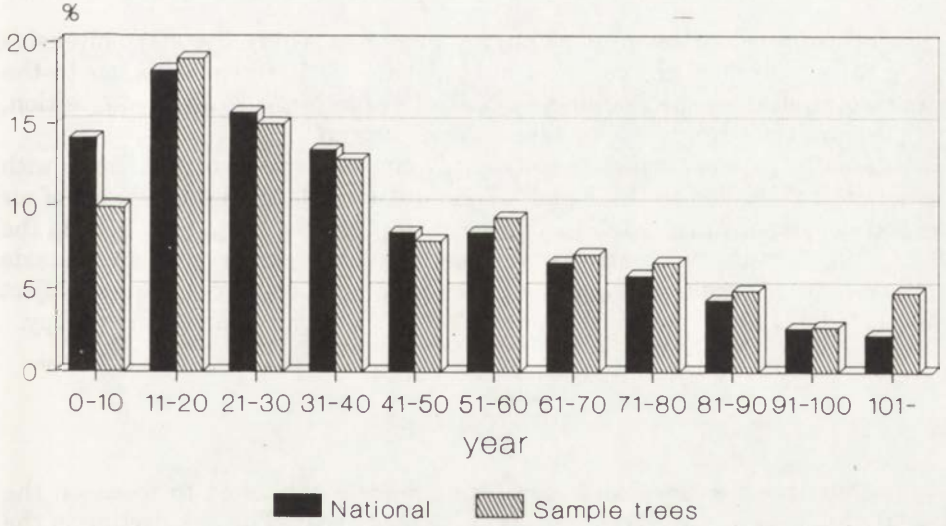

Fig. 2. Distribution of sample trees by age classes

Source: Nat. Forest Health Database and National Forestry Database

STUDIES ON PERMANENT PLOTS

INTENSIVE STUDIES

Following international recommendations, 65 plots were established in a 16 × 16 km network, based on the 4 × 4 km grid of the large scale survey.

About 50 to 100 trees were marked (0.1-0.25 ha) in each plot in 1989. The methodology based on the ECE manual is as follows:

- Geographical location;
- Climate, hydrology, and soil;
- Forest type and grass vegetation survey;
- Stand structure and dendrometrical measurements;
- Health survey.

In 1989 most of the first investigations were done. Most of the measurements and surveys are repeated annually, but some of them, such as the soil survey, are done every 5 years.

Because of the large variety of forest types as well as having correct information about the ecological changes and cause-effect relations in Hungarian forests, 100 more plots were selected concentrating on the most important tree species and typical site conditions. The former research plots (established for different research purposes 10 to 20 years ago) were highly preferred when obtaining information about the growth, yield, and site. The same methodology is used in this investigation as is used on the network plots.

ECOLOGICAL STUDIES

The third level of the damage survey project is where the most intensive ecological researches are done on seven plots. In 1988, in addition to the intensive studies — methodology, detailed meteorology, growth, deposition, and precipitation throughfall measurements began.

Automatic meteorological stations were established together with meteorological service on three plots. The most important characteristics of air and soil — temperature, wind, moisture content, precipitation, SO_2, NO_2 in the air as well as in the rainwater — were permanently registered in and outside the forest. Wet deposition is collected with automatic collectors. A new project was started in 1992 to measure the ozone content under and above the canopy.

SPECIFIC STUDIES

Specific investigations and monitoring were established to focus on the special problems of some tree species or defined areas. The oak decline in the 1980's is a good example when the sessile oak dieback was surveyed on hundreds of temporary sample plots throughout the country.

Special survey methods and research work for special studies are widely practiced, but whenever it is possible the standard methods of damage survey are applied. Today the surveys focus on three tree species — beech, sessile oak, and English oak.

BRIEF SUMMARY OF THE RESULTS

The large-scale damage survey started 5 years ago and the latest two levels of research work only a short time later; therefore, it is too early to draw any conclusions. There is no large-scale forest dieback because of air pollution in Hungary. Air pollution, however, can be a contributing factor to forest dieback by reducing the resistance of the trees and undermining the stability of forest ecosystems. The large-scale survey based on the assessment of 21,000 trees showed that 48.3% of the trees were healthy and 19.6% had a defoliation higher than 25% in 1991, close to the average in Europe. The most defoliated species are the English and sessile oaks, black locust, and Scots pine; while the healthiest ones are beech, hornbeam, and spruce (Fig. 3). Most of the spruce samples are in young stands, and consequently the health status seems to be good.

Since there were no damage surveys previously, it is difficult to distinguish between the natural and abnormal changes in the health status. The

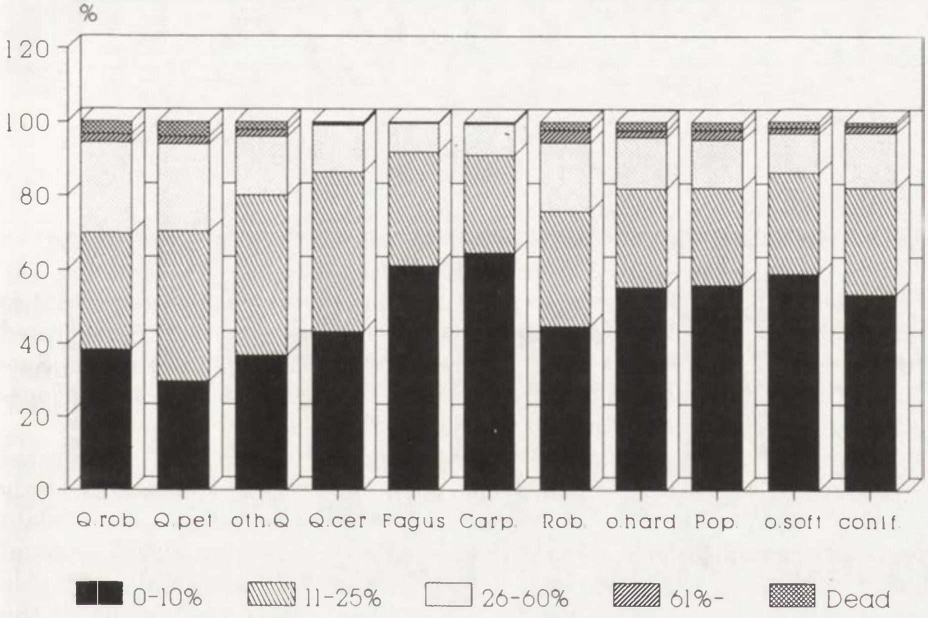

Fig. 3. Defoliation in 1991 by tree species

Source: Nat. Forest Health Database

study results of the last 4 years show that the situation seems to be worsening (Fig. 4).

The 1990 high values of defoliation can be attributed to the extreme drought, and the proportion of healthy trees decreased by 14% from 1988 to 1990 and stagnated in 1991. While oaks worsened permanently, most of the tree species improved in 1991, but defoliation was higher than in 1989.

Defoliation tendency, unidentified diebacks, and high levels of different damages have caused that our research is focused on ecosystem studies. It is necessary to identify and select the role of different factors, such as air pollution or drought, on a general status of forest health.

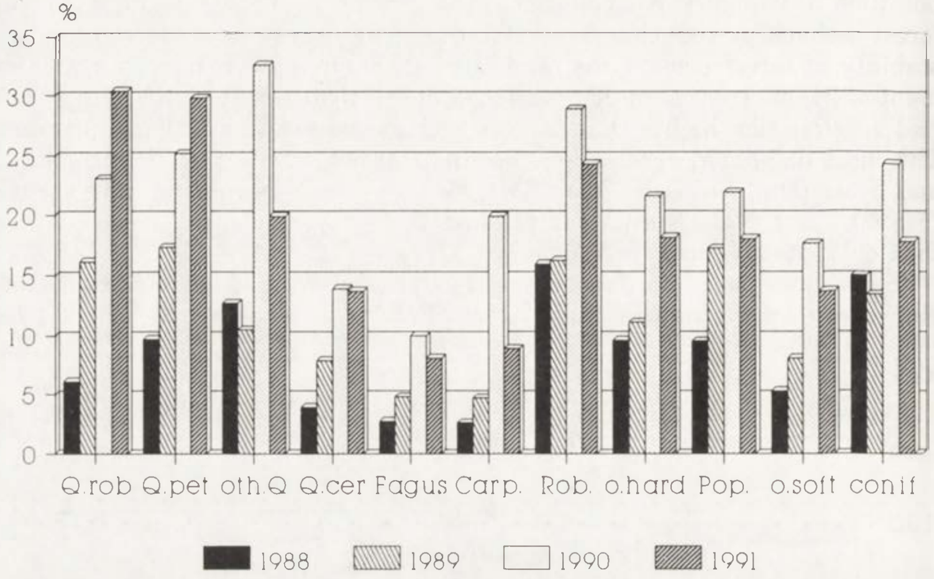

Fig. 4. Defoliation in 1988 to 1991 by tree species
Source: Nat. Forest Health Database

The forest damage survey is one of the few monitoring systems that is operating in Hungary. Through the common monitoring plots, it is connected with the Soil Monitoring System of the Nature Protection Information System that belongs to the Ministry of Nature Protection and Land Management. The field work of soil monitoring began this year.

Under the leadership of the same ministry, a Regional Integrated Monitoring (RIM) system is being developed and is in the feasibility study phase. The purpose is to collect various information to put into a metadata base which would provide excellent facilities for complex analysis, regional planning, disaster prevention, etc. Forest damage surveys are also valuable sources for RIM as forest ecosystems changes indicate the quality of the environment.

*J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:73-86, IGSO PAS, Warszawa*

RESULTS OF REGIONAL MONITORING OF FORESTS AND SOILS IN LITHUANIA

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Abstract: The results of IIASA (Austria) based on forest monitoring programmes indicate that nearly 80% of coniferous and 40% of deciduous forests in Europe suffer from air and soil pollution effects. Satellite observations show that in Central Europe the currents of polluted air are spread by the wind to a distance of 700 to 800 km. An increase in precipitation acidity, especially during winter, has been recorded in western Lithuania. For several months the pH indicator of precipitation was 3.8 to 4.0. In the eastern direction, the pH indicator becomes more alkaline. This proves that pollutants moved to Lithuania from Western Europe, including neighbouring Poland. Future investigations will give us information about the scale of pollution on air and forest soils as well as reasons for forest damages. This knowledge will give us an opportunity to develop the proper operations to save and protect our "green friend."

Key words: forest monitoring, pollution, defoliation, soil acidity, Lithuania.

INTRODUCTION

It is hard to imagine our planet, humanity, and all living beings without the greatest riches of our globe — forests. Forests are reliable indicators of the cleanness of air and soil.

It was calculated that each person during his lifetime uses an average of 100 m^3 of wood. No single branch of national economy can exist without wood. Forests on our planet contain more than 90% of the entire reserve of organic matter. Afforestation of the Earth was 75%; now it has decreased from 21% to 27%. During this time, wood resources decreased from 360 billions m^3 to 336 billions m^3 today. About 30 years ago approximately 5,000 different wood products were manufactured; today the industry produces more than 20,000 wood products. During the next 20 years, the world's use of wood is expected to increase twice. Today, throughout the world, 20 hectares of mature forests are destroyed every minute. Modern industry is able to manufacture wood substitution, but as yet, nothing can substitute for the forest.

About 5,000 years ago humanity, for the first time, came into conflict with nature. This conflict became more visible approximately 200 years ago as the use of coal rapidly increased. Because of the swift development of energetics, industry, road, and air transportation after World War II, the most intensive and fastest rate of air pollution was recorded.

Lithuania has had forest monitoring since 1988; however, the first investigations began in 1987. The purpose of this paper is to describe the results of those research efforts involving 1991 data on the conditions of forests and the dynamics of damage in Lithuania.

SOURCES OF POLLUTION

The atmosphere is polluted with CO_2, SO_2, NO_x. The northern hemisphere provides about 96% of the world's production of SO_2. Sulphur dioxide, together with nitrogen oxides, create "acid rains" which cause the decrease of the pH factor to 3 to 4 or even less in several areas.

In the territory of the former USSR, and partly in Lithuania, the environment is polluted mostly by energetics — 27.0%, metallurgy — 24.3%, nonferrous metallurgy — 10.5%, petroleum mining and petrol chemistry — 15.5%, road transport — 13.3%, building material industries — 8.0%, Ministry of Forest industries activity — 2.2%, and chemical industries — 1.3%.

World-wide use of energetic resources doubles every 12 years which means that industrial pressure to nature will increase 2.5 to 3 times by the year 2000.

The results of IIASA (Austria) show that only European countries acquire enough reliable data about current changes inside forest ecosystems from forest monitoring programmes which have been carried out for several years. Nearly 80% of coniferous and 40% of deciduous forests in Europe suffer from air and soil pollution. Satellite observations show that in Central Europe the currents of polluted air are spread by the wind to a distance of 700 to 800 km. According to the newest data presented by the World Resources Institute, about 25.8 mln tons of SO_2 and 13.8 mln tons of NO_x are emitted to the atmosphere every year in Europe (not counting the former USSR) — (World Resources 1992-93). In Central Europe 50 kg of sulphur (S) and 21 kg of nitrogen (N) are deposited per 1 ha every year.

An increase in precipitation acidity, especially during winter, has been recorded in western Lithuania. For several months the pH indicator of precipitation was 3.8 to 4.0. In the eastern direction, the pH becomes more alkaline. This proves that pollutants moved to Lithuania from Western Europe, including neighbouring Poland.

After the World War II, Lithuania developed from an agrarian type country to agrar-industrial type. Several giant plants have been built within the territory of Lithuania, such as "AZOT" in Ionav (Yonavskij AZOT), a chemical plant in Keidany, a petroleum refinery in Matcheiki (Mazeiki, Mazejkiajksoje), “Akmian Cement” (Akmianskij Cement), Elektren (Elektrenskaja) heating plant, a nuclear plant in Ignalina (Ignalinskaja), a cellulose plant in Klaipeda, and many other smaller plants as well (Fig. 1).

Fig. 1. The main atmospheric polluters in Lithuania
A — Mazeikiai Oil (refinery factor), B — Akmene Cement factory, C — Kedainiai chemical enterprise, D — Jonava “Azotas” factory of fertilizers, E — Elekrenai thermal electric power station, AT — Ignalina nuclear power station

Today in Lithuania more than 2,000 local sources of pollution exist that emit 1 to 1.5 million pollutants every year. Lithuanian industry produces approximately 120,000 various air pollutants. For energetic purposes, Lithuania receives from Russia mazout (crude oil) which contains 3 to 3.5% sulphur.

The average amount of sulphur, emitted as SO_2, is as follows: in northern Lithuania, 0.5-1.0 t/km^2; in southern Lithuania 0.25-0.5 t/km^2; emission of NO_x is 0.1-0.5 t/km^2 and 0.5-1.0 t/km^2. An average of 11 to 18 kg/ha/year by sulphur and 8 to 11 kg/ha/year by nitrogen compounds are deposited in Lithuania.

FOREST MONITORING IN LITHUANIA

PRINCIPAL FEATURES OF FOREST REACTION TO ENVIRONMENTAL POLLUTION

It has been accepted that forests accumulate 2 to 4 times more pollutants than open areas. Table 1 shows the indices of damage to coniferous forest in Lithuania and neighbouring countries (Executive summary... 1989, 1990, 1991).

Table 1. Indices of coniferous forest damage

Country	% of damaged trees		
	1989	1990	1991
Poland	82.2	88.5	-
Latvia	-	77.0	85.0
Estonia	61.2	63.0	-
Kalliningrad district	89.0	90.9	91.5
Lithuania	68.0	73.7	81.7

Many years of observation allow a conclusion that coniferous forests are less resistant to pollution than deciduous forests. Damage susceptibility increases as trees grow older. When relative air humidity is lower, forest resistance grows. Stand thinning causes a decrease in tree resistance. In autumn tree resistance to gaseous pollutants increases. Trees on poor and overwatered soils are less resistant to gaseous pollutants. Forests that grow on elevated areas are more exposed to destruction. Destructive factors are more intensive during windless, sunny weather, and during first half of the day.

In this paper we do not intend to discuss the question of Class of Damage (PDK). We only want to mention that PDK of gaseous pollution for forests is considerably smaller than that for people and animals. PDK classes should be established not only for the entire country but also for a particular region. There are many problems concerning this question.

Table 2. The effect of PDK and defoliation on the decrease in and increment according to Zackar (1990)

Class of damage	Defoliation (%)	Decrease in stand increment (%)
0	< 10	< 20
1	11-25	20
2	26-60	50
3	60-99	80
4	100	100

The effect of pollutants on decrease in stand increments is an important problem for foresters and research workers. Some studies by Zackar (1989, 1990), Yuknis (1990), and others refer to this question (Table 2, Table 3). As the figures presented in this paper show, decrease in stand increment intensifies as the defoliation stage increases.

Table 3. The effect of PDK on the decrease in stand increment in Lithuania (according to Yuknis 1990)

Class of damage	Decrease in stand increment (%)
1	14
2	37
3	70

METHODS, RESULTS, AND DISCUSSION

A forest monitoring program was carried out on a 500 km wide strip along the western border of the former USSR. Forest monitoring has been done in Lithuania during the past 5 years, 1988-1992; however, the first investigations began in 1987. A bioindicatory net 4 × 4 km was employed for this purpose (Fig. 2).

The total forested area in Lithuania is approximately 2 million hectares. Within this territory there are 960 permanent research stations and 3,840 monitoring points (satellites). Each year 23,040 trees have been observed. Until 1990, the regional forest monitoring was done within the first level; from 1991, within the second level; i.e., examinations of forest soils and the respiratory apparatus of trees.

In 1990, the average defoliation of different tree species was as follows: pine — 23.3%, spruce — 16.5%, and all coniferous in a total — 20.8% (Fig. 3); oak — 21.7%, ash — 12.4%, birch — 18.0%, black alder — 12.3, grey alder — 14.5%, aspen — 20.4%, and all trees in a total of 19.7% (Fig. 4). Leaf discolouration in Lithuanian forests is still only slighty marked. Data obtained in 1989 to 1990 show discolouration in 1.6% of coniferous forests and in 1.3% of deciduous forests.

As Figures 3 and 4 show, pine trees are damaged more than all coniferous species, and oak and aspen are damaged more than all deciduous species. Black alder, ash, and grey alder are the most resistant to gaseous pollutants of all deciduous species.

The condition of forests in Lithuania have constantly worsened until 1991, especially of the coniferous stands. Considerable changes were also observed in the grey alder and ash stands.

Air pollution caused by SO_2 and NO_x has been examined in 72 points spread over the entire forest area of Lithuania. The Japanese method of so called "candles," also adapted in Poland, was used. A filter paper impregnated with K_2CO_3 was the absorbent. The results of the examination show that air pollution in forests is considerably higher in winter (the average SO_2 absorption is 4-5 mg/m^2/24 hours; i.e., four times more as compared with

Fig. 2. Forest monitoring permanent observation plots (4 × 4 km)

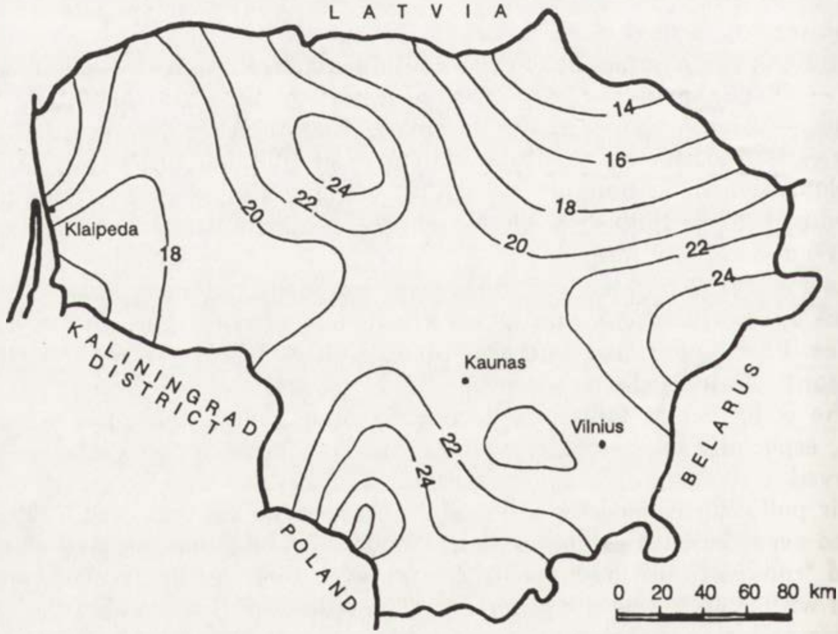

Fig. 3. Division of the Republic territory into zones according to crown defoliation of conifers (%)

that of summer; Fig. 5). The maximum amount of SO_2 in 1990 was 29.8 $mg/m^2/24$ hours. There are great differences in the pollution of air at several points within the territory (in summer — 10 times greater, in winter — 20 times greater). The heaviest air pollution, especially with SO_2, was recorded in the western part of Lithuania (Lietuvos... 1991).

The amount of NO_x in air fluctuates between 10 to 50 $micrograms/m^2/24$ hours (summer) and 300 to 500 $micrograms/m^2/24$ hours (winter). No particular dispersion conditions of NO_x were found (Fig. 6).

During the past few years the Lithuanian Forest Institute together with the Physics Institute of Lithuanian Academy of Science began to examine the amount of radionuclides in forest ecosystems. In the network 16 × 16 km, 142 examination points were selected (Fig. 7). At these points, samples of forest litter and higher layers of soil and fauna in those layers were taken. It was recorded that the pollution with ^{137}Cs in forest litter was the highest (47.4% of total radioactivity), the next highest was in mosses and lichens (29.4%) and in soil from 0 to 5 cm deep (10.9%). Radioactivity in trees was not high (3.3%). The greater part of Lithuania is polluted with radionuclides; radiation approaches the background radiation (70 to 100 Bq/kg), sometimes twice as much. The forest litter is heavily polluted in western Lithuania where concentration of ^{137}Cs outnumbers the background 10 times and in some places even 60 times (Lietuvos... 1991).

The regional monitoring of forest soils in Lithuania began in 1991. It was done by using a bioindicatory network 32 × 32 km and international methods (Fig. 8). In Lithuanian forests 72 points for investigation were selected. Field and laboratory investigations are still under way on the first level. During August and September samples of forest litter and higher mineral layers up to 20 cm deep were taken from 20 places at each point. In 1992, 288 samples were taken. In each sample it was determined: pH, organic C, total N, $CaCO_3$; also P, K, Ca, Mg, Na, Al, Fe in HF solution, exchangeable acidity (H + Al), exchange capacity, cations: Ca, Mg, K, Na, Fe, Al, absorbed bases. Because field work is unfinished, we describe only some results of regional monitoring of forest soils. The greatest acidity pH_{H_2O} 3.1-4.0) of forest litter was recorded in the western and southwestern regions; lowest acidity (or even alkaline reaction) was recorded in central Lithuania (Fig. 9). In eastern Lithuania the actual acidity of litter was between pH_{H_2O} 5.1-6.0. In the Ignalina area (nearby nuclear plant) this factor grows up to pH_{H_2O} 6.1 to 7.0, sometimes even to 7.1 to 8.0. Almost identical relations were found in higher mineral layers of soils (Fig. 10). The greatest acidity (pH_{H_2O} 3.1-4.0) was recorded in the surface layer 0 to 5 cm deep in western and southwestern Lithuanian forests. The lowest acidity (pH_{H_2O} 6.1 to 7.0, in some places, 7.1 to 8.0) was found in the north central regions. In southeastern forest areas (mostly pine stand) the reaction of soil was between 4.1 to 5.0. On this basis, the conclusion was that acidified and medium-acidified soils predominated in Lithuanian forests. Only in northern areas, where carbonates occur close

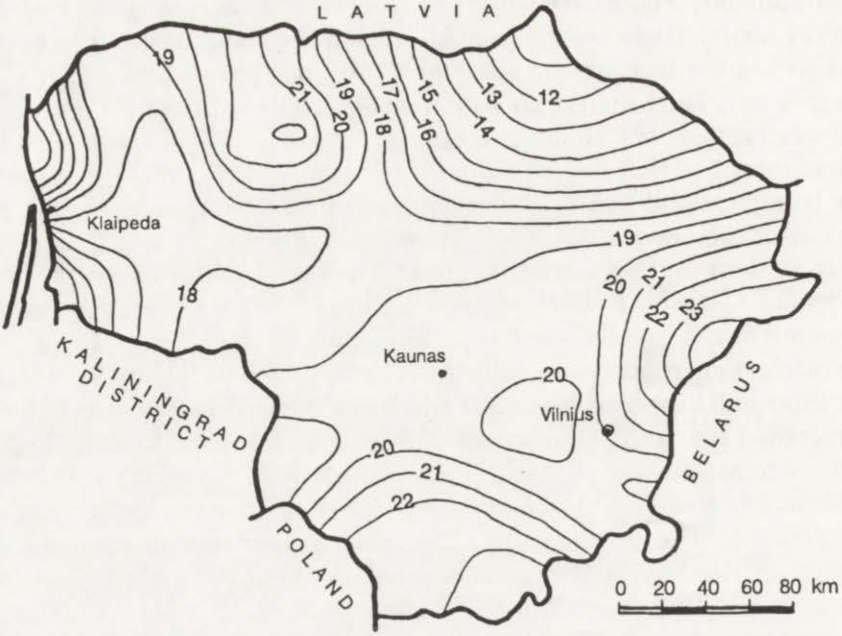

Fig. 4. Division of Republic territory into zones according to crown defoliation of all tree species (%)

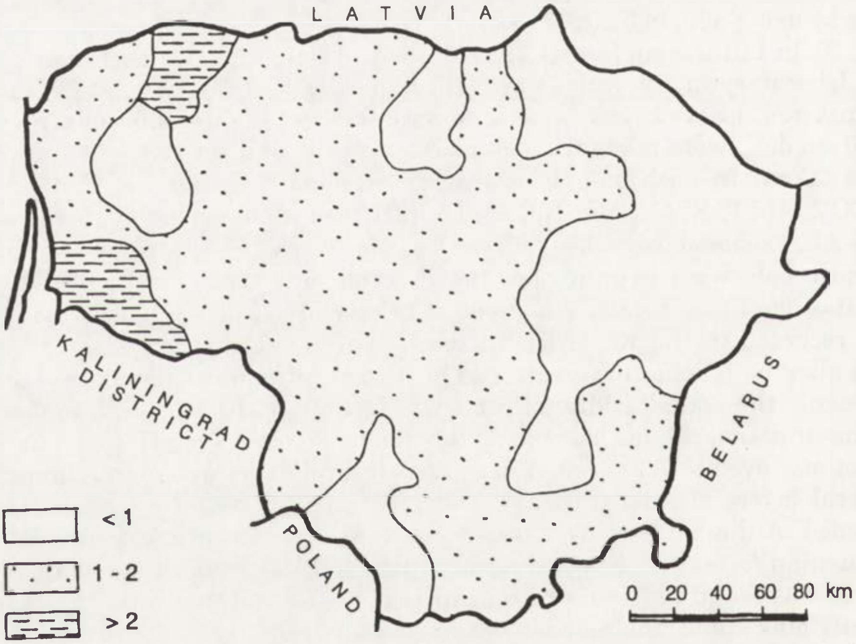

Fig. 5. Air pollution by SO_2 in the forests, mg/m^2 per day (August 1990)

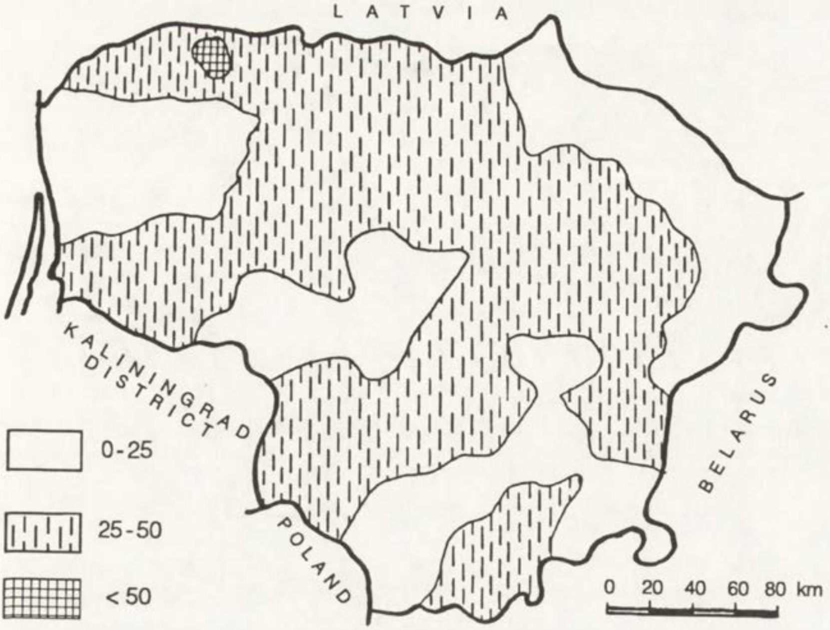

Fig. 6. Air pollution by NO_x in the forests, micrograms/m^2 per day (August 1990)

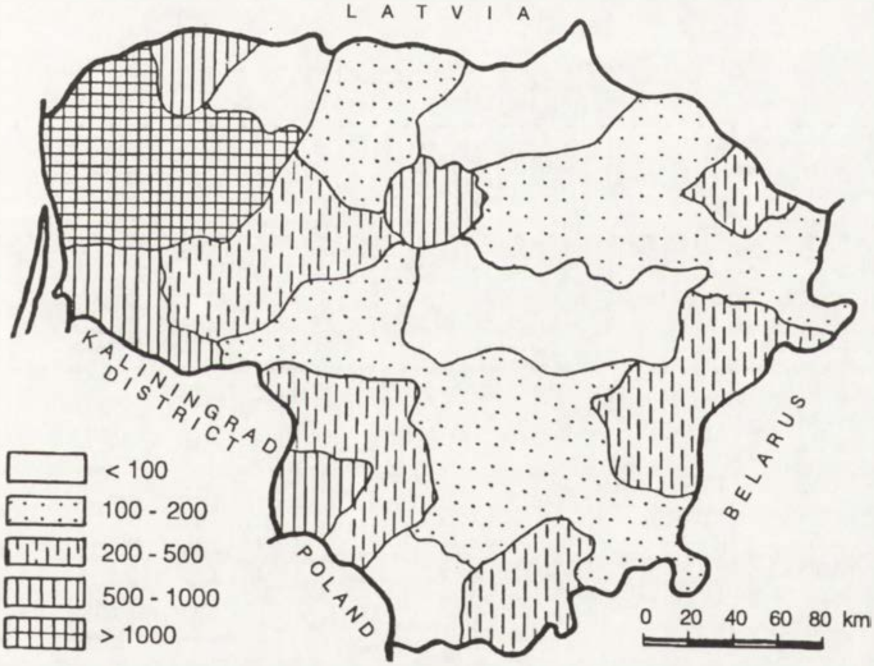

Fig. 7. Radioactive pollution of forest litter by ^{137}Cs, Bq/kg

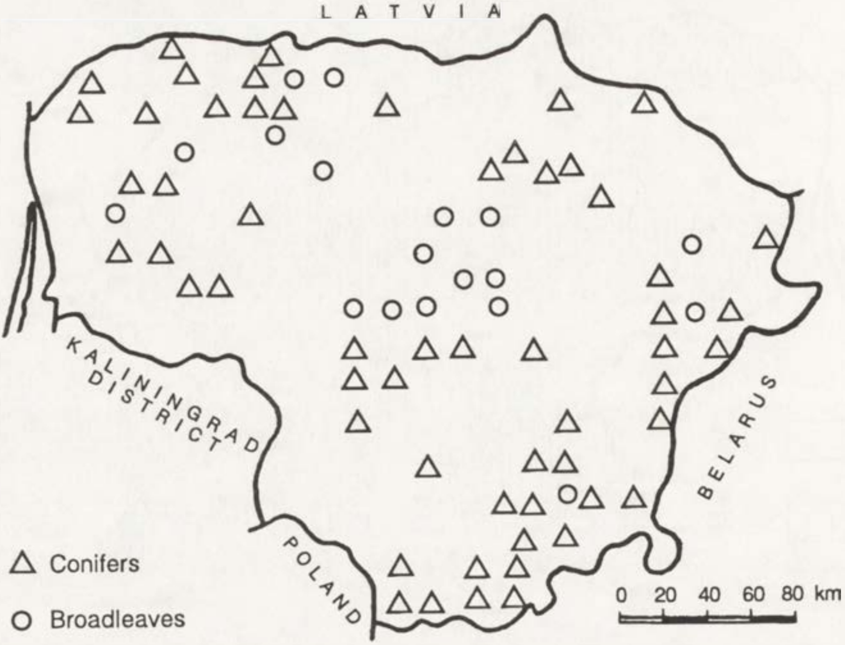

Fig. 8. Forest soils monitoring permanent observation plots (32 × 32 km)

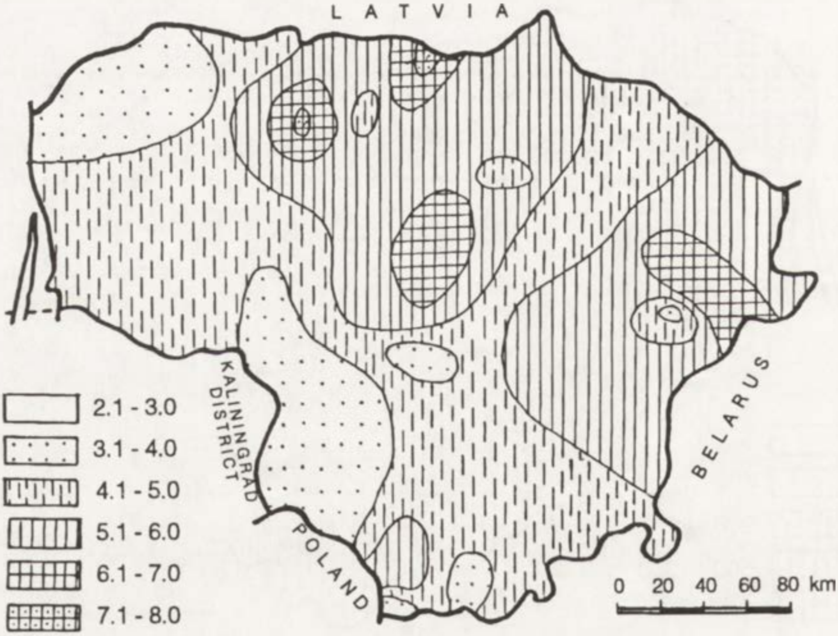

Fig. 9. pH_{H_2O} of forest litter

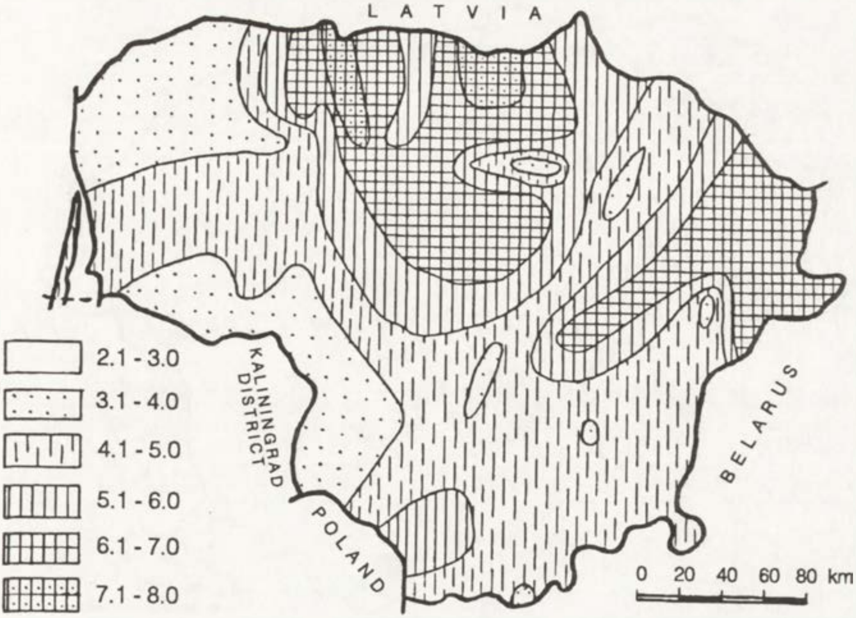

Fig. 10. pH$_{H_2O}$ of forest soils (0-5 cm depth)

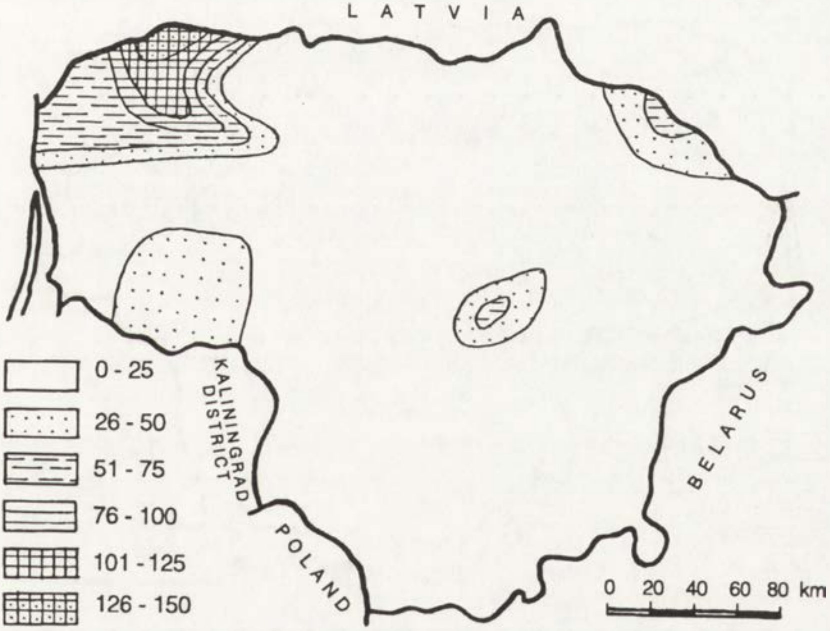

Fig. 11. Exchangeable acidity in the forest soils (m-ekv/100 g) (0-5 cm depth)

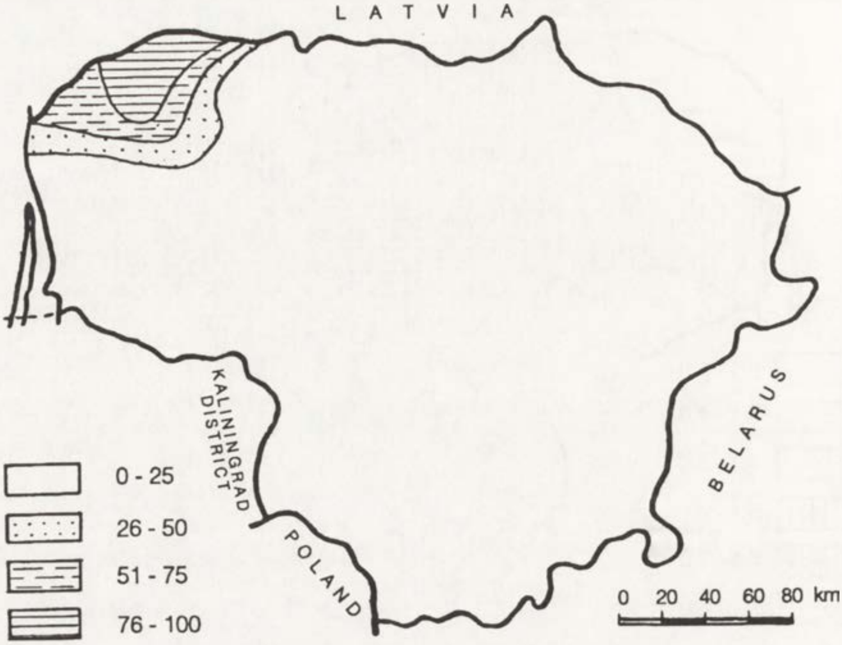

Fig. 12. Exchangeable H$^+$ in the forest soils (m-ekv/100 g) (0-5 cm depth)

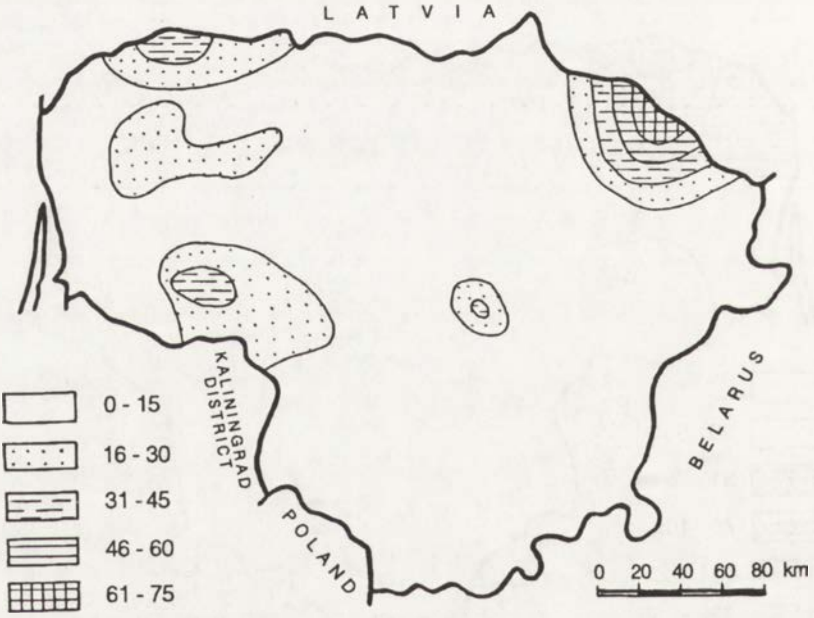

Fig. 13. Exchangeable Al^{+++} in the forest soils (m-ekv/100 g) (0-5 cm depth)

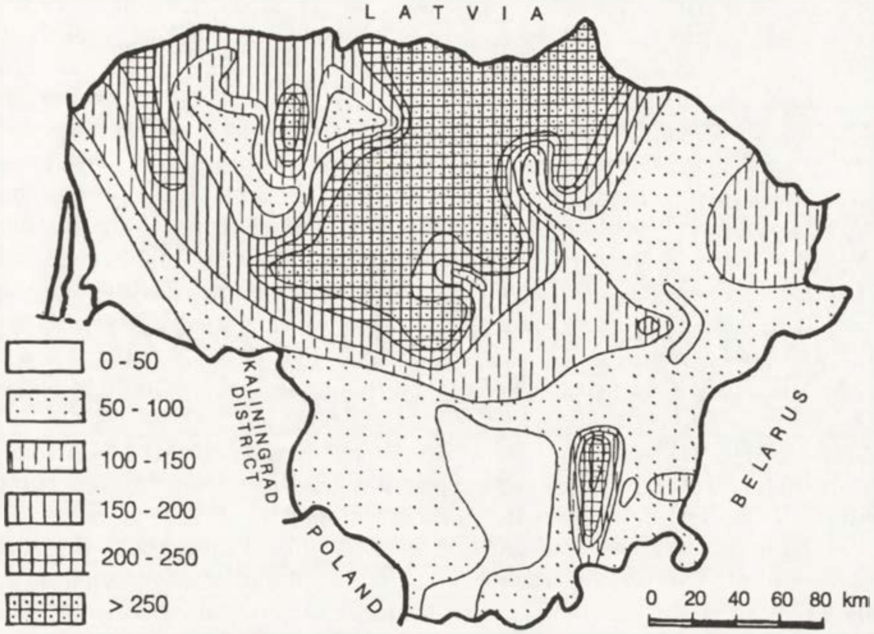

Fig. 14. Mobile sulphur (S) quantity in forest litter (mg/kg)

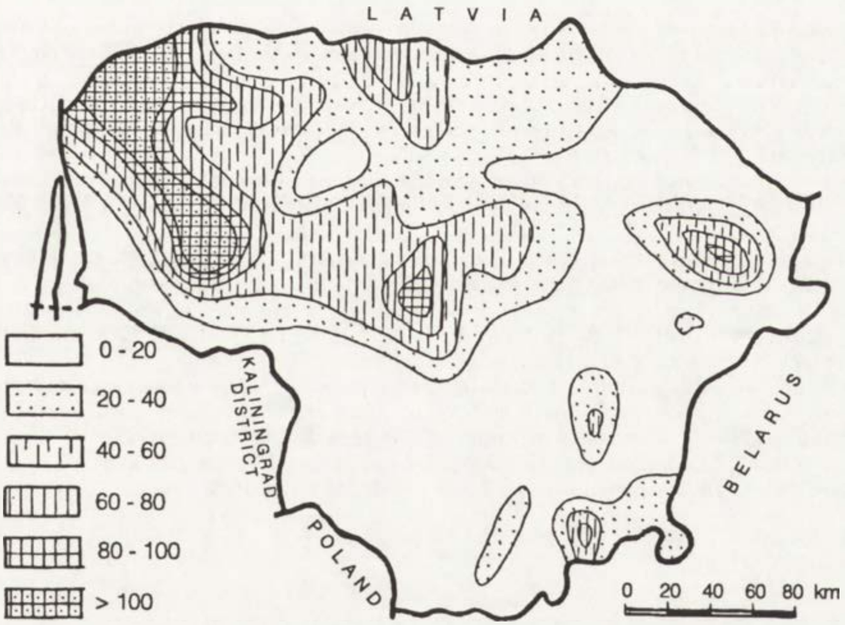

Fig. 15. Mobile sulphur (S) quantity in the forest soils (mg/kg) (0-5 cm depth)

below the soil surface, slightly acidified or almost neutral soils were found. Exchangeable acidity of the surface layer of soil (0 to 5 cm deep) reached the highest indices in the northeastern regions of Lithuania (Fig. 11). Almost identical distribution shows exchangeable H^+ (Fig. 12), and exchangeable Al^{+++} (Fig. 13). Preliminary data concerning the content of transferable sulphur in forest litter and mineral layers of soil was obtained. The greatest amount of transferable sulphur accumulating in forest litter was in north-central Lithuania (Fig. 14). It seems to be related to the high fertility of these soils, the amount of humus, and a deciduous type of forest stand. In the surface mineral layer of soils, the distribution of transferable sulphur is of another kind (Fig. 15). The greatest amount (> 80 mg/kg) was found in northwestern Lithuania, in the central region, and in some parts of the eastern region. A low concentration of transferable sulphur (up to 20 mg/kg) was recorded in soils in the southern and eastern regions.

Since 1980, the local monitoring was carried out around the main sources of pollution. Interesting data was obtained with this program, but the data would be too lengthy to report in detail in this paper.

We hope future investigations will give us information about the scale of pollution in air and forest soils as well as the explanations for forest damage. This knowledge would enable us to perform the proper operations to save and protect our “green friend.”

REFERENCES

Executive summary of the 1989 forest damage survey in Europe, International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (Draft).

Executive summary of the 1990 forest damage survey in Europe, International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (Draft).

Executive summary of the 1991 forest damage survey in Europe, International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (Draft).

Lietuvos misku monitoringas (Forest monitoring in Lithuania) 1991, Lietuvos misku ukio mokslinio tyrimo institutas, 64 p, Kaunas, Girionys.

World Resources 1992-1993, A Guide to the Global Environment, World Resources Institute; The United Nations Environment Programme; The United Nations Development Programme, 385 p., New York.

Yuknis R. 1990, Rost i produktivnost odnovozrastnych sosniakov v uslovyach zagrazniennoy prirodnoy sredy (Growth and productivity of equal-age pine brushwood under the conditions of polluted environment). Doctor’s thesis, Krasnoyarsk.

Zachar D. 1989, Imisie — najvačsie nebezpečenstvo lesov v Europe, *Les* 45.4.

Zachar D. 1990, Imisie a ich wplyv na jednotlive dreviny, *Les* 46.3.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:87-100, IGSO PAS, Warszawa

MONITORING OF FORESTS IN THE CZECH REPUBLIC

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Abstract: The terrestrial monitoring of forests in the Czech Republic is based on the harmonized methodology of International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (UNEP/ECE) and consists of three parts: (a) national network of permanent monitoring plots (16 × 16 km), (b) regional intensive monitoring (network 1 × 1 km in selected areas), (c) set of permanent research plots established for the purposes of forest inventory and management planning.
Key words: forest monitoring, permanent plots, defoliation, dendrometry, Scots pine, Norway spruce, Czech Republic.

INTRODUCTION

Forests in the Czech Republic cover an area of 2,417,000 ha corresponding to 33.4% of the total area of the Czech Republic. Conifer species with 78% of forest area are predominating. The principal tree species are Norway spruce (55% of forest area) and Scots pine (18%). Broadleaved species are presented mostly by beech and oak. The principal forest regions are mountains along the border of the Czech Republic: Šumava Mountains (Bohemian Forest), Ore, Jizera, Krkonoše (Giant), Orlické, Jesensky, and Beskydy Mountains.

The Czech Republic and, particularly, its northern part (Ore Mountains) has experienced heavy air pollution for the last two decades. The well-known "ecological disaster" began in the Ore Mountains in the 1950's. Following were the heavily damaged area of the Jizera Mountains (in the mid-1970's), and the Krkonoše and Beskydy Mountains (the 1970's-1980's). The main cause of forest decline in northern Bohemia is the extremely high concentration of SO_2 in the air. The mean annual concentration reaches 90 micrograms/m^3 as well as high acid deposition. Sulphur deposition in some parts of the Ore and Jizera Mountains exceeds 120 kg/ha a year. The main source of SO_2 pollution is the set of brown coal (lignite) power plants in northern Bohemia and also the transboundary air pollution from Germany and Poland.

The process of disintegration of forest ecosystems is related to other areas of northern Bohemia at the present time. The symptoms of forest decline are observed also in northern Moravia as well as western and southern Bohemia. It is nearly impossible to find any area in the Czech Republic without visible damage. The character of forest damage in these relatively new areas of forest damage differs from the situation in northern Bohemia. Contrary to direct impact of SO_2, the influence of acid deposition and subsequently the negative changes in the soils and disturbed forest nutrition take place in northern Moravia and western and southern Bohemia. The possible influence of other pollutants should be taken into account. Unfortunately, there is limited information on air pollution by important pollutants (ozone and nitrogen oxides) due to the lack of measurement equipment in forested areas.

THE STRUCTURE OF FOREST MONITORING

The structure of forest monitoring in the Czech Republic is presented in Figure 1. The network of monitoring plots, which is the base of the forest monitoring system, is related to the monitoring of other components of environment (air pollution, deposition, fauna, etc.) and to other research and management activities related to the forests and forest ecosystems; e.g., regular forest inventory for management purposes, which is carried out each 10 years, or a remote sensing approach to investigate the forest state.

The regular ground-based monitoring of forests in the grid of permanent monitoring plots is linked to the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP-Forests). This programme was established in 1985 under the Convention of Long-Range Transboundary Air Pollution (UNEP/ECE). Within the programme, the national 16 × 16 km grid of monitoring plots (altogether 120 plots) was established in 1986-1987 to obtain comparable data for European data base (Manual... 1989).

Basic national network is usable for processing and comparison on the European level, but these sparse data are hardly useful for national and, especially, regional level. For this reason, in 1989 the intensive regional monitoring has been started in selected regions of the Czech Republic (Fig. 2): Brdy Mountains, 1989 (Fig. 3); Šumava Mountains, 1990-1991 (Fig. 4); Krkonoše Mountains, 1991; Jizera Mountains, 1992; and Beskydy Mountains, 1992. The regional monitoring is based on a 1 × 1 km grid. The size and shape of the plots, as well as the investigative methodology, is the harmonized or extended ICP-Forest methodology. At present, the system of regional monitoring covers about 144,000 ha and accounts for 1,250 permanent plots. Contrary to the basic national level, the regional monitoring gives representative data for forest policy on the national and regional level; also, for the permanent upgrading of knowledge in the field of mechanism of forest damage and disintegration of forest ecosystems.

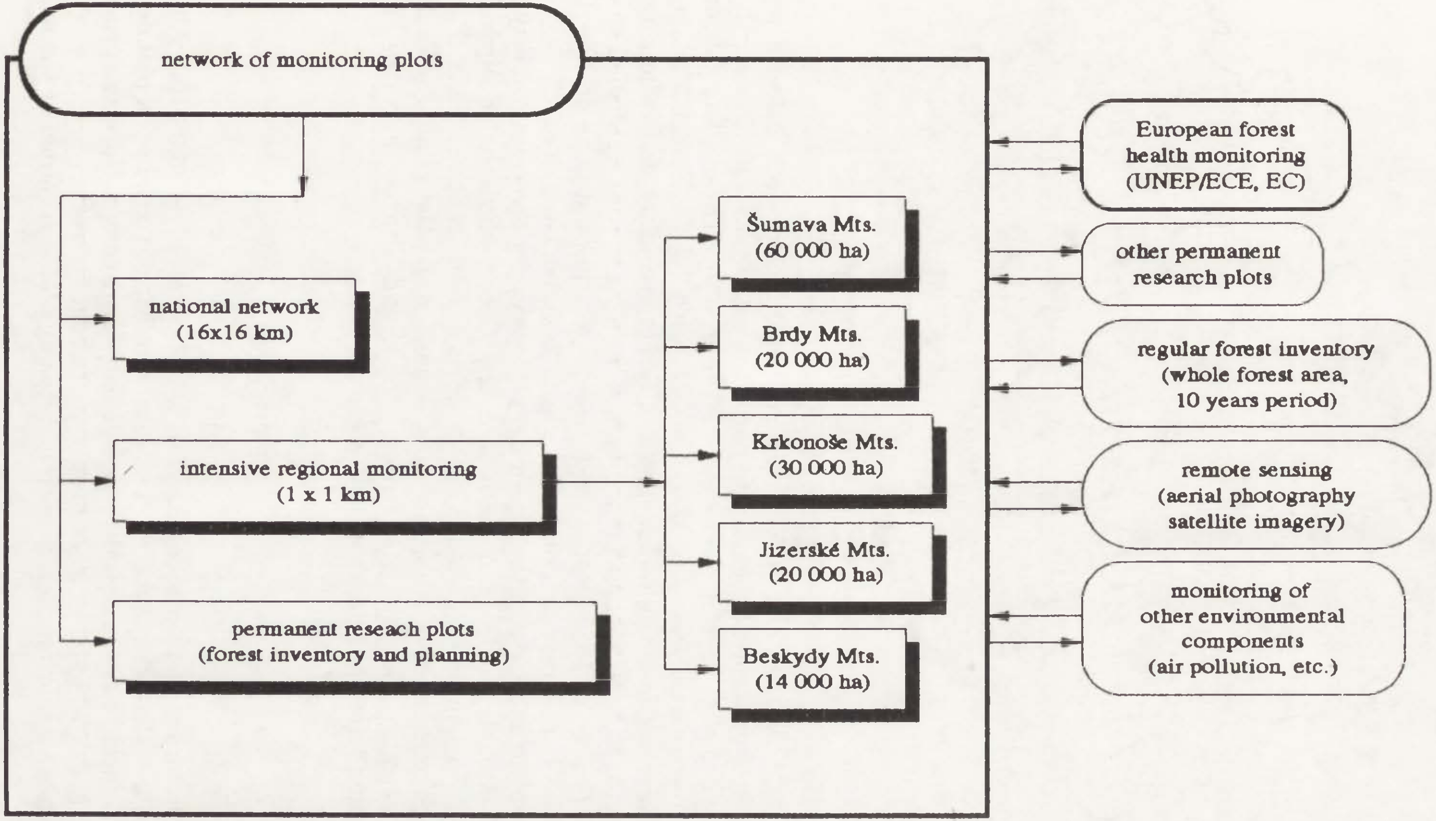

Fig. 1. Forest monitoring structure in the Czech Republic

Fig. 2. Regions of the Czech Republic with intensive monitoring (grid 1 × 1 km)

In addition to national and regional monitoring, both using a regular network of permanent monitoring plots, the set of permanent research plots is included also in the forest monitoring system. These plots (about 500 plots) were established during the last 15 years by the Forest Management and Planning Institute for purposes of forest inventory and collecting data for preparation of management plans. The plots were established to cover the diversity of forest types and forest growth conditions in the Czech Republic, but no regular grid for their establishment was used.

Forest monitoring in the Czech Republic is under the responsibility of the Czech Ministry of Environment and the Czech Ministry of Agriculture. Several institutions carried out the work on the contract base (Forestry Management and Planning Institute, Brand's n. L.; the group for Ecological Monitoring and Modelling of Forests, Davle nad Vltavou; Forestry Faculty, Brno; and Forestry Research Institute, Juloviště).

METHODS

Monitoring plots are circles with a radius of 16 m (0.08 ha). All trees within the plot are numbered. The total number of trees in the plot depends on the species, age, site index, and density. An average Norway spruce plot at the age of 70-to 90-years-old consists of about 50 trees.

The basic information for each monitoring plot is recorded at the moment

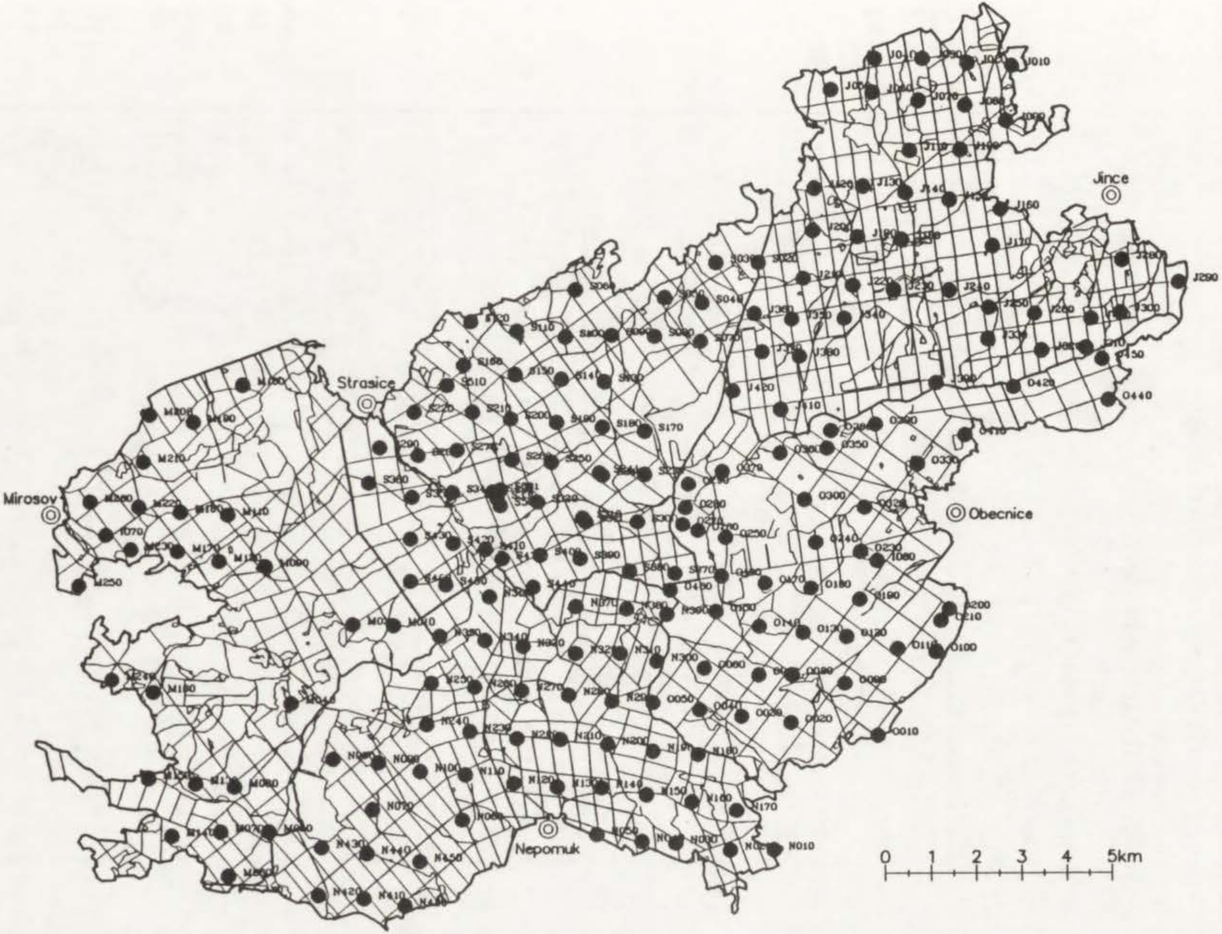

Fig. 3. Network of monitoring plots in the Brdy Mountains (grid 1 × 1 km)

of establishment (geographical coordinates, land owner, elevation, exposition, and slope).

Standard research programme on monitoring plots includes:

(a) Assessment of:
- — tree defoliation, yellowing;
- — social position of trees (Kraft's classes);
- — crown breaks;
- — mechanical damage to stem;

(b) Measurement of:
- — diameter at breast height;
- — tree height;

(c) Sampling of:
- — soil;

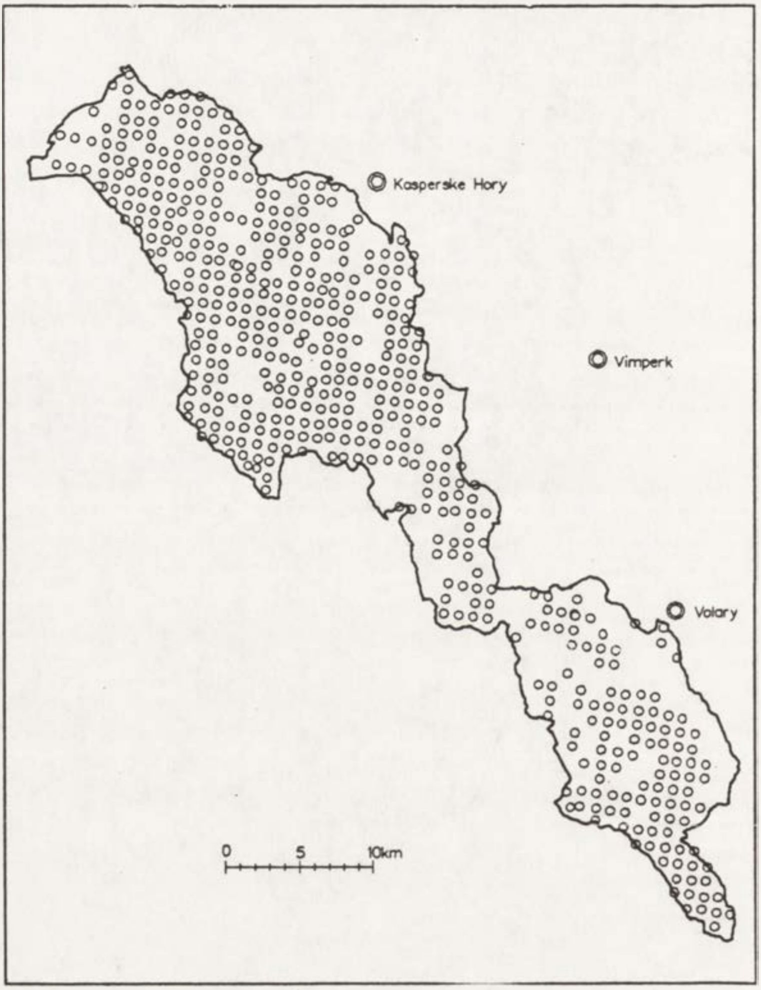

Fig. 4. Network of monitoring plots in the Šumava Mountains (grid 1 × 1 km)

— leaves/needles;
— increment cores;

(d) Site investigation (detail phytocenological description).

Soil samples are taken from approximately one-half of the total number of monitoring plots.

The frequency of repeated assessment and measurement is as follows:

Defoliation, yellowing	each year;
Dendrometrical data	3-5 years;
Soil sampling	5 years;
Leaf sampling	3-5 years;
Site investigation	5 years.

The most important part of methodology is assessment of defoliation. The scale for assessment of tree defoliation used in the Czech Republic was developed in the 1970's. Contrary to five classes of ICP-Forests' scale (0-4), it has six classes (0-5), and it is linear (Table 1). Since the defoliation is expressed in the percent of leaf lost, both scales are compatible.

Table 1. Scales for assessment of tree defoliation

ICP-Forests		Percent
0	not defoliated	0-10
1	slightly defoliated	> 10-25
2	moderately defoliated	> 25-60
3	severely defoliated	> 60
4	dead	
Czech Republic		
		Percent
0	not defoliated	0-10
1	slightly defoliated	> 10-30
2	moderately defoliated	> 30-50
3	severely defoliated	> 50-75
4	dying	> 75
5	dead	

The standard research programme, which is carried out in the grid of monitoring plots, allows conclusions on both the visible symptoms of damage and forest production and nutrition. Except for the standard research programme, the permanent monitoring plots are used for special investigations (phytopatology, physiology, etc.). All data from the lowest level of individual trees are stored in computer data base.

Tree data are processed according to standard ICP-Forests methodology (basic statistical outputs). At the same time, the plot and stand data are summarized and processed. Plot data with its geographical reference are processed in simple GIS, allowing data presentation in the form of maps.

RESULTS

The data development of defoliation in Czechoslovakia in comparison with the data of other Eastern and mid-European countries, expressed in percentage of trees according to classes of defoliation, are presented in Figure 5. Contrary to the improved or stable situation in Austria and the western part of Germany, the percentage of moderately and severely defoliated trees in Czech and Slovak Republics has increased significantly during 1986 to 1990. A similar trend was observed in Lithuania and Poland.

The spatial distribution of forest damage in the Czech Republic is documented by a map (Fig. 6). The most damaged stands are in the north (Ore,

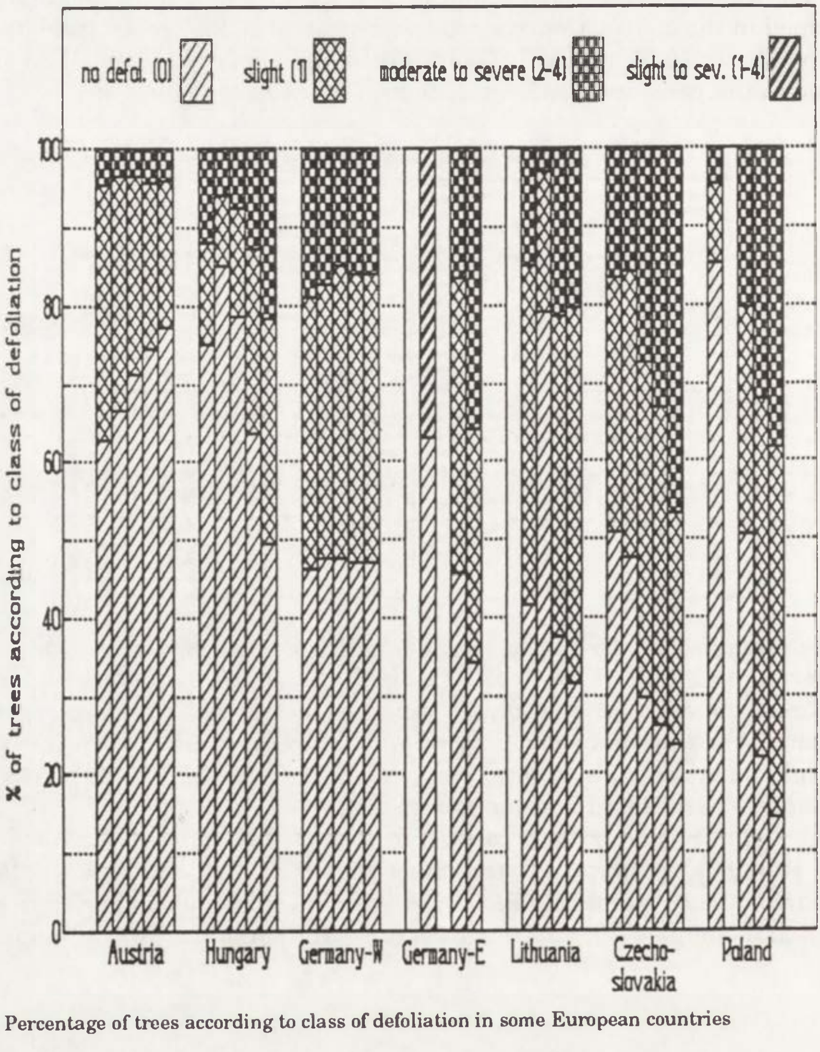

Fig. 5. Percentage of trees according to class of defoliation in some European countries

Jizera, and Krkonoše Mountains). In these regions, the mean stand defoliation is more than 40%. In such stands (preferably Norway spruce) the moderately and severely damaged trees represent about 80%. The serious situation is also in northern Moravia (Jesensky Mountains).

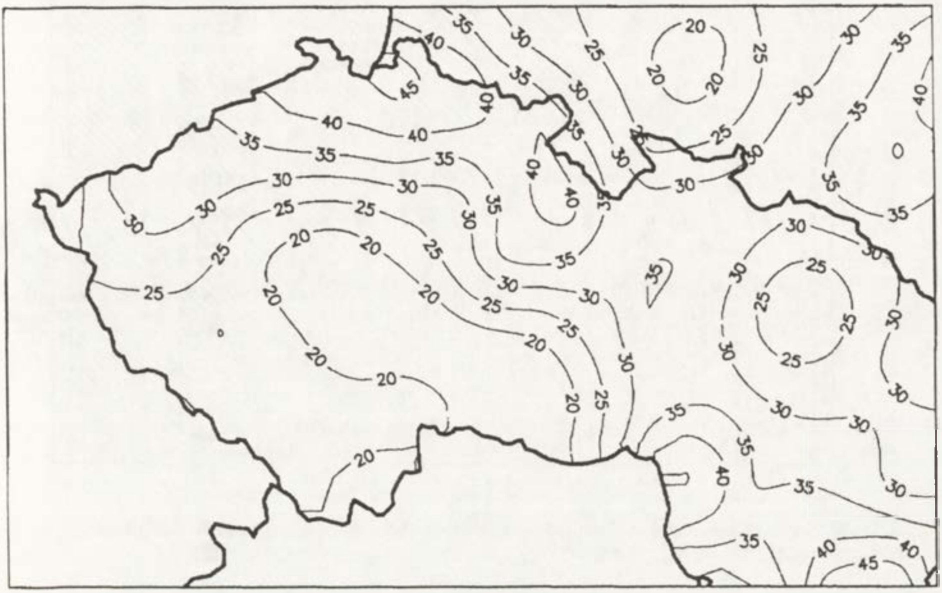

Fig. 6. Mean stand defoliation in the Czech Republic. Survey 1990, all species, all ages (Černy 1991)

The Brdy and Šumava Mountains are presented as an example of regional monitoring results. The monitoring data of plot I080, which was established in 1986, document relatively fast development of forest damage, especially in 1986 to 1989 (Fig. 7). In 1989-1991, the situation has been more or less stabilized (Fig. 8). This trend corresponds to the general situation in the Czech Republic: break in 1987-88 and then the relatively stable state of defoliation. Maps (Fig. 9, 10) document the spatial distribution of forest damage. Relationship between altitude and stand defoliation is clear.

Important data both for national and regional levels were obtained on soils and stand nutrition (based on the leaf analyses). The pH (KCl) of the upper layer of mineral soil (0-5 cm) is generally low (Fig. 11), in most of the sites below 3.5. Nutrient availability of a considerable part of forest stands is insufficient as shown by the results of leaf analyses. In the Šumava Mountains, the percentage of stands with a deficiency of calcium and magnesium exceeds 30-40% (Fig. 12).

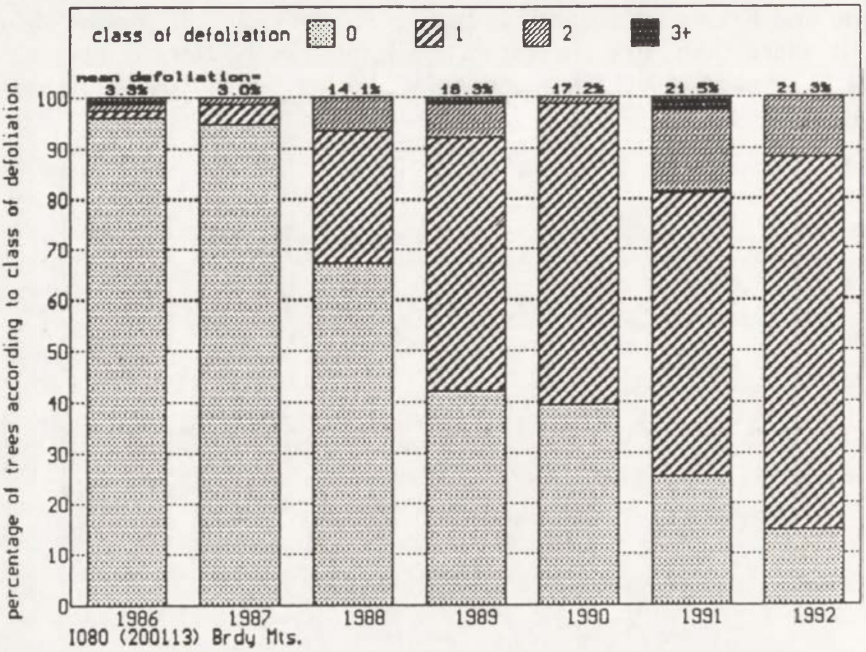

Fig. 7. Percentage of trees developed according to classes of defoliation in the Brdy Mountains. Long-term investigation of data from plot IO8O

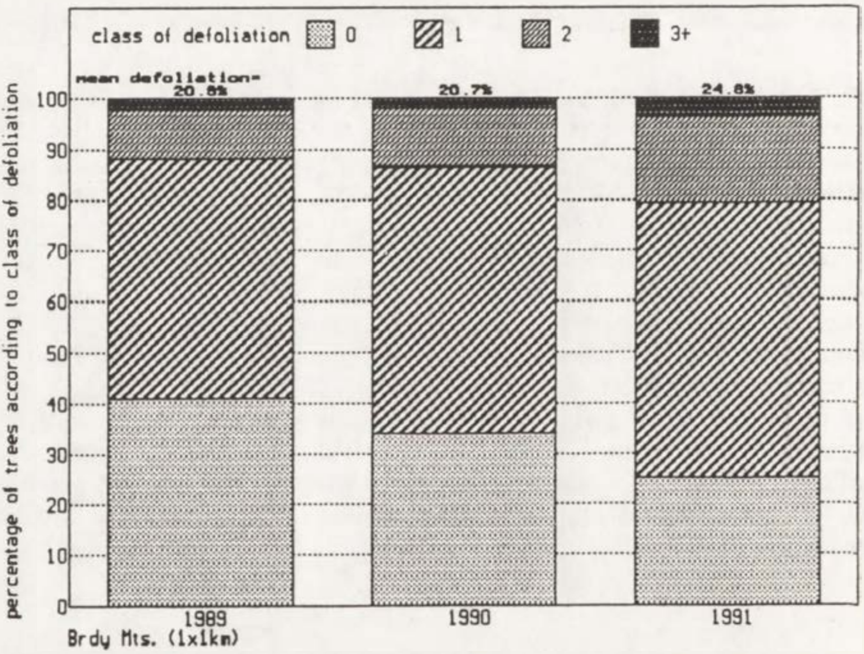

Fig. 8. Percentage of trees developed according to classes of defoliation in the Brdy Mountains. Survey 1989-1991

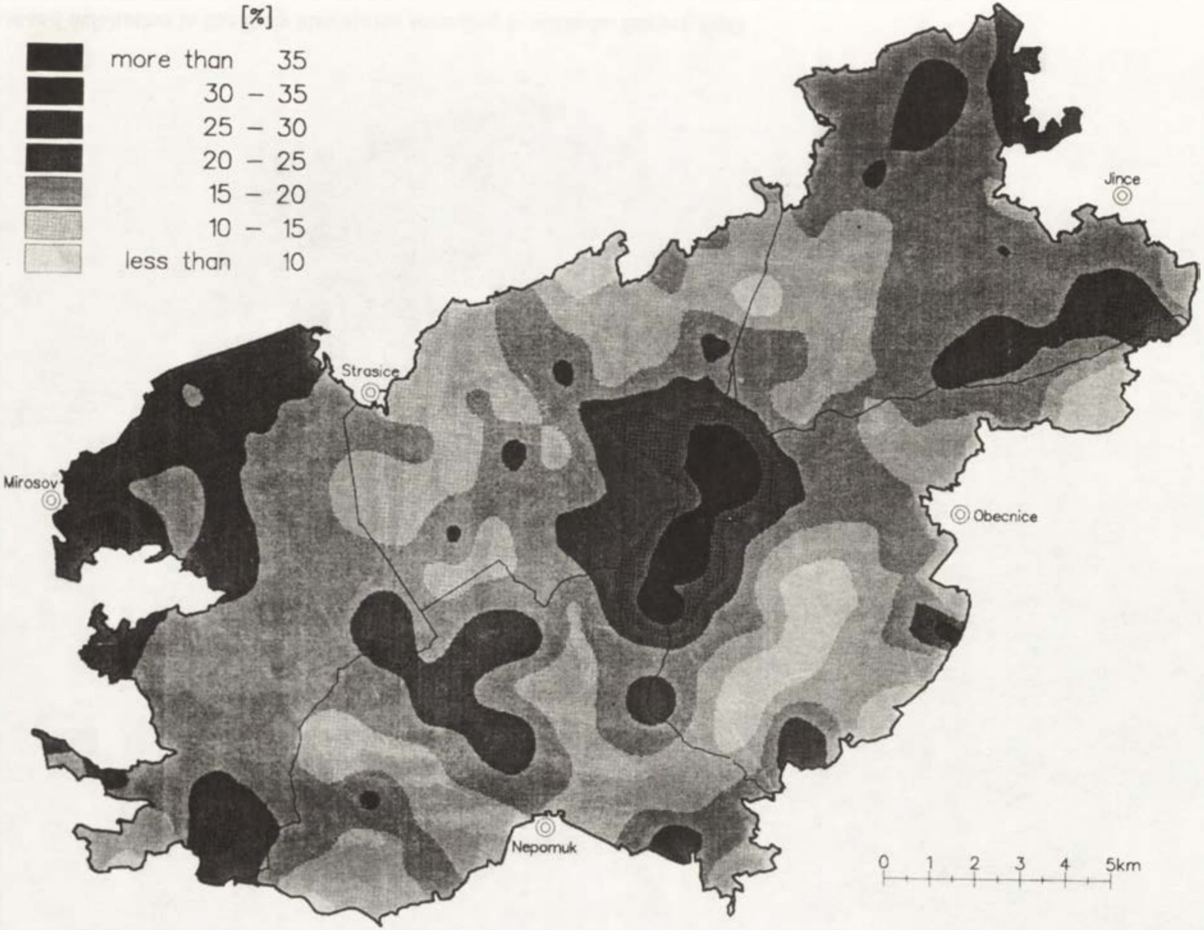

Fig. 9. Mean stand defoliation in the Brdy Mountains. Survey 1990

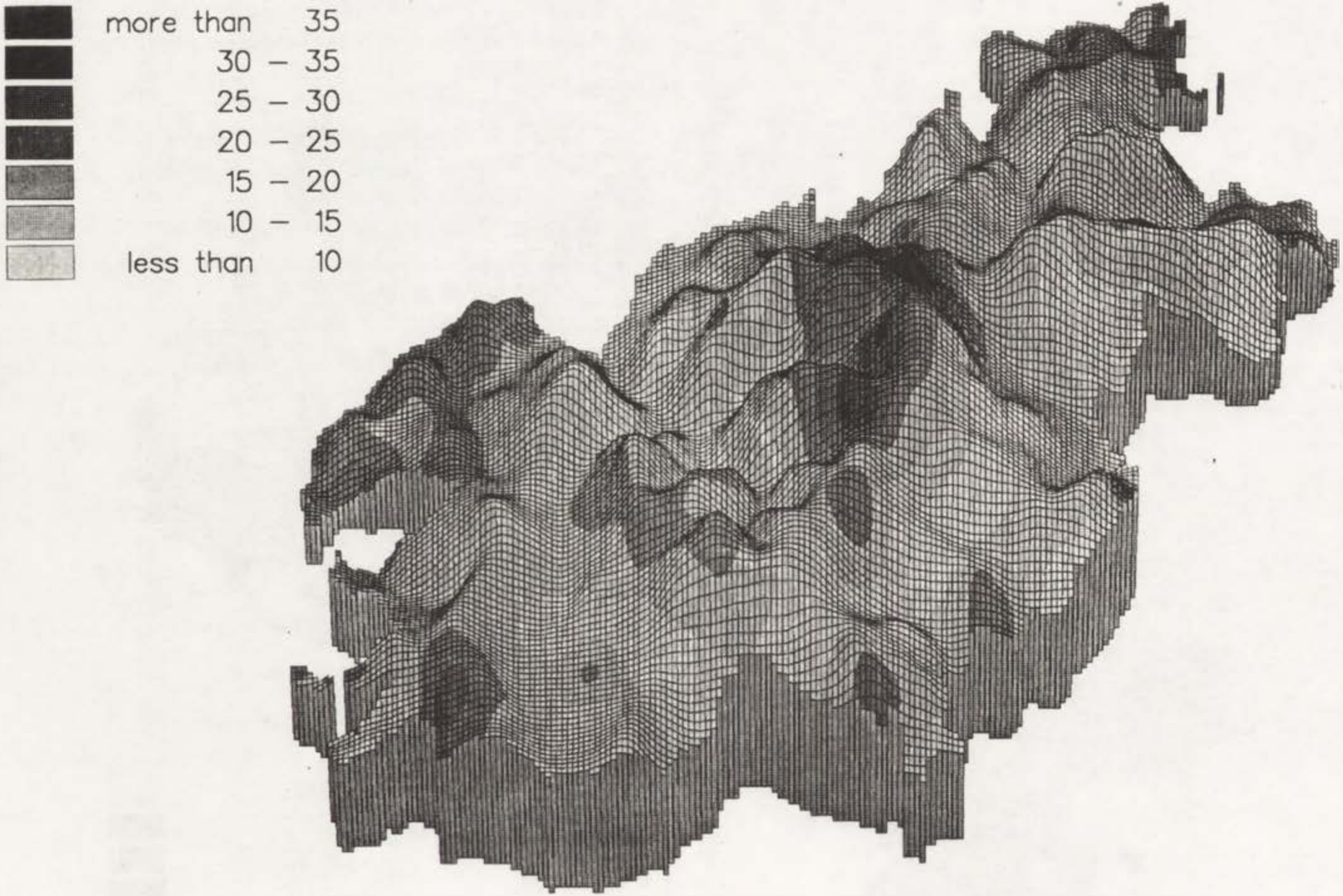

Fig. 10. Mean stand defoliation in the Brdy Mountains according to altitude. Survey 1990

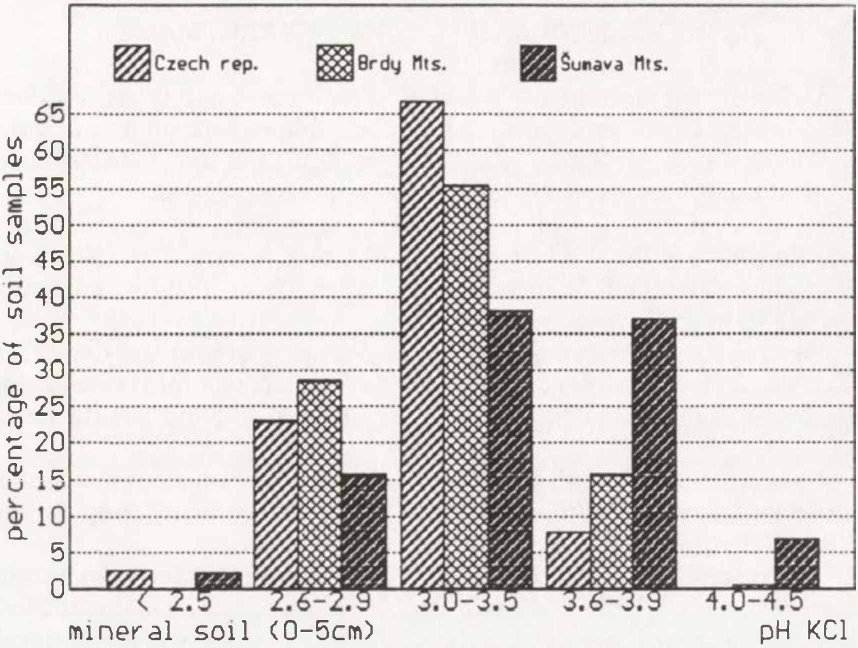

Fig. 11. Acidity in the upper layer of mineral soil. Data from national network and regional studies (Černy 1991)

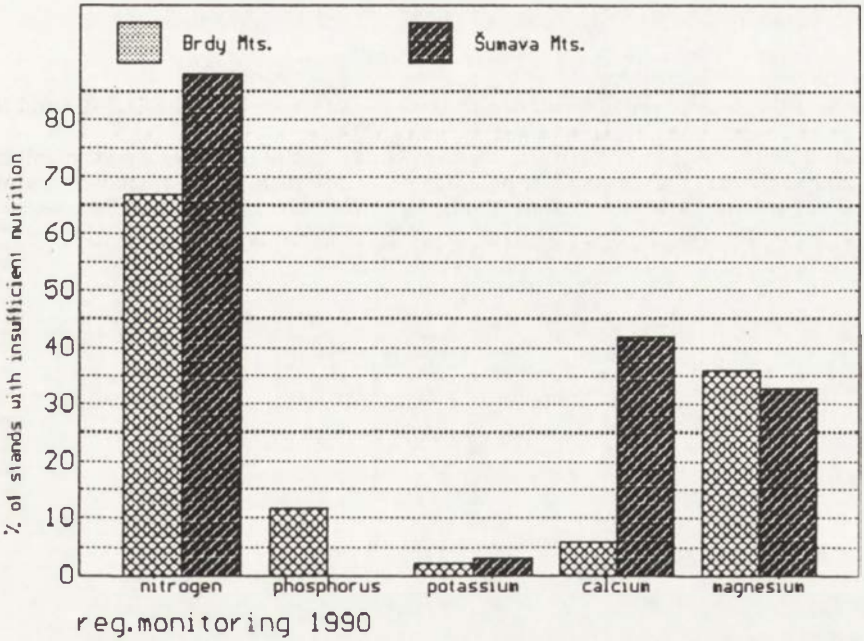

Fig. 12. The percentage of stands with insufficient nutrition. Comparison between the Brdy Mountains and Šumava Mountains

CONCLUSIONS AND FUTURE DEVELOPMENT

— Detailed and permanent flow of qualitative and quantitative information on the forest state is important for policymakers both on a national and international level, for forest practitioners, and also for a better understanding of the processes which take place in forest ecosystems.

— Results of the forest monitoring programme document the unfavourable health state of a large portion of Czech forests. The impact of air pollution has combined frequently with other stress factors, particularly with drought, in the last several last years.

— For a better and more detailed understanding of processes and factors responsible for deterioration of the Czech forests, the technical monitoring of air quality and deposition in the grid of monitoring plots should be completed.

— New approaches, such as direct leaf area index measurement, should be implemented into the field methodology of forest monitoring for more detailed and better physiologically interpretable data.

— The modelling approach will be used more widely to make extended monitoring data available and more usable for forest policymakers. Modelling will generalize the information describing the processes of forest development under different environmental conditions and will be used for prediction of forests development.

REFERENCES

Černy M. 1991, Monitoring of forest health state in the Czech Republic, IUFRO and ICP-Forests workshop on monitoring, Prachatice: 30-40.

Manual of methodologies and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests 1989, International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, 90 p.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
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FUNCTIONING OF FOREST ECOSYSTEMS IN GRADIENTS OF CLIMATE AND POLLUTION: PROJECT FOR COMPARATIVE ECOSYSTEM STUDIES ON TRANSECTS

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Abstract: Theoretical considerations on the ecosystems transect studies clarify the assumptions and definitions accepted in the program proposed for Warsaw group of ecologists. Natural conditions of Poland are shown on various maps (Fig. 1-3) and two-axes transect covering climatic and pollution gradients is proposed (Fig. 4). For the sub-project on litter fall/decomposition some earlier author's results are analysed to show the conditioning of both processes by climate (Table 1)

Key words:. gradient studies, forest ecosystems, ozone, litter fall, decomposition, Poland.

THEORETICAL INTRODUCTION

Various attempts undertaken in the last decades to monitor changes in the environment lack a sound basis in relevant ecological studies of ecosystems which are large and complicated ecological units. The achievements both in respects to data gathering and the selection of hypotheses are hardly applicable as a basis for global monitoring systems. This is probably due to the strong tendency for ecosystem ecologists to study a particular type of ecosystem at one or a few sites. Research that involves comparative studies of ecosystems on a geographical scale and focuses on their variation along transects are relatively rare. However, it becomes clear that without a knowledge of limits of natural ecosystem variability in present conditions on the Globe any anthropogenic deformation or climate impact cannot be assessed.

The general assumption in ecosystem studies on transects is relative stability of all environmental factors except one, which is assumed to change gradually, but strongly enough to modify certain characteristics of the ecosystem. It is also assumed that by a careful choice of stands in the transect one can select a series of ecosystems so similar, that they can be treated as the same system, successively placed in changing conditions. The active factor and the changing characteristics of the system are related as cause-and-effect. Sometimes the mechanism of this relation is known, sometimes unknown. The aim of study of transects is to determine the co-occurrence of changes in chosen parameters: the active factor(s) on one hand, and the ecosystem characteristic(s) on the other.

As is stressed in the title, ecosystems are treated here mainly as functional units. After some earlier publications (Breymeyer 1981, 1984; Breymeyer & Uba 1987) it is assumed that the capacity of ecosystems to environmental stress is measured by the capacity of basic ecosystem processes, of which the main ones are the production and decomposition of organic matter. These processes can obviously be intensified or reduced and the relative proportions (of production and destruction) can vary in the same ecosystem placed in different conditions. However, the processes must continue. If any of them disappears, the ecosystem, according to the definition, no longer exists. The disappearance of ecosystem processes is measurable, so the capacity (vulnerability) of an ecosystem can be measured, too.

Why do we concentrate on processes? It seems that outside impacts on a system, as well as its corresponding responses, can be more rapidly recorded through appropriate measurements of the rates of ecosystem processes, since structures respond less rapidly to external impacts, and structure transformation — especially in the forest — takes more time. For instance, the rebuilding of species composition needs at least the time of one generation, like the transformation of the spatial structure of plant communities. A much longer time is needed for the structure of a whole ecosystem to change e.g. to enrich or reduce whole trophic levels made up of many competing species that can replace each other. Instead, the rate of a process through which a given trophic level is created or used can often be estimated rapidly. Also, the rate of these processes varies rapidly as a result of changes in abiotic environmental factors (for example, the rate of decomposition under the influence of chemical changes in the environment or a distinct change in climate).

Summarizing, the functional definition of an ecosystem and following measures of its function is comfortable in searching for system responses to changing conditions. However, it is not useful when one needs to delimit an ecosystem's borders or to read its history over the last decades. Then structural characteristics must be used. The history of an ecosystem in a given place can be read from tree rings and soil layers. The composition of tree and herb communities delimit easily the range of a given ecosystem type in the landscape. What is more, it enables the ecosystem to be placed in phytosociological classification and successional series.

FOREST TRANSECT STUDIES

Forest ecosystems, particularly the temperate and cold zone forests, seem to fulfil the conditions necessary for transect studies. It is known that they react clearly to climatic changes and they have strong and easily measurable reactions to air pollution. It is easy to find on both continents (Europe and North America US) similar climatic gradients and comparable pollution levels.

As a basis for transect tracing in Poland, the maps of climate, phenologic periods and forest pollution were used (Fig. 1-3). The maps cover the territory of Poland and were published in the ecological literature in Polish and English. The transects (Fig. 4) are marked along selected stands monitored by the Forestry Research Institute in the program of forest health evaluation.

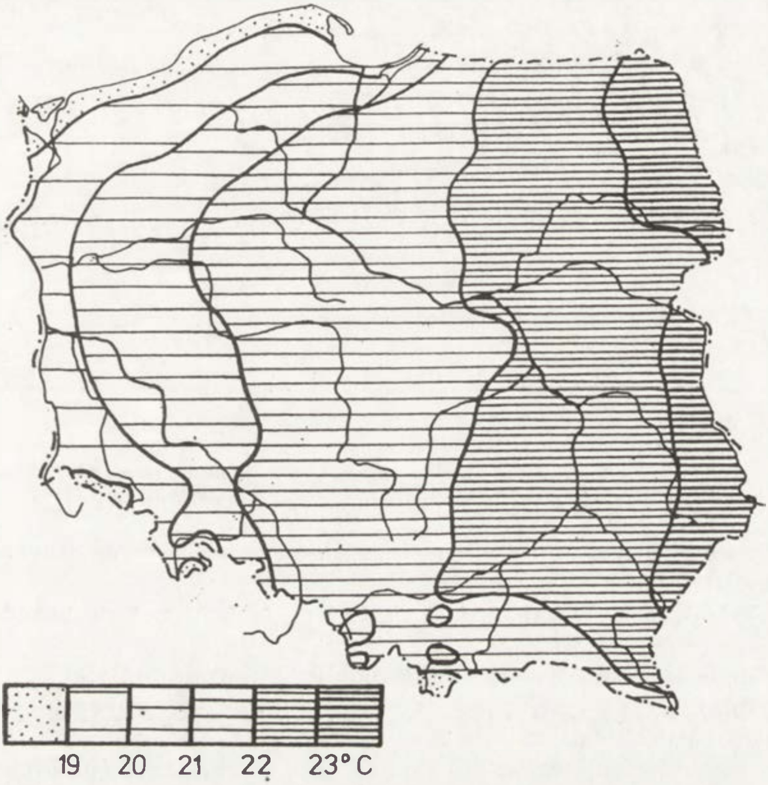

Fig. 1. Poland west-east gradient of continentality expressed as mean annual isoamplitudes of air temperature (after the Climatic Atlas of Poland)

The measuring stands will be situated along two axes crossing the territory of Poland; the west-east axis crossing relatively unpolluted areas with a distinct gradient of continentality increasing eastwards, and the southern axis ending in Silesia — the most polluted region. Both axes cross the country's territory from the warmest to the coldest regions, and thus reflect Poland's thermoclimatic diversification. It is assumed that climatic stations will be accessible in the vicinity of all stands, and this will make it possible to use the gathered data to determine stands characteristics.

10 stands of similar pine forest type will be situated along each transect (on both, the northern and southern lines). Thus the data for the programme

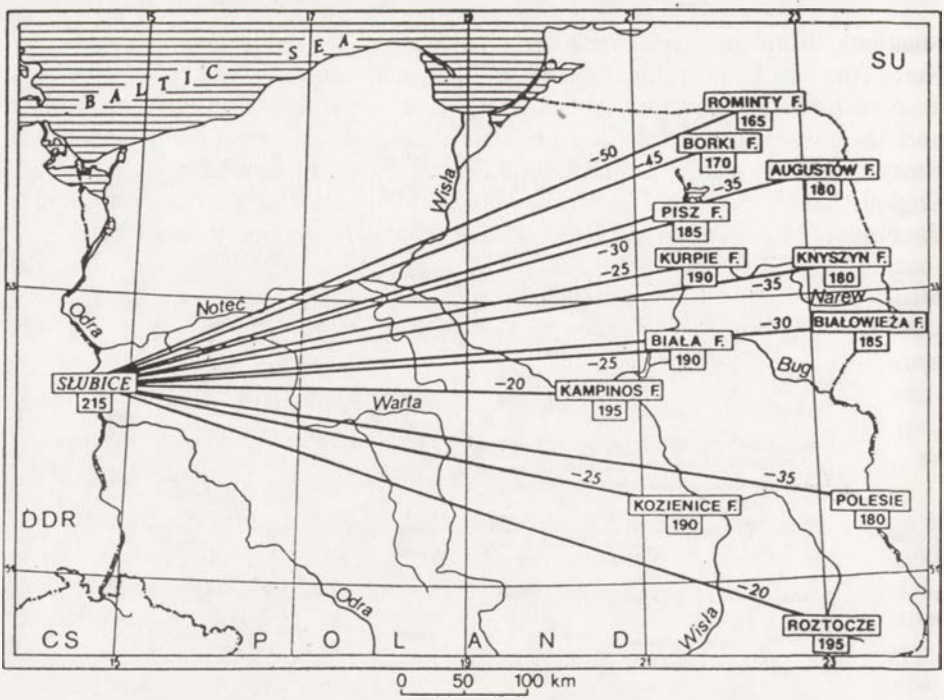

Fig. 2. Duration of the vegetation period (days) in various forests. Numbers placed on the lines show the difference between the warmest stand "Słubice" and any given stand (after Faliński 1986)

will be gathered from 20 stands situated on two gradients (thermal and pollutional).

The following environmental factors are or will be measured on all stands:

— elements of the topoclimate (particularly thermic climate),
— deposition of the principal industrial pollutants in leaves and soil,
— ozone concentration in the air.

As basic ecological studies the following complementary sub-projects will be carried out:

1. Monitoring of the health of forest tree-stands.
2. Study and classification of the stands according to soil type, phytosociological character and bioindicators presence.
3. Monitoring of the forest litter fall and decomposition.
4. Monitoring of the forest litter respiration rate.
5. Evaluation of the density of soil fauna (selected groups of decomposers).

Point 3 involving the author's own studies will be introduced in detail. Measurements of the fall and decomposition of forest litter are treated as ecological indices reflecting the rate of matter circulation in forest ecosystems.

Both indices — litter fall and its decomposition — response very well to distinct change of thermoclimate. The author's own studies on transect from northern Sweden to central Poland show litter fall/decay gradual changes in coniferous forests (Table 1).

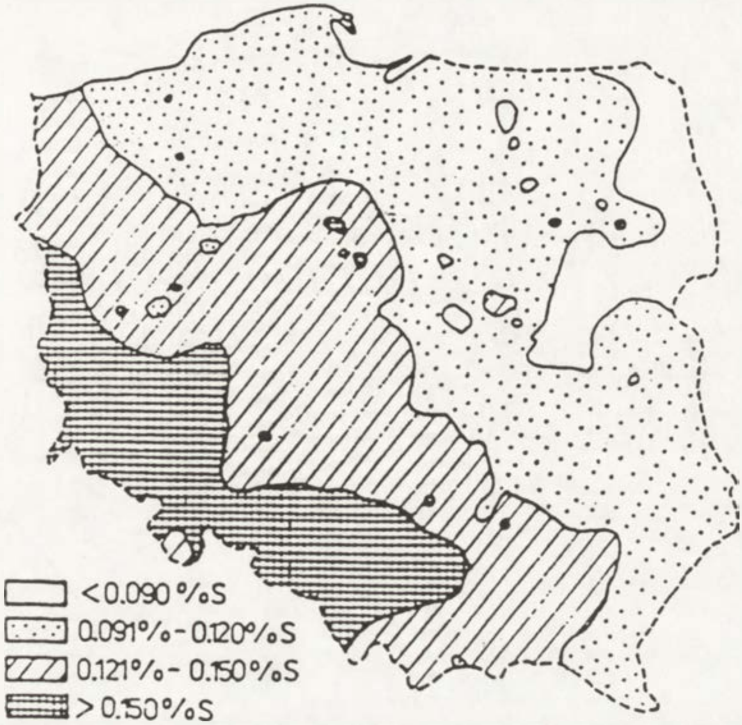

Fig. 3. Sulfur content in second-year pine needles (*P. sylvestris*) in Poland. Zonation based on sulfur content as percentage of normal content — 650 ppm (after Molski & Dmuchowski 1990)

Table 1. Litter fall and decomposition in pine forests situated along thermic gradient from northern Sweden to central Poland. Breymeyer 1991

Stand characteristics			Forest characteristics	
Stand names, numbers, years	Geographical latitude	Mean annual temp. (°C)	Litter fall (g m^{-2} y^{-1})	Yearly decomposition rates in %
Torenetrask (1; 1986, 1987)	68°14'N	-0.7	55.3; 61.5	11.4-14.0
Jadraas (4; 1986, 1987)	60°49'N	3.8	112.6; 199.1	17.8-19.1
Borecka (2; 1987)	54°10'N	6.7		22.3-23.7
Czerlonka (1; 1987, 1988)	52°41'N	6.6		22.9-23.4
Kampinos[1] (2; 1975)	52°22'N	7.8	231.7; 244.6	
MIE.II LI.III (2; 1988)	52°20'N	7.2	224.0; 241.4	
Pińczów (1; 1987, 19988)	50°30'N	7.6		22.3-28.4

[1] After Józefaciukowa 1975

Fig. 4. Coniferous and broadleaf stands registered in seventeen forestry districts in the territory of Poland. Coniferous stands (*Pinus*, *Picea* and *Abies*) and deciduous stands (*Quercus*, *Fagus* and *Betula*) are recognized by forestry service in numbers shown in each district. Ecological measurements are planned along two axes following reasonably clean (northern line) and polluted (southern line) conditions

As it could be seen in Table 1 the difference between the most northern and southern stands equals 8.5°C and more than 18° of latitude. In this range very distinct and regular changes of litter fall and decay were registered. In the case of litterfall the most southern stand receives 4 times more litter than the most northern one; the rate of change per 1°C equals 21.1 g $m^{-2} \cdot y^{-1}$. In the case of decomposition, the most southern stand decomposes litter 2 times faster than the most northern one; the rate of change per 1°C equals 1.8 percent.

Summarizing, in long north-south transect both studied processes speed the rates regularly moving southward. Should we expect similar response in the case of west-east gradient of continentality?

Litter bags will be used in litter decomposition measurements. This simple method is often used in ecological surveys. Placed in each stand will be 60 litter bags with original, mixed litter, and fractions of it. These will be gathered twice a year, after the growing season (in October-November) and after winter (March-April). The decomposition rate can be inferred from the loss of weight of the litter. To ensure that the litter is homogenous and of equal age, litter bags are prepared from its fall collected annually from special surfaces (on each stand 3 × 1 m^2 surfaces will be prepared).

REFERENCES

Breymeyer A. 1981, Monitoring of the functioning of ecosystems, (in:) *Environmental Monitoring and Assessment* 1: 175-183, D. Reidel Publishing Co., Dordrecht, Holland and Boston, USA.

Breymeyer A. 1984, Ecological monitoring as a method of land evaluation, *Geographia Polonica* 371-384.

Breymeyer A. 1991, Comparative analysis of organic matter transformations in coniferous forests in Europe, (in:) Nakagoshi N. & Golley F.B. (eds.), *Coniferous forest ecology from an international perspective*: 161-177.

Breymeyer A., Uba L. 1984, Monitoring ekosystemów: program ekologicznej kontroli stanu ekosystemów lądowych na obszarze Polski (Ecosystems monitoring: the program of ecological control of terrestrial ecosystems condition in Poland) in:) *Człowiek i Środowisko* 471-495.

Faliński J.B. 1986, Vegetation dynamics in temperate lowland primeval forests, *Geobotany* 8: 1-537. Dr W. Junk Publishers, Dodrecht/Boston/Landcaster.

Józefaciukowa W. 1975, Variation of the fall rate of plant debris from trees in the association *Vaccinio myrtylli-Pinetum typicum* (Kobendza 1930) Br.-Bl. et Vlieger 1939 in the Kampinos National Park, *Ekol. Pol.* 23: 93-101.

Molski B.A. & Dmuchowski W. 1990, Distribution and movement of selected elements in Poland using pine needle analysis, (in:) Grodziński W., Cowling E. & Breymeyer A. (eds.), *Ecological Risks. Perspectives from Poland and United States*: 215-231. Washington.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:109-115, IGSO PAS, Warszawa

STUDYING THE EFFECTS OF AIR POLLUTION ON FORESTS ALONG EXPOSURE GRADIENTS: EXPERIENCES IN THE UNITED STATES AND OPPORTUNITIES FOR COOPERATION

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Abstract: The design of field studies investigating the effects of air pollution on forest ecosystems is discussed with an emphasis on the use of permanent plots along exposure gradients. Results from the Michigan gradient study in the United States are summarized. In general, there has been no detectable loss in aboveground productivity but there have been very clear changes in the cycling of mineral elements in the ecosystems due to acidic inputs. Exposure levels in central and eastern Europe are much greater than those in the United States and this provides an opportunity for scientists in both countries to effectively extend their gradient studies through cooperative efforts. Specific areas of cooperation that are being initiated with Polish scientists are summarized.

Key words: gradient studies, air pollution, forest ecosystems, permanent plots, acidic inputs, sulfate leaching, Michigan.

INTRODUCTION

Information needs for policy decisions concerning the effects of air pollution on forest ecosystems far outstrip scientific knowledge. The overall concern is whether or not the health or productivity of forest ecosystems have been impacted as a result of pollution inputs. The population for which forest response studies need to make inferences has several properties which must be considered when conducting a scientific investigation:

1. Inference is desired at the ecosystem level for policy decisions;
2. Pollution inputs vary considerably, and in a continuous fashion, both spatially and temporally; and
3. Pollution inputs are often associated with, and are possibly confounded by, climate trends in the populations of interest (Reed 1990).

SCIENCE BEHIND THE POLICY

Given the complexity of science-based policy decision-making, it is clear that no single experiment or even a single experimental method can address all of the issues. The scientific questions must be approached from several sides simultaneously and in a coordinated fashion to efficiently address the problem. Examples of coordinated studies are evident in other fields of science. In medical science, for example, the use of epidemiological studies, molecular biological methods, model systems, and clinical trials are all recognized as necessary in comprehensive disease treatment and control programs. In forest science, there have been two major approaches to investigating the effects of pollutants on forest ecosystems: experimental and observational studies.

From a statistical viewpoint, the major difference between the approaches is that in experimental studies, the assignment of treatments to experimental units is under the control of the investigator but this is not the case in observational studies. Another difference between experimental and observational studies is in the actual experimental material. In classical hierarchical organizational theory, the functions at one hierarchical level cannot be completely deduced or inferred from information obtained from other hierarchical levels. This implies that a result at the ecosystem level cannot be completely predicted from studies at other levels. This creates a difficulty for establishing governmental policy. The nature of experimental forest response studies dictates that they be conducted at "lower" hierarchical levels (tissue-organ-individual) while the inference required for policy decisions must be made at "higher" levels (individual-population-community-ecosystem-landscape).

In the analysis of forest response data, much has been made of the causality criteria given by Moesteller and Tukey (1977): consistency, response, and mechanism. Experimental studies are best suited for demonstrating mechanism and, to a certain extent, responsiveness. However, one could argue that establishing mechanism or responsiveness at the organ level has very little relevance to policy decisions unless it is framed in the context of ecosystem response. The value of observational studies in establishing responsiveness and consistency is not generally appreciated but the use of observational studies at "higher" organizational levels is absolutely necessary since ecosystem response is of primary interest in making policy. In formation needed for policy decisions, therefore, must come from both experimental and observational studies.

FOREST RESPONSE STUDIES

Many forest response studies fall into the gray area between experimental and observational studies. Through careful site selection and characterization, relative homogeneity of experimental material and meaningful environmental covariates can be obtained. Intensively monitored permanent plots provide the opportunity for experimental-type studies in the field. Of key importance is the establishment of permanent plots and their maintenance over long time spans. While it is difficult to insure continuity and funding for such efforts, it is only through study over many years that the effects of multiple stress agents can be addressed.

The establishment of well-selected permanent plots along gradients of pollutant exposure provides the opportunities described above. The underlying idea is that truly controlled experiments are impossible to conduct at the ecosystem level in field settings and that, by locating study sites along exposure gradients, space is substituted for time in the investigation of the effects of pollution on forest ecosystems. The Michigan Gradient Study is described below in order to illustrate the use of ecosystem-level gradient studies in determining the response of forests to pollutant inputs and to provide examples of opportunities for cooperation between US and Polish scientists in such studies.

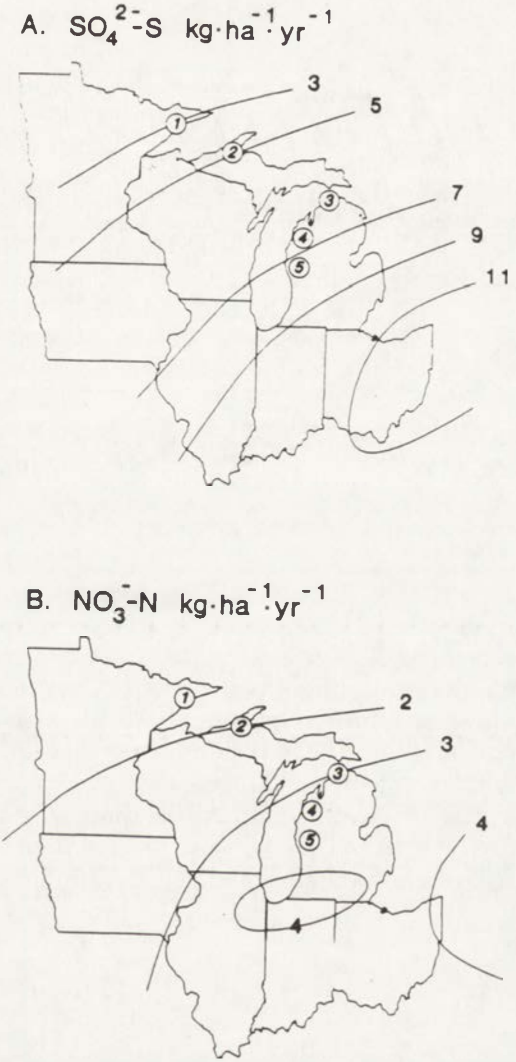

Fig. 1. Location of study sites (circled numbers) along the regional acid deposition gradient. a) Sulfate and b) nitrate deposition data obtained from the National Acid Deposition Program records for 1980-84 (from Burton et al. 1991)

THE MICHIGAN GRADIENT STUDY

The Michigan Gradient Study was established in 1986 along wet deposition gradients in the north-central United States (Fig. 1). The study is located in northern hardwood (*Acer-Betula*) forests typical of those found on upland sites in the region. Pollutant levels at the study plots ranged from less than 3 to slightly greater than 11 kg/ha/yr of wet sulfate S deposition. Nitrate N deposition ranges from less than 2 to nearly 4 kg/ha/yr. These levels are less than those found in most of Poland, though wet sulfate inputs in northeastern Poland are similar to those at the sites with the most deposition in the Michigan study.

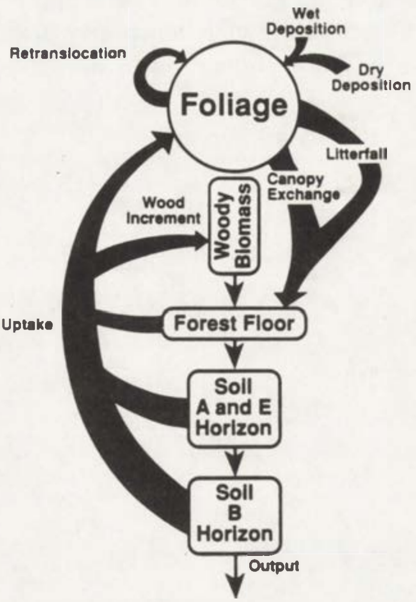

Fig. 2. Conceptual model for assessing the influence of atmospheric deposition on forest ecosystems

An ecosystem level approach (Fig. 2) was used to investigate structure (biotic and abiotic components) and function (exchange of matter and energy between biotic and abiotic components). The interactions between components of the ecosystem and the temporal variability in content and exchange rates between components were all of interest.

A key to the study was the establishment of analogous study plots with the goal of minimizing differences between sites in order to increase the likelihood of detecting possible impacts of pollutants at the different sites. The site identification and establishment procedure was described by Burton et al. (1991). The success of subsequent investigations is dependent on the site identification process.

Another key element is the comparison of similar measures in various components of the ecosystem. This provides the opportunity to integrate results from different parts of the system. The examination of the effects of nitrogen inputs, for example, utilizes measures which are inherently variable and difficult to interpret. By examining processes in the soil, vegetation, and hydrological components of the ecosystem, consistency of relationships can be determined. It is the comparison between compartment pools, and fluxes between pools, that pro-vides the opportunity to truly evaluate the ecosystem-level effects of pollutant inputs.

FINDINGS

The overall results indicate that there have been significant impacts on nutrient cycling as a result of pollutant inputs into these systems. These impacts have not resulted in losses of productivity or noticeable declines in health status of the overstory trees to date. There are some indications that increased cation leaching, particularly of Ca, due to sulfate inputs may be leading to long term depletion of the nutrient pools in these stands. Specific findings include:

1. Atmospheric deposition has altered the exchange patterns of nutrients in forest canopies (Liechty et al. 1993). Hydrogen ions are consumed by the canopy resulting in increased Ca and Mg in throughfall. Cation-anion balances indicate that organic acids balance proportionally more cations in unpolluted areas while sulfate balances more cations in polluted areas.

2. Atmospheric sulfate deposition has altered the assimilation and cycling of sulfur (Pregitzer et al. 1992). Foliar and litter sulfate content was highly correlated with the atmospheric deposition of sulfate. Evidence suggests that the excess sulfur is accumulated in the vacuoles and not incorporated in amino acids.

3. Atmospheric nitrogen deposition may have altered nitrogen cycling (Pregitzer et al. 1992). Though not as clear as the results with sulfur, there are indications that atmospheric deposition of nitrogen may have impacts on nitrogen cycling. This is a more difficult issue to unravel due to the changes in N cycling due to natural events, such as heavy production of seed crops (Pregitzer & Burton 1991), insect defoliation, or variation in nitrogen mineralization (Ouyang 1990).

4. Soil sulfur and nitrogen levels appear to be related to atmospheric deposition (MacDonald et al. 1991). Exchange- able cations in soil B horizons decreased as sulfate deposition increased but were also related to inherent trends in clay and organic matter content.

5. Sulfate leaching increased with deposition and there were associated increases in leaching of Ca and Mg from the soil (MacDonald et al. 1992). Nitrate leaching did not increase with deposition but appeared to be assimilated into the vegetation at most sites.

6. There is no detectable relationship between pollutant input and aboveground productivity. There were no differences in average three-year biomass or basal area productivity that could be related to pollutant input. Productivity is highly variable and appears to be related to carbohydrate storage which depends on leaf area production, seed crop production, timing of initiation and cessation of growth in the previous year, defoliation, etc.

7. Biotic and abiotic factors can confound relationships between nutrient cycling, productivity, and air pollution. One example involves the use of amino acid analyses as indicators of stress. The Scandinavian literature contains numerous studies linking high levels of arginine, in particular, in seedlings to atmospheric pollutant deposition. Results from the Michigan Gradient Study (McLaughlin 1992) show arginine analysis to be a non-discriminating indicator of stress with high levels being related to other stressors besides pollutant deposition.

OPPORTUNITIES FOR COOPERATIVE WORK

There have been many discussions over the past two or three years on the opportunities to link forest response studies in the United States and

Poland. One of the major reasons to do this is the fact that forest ecosystems in Poland are subject to far greater pollutant loadings than are those in the United States. Linkages can, in effect, extend existing gradients. This provides the opportunity to extrapolate and test findings from studies in the US at the greater pollutant deposition levels in Poland. Conversely, the benefits of reducing pollutant deposition levels in Poland may be estimated based on findings at lower deposition levels in the US. The geographic and climatic conditions in Poland provide the opportunity to design gradient studies that may improve the ability to separate the effects of important natural factors, such as climate, from anthropogenic pollution.

Studies which utilize common methodology to investigate such ecosystem functions as litter decomposition and sulfur assimilation to provide comparisons between forest ecosystems are being initiated in the US and Poland. Data from studies in the US are being utilized by Polish scientists to formulate and test hypotheses concerning early effects on the biodiversity of the understory community. There are additional opportunities and these have been identified for immediate attention because they have the potential to quickly yield valuable information.

There is a significant foundation of studies in Poland on which comparisons can be based. Studies such as those at the Niepołomice Forest, which have been ongoing for 50 years or more, are tremendous information resources that do not exist in the US. The longer history and spatial component of these studies provide new perspectives of value when analyzing information from relatively new studies, such as those in the US. Gradient studies are inherently spatial and the logical next step in gradient analyses is the use of geographic information systems to examine results in a regional context. The use of long term studies in relatively small areas, such as the Niepołomice Forest, provide the opportunities to develop the framework for such analyses utilizing long term records. This technology also provides a greater ability to integrate and synthesize the results of such studies while increasing the scientific infrastructure in Poland. All in all, cooperative efforts between US and Polish scientists provide the means to make great progress in assessing the impacts of air pollution on forest ecosystems and in supplying the information required for policy analyses that will guide planning efforts in both countries.

REFERENCES

Burton A.J., Ramm C.W., Pregitzer K.S. & Reed D.D. 1991, Use of multivariate methods in forest research site selection, *Canadian Journal of Forest Research* 21: 1573-1580.

Liechty H.O., Mroz G.D. & Reed D.D. 1993, Cation and anion fluxes in northern hardwood throughfall along an acidic deposition gradient, *Canadian Journal of Forest Research* 23: 457-467.

MacDonald N.W., Burton A.J., Liechty H.O., Witter J.A., Pregitzer K.S., Mroz G.D. & Richter D.D. 1992, Ion leaching in forest ecosystems along a Great Lakes air pollution gradient, *Journal of Environmental Quality* 21: 614-623.

MacDonald N.W., Burton A.J., Jurgensen M.F., McLaughlin J.W. & Mroz G.D. 1991, Variation in soil properties along a Great Lakes air pollution gradient, *Soil Science Society of America Journal* 55: 1709- 1715.

McLaughlin J.W. 1992, First year sugar maple (Acer saccharum Marsh.) seedling nutrition, vesicular-arbuscular mycorrhizal colonization, physiology, and growth along an acidic deposition gradient in Michigan, Ph.D. Dissertation, Michigan Technological University, Houghton, Michigan. 196 p.

Moesteller F. & Tukey J.W. 1977, Data analysis and regression, Addison-Wesley Publishing Co., Reading, MA.

Ouyang H. 1990, The effects of acid deposition on nitrogen mineralization in forest soils of the Great Lakes region, M.S. Thesis, Michigan Technological University, Houghton, Michigan. 66 p.

Pregitzer K.S. & Burton A.J. 1991, Sugar maple seed production and nitrogen in litterfall, *Canadian Journal of Forest Research* 21: 1148-1153.

Pregitzer K.S., Burton A.J., Mroz G.D., Liechty H.O. & MacDonald N.W. 1992, Foliar sulfur and nitrogen along an 800-km pollution gradient, *Canadian Journal of Forest Research* 22: 1761-1769.

Reed D.D. 1990, Investigating the effects of regional air pollution on forest ecosystem productivity, (in:) *Proceedings of the 1990 Annual Meeting of the Society of American Foresters*, pp. 107-110, Washington, DC.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:117-135, IGSO PAS, Warszawa

ATMOSPHERIC POLLUTION DEPOSITION GRADIENT STUDIES IN ESTONIA

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Abstract: In 1990-1991, five Scots pine forest stands of IV-VI age classes belonging to the *Vaccinium*, *Myrtillus*, and *Cladonia* forest-site type were observed along the atmospheric pollution deposition gradient in Estonia. In 1992, two new sites were added for future study. The soil and water regime differences between sites were determined. On the selected sites, increment cores were taken to determine stand age and synchrony of the growth curves. In 1990, 10 randomly chosen Scots pine canopies were observed for general health evaluation at each site. In June 1991, needle samples were collected from five trees at each site. The impact of air pollution on the anatomical structure of Scots pine needles was studied in 1992. Additionally, the presence and species composition of epiphytic lichens as well as bioaccumulation of different substances were evaluated. Results are presented in Figures 2-14 and Tables 1-10.

Key words: gradient studies, air pollution, pine forest, permanent plots, sulphur deposition, needle mass, Estonia.

INTRODUCTION

Understanding ecosystems' response on any stress factor is the goal of this study on impacts on the ecosystem level. This is the only way the dynamics of response can be fully evaluated and interpreted. It is difficult for two reasons: (1) the complexity of ecosystems, and (2) lack of knowledge of how many components of the ecosystem function. Studies at the ecosystem level, with their inherent limitations, however, are the most thorough type of investigative tools available.

To evaluate the response of forests to air pollutants, gradient studies represent one important approach at the ecosystem-level. Gradient studies involve establishing sample plots in forest stands that are as similar as possible to biological and physical characteristics; i.e., soil characteristics, climate, species composition, and stand structure over a transect where pollutant concentrations range from low to high. Community responses to the pollutant are then evaluated through mechanistic and correlative studies (Reed et al. 1991).

ENVIRONMENTAL CONDITION ALONG THE GRADIENT

In 1990, stationary sources of the Estonian enterprises emitted 610.9 thousand tons of air pollutants including 302.1 thousand tons of solids (dust, ash) and 308.9 thousand tons of gasses — mostly SO_2, CO, and NO_x (Kallaste et al. 1992).

The biggest polluters are located mostly in northeastern Estonia: they are two large power plants — the Baltic and Estonian Thermal Power Plants, and the Kohtla-Järve and Kiviôli Plants of Oil-Shale Chemistry. Estonian oil-shale has a complicated chemical composition. More than one-half of the material is its mineral part which remains in the kilns as ash. Sulphur makes approximately 1.655%, nitrogen 0.1%, and chlorine 0.2% of the organic and inorganic part of oil-shale (Jegorov et al. 1988).

Gases emitted from the power plants contain different hazardous compounds, fly ash (including heavy metals and natural radioactive compounds). Within the European Monitoring and Evaluation Program (EMEP) framework, it was calculated in 1980 that 71,000 tons of sulphur precipitated on the surface of Estonia (making 1.57 g S/m^2 per year on the average), 26,000 tons of which are of Estonian origin. The corresponding figures for 1988 were 57,000 tons (1.26 g S/m^2 per year), of which 20,000 tons were from local sources (Tuovinen 1989).

An important indicator of air pollution is dry and wet deposition of sulphur and nitrogen. As no data was available concerning dry deposition, we only consider wet deposition.

Table 1 shows SO_4 load (mg/m^2 per year) at some EMEP stations in and around Estonia (Fig. 1), characterizing regional distribution of this pollutant. Loads of sulphur and nitrogen (mg/m^2 per month, average) are given in Table 2.

Table 1. Loads of sulphate and nitrogen (mg/m^2 per year) at the selected EMEP stations

	SO^4			N
	1986	1987	1988	1987
Lesogorskij	-	3570	8460	1565
Virolahti	3510	2831	2665	780
Lahemaa*	-	1560	1280	440
Sôrve*	-	2070	2240	600
Rustava	-	2400	2280	820
Nida	4866	4620	3210	1400

* EMEP stations in Estonia

The total sulphur and nitrogen wet deposition at the selected meteorological stations (Fig. 1) along the northeastern-southwestern transect are shown in Table 3, pollutant loads per year are shown in Table 4, and sulphur accumulated in snow is shown in Table 5.

Data from EMEP stations concerning wet deposition in Estonia and in the Baltic region show both the existence of Baltic and Estonian continental air pollution deposition gradients.

Table 2. Loads of sulphur and nitrogen (mg/m^2) at the selected meteorological stations in Estonia (average per month, 1981, 1990)

	SO_4	NO_3	NH_4	N	SO_4	NO_3	NH_4	N
	Jôhvi				Tiirikoja			
1981	262.40	20.78	32.84	53.76	138.45	35.94	10.58	46.53
1990	372.48	10.63	10.59	21.23	193.26	4.49	30.07	35.68
	Tooma				Sôrve			
1981	129.18	20.24	33.04	53.23	128.45	19.15	38.94	58.09
1990	85.18	7.10	21.87	28.98	90.34	4.58	19.97	24.55

Table 3. Sulphur and nitrogen wet deposition (mg/m^2 per year) at selected meteorological stations in Estonia (1988)

Station	S	N
Jôhvi	5721	1124
Tiirikoja	2583	1307
Voore*	1560 (1800 in 1986-89, mean)	
Tipu*	1080 (1300 in 1986-89, mean)	
Tooma	2096	1639
Sôrve	1746	826

* Data from J. Frey et al., 1991

Table 4. Pollutant loads per surface area unit (mg/m^2 per year) at the selected meteorological stations (1986)

Station	SO_4	Cl	NO_3	Ca	NH_4
Jôhvi	12062	7694	848	4173	848
Tiirikoja	6107	2878	1053	1825	772
Tooma	4782	2429	987	1214	683
Sôrve	3796	4595	999	1732	599

Table 5. Sulphur (mg/m^2) in snow cover at the selected meteorological stations along the northeastern-southwestern transect (1985)

Station	S
Narva	4628
Jôhvi	3058
Tiirikoja	302
Tooma	799
Viljandi	589
Nigula	350
Virtsu	261

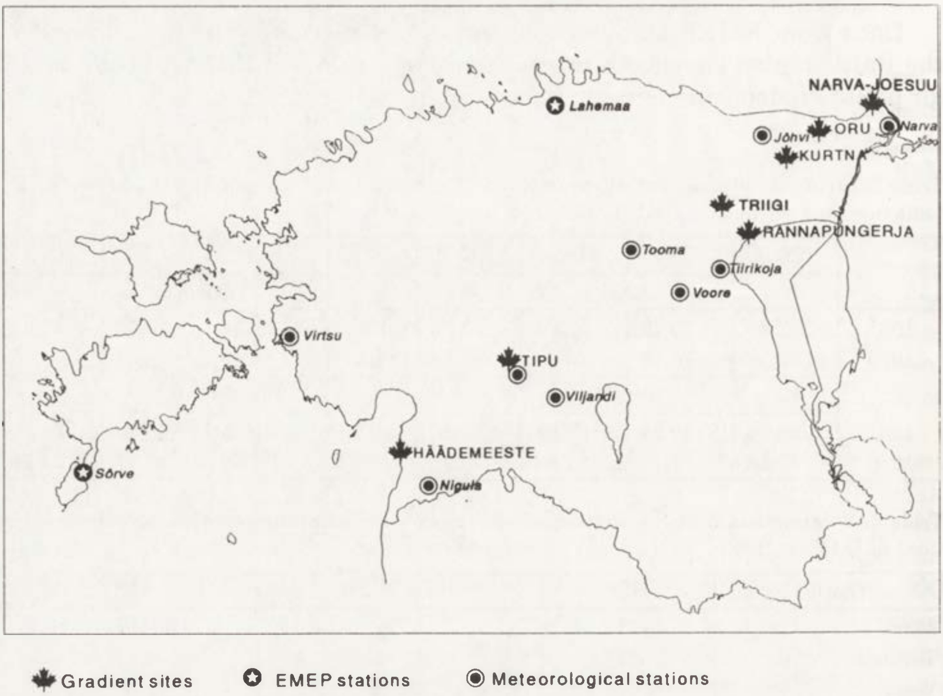

Fig. 1. EMEP stations, selected meteorological stations, and gradient sites in Estonia

Air pollution components of deposition gradient are mostly alkaline dust, sulphates, and nitrogen compounds from both oil-shale consuming power plants and oil-shale chemical processing plants (Estonian and Baltic Thermal Power Plant). We see increasing acidic deposition from the three northernmost sites southwards which is possibly formed by a long-range transport of pollutants.

STUDY SITES

Scots pine forest stands of IV-VI age classes belonging to the *Vaccinium*, *Myrtillus* and *Cladonia* forest site type were observed along the atmospheric pollution deposition gradient in Estonia in order to select suitable study sites and establish circular plots. These forest-site types are common in Estonia (Estonian Forests 1974).

In 1990-1991, five sites located on the Estonian air pollution deposition gradient were studied: I — Oru (ORU), II — Kurtna (KUR), III — Rannapungerja (RAN), IV — Tipu (TIPU), and V — Häädemeeste (HDM). These sites are distributed from northeastern to the southwestern part of Estonia to the Latvian border and the Baltic Sea (Fig. 1).

In 1992, selection of sample plots on study sites was continued and also two new sites were added for future study: Narva-Jôesuu (NARVA) and

Triigi. This report deals with 1990 and 1991 results, with only rare exceptions (needle data of the Narva-Jôesuu site).

FOREST STANDS

On the selected sites of Oru, Rannapungerja, Kurtna, Tipu, and Häädemeeste, increment cores were taken to determine stand age and synchrony of the growth curves. The data characterizing the synchrony of growth dynamics are presented in Table 6.

Table 6. Synchrony of stand increment at the selected sites (%)

	ORU	KUR	RAN	TIPU	HDM
Oru	*				
Kurtna	56.4	*			
Rannapungerja	61.8	58.0	*		
Tipu	60.0	65.2	60.8	*	
Häädemeeste	61.8	60.9	62.3	66.7	*

As it is seen in the table, the synchrony of stand growth curves (Bitvinskas 1974) is higher than 50%, making it possible to find on these sites the plots which may be compared dendroecologically. Radial increment can be used to demonstrate dissimilarity of stands also. This was done using Student's t-criterion (Table 7).

Table 7. Differences of radial increment between forest stands on selected sites (Student's t-criterion)

Sites	ORU	KUR	RAN	TIPU	HDM
Oru	*				
Kurtna	3.26	*			
Rannapungerja	9.02	6.04	*		
Tipu	11.38	10.57	5.71	*	
Häädemeeste	12.62	12.33	8.03	1.47	*

Calculations show that forest stands located far apart differ much more than in neighbouring stands. The values of t-criterion indicate that the differences between means and variances of tree-ring width of observed forest stands are not random, but are influenced by some factor or group of factors. Further investigations are to find these factors and their impact on tree growth.

SOILS

The soil texture of selected digs of five sites is demonstrated in Table 8. The soils of the sites are well-aerated, sandy forest podzols. The reason to select the forest-site types on sandy soils is their sensibility to both acidic and alkaline deposits. It is prognosed that the damage to Scots pine forests on pure sandy soils begins earlier than in forests on rich soil habitats. Depending on the depth of groundwater and forest stand age, the tree increment may increase or decrease (Aaspôllu 1984). To establish comparable plots on a site, we must investigate forest stands of different forest-site types.

Table 8. Texture of the soils on study sites (diameter of soil particles, mm)

Sites, horizons	1- 0.5	0.5 - 0.25	0.25 - 0.05	0.05 - 0.01	0.01 - 0.005	0.005 - 0.001	0.001 <	clay (%)
Oru								
A2	35.0	48.3	13.8	0.9	1.0	0.5	0.5	2.0
B	2.9	44.2	49.7	0.9	1.0	0.7	0.6	2.3
BC	24.6	62.0	12.1	0.2	0.2	0.9	< 0.1	1.1
Kurtna								
A2	0.6	21.4	73.6	1.6	1.0	0.7	1.1	2.2
B1	0.2	21.5	75.4	0.2	0.7	0.2	1.8	2.7
B2	0.1	19.8	78.2	0.2	1.0	0.5	0.2	1.7
C	0.2	24.4	73.7	0.3	0.7	0.6	0.1	1.4
Rannapungerja								
B1	13.1	41.3	41.3	1.5	0.3	0.7	1.8	2.8
B2	9.2	37.6	51.1	1.1	0.2	0.6	0.2	1.0
BC	14.2	31.1	53.6	0.2	0.3	0.1	0.5	0.9
Tipu								
A2	3.2	3.8	88.9	2.4	0.2	1.0	0.5	1.7
B	13.1	26.0	67.7	1.3	0.1	1.2	0.6	1.9
B2	2.6	23.6	72.7	0.2	0.2	0.5	0.2	0.9
BC	6.9	32.7	59.7	0.2	0.2	0.3,	< 0.1	0.5
Häädemeeste								
A2	6.2	68.5	22.3	0.1	1.5	0.5	0.9	2.9
B1	5.7	68.8	22.5	0.9	0.2	0.5	1.4	2.1
B2	7.0	77.4	15.1	0.1	0.1	0.1	0.2	0.4
BC	14.5	75.3	10.0	0.1	0.1	< 0.1	< 0.1	0.1
C	8.0	79.7	11.9	0.2	0.2	< 0.1	< 0.1	0.2

At first, we tried to determine the soil and water regime differences on the sites. We found that the depth of groundwater was 0.72 m in Oru, more than 2.5 m in Kurtna, 130 cm in Rannapungerja, 2 m in Tipu, and more than 4 m in Häädemeeste. The further digs showed that in our sites it is possible to establish analogous plots on parts of relief where groundwater depth is 1.3 m. These sites have sands of different geological origin. Because of these circumstances, the phosphorus content is high in lower soil horizons (Table 9). In such soils, phosphorus is not the growth-limiting factor.

Table 9. Content of P, K, Mg and Fe (kg/ha) in soil horizons

Site, forest site type	Horizon Thickness (cm)	pHKCl	P	K	Mg	Fe
Oru (*Myrtillus*)						
Ao	0.0-5.9	5.9	10	141	100	-
AoA2	5.9-8.0	5.9	1	11	23	747
A2	8.0-23.0	5.6	39	39	174	532
B	23.0-60.0	5.5	359	60	359	3034
BC	60.0-72.0	5.7	86	9	104	414
Total in 72 cm layer			495	260	760	4727
Kurtna (*Vaccinium*)						
Ao	0.0-2.2	4.9	2	21	10	-
AoA2	2.2-4.0	5.8	2	17	20	130
A2	4.0-6.0	5.6	11	5	13	162
B1	6.0-14.0	5.5	79	9	53	808
B2	14.0-44.0	5.6	632	45	186	2394
C	44.0-100.0	5.7	922	46	368	784
Total in 100 cm layer			1648	143	645	4278
Rannapungerja (*Vaccinium*)						
Ao	0.0-4.5	3.2	2	9	9	-
A2	4.5-8.5	3.7	11	7	22	65
B1	8.5-11.2	4.4	80	5	52	512
B2	11.2-47.0	5.1	796	28	512	2701
BC	47.0-100.0	5.3	802	89	534	3563
Total in 100 cm layer			1691	138	1129	6841
Tipu (*Myrtillus*)						
Ao	0.0-3.9	2.6	5	18	14	-
AoA2	3.9-5.0	3.0	1	5	6	8
Ao	5.0-25.7	3.8	81	27	161	269
B1	25.7-46.0	5.0	1705	120	339	3491
B2	46.0-87.0	5.6	2597	65	260	5908
BC	87.0-100.0	5.6	967	12	144	1474
Total in 100 cm layer			5356	247	924	11150
Häädemeeste (*Vaccinium*)						
Ao	0.0-3.2	2.7	2	11	9	-
AoA2	3.2-4.0	3.1	1	2	5	14
A2	4.0-13.5	3.8	13	13	52	220
B1	13.5-24.5	4.5	542	8	143	1714
B2	24.5-43.5	5.2	1316	19	150	2163
BC	43.5-63.5	5.7	1467	18	143	412
C	63.5-100.5	5.6	2755	31	250	1096
Total in 100 cm layer			6096	102	752	5619

Because all soils of the sites consist little clay (Table 8), the soils are primarily low in potassium content, which is significantly higher in Ao soil horizon in northeastern Estonia at the Oru and Kurtna site (Fig. 2). An explanation for this, and also for the higher magnesium (Table 9) and calcium (Fig. 3) content in A_0 horizons in the Oru and Kurtna sites, is the alkaline dust emissions from thermal power plants in northeastern Estonia. The pH of A_0 horizon is higher in comparis on with the studied sites in southwestern Estonia at Häädemeeste (Fig. 4). The reaction of Ao horizon in southwestern Estonia (Häädemeeste) is strongly acidic. Simultaneous impact of acidic and alkaline atmospheric deposits in Estonia on different components of ecosystems complicates the possibilities of studying the soils response to these deposits. A_0 soil horizon is often necessary to value the influence of pollutants. Different concentrations of these deposits and variable physical and chemical qualities of soils may inhibit or favour the growth of forest stands.

ENVIRONMENTAL EFFECTS ON COMPONENTS OF FOREST ECOSYSTEMS

FOREST STAND HEALTH[1]

In 1990, 10 randomly chosen Scots pine canopies were observed for general health evaluation at each site. Table 10 shows a comparison of the median values of live crown ratio, crown transparency, twig dieback, and branch dieback. Median live crown ratio was uniform among the four sites (Oru site was not observed). Twig and branch dieback were minimal. However, crown transparency varied among the sites. The canopies in Kurtna and Häädemeeste sites had the highest crown transparency. This could be a reflection of many factors, but the most important is certainly pollutant stress, alkaline dust impact in the northeast, and acidic deposition in the southwest.

Table 10. Comparison of median values for forest stand health evaluation

Site	Live crown ratio	Crown transparency	Twig dieback	Branch dieback
Kurtna	20	40-50	0	0
Rannapungerja	30	20	0	0
Tipu	20	30	0	0
Häädemeeste	30	40	0	0

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[1] Data were collected in 1990 by Dr. D. Davis, Department of Plant Pathology, Pennsylvania State University.

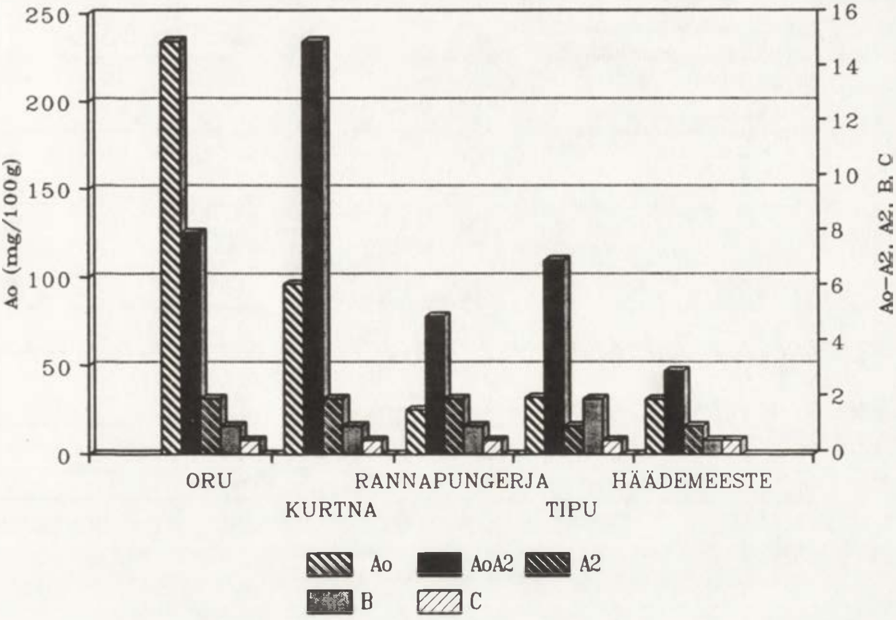


Fig. 2. K content in soil horizons (mg/100 g)

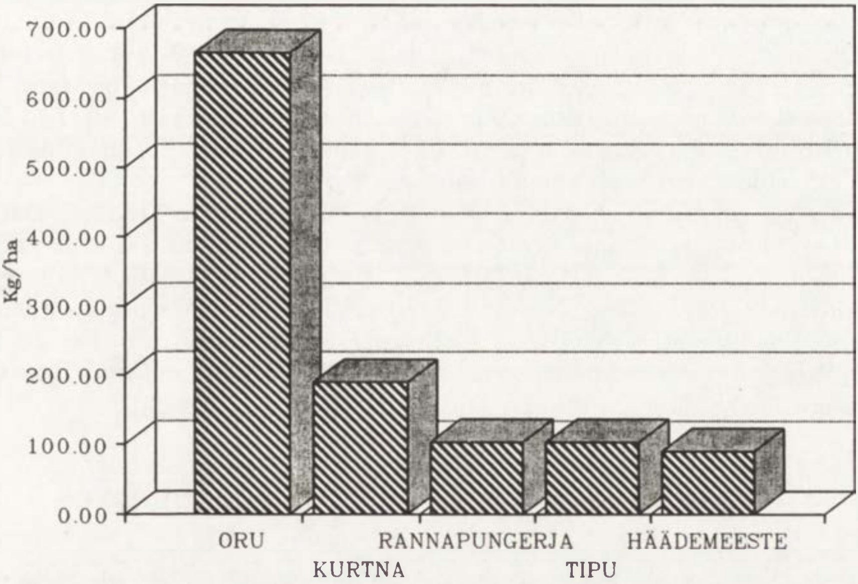
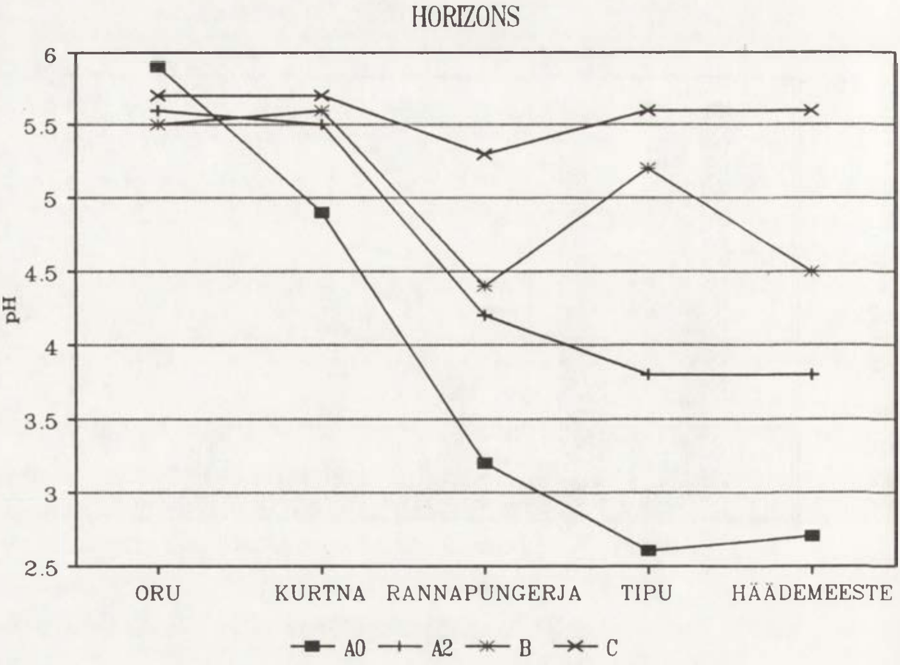


Fig. 3. Ca content in A_o (kg/ha)



g. 4. pH_{KCl} of soil horizons

QUANTITATIVE ANALYSIS OF SCOTS PINE NEEDLES

In June 1991, needle samples were collected from five trees per site at Häädemeeste, Rannapungerja, Kurtna, Oru, and seven trees at Tipu. Twig samples were taken from the seventh to tenth whorl from the top of the tree. Needle mass, twig mass, and twig length of the past 2-year increments (excluding the current year) were measured in 25 sequences per tree. The purpose of this research is to compare data sets obtained from 1991 to 1992 (measurement in progress) and estimate needle loss and its possible links with other parameters obtained from sample plots.

The general overview of the 1991 data is represented in Figure 5. Data of twig length and twig mass are 10.8% and 34.5% higher in the 1989 growth year than that in 1990. Also on all sites, except Häädemeeste, needle mass was lower in 1990 (6.7%). Needle density and needle mass per twig length (g/mm) was higher in the 1990 growth year, except in Kurtna (Fig. 6). The magnitude of measured biomass parameters for Häädemeste and Tipu sites is lower than that for the others.

ANATOMICAL STRUCTURE OF SCOTS PINE NEEDLES

The impact of air pollution on the anatomical structure of Scots pine needles was studied in 1992 on three sites: Narva, Häädemeeste, and Ran-

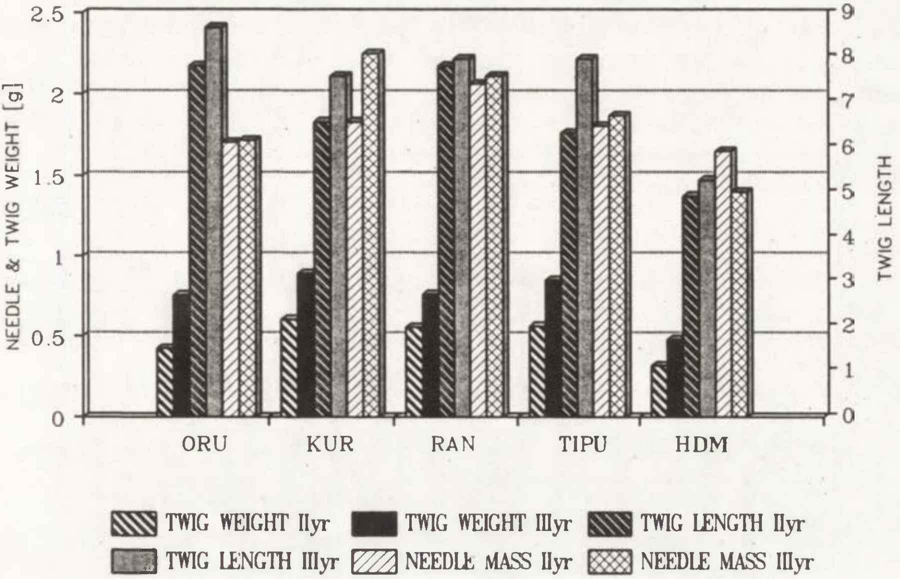


Fig. 5. 1991 quantitative analysis of Scots pine needles (needle mass, twig weight, twig length)

napungerja. Samples were fixed in 70% alcohol and cross sections were studied in glycerine droplets under a light microscope. The following measurements were carried out: thickening of needle cross sections (height and width ratio), thickness of hypodermis layers, thickness of mesophyll, endodermis, thickening of transfusion tissue (height and width ratio), quantity

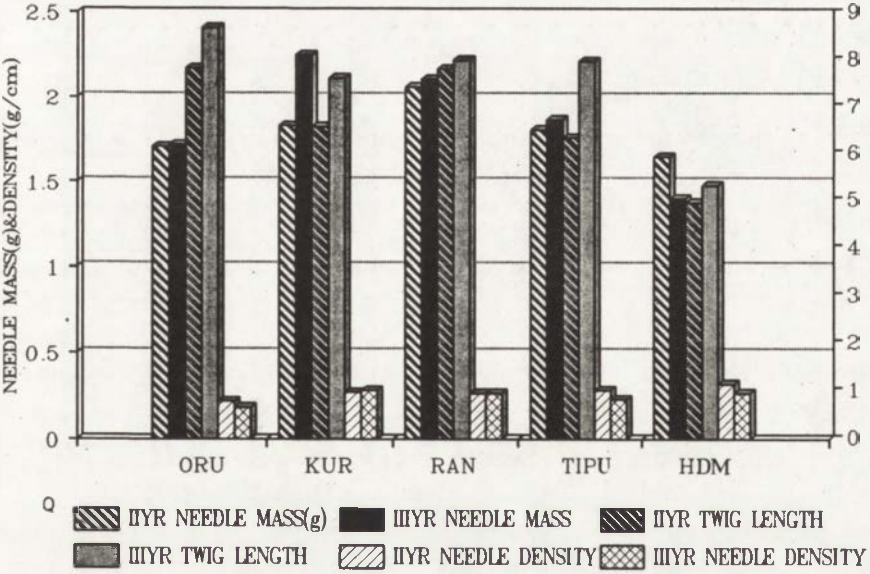


Fig. 6. 1991 quantitative analysis of Scots pine needles (needle mass, needle density, twig length)

of vascular bundles, and quantity of resine ducts. The results, representing from 60 to 100 measurements for each parameter, are presented in two diagrams (Fig. 7 and 8). The measurements did not show any significant difference between tissue sizes of needle cross sections from different study sites.

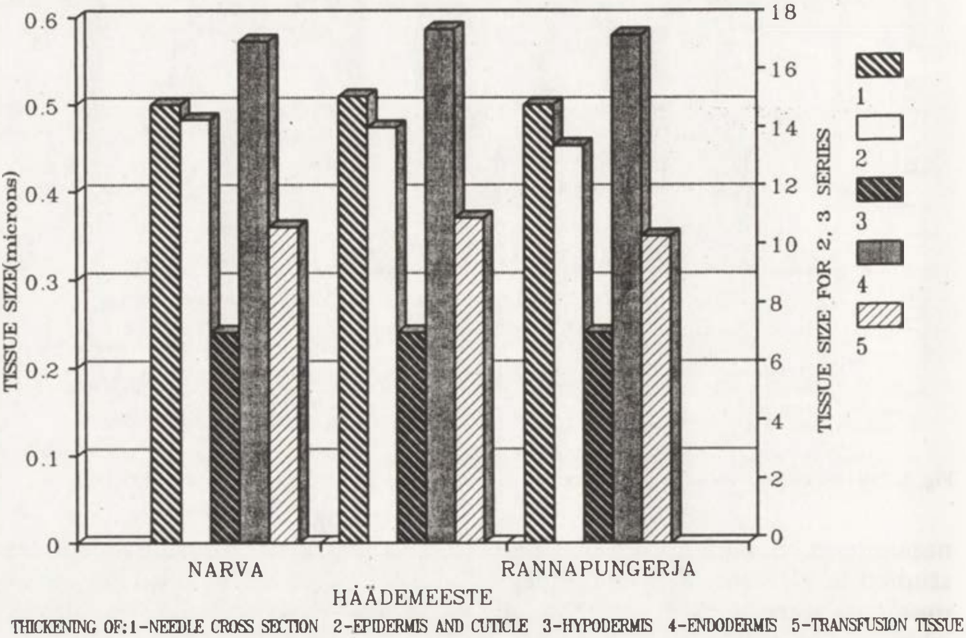


Fig. 7. 1992 anatomical structure of Scots pine needles (thickening of tissues)

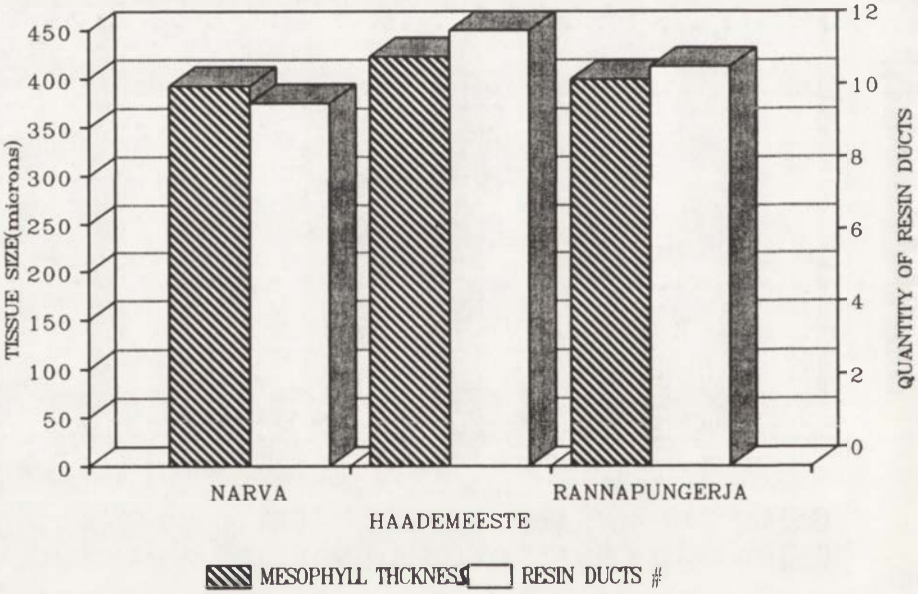


Fig. 8. 1992 anatomical structure of scots pine needles (mesophyll thickness, and resin ducts)

The needles from all sample sites had undergone morphological changes; samples from the Rannapungerja site, especially, had slightly expressed symptoms of damage. Needle cross sections had outlines with hollowness and stretched form, also an enlarged intercellular space near the stomatal cavity was observed. The central vacuoles of endodermis cells were larger on one tree only and the quantity of resin ducts decreased from three to four. Therefore, we can assume slight morphological damage to needle tissues on the Rannapungerja site.

Such characteristics as the quantity of hypodermis layers and vascular bundles were normal and constant on all sites.

EPIPHYTIC LICHENS AND TREE BARK

Epiphytic lichens are considered as sensitive indicators of air pollution both on lichen community and on the individual species level. It was established that the species composition of pine bark inhabiting lichen communities changes along the gradient.

Total sulphur content and pH of pine bark at different sites at north and south expositions are presented in Figure 9. It shows the differences between pH and total sulphur content on the sides of the tree bole.

Change in some lichen synusia characteristics, such as average of coverage degree, average number of species per lichen sample quadrate (20 × × 20 cm), average coverage per species, and average coverage for *Hypogymnia physodes* are shown in Figure 10. The coverage of lichen communities increases along the gradient up to the Tipu site and decreases at the Häädemeeste site. The highest number of lichen species was found at the Kurtna site. The highest figure for coverage per species was determined at the Tipu site, and the highest coverage for *H. physodes* was observed at the Rannapungerja site.

BIOACCUMULATION

BIOACCUMULATION OF SULPHUR IN LICHENS

On five sites along the northeastern-southwestern transect through Estonia, samples were taken to establish possible variations in total sulphur content in lichens. The results of analyses of sulphur content in lichens are shown in Figure 11. It can be seen that the total sulphur content in two selected lichen species, *Hypogymnia physodes* and *Pseudevernia furfuracea*, show significant differences between the sites along the transect. In *P. furfuracea* the content of sulphur is higher than that in *H. physodes*.

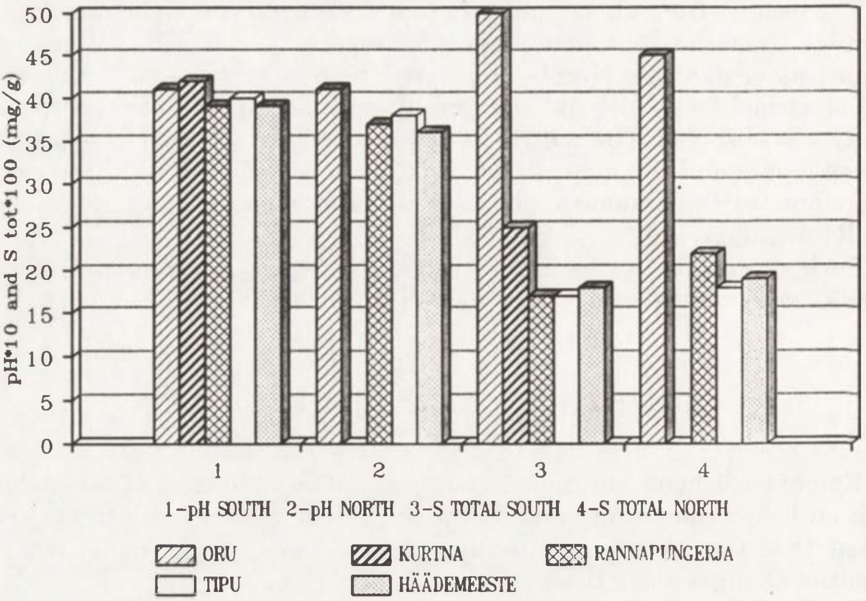


Fig. 9. Scots pine bark pH and total sulphur content

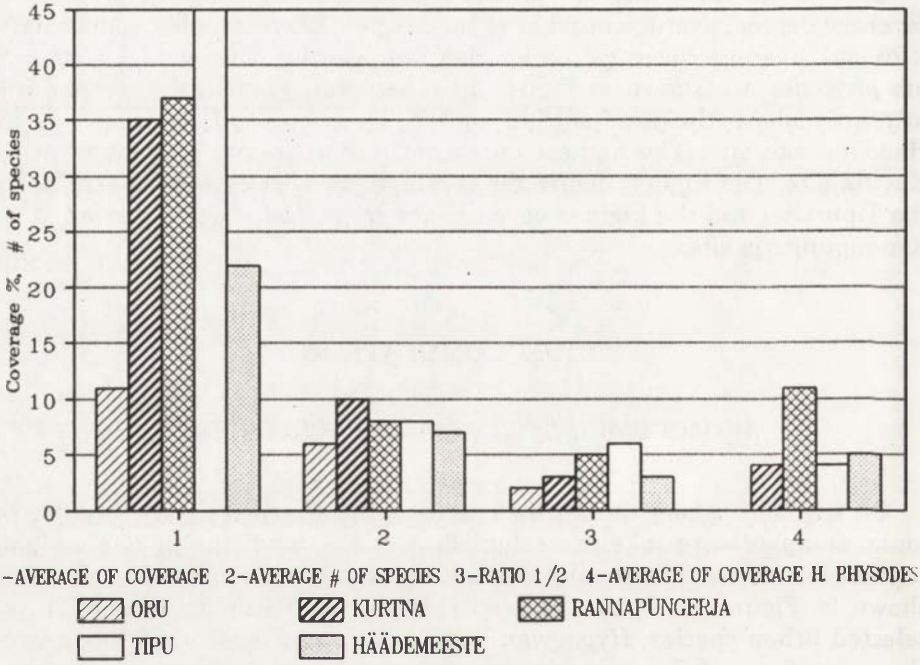


Fig. 10. Lichen synusiae characteristics on Scots pine (south study)

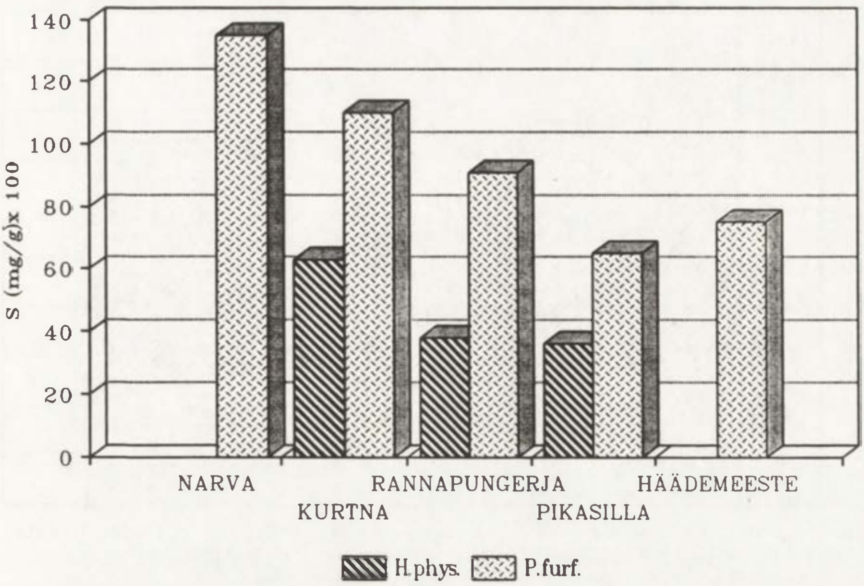


Fig. 11. Total S content in moss *Hypogymnia physodes* and *Pseudevernia furfuracea*

BIOACCUMULATION OF SULPHUR IN MOSSES

Mosses are widely used for studies of bioaccumulation of airborne deposits. Five common forest mosses in Estonia, *Hylocomium splendens*, *Pleurozium schreberi*, *Dicranum polysetum*, *Hypnum cupressiforme*, and *Rhytidiadelphus triquetrus* were studied for sulphur accumulation (Tekko 1991). More sample sites were used in this work than in the present transect study to detect possible variations in sulphur content. The greatest content of sulphates was found in northeastern and central Estonia and also in the vicinities of the industrial towns (Tallin, Tartu, and Pärnu). The greatest content coincides well with the main pollution sources. The maximum content of sulphur in the transect sites is detected in northeastern Estonia.

Sulphur (S) content in one of the most common moss species on these sites, *H. splendens*, November 1990, is shown in Figure 12. The differences in S content of this species among the sites demonstrate the presence of the atmospheric pollution deposition gradient in Estonia. Figure 12 shows also that the highest S content was determined in dead parts of mosses. Figure 13 shows seasonal S content variation in *P. schreberi* from November 1990 to June 1991. In autumn, S content, both in living and dead parts of moss, is considerably higher than at the beginning of the next summer. In the Oru site, which is located in the most polluted area, the picture is somewhat more complicated. Further research is needed to find out the reasons for this difference.

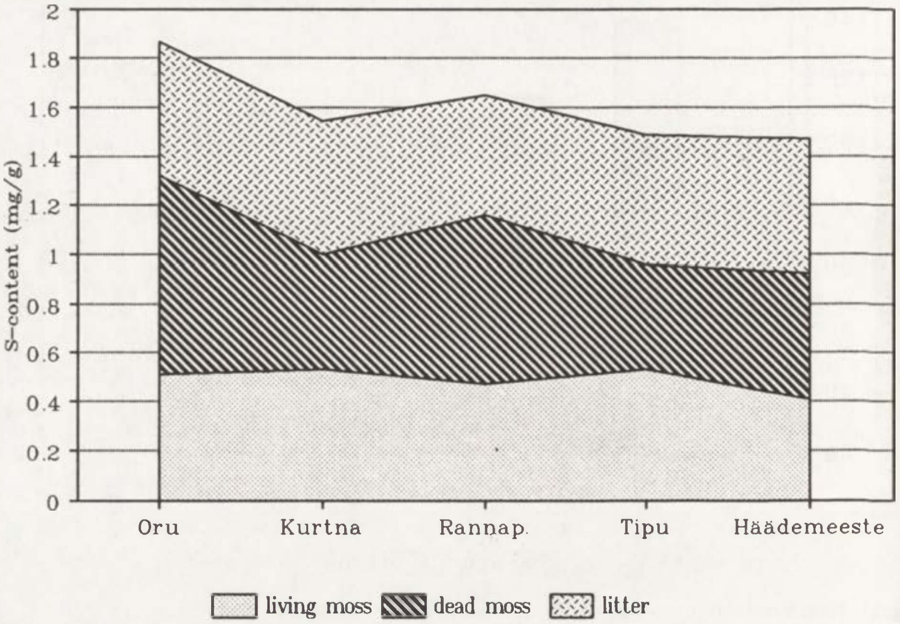


Fig. 12. Total S content in moss *Hylocomium splendens* and in the litter

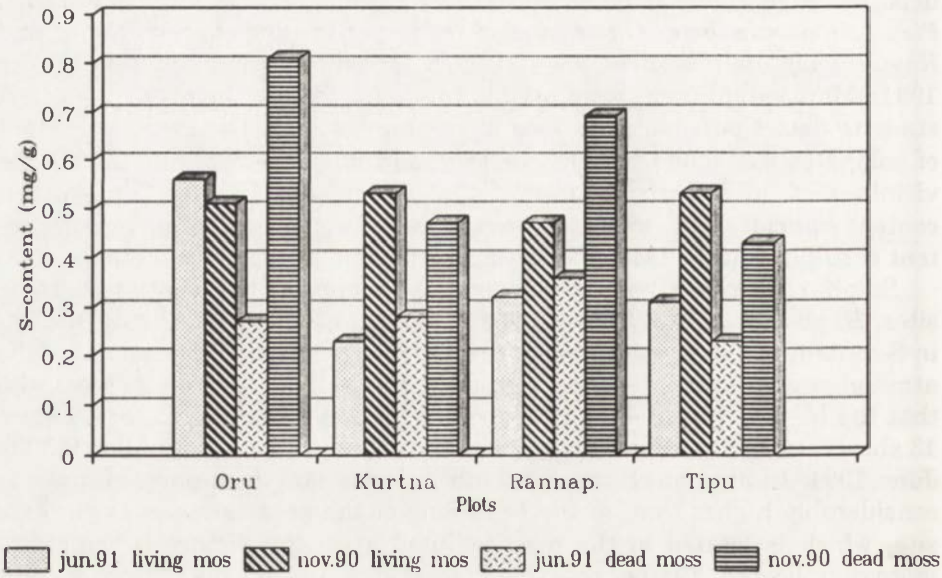


Fig. 13. Seasonal S content variation in *Pleurozium schreberi*

BIOACCUMULATION OF CESIUM AND STRONTIUM RADIONUCLIDES

A remarkable amount of radioactive substances reached Estonia after the catastrophe in the Chernobyl nuclear power plant in 1986. The total amount of radionuclide fallout is difficult to estimate as the amount of precipitation in various areas was uneven. The International Plant and Pollution Search Laboratory (IPPL) began to monitor the accumulation and dynamics of cesium (Cs) and strontium (Sr) radionuclides in the land ecosystems of Estonia immediately after the catastrophe (Martin 1991; L. Martin, Nifontova & Martin 1991).

In 1990, specifically in the northeastern-southwestern transect crossing Estonia, ^{137}Cs and ^{90}Sr were determined in forest soils, litter, and mosses.

The samples show pattern-like deposition of Cs as well as variations of these radionuclides amounts in different components of terrestrial ecosystems (Fig. 14). The quantities of Sr were insignificant.

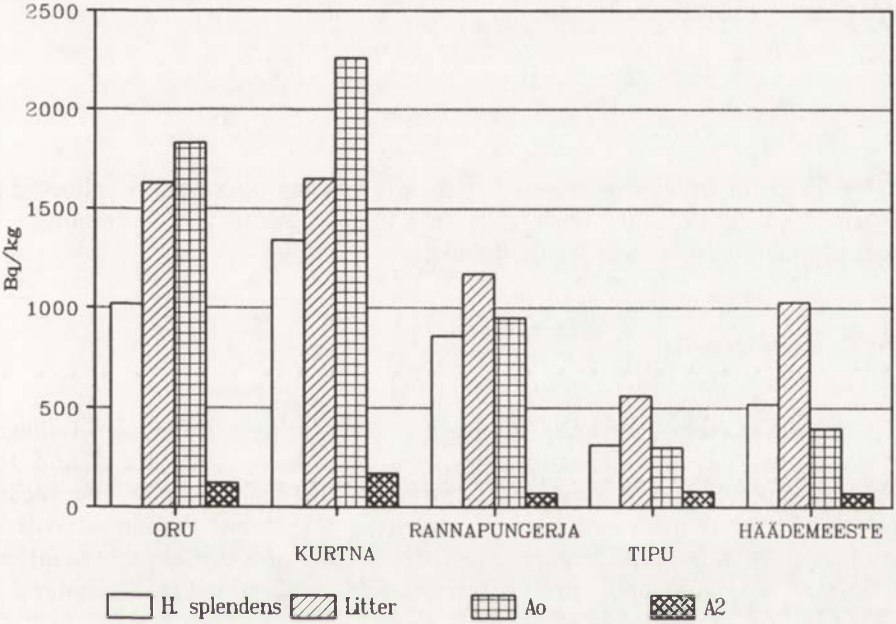


Fig. 14. ^{137}Cs in *Hylocomium splendens*, litter and soil. October 1990

RESEARCH IN PROGRESS

ISOZYME ANALYSIS

Seed collection from selected trees were completed in October-November 1990; and seed lots for each tree and each stand were shipped to Dr. D.B. Houston, School of Natural Resources, Ohio State University, Wooster, Ohio, for analyses. Analyses will be based on 15 to 20 isozyme systems in both seeds and seedlings. Analyses of isozyme banding patterns will provide preliminary data on (1) the genetic composition and structure of each stand, (2) variation among stands along the gradient, and (3) variability in gene and genotype frequencies among and within stands that may be related to selection effects on residua populations because of the impacts of the alkaline deposition gradient.

DENDROECOLOGICAL EVALUATION

Growth patterns analysis of tree cores collected from Scots pines from each study site is in progress at IPPL, Estonian Academy of Sciences, and at the School of Natural Resources, Ohio Agricultural Research and Development Center, Ohio State University (J. McClenahen).

SOIL STUDY

Detailed soil chemistry research is in process, using samples collected in 1990 to 1992 to evaluate trace elements deposition as well as changes in physical and chemical properties of soils.

VEGETATION STUDY

Pollution-caused changes of the herb and moss layer have been followed by using five permanent sample squares that have been fixed and the species composition and coverage determined on each plot. In the second stage of the gradient studies, the vegetation structural responses will be examined, which include: biomass measurements, differences and variations in canopy tree needles, species composition and structural changes of epiphytes, and understory vegetation.

PRECIPITATION AND SOIL WATER CHEMISTRY

Comparative research is planned for ecosystem water chemistry including open areas of precipitation, stemflow and throughfall, and lysimetric water and ground water.

REFERENCES

Aaspôllu J. 1984, Impact of contrary active pollution components on forest ecosystems in the vicinities of Narva-Jôesuu, (in:) *Impact of industrial pollution on forest ecosystems and methods of increasing their durability*: 63-64, Kaunas (in Russian).

Bitvinskas T.T. 1974, Dendroclimatic Research, Gidrometeoizdat, Leningrad, 220 pp. (in Russian).

Estonian Forests 1974, Valgus, Tallinn, 307p. (in Estonian).

Frey J., Frey T. & Rästa E. 1991, On pollution of precipitation in 1986-1989 (in:) *Problems of contemporary ecology, Ecology and energetics*: 25-29, Tartu (in Estonian).

Jegorov D., Rajur K., Trapido M. & Loosaar J. 1988, Air pollution emissions of thermal power plants into environment (in:) *Ecological Studies*: 98-109, Tallinn.

Kallaste T., Roots O. & Saare L. 1992, Air Pollution in Estonia 1985-1990, Environmental Report 3, Environment Data Centre National Board of Waters and the Environment, Helsinki, 61 p.

Martin J. 1991, Radionuclides Cs-137 and Sr-90 in the land ecosystems, (in:) Estonian Environment 1991. Environmental report 4, Environment Data Centre, National Board of Waters and the Environment, Helsinki: 37-40.

Martin L., Nifontova M. & Martin, J. 1991, Radionuclides variation in macrolichens in Estonia after the Chernobyl accident, *Proc. Estonian Acad. Sci. Ecol.*, 1.1: 42-51.

Reed D., Medlarz S. & Noble R. 1991, Investigation of effects of forest stress factors along exposure gradients in the United States, *Proc. Estonian Acad. Sci. Ecol.*, 1.1: 10-26.

Tekko S. 1991, Bioindication of sulphur distribution in Estonia using mosses, *Proc. Estonian Acad. Sci. Ecol.*, 1.4: 179-182.

Tuovinen I.P. 1989, Transboundary air pollution between Finland and the Soviet Union, Finnish Meteorological Institute 15p.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:137-140, IGSO PAS, Warszawa

DYNAMICS OF TREE HEALTH CATEGORIES IN PINE STANDS

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Abstract: The purpose of this paper is to show the process of increasing mortality in the damaged stands growing in the zones of nitrogen fertilizer plants. The main air pollutants are sulphur dioxide, nitrogen oxide, ammonia, and fluorine compounds. To show the tendencies of increasing tree mortality, data was used from permanent sample plots in pure pine forests growing at various distances from the pollution source. Traditional inventory data of some sample stands were also analysed. The dieback process of the stands shows the relation of growth development classes and tree health. Considering all the air pollution factors, the authors are able to describe a stand's dieback for the next 1 to 2 years.

Key words: pine forest, forest damage, pollution, sensitivity, permanent plots, pine dieback, Lithuania.

INTRODUCTION

At the present time, the question of local pollution of forest ecosystems has a global meaning and character. The increasing anxiety for clean air and an intensified control, however, do not preserve the environment from the negative impact of industrial pollutants.

Reaction of forest ecosystems to industrial pollutants depends on the sensitivity of individuals and on ecological and local factors. Heterogeneity of pollutant streams in vertical and horizontal sections caused by meteorological, physiogeographical, and other factors give a coincidental character to the damage.

Pollution control is a very complicated problem. The harm of emission may be disclosed when describing the state of the stand which should be considered the principal component of the forest ecosystem. The damaged trees indicate the pollution level.

In many cases, the extent of damage could be described by analysing phenological data of the morphological characteristics of trees. The appearance of the crown represents the health state of trees in a damaged stand. The productivity losses are big.

The purpose of our investigation was to study the mortality process in damaged stands and growth in the zone of nitric fertilizer plants. The main air pollutants were sulphur dioxide, nitrogen oxides, ammonia, and fluorine compounds.

RESULTS AND CONCLUSIONS

To show the tendencies of increasing tree mortality, we have used data from permanent sample plots in pure pine forests growing on plots located at various distances from the pollution source. Also, we have used the traditional inventory data of some sample stands (Table 1).

Table 1. Characteristics of the experimental material

Type of experimental material	Number of sample plots or stands	Distance from the plant (km)	Age (years)	H (m)	D (cm)	Number of measured trees	Site type
Permanent sample stands	3	2.4-6.0	30	10.0-12.5	8.5- 11.5	542-618	B2(Nb)
Permanent sample stands	3	3.3-7.9	50	17.5-18.0	14.9-17.8	203-397	B2(Nb)
Permanent sample stands	5	2.5-6.5	70	20.0-23.5	21.3-24.4	193-250	B2(Nb)
Sample stands	10	2.7-9.5	25-30	10.0-15.0	10.0-16.0	164-264	B2(Nb)

As a result, we conclude that under the influence of industrial pollutants (compounds of sulphur and nitrogen) the dieback process may be divided into the following phases:

— Composition of grass cover in forest stands changes;

— Trees become weaker at the stands' edges;

— Radial increment and tree growth decreases;

— Tree crowns are thinned; needle age becomes 1 to 2 years shorter; and damaged trees get some tops tic in many tops, and they die;

— Pests settle in the tree stems and forest decomposition begins.

Decomposition rate depends on the site character as well as on the stand age and density. Middle-aged pine stands are the most resistant (Table 2).

Young pine stands are characterized by increased sensitivity. The reason might be because the longer part of their existence is spent in extremely bad conditions.

In damaged stands the undersized trees die off first. Figure 1 shows the dynamics of tree mortality in young stands depending on their diameter and the distance to the pollution source. We conclude that air pollution accelerates this process. As a rule, stunted trees in stands do not constitute more than 10% of all trees. Tree differentiation on such stands was compared with the fifth or fourth growth development classes by Kraft. Stunted trees under the influence of pollutants die first. We have investigated the changes in tree states according to their development class by the Kraft classification scale.

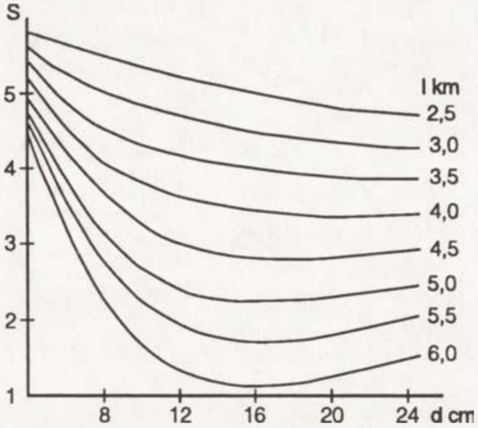

Fig. 1. Average category dynamics of young stands (S) according to diameter (D), years and distance to the pollution source (l)

Table 2. Dynamics of dead trees volume

Level of damage in the beginning of the investigation	Distance to the source of pollution (km)	Age of the stand (years)	Number of dead trees (%) in different years			
			1979	1981	1983	1991
High	2.5-3.5	30	46	58	75	78
		50	31	44	65	66
		70	37	51	70	72
Middle	5.5-7.9	30	10	24	32	32
		50	10	15	20	28
		70	15	20	25	29

On the basis of permanent sampling plots in young pine stands, we have stated that the correlation coefficient between development classes and the categories of the health state constitutes 0.6368-0.8255. We have investigated the state of trees and their development classes by calendar years, taking into account that tree change occurs in healthy stands according to their growth development classes. One-half of the trees in every class remained approximately the same. Using data from 1978 to 1991, we developed a model reflecting the dynamics of dieback of young pine stands. The tree state is estimated by the following equation:

$$S = 5.6563 - 24.7739K - 0.011b + 0.3182Kb + 3.5460K^2 + 0.0442K^{2b}$$

where: S — category of the state of the trees (1,...,6); K — growth development classes according to Kraft (1,.,V); b — years (78,...,84).

Standard deviation according to the first equation constitutes mx = = mx × 7.2% (age 30 years, site class = II, distance from the pollution source is 3-3.2 km).

Figure 2 gives the results of pine stand dieback. Analyzing the change of health state over many years, we see that the curves in Figure 2 reflect different damage levels in the stand. The lower curves, 3 to 5, reflect a low damage level. The next three curves show middle damage level (1979 to 1991), the last two curves show a high damage level turning into stand decomposition. Two lower dotted lines characterize healthy stands because the middle categories of prevailing trees constitute 1-1.5.

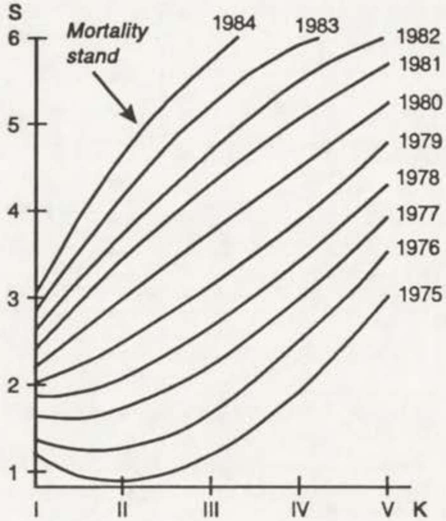

Fig. 2. Tree mortality dynamics in young stands (S) in relation to Kraft's development classes (K)

The rate of stand decomposition depends on the direction and distance to the pollution source, stand age, and many other factors. The influence of distance on the damage of maturing pine stands depends on their development classes (Fig. 3) and is expressed by the following equation:

$$S = -0.7104 - 0.2247K - 15.6268/l - - 0.0037K/l - 0.2812K^2 - (0.5350K^2)/l$$

Where l is the distance from the resource of pollution (km).

Standard deviation makes mx = = mx × 12.6%, 2,5 × l × 12, age 70 years, site class = II.

Generally, our results show a relationship between growth development classes and tree health in the process of stand dieback. Considering all the factors of air pollution, we are able to describe a stand's dieback for the next 1 to 2 years.

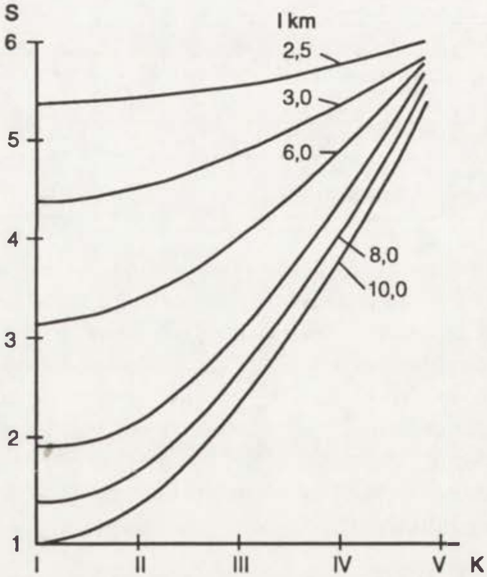

Fig. 3. Tree health dynamic categories in mature pine stands in relation to trees development classes (K) and stand distance from the pollution source (l)

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Climate and Atmospheric Deposition Studies in Forests,
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THE EFFECTS OF ENVIRONMENTAL POLLUTION ON SCOTS PINE IN THE NORTH TAIGA FORESTS OF RUSSIA

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Abstract: Peculiarities of the impact of permanent chronic air contamination by dust and gaseous waste of the copper-nickel industry on morphological structure of Scots pine crown in secondary north taiga forests of the Kola Peninsula were investigated. The negative impact of contaminants on life duration and the state of pine needles, upon phytomass formation, and the growth and state of the skeleton fraction of the crown was traced. Substantial difference in density of needle coverage, needle dimensions, and weight, either due to the position within the crown or proximity to the source of pollution, was revealed. The destructive role of air pollution in the formation and development of forest ecosystems is clearly seen in the crowns of Scots pines. Types of suppression of growth processes and dying off of separate trees and whole pine stands can be estimated as apical due to chronic air contamination by SO_2 and heavy metals (Ni, Cu, Co, etc.) under the conditions of northern Kola.

Key words: scots pine, taiga forest, pollution, tree crown morphology, growth suppression, Russia.

INTRODUCTION

Long-term observations and the evaluation of impact of industrial air contamination upon forest ecosystems revealed vast shifts in seasonal and annual dynamics of Scots pine. The data obtained, however, reflect a general effect on physiological and biochemical processes, as well as on morphological transformations in plants. Therefore, we are facing an alternative: either restrict ourselves to the registration of experimental data or determine what structural transformations result in growth changes and vital state of trees and stands under the impact of air pollutants following a classical ecological-morphological approach. Consideration of these problems enables one to understand the ecological nature of the development of trees in the process of interspecific competition, and to obtain a fundamental base for the estimation of the population state in background pine stands. On the other hand, deepened insight into morphological reactions of trees allows us to better understand those adaptive features and the structural organization of pines which provide their stable existence not only near timber line but under the impact of various anthropogenic factors. Both of these aspects are aimed to reveal and evaluate the effect of chronically polluted air by SO_2 and heavy metals (Ni, Cu, Co, etc.) of different concentration on morphological structure and the state of pine crowns in the Kola Peninsula.

MATERIAL AND METHODS

Our studies were performed on permanent sample areas (PSA) in pine stands located at different distances from the factory "Severonickel" with an annual air emission of more than 250-280 thousand tons of SO_2 with the admixture of heavy metals. Selection of PSA for combined scientific research studies envisaged their collation according to basic taxation and typological indices of plant communities existing in regions of different levels of air and soil contamination.

Table 1 contains brief characteristics of edificator synusia of forest phytocoenoses on typical plots in three main zones: (I) the zone of intact (undamaged) forest ecosystems (background), (II) the zone of damaged ecosystems, and (III) the zone of destruction. Subdivision of investigated territory into zones on the basis of the degree of damage by air pollutants was proposed earlier (Alekseev & Yarmishko 1985) and confirmed later on (Gorshkov & Yarmishko 1990). Basic results of the study and evaluation of the vitality of trees are the following: duration of needle life, chloroses and necroses effect, thinning of needles' coverage of the crown, increment intensity in terminal and lateral shoots, quantity and weight of dry branches and their localization within the crown, crown habitus, etc. The data show evidence of the worsening of pine stands the closer they are to the source of pollution. For instance, Figure 1 shows that in the background intact zone the young pine stands are composed of healthy specimens (> 70%); drying-out trees are lacking, while dry specimens compose less than 1% of the total number. Strong differentiation in vitality grades is observed in the zone of damage (35 km south of the "Severonickel" factory). Under increased pollution, ancestral forests die off; only depressed and disordered young stands remain (the zone of ecosystem destruction). Here, strongly damaged and dry pines are dominant. The majority (more than 70%) of live trees bear dry stems on the upper third or upper half of their crowns.

Shrub storey of these pine stands is poor, bearing solitary specimens of *Juniperus communis* L. and *Salix glauca* L. Grass under the shrub canopy is formed mostly of *Empetrum hermaphroditum* Hagerup, *Arctostaphyllos uva-ursi* (L.) Spreng., *Vaccinium vitis-idaea* L., *V. myrtillus* L., *Calluna vulgaris* (L.) Hall, and other species. The average height of canopy is 8 to 10 cm. The density on permanent sample areas in zones I and III reaches 0.4 to 0.5. Lichen-moss storey is mostly composed of *Cladina rangiferina* (L.) Harm., *C. stellaris* (Opis) Brodo, *C. mitis* (Sandst.) Hale et W. Culb, *Pohlia nutans*

Table 1. Brief taxation characteristics of pine stands from permanent sample areas (PSA) in the Kola Peninsula

Number, distance from the pollution, km	Forest vitality	Tree stand composition	Stand age	Mean height m	Mean diameter cm	Trees per ha	Wood stock m^3/ha	Stand density	Site class	Vitality index acc. to:		Forest type
										on stems number	on wood stock	
1, 15	Destruction	10P[1]	45	4.8	4.8	4650[2] 3350	23.23 12.0	0.8	V	3.9	3.8	*Pinetum cladinosum*
2, 30	Damaged	10P	45	7.0	7.8	1960 320	67.2 2.2	0.5	V	2.5	3.1	*Pinetum myrtilloso-cladinosum*
3, 75	Background, control	10P	45	8.0	6.4	6815 22	126.7 0.1	1.0	V	1.1	1.0	*Pinetum myrtilloso-hylocomiosum*

[1] P — abbreviation for pines;

[2] in nominator the number of alive trees, in denominator the number of dry trees;

[3] in nominator wood stock of alive trees, in denominator stock of dry trees

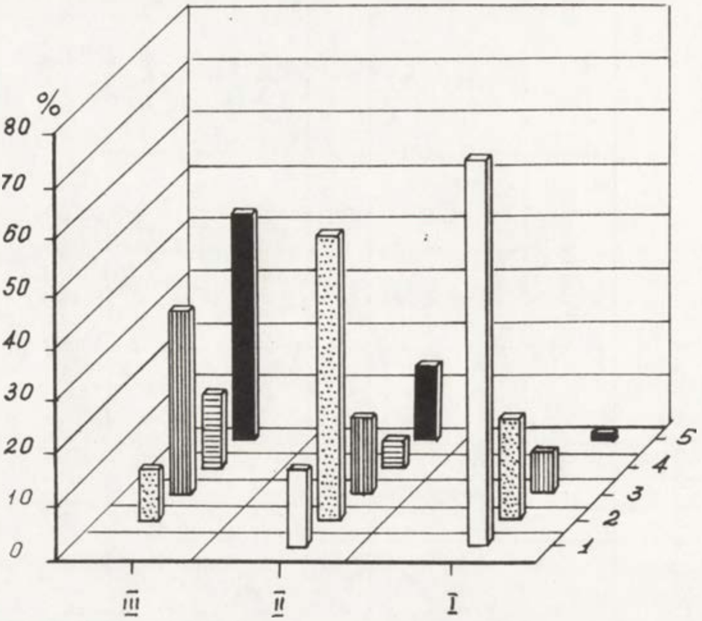


Fig. 1. Relative distribution of Scots pine trees according to vital categories on permanent sample areas, located at various distances from air pollution sources. Absciss axis: site classes of forest ecosystems: I — the zone of intact (undamaged) forest ecosystems; II — the zone of damaged ecosystems; and III — the zone of destruction of forest ecosystems; ordinate axis: the number of trees of each category of vitality: 1 — healthy; 2 — weakened; 3 — strongly weakened; 4 — dying off; and 5 — dry (in percent)

(Hedw.) Lindb., and other species. The storey coverage on investigated areas of intact and damaged forest ecosystems reaches 70% to 75%, with the average height equal to 5 to 7(10) cm. In zone III, destructive, interrupted patterns of understorey are observed (patches of barren soil or stones represent nearly 60% to 70% of the surface). An overwhelming majority of plants from all strata bear features of damage (chloroses and necroses of needles and leaves, dying-off shoots and assimilatory organs, etc.) and are in an extremely depressed state.

Soils of these permanent sample areas are rough humic podzols, iron-illuvial, and sandy loams. After selection and visual evaluation of a model tree and neighbouring trees, the model tree was cut through the root neck and placed upon a tarpaulin or a supporter. Detailed measurements and description of every model tree included stem diameter on different distances from the root neck, annual increment of the main axe, the increment of the mean lateral shoot of zone II order in each whorl, crown dimensions, the number of shoots per whorl with their arrangement according to the orders of branching and vital state (live and dry), needle age in the upper, middle, basal parts of the crown, the percentage of needle coverage, and the general state of the model tree. Further detailed studies of the described model tree, branch cutting from uneven whorls corresponding to 1989, 1987, and 1985 years formation were made. Descriptions of branch cuts included annual increments of shoots, quantity and weight of needles, needle size and the character of their damage, and other features which enable us to quantitatively describe the model and its vitality. Special attention was paid to the evaluation of the state of assimilation organs (needle) on models. Simultaneously needle samples for determination of absolute dry weight and chemical analysis were taken. Also selected for annual increment determination and estimation of chemical elements and pollutants were wood samples from stem, branches, and roots.

RESULTS AND DISCUSSION

It was established earlier (Yarmishko 1989, 1990) that in young pine stands in the Murmansk region that needle life averages 6 to 8 years. Life duration of the Norway spruce is twice as long as that of the Scots pine. In 1989, 40- to 50-year-old pine stands with 12-year-old needles were found at the spurs of Lovosersk tundras specimens (without taking needles of the year of observation into consideration). Yarmishko (1989) found that life duration in Scots pine needles is longer in more northern limits of distribution and they endure more severe ecological conditions for growth. Duration of needle life in the upper part of crowns is 1 to 1 1/2 years less than in the basal part.

The deterioration of tree vitality is caused by various factors including air pollution, and it is evident mostly in the decline of the life duration of pine needles. In 1990, special studies were made on estimating the impact of air pollution by gaseous emission of the copper-nickel industry on the life duration of pine in the Kola Peninsula. In this study, calculation was made on the needle age of Zone II shoots from the basal part of crowns of 180 to 200 trees in young pine stands (30- to 50-years-old) at various distances from the emission source. The results of this study are illustrated in Figure 2. Data analysis enables us to subdivide pine stands conventionally into four groups: (1) background stands at a distance of 75 to 100 km with maximal duration of needles life (7 to 8 years, and frequently 9 to 10 years); (2) pine stands at a distance of 50 to 65 km southwest of the Severonickel factory (life duration of needle is 6 to 7 years, and frequently 5 years); (3) pine stands at a distance of 30 to 35 km southwest from the emission source with an average duration of needle life of 4 years (also, conventionally healthy trees with 5-year needles; damaged pines occur with 4-year needles mean duration of needle life; severely damaged trees, 2- to 4-years-old and drying off pines with 1 year needles); and (4) remains of destroyed pine stands at a distance of 8 to 15 km southwest from the factory with 1-2-year old needles.

Shortening of life duration of pine needles is connected with damage and early needles fall. External symptoms of disease are of diagnostic value. Because of directed water movement in leaves under low concentration of toxicants, chlorosis of needle surface and apical necrosis develop as the most

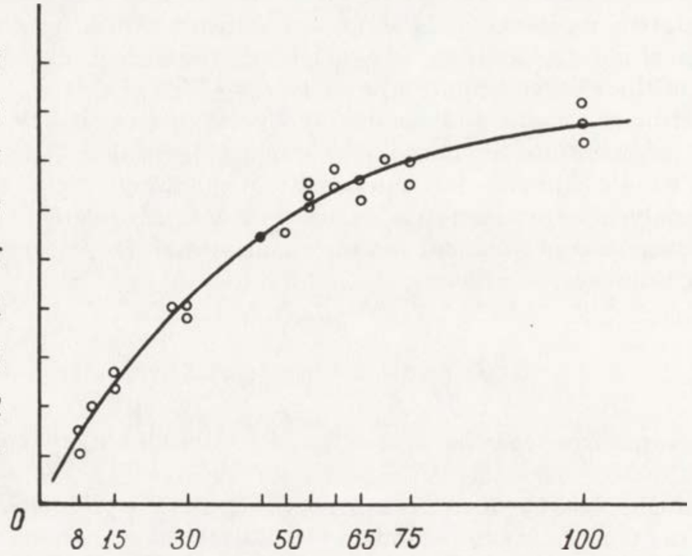


Fig. 2. The change of needle life duration in pine ecosystems depending on the distance from the source of pollution in the Kola Peninsula. Absciss axis: distance from the pollution source, km; ordinate axis: age, years

common damage form under air pollutant's impact. In a higher concentration of toxicants or prolonged action period, needle surface bears necrotic spots and patches of various sizes.

In background pine stands of the Kola Peninsula, the needles have no damage traits and are practically healthy. Three to five percent of older age needles bear 5% of light-green dots, bands and spots of chloroses, or brown microscopic dots (necroses). The analysis of needles within the crown shows that its state depends only slightly on its position in the crown under the conditions considered.

The closer the emission source, the higher the content of Ni, Cu, Co, and Fe in needles of all ages is observed (Lyanguzova 1990). The rise of heavy metals accumulation in needles corresponds to soil contamination by Ni, Cu, Co (Lyanguzova, Menshikova & Yarmishko 1990), and reflects the total pollution of the territory. In these conditions, almost all of model trees' shoots bear 10% of 1-year-old needles damaged by chloroses and necroses. Two-year-old and older needles sustain more damage. The damaged area reaches 10%, sometimes 25% of the total needle area. It is worth mentioning that needles of central shoots and lateral branches of crown tops are damaged more than those on lower-placed whorls.

In the zones of ecosystem destruction where concentration of contaminants in plant and soil was about 10 times higher than in background areas, the needle colour changes considerably because of intensive necrotic damage. Needle damaged areas reach more than 75% of the total area, while part of the needle colour is red or light-brown. In this instance, only 1-year-old needles from the middle or basal part of the crown are healthy. A tendency to a better vitality can be observed from the top to the bottom of the crown.

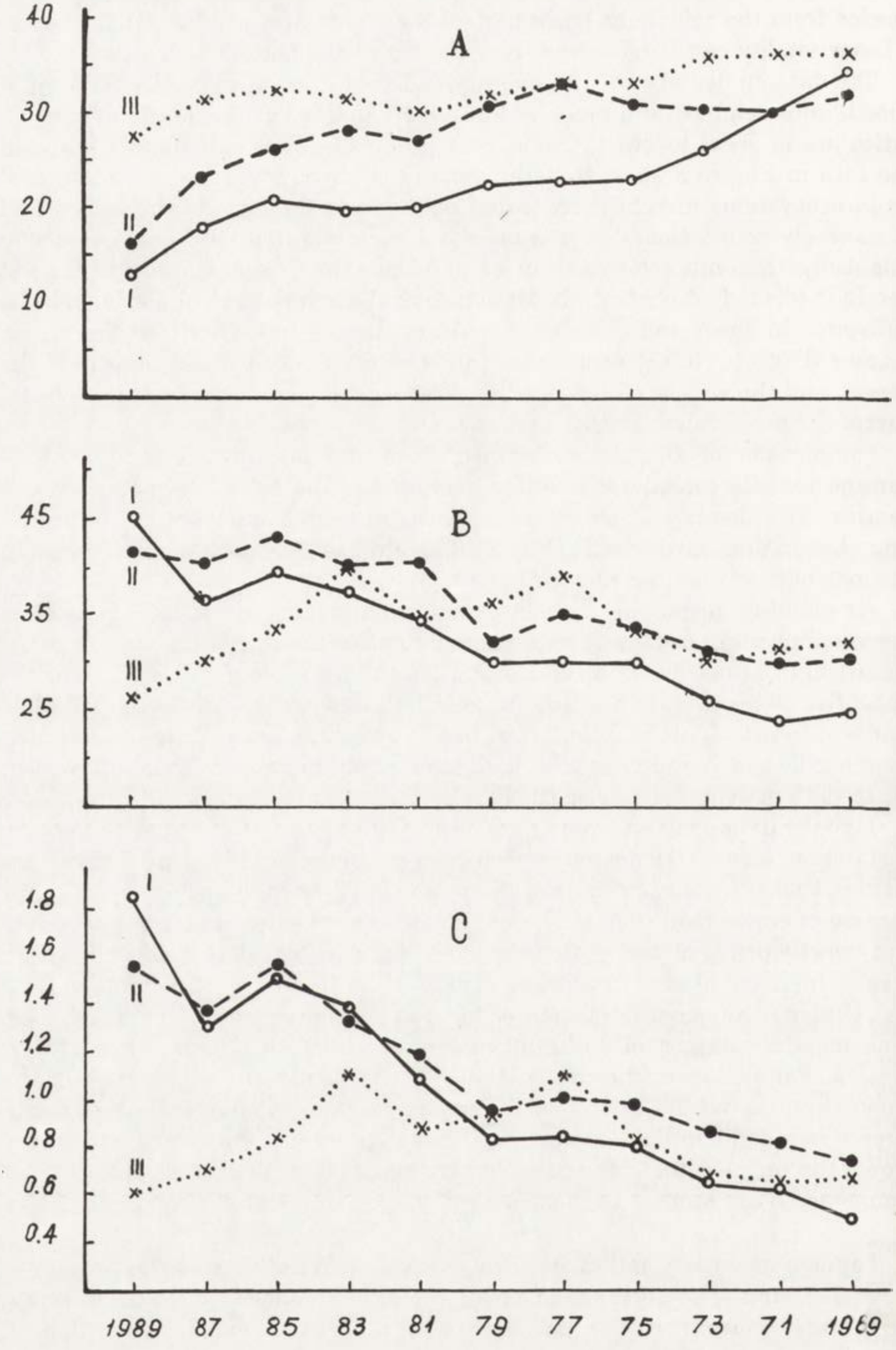
The data on density shoots coverage (number of needles per length unit of shoot), and weight and dimensions of needle under various levels of air pollution are of great interest. Our earlier studies (Yarmishko 1989, 1990) and the data in Figure 3 show that the density of shoot coverage in undamaged forest ecosystems increases from the top towards the base of the crown and is inversely proportional to annual shoot increment. In the pine stands in this study, this index varies from 12 to 44 per cm. The heaviest and largest needle is formed on central (axial) and lateral shoots of the upper whorl; the difference in these indices on the top and in the basal part of the crown reaches 350% to 400%, sometimes 500% to 600%. The mean length of the needle, and the weight of 100 needles, are lessening from the top to the basal part of the pine crown (Fig. 3).

Comparison of the data obtained from the background and zone of damage reveals considerable differences in the the basic characteristics of needles. The density of shoot coverage in damaged pine stands is higher than that in standard stands (Fig. 3). This difference can reach 200% and in the zone of destruction it may be even higher.

Air pollution negatively influences not only linear and radial increment of the tree, but also needle and leaf blade dimensions. Figure 3B shows that the mean length of needle from central and lateral shoots of the zone II from the upper five to six whorls has 10% to 20% less damage in forests than that in standard forests. This is reflected in needle weight. Closer to the bottom, the mean needle length decreases as in backgrounds; but in absolute values, it exceeds the needle length in undamaged stands of correspondent whorls by 30% to 50%.

Heavily damaged and dying off pines in the zone of forest ecosystem destruction (zone III) do not reveal those trends (or they are almost invisible), that are characteristic of the majority of pines in background stands because of crown thinning, slight self-shadowing needles, sharp suppression, and growth break of the skeleton base of crowns. The latter causes even a greater increase of shoot coverage density than in the zone of damage (Fig. 3A). Under heavy contamination of air and soil observed in the destruction zone, negative impact of pollutants upon assimilation organs is clearly expressed. For instance, the mean length of needles in the upper part of the crown is equal to 60% to 80% of the standard value. Considerably more difference in weight indices of pine needles is observed. Downward within the crown, the mean values of needle characteristics (length and weight) of trees from zone III are similar to those of undamaged tree stands (Fig. 3c).

Damage and early fall of needles unfavourably influences the growth of crown skeleton. The decrease of linear increment especially the stem (main axis) under permanent air pollution was reported several times (Jensen 1982; Yarmishko 1985, 1990). These features are revealed most vividly in young- and middle-aged pine stands. Under severe pollution growth supres-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sion not only occurs, but also the loss of ability to grow in height takes place (such specimens were studied but the results of their treatment are not incorporated into this contribution).

The weakening of stem apical growth under acute contamination of air and soil is accompanied by substantial decrease of linear increment of the zone II branches. The scales of growth decrease for stem and lateral shoots, however, are different. This changes the shape of the crown, its form, and dimensions. Figure 4 illustrates the annual dynamics of crown formation in Scots pine from background stands (Fig. 4A) and the gradual degradation of the skeletal part of the crown under different levels of soil and air pollution (Fig. 4B, 4C). It should be noted that in the zone of ecosystem destruction more than 70% of live pines have dry central (stem) and lateral shoots in the upper third or one-half of the crown. Here, young pines generally bear a slightly developed crown with intensively necrotic needles, thinner stems, and a pronounced dwarf appearance (i.e., tree "aging" occurs). The extreme stage of young pines transformation under the impact of pollutants is characterized by the lack of well-developed "live" crowns and the presence of several (one to three) branches below destroyed crowns. In some trees these branches are well developed (live root systems supply living branches with necessary food resources), they have intensive increment and vital three- to four-year-old needles. Some of these living branches, because of their weight and the weight of snow, are bent downwards, and recline above the ground, sometimes covering the surface. They become snow covered for 6 to 7 months during the year and, thus, the needles are protected from air pollutants and winter dessication (Alekseev et al. 1986).

Yarmishko (1990) has already indicated that the closer the source of pollution, the more intensive is the increase in the thinning of the tree's crown. Thinning is caused not only by early needle fall but also by dying off of branches of different orders of branching throughout the crown. For instance, in the zone of ecosystems' destruction, the quantity of the third order dead branches exceeds 52.4% of all branches of the corresponding order on the model, while 21.3% of the third order branches perished, remain within the crown. In this instance, intensive dying off of shoots of the fourth — 14.6% and the fifth — 8% orders takes place. The estimation results of the change of needle share and dry branch share in the total overground phytomass of young pine stands in the Kola Peninsula under the impact of SO_2 and heavy metals are represented in Figure 5. The data obtained reflect the reactions of stands in the regions studied so clearly that no further explanation is necessary.

Fig. 3. The change of needle coverage (A), length (B) and weight (C) of 1-year-old needles of Scots pines depending on their position in the crown and the concentration of SO_2 and heavy metals (Ni, Cu, Co). Absciss axis: years of branch formation in whorls under study; ordinate axis: A — density of coverage of lateral shoots of the II order, number per cm; B — mean length of needle, mm; C — weight of 100 needles, g absol. dry weight. I — the zone of intact (undamaged) forest ecosystems; II — the zone of damaged ecosystems; and III — the zone of destruction of forest ecosystems (on the A, B, C)

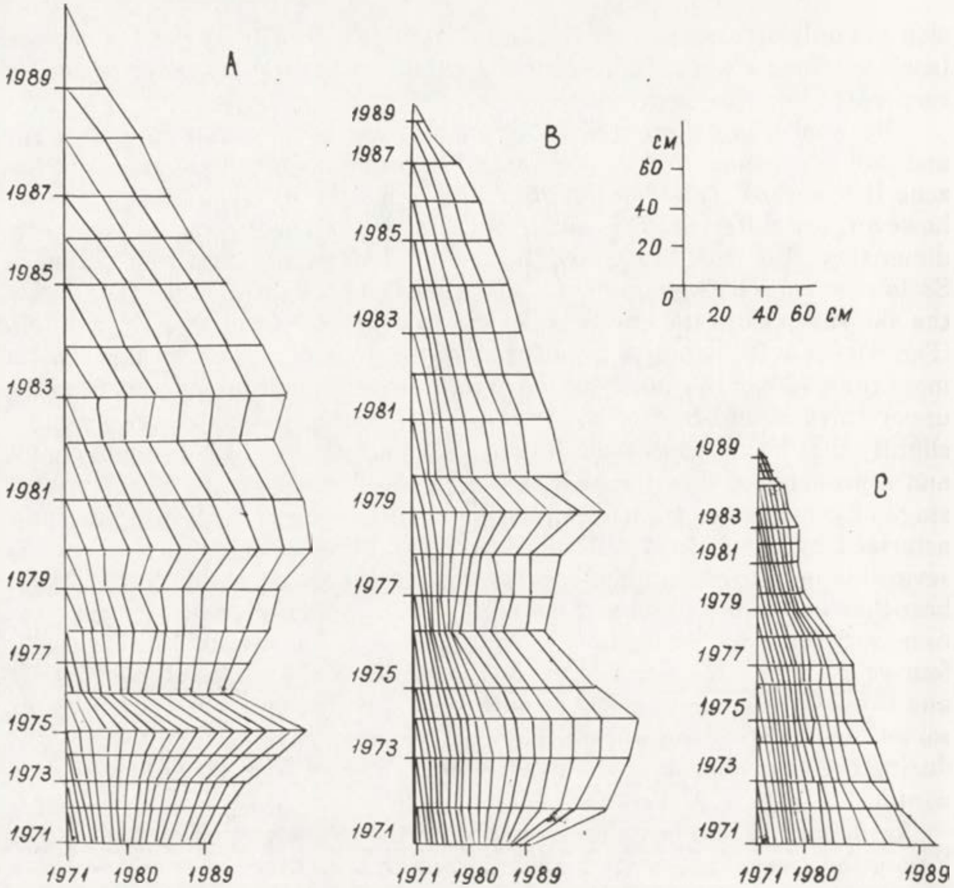

Fig. 4. The annual dynamics of skeleton fraction of crown formation in Scots pine from an undamaged zone (A), from a damaged zone (B), and from forest ecosystems destruction zone (C), in the Kola Peninsula. Absciss axis: increment of lateral shoots of II order, cm; ordinate axis: linear increment of stem, cm.

CONCLUSIONS

The analysis of the data obtained enables us to conclude the following:

1. One of the early visual symptoms of the breakdown of natural processes in Scots pine stands is the shortening of needle life duration. Because of chronic contamination by SO_2 with the admixture of Ni, Cu, Co, etc., life duration of needles declines from 7 to 8 years in background stands to 2 to 3 years and, in some regions near the source of emission, to 1 year.

2. The change of natural colour of Scots pine needles, as a result of chloroses and necroses, is a good symptom of deviation from the normal vitality of trees. Surface damaged areas can reach 75% or more (depending on the level of pollution) and, sometimes, needles become red or red-brown. Needles of terminal and lateral shoots from the crown's upper third is damaged more than that of the lower branches.

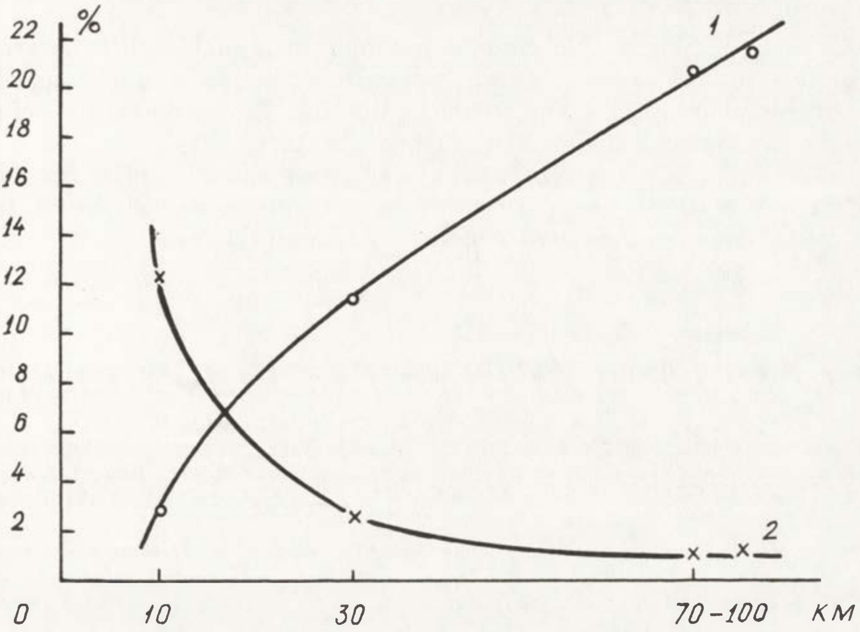

Fig. 5. The change of needle weight (1) and dry branches weight (2) in young pine stands in the Kola Peninsula depending on the distance from the source of pollution. Absciss axis: distance from the factory "Severonickel" km; ordinate axis: needle weight and dry branches weight in percent of the total phytomass of the models investigated

3. The density of needle coverage in undamaged forest ecosystems increases downward and is inversely proportional to annual increment of the shoots. Tree growth under air pollutant's impact is suppressed and, consequently, the density of needle coverage of the shoot rises. Needle density is considerably higher than in background stands and is more or less the same throughout the crown in regions with severe contamination of soil and air.

4. In undamaged ecosystems of pine stands in the Kola Peninsula, the heaviest and largest needles are formed at the top of young pines; towards the base of the crown, linear and weight parameters diminish considerably. Under air pollution impact, these differences gradually disappear. Thus, in heavily damaged and drying-off specimens of young pines, the mean length and weight of needles from the top are practically the same as those at the base.

5. Nearing the source of emission one can notice the increasing thinning of tree crowns due to needle shortening and the increase of dry branches of various orders located throughout the crown.

6. High levels of air contamination cause obvious structural transformation and gradual degradation of crowns, the development of dwarfish features and accelerated "aging" of Scots pine trees. One of the last stages of pine existence in the zone of destruction is characterized by a stagheaded pattern and by the presence of separate branches at the bottom of dead crowns. In some specimens, these branches creep over the surface of the ground forming an unusual life form.

7. Detailed analysis of all changes in pine crowns enables us to determine as apical the type of plant growth processes suppression and dying off of separate trees and Scots pine stands in the Kola Peninsula because of permanent air contamination by SO_2 and heavy metals.

8. The majority of the symptoms of weakening and damage to Scots pine overground parts is used diagnostically for estimation of the state of edificatory synusia in forest ecosystems of northern Europe.

REFERENCES

Alekseev V.A. & Yarmishko V.T. 1985, The change of structure of forest communities in the Murmansk region under air and soil pollution, Stability and productivity of forest ecosystems, *Abstr. All-Union Conference*: 4-5 (in Russian), Tartu.

Alekseev V.A., Lyanguzova I.V. & Yarmishko V.T. 1986, The influence of snow cover on survival of young trees of Scots pine under air impact, (in:) *Ecological and physiological-biochemical aspects of anthropotolerance of plants*, Part I: 41-43 (in Russian), Tallinn.

Gorshkov V.V. & Yarmishko V.T. 1990, The state of pine forest ecosystems under various levels of air pollution, (in:) Norin B.B. & Yarmishko V.T. (eds.), *The influence of industrial air pollution on pine forests of the Kola Peninsula*: 167-178 (in Russian), Komarov Botanical Inst., L.

Jensen K.F. 1982, Air pollution and forest trees growth, (in:) *Interrelationship of forest ecosystems and air pollutants*, Part 2: 116-131 (in Russian), Tallin.

Lyanguzova I.V. 1990, Contents of chemical elements in different fractions of pine phytomass, (in:) Norin B.B. & Yarmishko V.T. (eds.), *The influence of industrial air pollution on pine forests of the Kola Peninsula*: 48-55 (in Russian), Komarov Botanical Inst., L.

Lyanguzova I.V., Menshikova G.P. & Yarmishko M.A. 1990, Soil contamination, (in:) Norin B.B. & Yarmishko V.T. (eds.), *The influence of industrial air pollution on pine forests of the Kola Peninsula*: 38-48 (in Russian), Komarov Botanical Inst., L.

Yarmishko V.T. 1985, Assessment of the air pollution on pine stands under conditions of the north European part of the USSR, Air pollution and stability of coniferous forest ecosystems, Proc. Intern. Symp. Brno: 309-324.

Yarmishko V.T. 1989, The formation of pine phytomass in young pine stands in the Kola Peninsula, *Bot. Journ.* 74.9: 1376-1386 (in Russian).

Yarmishko V.T. 1990, Alteration of arboreal layer under air pollution, (in:) Norin B.B. & Yarmishko V.T. (eds.), *The influence of industrial air pollution in pine forests of the Kola Peninsula*: 55-78 (in Russian), Komarov Botanical Inst., L.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:153-164, IGSO PAS, Warszawa

A RETROSPECTIVE STUDY OF ELEMENT CONTENT IN LICHENS FROM THE GREAT SMOKY MOUNTAINS NATIONAL PARK[1]

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Abstract: Samples of ten species of epiphytic lichens collected in the Great Smoky Mountains National Park (GSMNP) in 1939, 1966, and 1982 were analyzed for 31 elements by inductively coupled plasma-optical emission spectroscopy (ICP-OES). For most species, there were decreases over time for concentrations of Al, Ca, Fe, Mn, Si, Sr, and Zn and increases for Cu. For Pb, concentrations in the 1966 collections were generally higher than in the 1939 or 1982 collections. Although the lichens had location and substrate in common, there were species differences in the accumulation patterns. Metal and cation concentrations in GSMNP lichens were lower than concentrations reported elsewhere. Analysis of tree rings in another study showed increases of Al, B, Cu, Mn, Ni, and Zn for conifers from the same locations and time periods. Leaching by acidic precipitation may be contributing to decreased elemental concentrations in lichens: such leaching would contribute to the available pools of soluble metals in this high-elevation spruce-fir forest.

Key words: lichens, element content, retrospection, Tennessee.

INTRODUCTION

Historical changes in the atmospheric deposition of heavy metals can be followed through chemical analysis of herbarium collections of lichens and mosses. Most retrospective studies of this type have dealt with mosses, which were analyzed for various elements (Rasmussen 1977; Johnsen & Rasmussen 1977; Ruhling & Tyler 1968, 1969; Rao et al. 1977). Retrospective studies with lichens have dealt with specific elements, e.g., lead (Persson et

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al. 1974; Lawrey & Hale 1981; Blum & Tjutjunnik 1985), chromium (Schutte 1977), or radionuclides (Hanson 1982). In most cases, uncertainties associated with the use of historical collections were noted. These included the lack of information about collection, preparation, and storage techniques; the limited number of samples, which provides scanty material for chemical and statistical analyses; and the lack of information about the exact sampling site, substrate, and exposure. Nevertheless, these retrospective studies showed elevated concentrations of metals in lichens and mosses over time, which were attributed to atmospheric pollution from coal burning, manufacturing, leaded gasoline, and weapons testing.

Because lichens are perennial, lack cuticles, and have large surface area to weight ratios, they are viewed as adapted to absorbing water, needed nutrients, and other elements from air, rain, fog, and dew. The elements are accumulated via particulate trapping, ion exchange, and passive and active uptake onto the algal and fungal cell walls and into the cytoplasms (Nieboer & Richardson 1981). The capacity for element accumulation is not only dependent on the nature of the aqueous solution but also on the morphology and chemistry of the lichen thallus; thus, different species collected from the same location can vary in element content (Seaward 1974; Rao et al. 1977; Brown 1984). Laboratory studies have shown that lichen uptake of metal ions from solution is relatively fast (≈ 15 min; Nieboer & Richardson 1981). Field studies around industrial sites show that enrichment factors for various elements in lichens can be high, e.g., Cd, 74; Pb, 62; Cu, 35; Cr, 34; V, 31; Fe, 28; Mn, 28; Zn, 26; and Ni, 9 (Nieboer & Richardson 1981).

Although there is considerable information on the uptake of metals by lichens and mosses (Burton 1986), the relationship between metal uptake and other atmospheric pollutants (e.g., ozone O_3, sulfur dioxide SO_2, and acidic precipitation) is less well known. Data are lacking for O_3, but laboratory studies with lichens and SO_2 and metal ions have shown deleterious effects that are either additive or synergistic (Nieboer & Richardson 1981). In general, it is thought that heavy metal absorption by lichens increases under conditions of acidic precipitation (Rao et al. 1977), but it has also been suggested that accumulated metals may be removed by low pH rainwater (Lawrey & Rudolph 1975).

The objective of this retrospective study was to determine whether ten lichen species collected from spruce and fir trees in 1939, 1966, and 1982 at three locations in the Great Smoky Mountains National Park (GSMNP) showed changes in levels of elements. In addition, data from this study were compared to the Baes & McLaughlin data (1986) on the elemental content of annual rings from conifers from the same collection sites for similar time periods.

METHODS

In 1982, samples of corticolous lichens were collected from the boles of *Abies fraseri* (Pursh) Poir. and *Picea rubens* Sarg. at Mt. LeConte, Mt. Kephart, and Clingman's Dome in the GSMNP by the senior author (Fig. 1). Historical lichen material for ten species was obtained from collections made from the same substrates at the same locations by Gunnar Degelius in 1939 and by Mason Hale in 1966 (see Table 2 for a list of lichens). The historical samples were taken with permission from collections in the U.S. National Herbarium that contained sufficient material so that the value of the collections was not impaired. As a result, the choice of species, the amount of material available for analysis, and the number of samples were limited. The sample size was 1 except as noted in Fig. 2. Because the methods of handling and storage of the historical collections were unknown, all samples were cleaned of bark particles and then washed for 30 s in distilled water in beakers and dried for 24 h at 18° C before weighting, ashing, and analysis.

Samples were handled with stainless steel instruments. All glassware was acid washed with 6N HNO_3 and rinsed with distilled water; two

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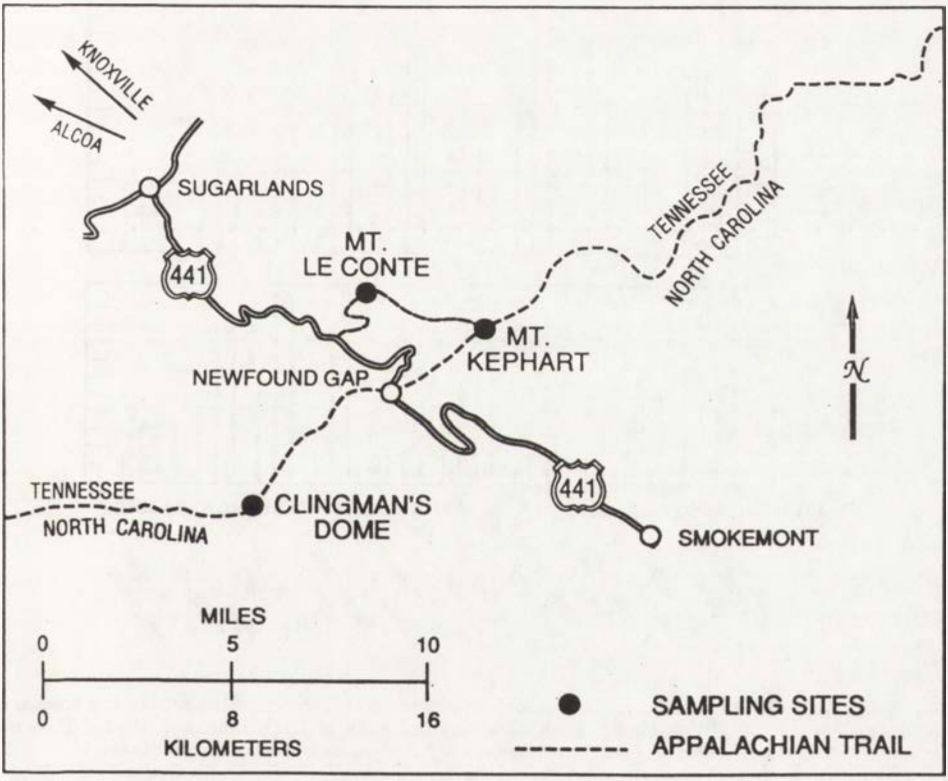


Fig. 1. Map of collection areas, Great Smoky Mountains National Park

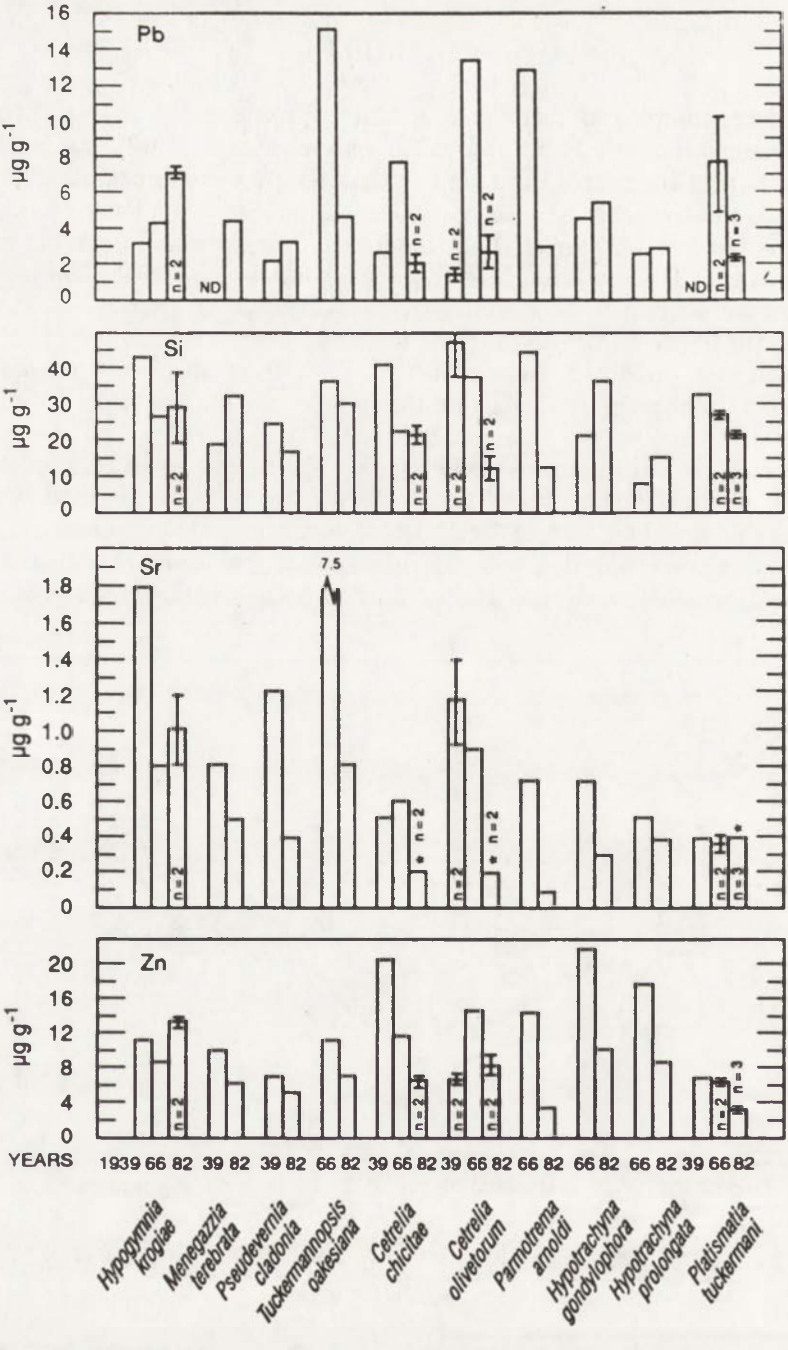
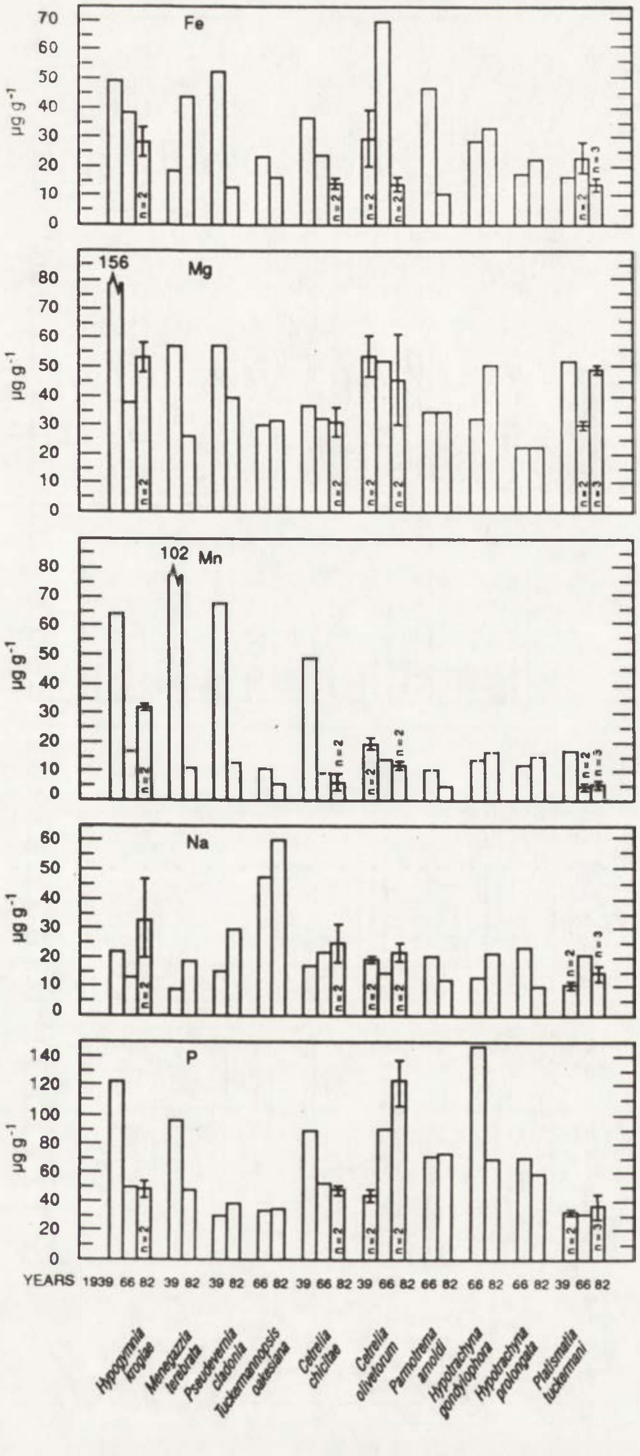


Fig. 2. Concentrations (micrograms per gram oven dry weight) of various elements in ten species of lichens collected in the Great Smoky Mountains National Park in 1939, 1966, and 1982 (ND — not detectable). The standard error (+) is given when n > 2; * designates a standard error of zero



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Pseudevernia cladonia
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Cetrelia chicitae
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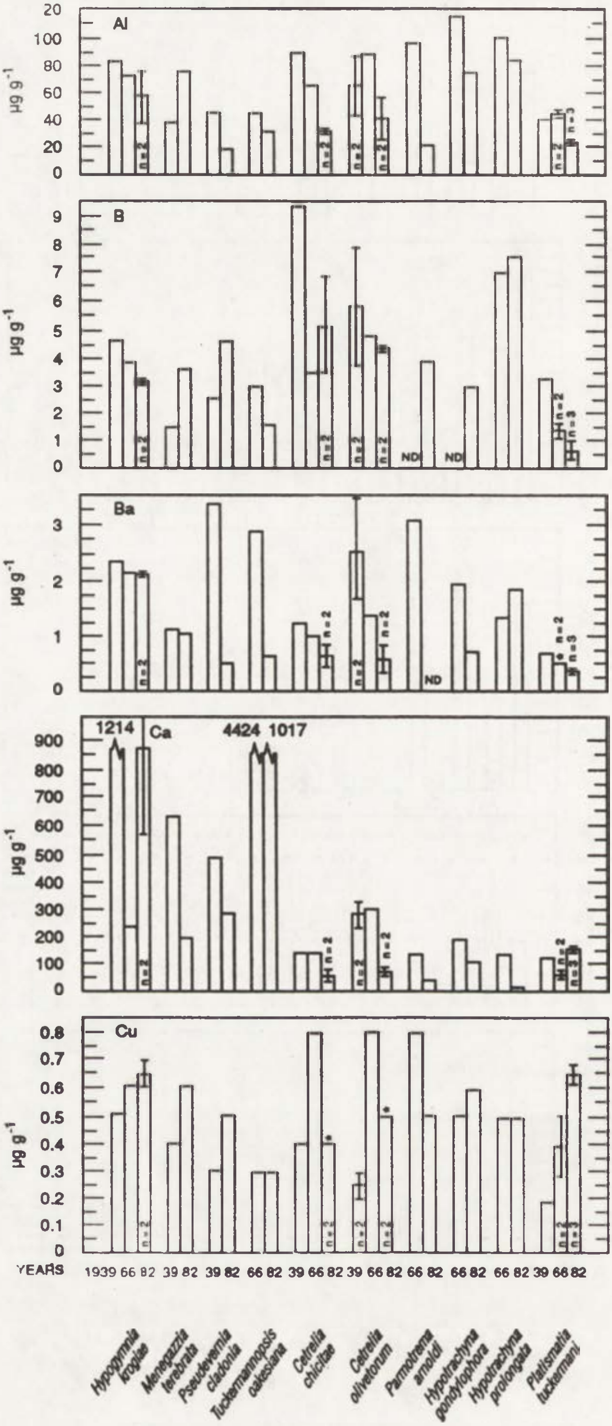
Parmotrema arnoldi
Hypotrachyna gondylophora
Hypotrachyna prolongata
Platismatia tuckermani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2
1
0
ND
Ca
1214
4424
1017
μg g⁻¹
900
800
700
600
500
400
300
200
100
0
Cu
μg g⁻¹
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
YEARS
1939 66 82
39 82
39 82
66 82
39 66 82
39 66 82
66 82
66 82
66 82
39 66 82
Hypogymnia krogiae
Menegazzia terebrata
Pseudevernia cladonia
Tuckermannopsis oakesiana
Cetrelia chicitae
Cetrelia olivetorum
Parmotrema arnoldi
Hypotrachyna gondylophora
Hypotrachyna prolongata
Platismatia tuckermani

"blanks" (beakers with ashless filter paper) were run to monitor for contamination. After being weighed to the nearest 0.01 mg, samples were ashed in 50-ml beakers covered with perforated aluminium foil in a muffle furnace at 400° C for 9 h. Although lower than 100% recovery results from volatilization of elements with this method, we used it in order to compare elements in lichens with the tree ring data of Baes and McLaughlin (1986). The ash was taken up in 10 ml of 10% HNO_3. One drop of 30% hydrogen peroxide was added (to remove any precipitation and colouration), and the solutions were placed in small covered polypropylene test tubes prior to multielement analysis.

Multielement analysis was performed by inductively coupled plasmaoptical emission spectroscopy (ICP-OES) in the Chemical Technology Division at Oak Ridge National Laboratory (ORNL). The technique affords rapid, simultaneous analysis of 31 major and minor trace elements with high accuracy and precision and low detection limits (Fassel & Kniseley 1974a, 1974b). Appropriate blanks and standards were run by the laboratory. Detection limits of ICP-OES at ORNL are more conservative (10 times greater than the standard deviation of background noise) than generally reported in the literature (3 to 5 times background noise). Results are expressed as micrograms per gram with respect to the oven dry weight of lichen.

Because the same measure was used throughout this study, we are confident of the observed differences among species and time. However, comparison of our results with other values reported in the literature should be made cautiously due to differences in the methods used. Only summary measures (i.e., means and standard errors) were used in the statistical analysis because of the small sample size and lack of replicate observations.

RESULTS

Of 31 elements available with ICP-OES analysis, only 17 elements were detectable in the lichens. These elements were Al, B, Ba, Ca, Cd, Co, Cu, Fe, Mg, Mn, Na, P, Pb, Si, Sr, V, and Zn. Concentrations of 14 of the elements are illustrated in Table 1. The range of concentrations of Cd [not detectable (ND) - 0.3 ppm], V (ND - 0.4 ppm), and Co (ND - 0.1 ppm) did not vary appreciably among species or over time, and they are not described further.

For most species, there were decreases over the collection times for concentrations of Al, Ba, Ca, Fe, Mn, Si, Sr, and Zn and increases for Cu. For most elements, there were decreases over the collection times for samples of *P. cladonia*, *T. oakesianna*, *C. chicitae*, and *P. arnoldii*. For *M. terebrata*, *H. gondylophora*, and *H. prolongata*, no general patterns existed; however, each species showed decreases in concentrations of Ca, P, Sr, and Zn and increases for Si when early collections were compared with later collections. For Pb, there were decreases in concentrations in most species for which there were data (5 of 8) for 1982 collections compared with 1966 collections and increases or very little change for 1982 collections compared with 1939 collections. For species with collections from three time periods (*H. krogiae*, *C. chicitae*, *C. olivetorum*, and *P. tuckermanii*), the concentrations of elements often increased or decreased for the 1966 collection with no discernable pattern except for Ba, Mn, and Si (which decreased) and Cu (which increased). However, for these species from 1939 to 1982, there were generally decreases in concentrations of B, Ba, Fe, Mn, Si, and Sr and an increase of Cu.

Table 1. Comparison of reported background concentrations of elements in lichens compared to concentrations in lichens from the Great Smoky Mountains National Park (GSMNP) and for *Usnea spp.* from the Flat Tops Wilderness Area, Colorado, and Redwood National Park, California. (Values given are in micrograms per gram dry weight)

Element	Background[a]	GSMNP[b]	*Usnea* spp.[c]
Al	300 — 2000	19 — 116	100 — 1187
B	–	ND[d] — 9	17 — 46
Ba	24 — 79	0.3 — 3.3	10 — 44
Ca	200 — 40,000	1 — 4425	1900 — 8757
Cd	–	ND — 0.3	0.1 — 0.2
Co	0.2 — 0.7	ND — 0.1	0.1 — 0.4
Cu	<1 — 120	0.2 — 0.8	1.3 — 28
Fe	50 — 3900	10 — 69	60 — 879
Mg	100 — 1000	21 — 156	579 — 2600
Mn	10 — 250	3 — 102	49 — 330
Na	50 — 1000	9 — 59	96 — 560
P	200 — 2000	22 — 145	270 — 1592
Pb	4 — 38 5 ±5[e] 20 — 100[f]	ND — 15	5.5 — 28
Sr	0 — 700	0.1 — 8	12 — 30
V	2 — 6	ND — 0.4	0.2 — 1.2
Zn	20 — 500	3 — 22	29 — 48

a — As given in Table 1 of Nieboer et al. (1978) (various species, preparation details not given) and Gough et al. (1988a, 1988b); b — Ranges for ten species; samples were washed prior to chemical analysis; however, leaching of metals during washing was not found to be statistically significant by Goyal & Seaward (1981); c — Concentrations for *Usnea* spp.; samples were unwashed (Hale 1982; Gough et al. 1988a); d — Not detectable; e — Arctic; f — Rural areas in Canada

For *H. krogiae*, there were decreases in most elements (9 of 14) for 1982 collections compared with 1939 collections at the LeConte site and increases in most elements (11 of 14) for 1982 collections compared with 1966 collections at the Clingman's Dome site. Pooling the data for each element resulted in an overall decrease in the concentrations of 7 of 14 metals (Fig. 2). However, at both sites, B and Fe decreased over time, and Cu, Pb, and Zn increased.

For *C.chicitae*, there were decreases in 11 of 14 elements from the 1939 to the 1982 collections from the LeConte site and decreases in most elements (12 of 14) for 1982 collections compared with 1966 collections at the

Clingman's Dome site. At both sites there were decreased levels of Al, Ca, Ba, Fe, Mg, Mn, P, Sr, and Zn.

For *C. olivetorum*, there were decreases in 8 of 14 elements from the 1939 to the 1982 collections from the LeConte site and overall decreases for 8 of 14 elements from the Clingman's Dome site for the 1939, 1966, and 1982 collections. For the Clingman's Dome species, 12 of the elements showed elevated levels in 1966 compared with the 1939 and/or 1982 levels. However, at both sites for all collection times there were decreased levels of Al, Ca, Fe, Mn, Si, and Sr and increased levels of Cu, P, and Pb.

For *P. tuckermanii*, there were decreases in 7 of 14 elements, increases in 5, and no change for 2 for 1982 collections compared with 1939 collections from the LeConte site. At the Clingman's Dome site, there were decreases for 9 of 14 elements, increases for 4, and no change for 1 for 1982 collections compared with 1966 collections. At Mt. Kephart, there were decreases for 6 of 14 elements, increases for 5, and no change for 3 for 1982 collections compared with 1966 collections. However, at all sites, Al, Fe, Si, and Zn decreased over time, and Ca and Cu increased.

DISCUSSION AND CONCLUSIONS

In general, retrospective studies with lichens and mosses have shown increases in metal levels over time, except for Cd, which remains almost constant (Puckett & Burton 1981). Rao et al. (1977) suggested that acidic precipitation increases metal uptake by lichens and mosses, but it has also been suggested that heavy metals accumulated by lichens and bryophytes may be removed by low pH rain or snow water (Ruhling & Tyler 1968; Lawrey & Rudolph 1975; Lang et al. 1976; Rao et al. 1977; Nieboer et al. 1978; Pike 1978; Puckett 1984). Laboratory studies with lichens have shown that Ni and Fe, Pb and K, and Al, Na, Ti, V, and K can be eluted with dilute acid (Puckett et al. 1973; Brown and Slingsby 1972; Puckett 1984, respectively). Lawrey and Rudolph (1975) reported the elution with distilled water off significant amounts of Fe and Al, and some Mo, but not Mn, Cu, or Zn. Thus it appears that elements taken up by lichens may reach surrounding plant communities by leaching. However, the relative importance of lichens in mineral recycling is poorly known; this importance probably ranges from major to trivial, depending on the lichen biomass (Pike 1978). In our study, element levels in lichens usually decreased over time, but Cd remained almost constant for all ten species, as expected. A possible explanation for these decreases is the enhanced acidity of precipitation starting in the early 1940s, which has resulted in leaching elements from some of the lichens. The increases (1939 and 1966) and decreases (1966 and 1982) seen for Pb probably reflect the increased use of gasoline in the earlier period and the subsequent use of unleaded gasoline in the later period.

It should be noted that the various lichens responded differently to the atmospheric conditions in the GSMNP. For instance, *H. krogiae* showed increases in most elements for 1982 compared with 1966, whereas *T. oakesiana*, *C. chicitae*, and *P. arnoldii* showed decreases. This variation in response suggests that the choice of bioindicator species for elemental analysis is critical and may affect the results of a study. It also suggests that generalizations about lichens and their elemental uptake should be made cautiously.

The Baes and McLaughlin tree ring data (1986) for 1939 to 1982 showed two general elemental distribution patterns in the xylem of spruce and fir boles cored in 1982 and 1983 in the GSMNP. In the first pattern, the concentrations of Ba, Ca, Cd, Fe, Mg, and Sr decreased in rings from the time periods 1929-1938, 1964-1968, and 1979-1983; in the second pattern, Al, B, Cu, Mn, Ni, and Zn increased. However, the increases for Zn were generally seen in rings from the 1979-1983 period, whereas concentrations in the 1929-1938 and 1964-1968 periods were similar. In the GSMNP trees, Be, Cd, and Pb were rarely detected even though Cd and Pb are often indicative of air pollution from smelters, automobile exhaust, and industrial activities — all of which occur or have occurred nearby. Baes and McLaughlin found that GSMNP trees were similar to those from relatively unpolluted sites, except for trees at Mt. LeConte which, since 1950, showed increased concentrations of metals indicative of anthropogenic pollution (Al, B, Cu, Fe, Mn, Ni, and Zn). These metals are released routinely from the burning of fossil fuels, and fossil fuel emissions have increased about 200% since 1950 in an area within 900 km upwind of the GSMNP. Thus, on the basis of these data and data in other lichen studies, increased concentrations of these metals might also be expected in the lichens from the GSMNP. However, comparisons of the ranges of elements found in the ten lichen species from the GSMNP with reported background ranges for various other species and with *Usnea* from a wilderness area in Colorado and a national park in California (Table 1) showed that concentrations in the GSMNP lichens were generally lower than the reported concentrations for other species. In marked contrast to the tree ring data, for most of the lichen species, there were decreases over time for Al, B, Fe, Mn, and Zn (Ni was not detectable and Cu increased). Baes and McLaughlin (1986) found that Zn and Mn concentrations began to increase in Fraser fir from about 1966 to 1973 and reached maximum concentrations in the most recently formed xylem. We found that Zn concentrations were generally high in the 1966 lichen collections and decreased in the 1982 collections and that Mn concentrations were generally lower in the 1982 collections than in the 1939 collections; however, Mn in the 1966 collections did not differ dramatically from that in the 1982 collections.

Baes and McLaughlin (1986) suggest that the increased concentrations of Al, B, Cu, Fe, and Ni in the tree rings since the 1950s at most sites in the GSMNP may be related to increases in wet and dry deposition or to increases in their availability from the soil since that time. We suggest that the lower concentrations of metals seen in the lichens in 1982 may be due to leaching of the thalli and that the lichens are contributing to the available pools of metals in the soils. However, neither increases nor decreases in the metal concentrations in the lichens analyzed appear to be affecting their distribution. Table 2 shows that the distribution of the ten species was judged to be similar by three different collectors for three different time periods.

Table 2. Comparison of the reported distribution of lichen species on spruce and fir trees in the Great Smoky Mountains National Park for three collection periods; c — common; w — widespread; i — infrequent; s — sparse; v — very sparse. Nomenclature after Egan (1987)

	1939[a]	1972-1973[b]	1982[c]
Hypogymnia krogiae Ohlsson	c	v, c	c
Menegazzia terebrata (Hoffm.) Massal.	c	c	w
Pseudevernia cladonia (Tuck.) Hale & Culb.	c	c	c
Tuckermannopsis oakesiana (Tuck.) Hale	c	c	c
Cetrelia chicitae (Culb.) Culb. & C. Culb.		c	w
olivetorum (Nyl.) Culb. & C. Culb.		i	i
Parmotrema arnoldii (Du Rietz) Hale	v, s	c	i
Hypotrachyna gondylophora (Hale) Hale		c	w
prolongata (Kurok.) Hale	c	c	w
Platismatia tuckermanii (Oakes) Culb. & C. Culb.	c	c	c

[a] Degelius 1941; [b] Dey 1978; [c] Sigal L.L., unpublished data.

REFERENCES

Baes C.F.III & McLaughlin S.B. 1986, Multielemental analysis of tree rings: A survey of coniferous trees in the Great Smoky Mountains National Park, Oak Ridge National Laboratory, ORNL-6155, Oak Ridge, Tennessee.

Blum O.B. & Tjutjunnik J.G. 1985, Historical biomonitoring of the lead content in the atmosphere by lichens, Dokladi Akademii nauk Ukrain. S.S.R., Ser. B, 10: 52-54.

Brown D.H. 1984, Uptake of mineral elements and their use in pollution monitoring, (in:) Dyer A.F. & Duckett J.G. (eds.), *The Experimental Biology of Bryophytes*, pp. 229-255, Academic Press, London.

Brown D.H. & Slingsby D.R. 1972, The cellular location of lead and potassium in the lichen *Cladonia rangiformis* (*L.*) Hoffm, *New Phytologist* 71: 297-305.

Burton M.A.S. 1986, Biological monitoring of environmental contaminants (plants), Monitoring and Assessment Research Centre, MARC Report No. 32, King's College, University of London.

Degelius G. 1941, Contributions to the lichen flora of North America II. The lichen flora of the Great Smoky Mountains, *Arkiv for Botanik* 30: 1-80.

Dey J.P. 1978, Fruticose and foliose lichens of the high-mountain areas of the southern Appalachians, *The Bryologist* 81: 1-93.

Egan R.S. 1987, A fifth checklist of the lichen-forming, lichenocolous and allied fungi of the continental United States and Canada, *The Bryologist* 90: 77-173.

Fassel V.A. & Kniseley R.N. 1974a, Inductively coupled plasmas, *Analytical Chemistry* 46: 1155A-1164A.

Fassel V.A. & Kniseley R.N. 1974b, Inductively coupled plasma-optical emission spectroscopy, *Analytical Chemistry* 46: 1110A-1120A.

Gough L.P., Jackson L.L. & Sacklin J.A. 1988a, Determining baseline element composition of lichens II. *Hypogymnia enteromorpha* and *Usnea spp*. at Redwood National Park, California, *Water, Air, and Soil Pollution* 38: 169-180.

Gough L.P., Severson R.C. & Jackson L.L. 1988b, Determining baseline element composition of *lichens I. Parmelia sulcata at Theodore Roosevelt National Park, North Dakota, Water, Air, and Soil Pollution* 38: 157-167.

Goyal R. & Seaward M.R.D. 1981, Metal uptake in terricolous lichens. I. Metal localization within the thallus, *New Phytologist* 89: 631-645.

Hale M.E., Jr. 1982, Lichens as bioindicators and monitors of air pollution in the Flat Tops Wilderness Area, Colorado. Final Report: Forest Service Contract No. OM RFP R2-81-SP35.

Hanson W.C. 1982, ^{137}Cs concentrations in northern Alaskan Eskimos, 1962-1979: Effects of ecological, cultural, and political factors, *Health Physics* 42: 433-447.

Johnsen I. & Rasmussen L. 1977, Retrospective study (1944-1976) of heavy metals in the epiphyte *Pterogonium gracile* collected from one phorophyte, *The Bryologist* 80: 625-629.

Lang G.E., Reiners W.A. & Heier R.K. 1976, Potential alteration of precipitation chemistry by epiphytic lichens, *Oecologia* 25: 229-241.

Lawrey J.D. & Hale, M.E. Jr. 1981, Retrospective study of lichen lead accumulation in the northeastern United States, *The Bryologist* 84: 449-456.

Lawrey J.D. & Rudolph E.D. 1975, Lichen accumulation of some heavy metals for acidic surface substrates of coal mine ecosystems in southeastern Ohio, *Ohio Journal of Science* 75: 113-117.

Nieboer E. & Richardson D.H.S. 1981, Lichens as monitors of atmospheric deposition, (in:) Eisenreich S.J. (ed.), *Atmospheric Pollutants in Natural Waters*, pp. 339-388, Ann Arbor Science, Michigan.

Nieboer E. & Richardson D.H.S. & Tomassini F.D. 1978, Mineral uptake and release by lichens: An overview, *The Bryologist* 81: 226-246.

Persson B.R., Holm E. & Liden K. 1974, Radiolead (210Pb) and stable lead in the lichen *Cladonia alpestris*, *Oikos* 25: 140-147.

Pike L.H. 1978, The importance of epiphytic lichens in mineral cycling, *The Bryologist* 81: 247-257.

Puckett K.J. 1984, Temporal variation in lichen element levels, (in:) Brown D.H. (ed.), *Lichen Physiology and Cell Biology*, pp. 211-225, Plenum Press, New York.

Puckett K.J. & Burton M.A.S. 1981, The effect of trace elements on lower plants, (in:) Lepp N.W. (ed.), *Effect of Heavy Metal Pollution on Plants*, Vol. 2, Metals in the Environment, pp. 213-238, Applied Science Publishers, London.

Puckett K.J., Nieboer E., Gorzynski M.J. & Richardson D.H.S. 1973, The uptake of metal ions by lichens: A modified ion-exchange process, *New Phytologist* 72: 329-342.

Rao D.N., Robitaille G. & LeBlanc F. 1977, Influence of heavy metal pollution on lichens and bryophytes, *Journal of the Hattori Botanical Laboratory* 42: 213-239.

Rasmussen L. 1977, Epiphytic bryophytes as indicators of the changes in the background levels of airborne metals from 1951-75, *Environmental Pollution* 14: 37-45.

Ruhling A. & Tyler G. 1968, An ecological approach to the lead problem, *Botanical Notiser* 121: 321-342.

Ruhling A. & Tyler G. 1969, Ecology of heavy metals — a regional and historical study, *Botanical Notiser* 122: 248-259.

Schutte J.A. 1977, Chromium in two corticolous lichens from Ohio and West Virginia, *The Bryologist* 80: 279-283.

Seaward M.R.D. 1974, Some observations on heavy metal toxicity and tolerance in lichens, *Lichenologist* 6: 158-164.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:165-176, IGSO PAS, Warszawa

STUDIES ON NITROGEN DEPOSITION TO FORESTS IN CALIFORNIA

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Abstract: Information about studies on nitrogen (N) deposition to forests in California performed by the researchers of the USDA Forest Service's Pacific Southwest Research Station, and the University of California's Statewide Air Pollution Research Center in Riverside is provided. Methods used for determinations of concentrations of NO, NO_2, HNO_3, NH_3, and particulate NO_3^- as well as dry deposition of N to plants are described. Concentrations of NO_2, HNO_3, NH_3, particulate NO_3^- at the California forest locations are compared with those at other locations in North America and Europe. Dry deposition fluxes of NO_3^- and NH_4^- to plant canopies are discussed. Estimates of annual dry deposition of N to California forest sites are presented and compared with deposition values for other areas.

Key words: nitrogen deposition, urban areas, forest, California.

INTRODUCTION

Nitrogenous pollutants occur in the atmosphere as oxidized compounds such as nitric oxide (NO), nitrogen dioxide (NO_2), gaseous nitric (HNO_3) and nitrous (HNO_2) acids, peroxyacetyl nitrate (PAN), or particulate nitrates (NO_3^-), and also as reduced compounds such as ammonia (NH_3) or particulate ammonium (NH_4^-) (Finlayson-Pitts & Pitts 1986). Near urban centers, concentrations of oxidized N compounds are high (National Academy of Sciences 1977; Grosjean 1983). Near farmlands, especially where animal breeding is intensive, concentrations of ammonia and particulate ammonium are high (ApSimon et al. 1987; Allen et al. 1988).

Compared to ozone or sulfur dioxide, relatively little is known about the phytotoxic effects of N compounds. Nitrogen dioxide can injure plants only in high concentrations (National Academy of Sciences 1977; Wellburn 1990). Nitric oxide, in contrast, may be phytotoxic even at very low concentrations because of high toxicity of the nitrite (NO_2^-) ion (Wellburn 1990). Phytotoxic effects of gaseous nitric acid begin at much higher levels than the current ambient concentrations (Marshall and Cadle 1989). However, direct toxic effects of long-term elevated HNO_3 concentrations on plant foliage cannot be excluded and should be investigated. Very little is known about the effects of gaseous nitrous acid on plants (Taylor et al. 1988). Although in most forest locations concentrations of this pollutant are very low (Legge and Krupa 1989), its potential for phytotoxicity (due to dissociation to highly toxic NO_2^- ion and proton) warrants future investigations.

Ammonia phytotoxicity has been reported where emissions of ammonia gas are high (Draijers et al. 1989; Van Der Eerden et al. 1991). In some areas, the nitrogenous air pollutants may also modify toxic effects of other air pollutants. Interactions have been reported between nitrogen dioxide and ozone (Runeckles and Palmer 1987). In some areas (e.g. Los Angeles Basin and the surrounding mountains) these two pollutants may co-occur in high concentrations (Bytnerowicz et al. 1987a). Because nitric acid is deposited mainly on plant surfaces and may accumulate in stomatal cavities (Taylor et al. 1988), the stomataclosing mechanism may be impaired and the increased uptake of ozone by the plants could be expected. Increased uptake of nitrogen by plants may also change their physiological activity and, therefore, modify their responses to air pollutants. Therefore, synergistic phytotoxic effects of gaseous nitric acid and ozone seem to be possible.

Dry deposition represents more than half of an annual input of major ions to forests in the eastern United States (Waring and Schlesinger 1985). In California, which is characterized by a mediterranean climate, dry deposition of ions and gases to forests plays an even greater role (Schlesinger et al. 1982; Ellis et al. 1983). Because of the nutritional importance of nitrogen, an addition of airborne N compounds may have strong impacts on forest ecosystems. This may be especially true for forests growing on poor granitic soils. Increased deposition of nitrogen may have beneficial effects and increase forest productivity. However, when the "critical loads" of nitrogen are exceeded, various negative effects can be expected (Aber et al. 1989; Schulze et al. 1989).

This paper reports information on N air pollution concentrations and estimates of fluxes in selected locations of the California mountains, and of comparable results found in forests, remote sites, and urban areas both in North America and Europe.

METHODS

CONCENTRATION MEASUREMENTS

In most of our studies the concentrations of NO and NO_2 were determined with chemiluminescence Monitor Lab Model 8440 instruments[1]. Concentrations of gaseous HNO_3, HNO_2, NH_3 as well as NO_3^- and NH_4^+ in fine (< 2.2 μm diameter) and coarse particles (> 2.2 μm diameter) have been measured with annular denuder systems developed by Possanzini et al. (1983) and modified by Peake and Legge (1987).

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[1] Mention of trade names or products is for information only and does not imply endorsement by U.S. Department of Agriculture

DEPOSITION FLUX MEASUREMENTS

Nitrogen compounds deposited to tree foliage via dry deposition have been measured as NO_3^- and NH_4^- ions. A leaf-washing technique developed by Lindberg et al. (1984) and modified by Bytnerowicz et al. (1987b) was used in the author's studies. Results of these studies were compared with other results in which dry deposition was calculated by analysis of chemical composition of throughfall and bulk precipitation (Eaton et al. 1973).

Locations of California field sites where air pollution has been determined by the author and his co-workers are shown in Figure 1.

RESULTS AND DISCUSSION

NO_2 CONCENTRATIONS

Our results and other studies indicate that concentrations of NO_2 in the urban areas were much higher than in forests and other remote sites. The highest recorded NO_2 concentrations among the forest and remote sites were obtained at Tanbark Flat of the San Gabriel Mountains. At Shirley Meadow of the western Sierra Nevada the concentrations of NO_2 were also elevated when compared with forest locations outside of California (Fig. 2).

HNO_3 CONCENTRATIONS

Similar to NO_2, gaseous HNO_3 also occurred at Tanbark Flat in high concentrations. At Shirley Meadow and Whitaker Forest of the western Sierra Nevada, the concentrations of gaseous HNO_3 were elevated and several times higher than at Eastern Brook Lake, Point Arena on the northern California coast, Smoky Mountains in Tennessee, or Fortress Mountain in Alberta (Fig. 3).

NO_3^- CONCENTRATIONS

Concentrations of NO_3^- in fine particles at Tanbark Flat were high, only slightly lower than those determined for the Claremont site in the Los Angeles Basin, and higher than the concentrations determined in Toronto, Edmonton, and Calgary in Canada. Also Camp Paivika, western San Bernardino Mountains, was characterized by highly elevated concentrations of this pollutant. Concentrations of NO_3^- in the San Bernardino Mountains were reduced as the distance from the Los Angeles Basin increased (Camp Osceola). Concentrations of NO_3^- in the remote site of the Canadian Rockies

(Fortress Mountain) were many times lower than the concentrations determined in the California mountain locations (Fig. 4).

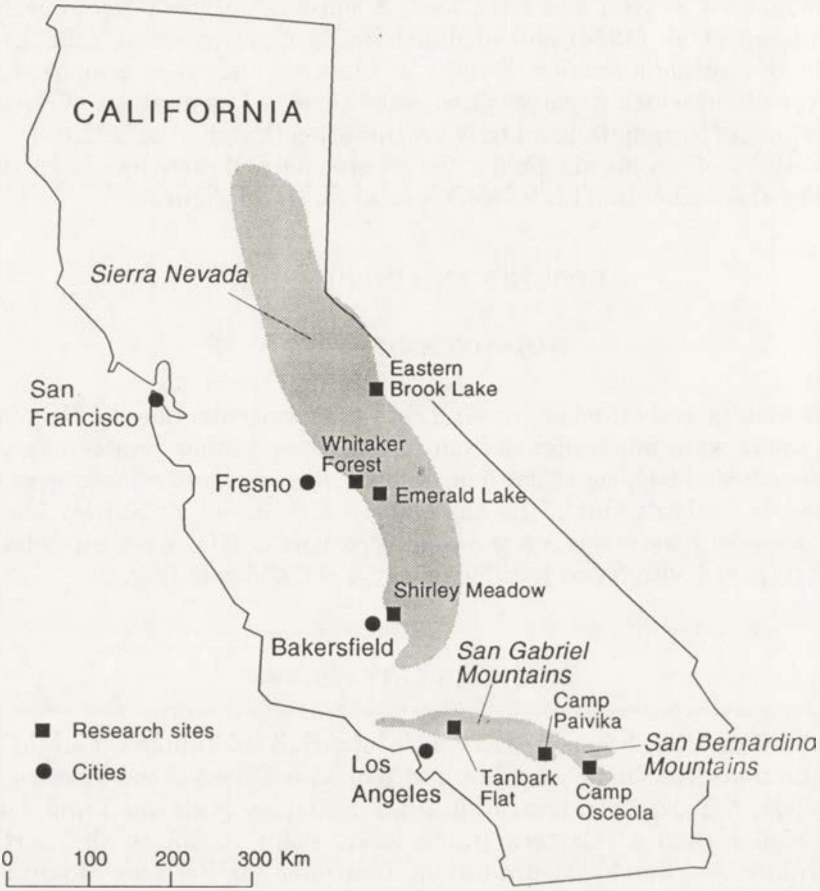

Fig. 1. Location of experimental sites in California where nitrogen air pollution has been measured by the author and his co-workers

High concentrations of NO_2, gaseous HNO_3, and particulate NO_3^- at the sites of the San Bernardino and San Gabriel Mountains were the result of the long-range transport of the polluted air masses from the urban areas of the Los Angeles Basin (Farber et al. 1982). Elevated concentrations of these pollutants on the western slopes of the Sierra Nevada resulted from transport of the pollutants generated in the California Central Valley and the San Francisco Bay area (Miller et al. 1972; Stohlgren et al. 1987).

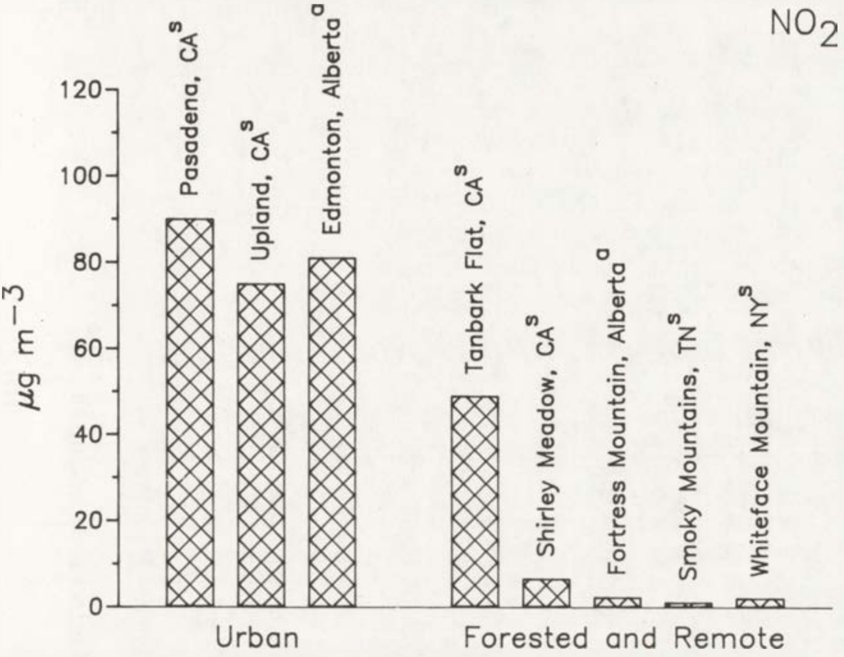

Fig. 2. Comparison of NO_2 concentrations at different locations: s — summer 24-hr average; a — annual 24-hr average. Denver (1965-1973), a — 75-94μg^{-3}; Los Angeles (1965-1972), a — 122-14 μg^{-3} Results for Pasadena and Upland during the 1985 summer are taken from South Coast Air Quality Management District (1985); for Edmonton during the 1982/1983 period from Peake et al. (1988); for Tanbark Flat during the 1985 summer from Bytnerowicz et al. (1987a); for Shirley Meadow during the 1989 and 1990 summers from Bytnerowicz & Miller (1991); for Fortress Mountain during the 1985-1987 period from Legge & Krupa (1989); for Smoky Mountains and Whiteface Mountain during the 1986 summer from Cadle & Mulawa (1988); for Denver and Los Angeles from National Academy of Sciences (1977)

NH_3 CONCENTRATIONS

Concentrations of NH_3 in the urban locations of Claremont, Los Angeles Basin, and Warren, Michigan, were similar to those at the forest locations. The highest concentrations for the forest and remote locations were determined at Shirley Meadow, followed by the Whitaker Forest, and Tanbark Flat. The determined concentrations of NH_3 were similar to those found in the Smoky Mountains but several times higher than the concentrations recorded at the Fortress Mountain site (Fig. 5). Increased NH_3 concentrations in the Sierra Nevada locations resulted from the long-range transport of air masses from the farmlands of the California Central Valley. Intensive use of fertilizers and increased volatilization of NH_4NO_3 were probably the main causes of this phenomenon (Nihlgard 1985).

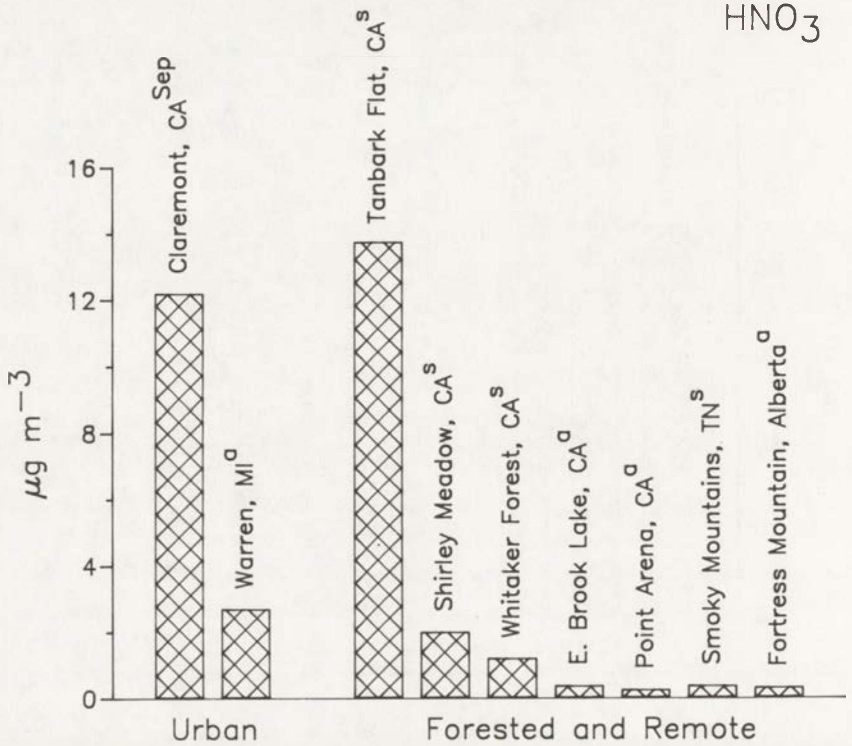

Fig. 3. Comparison of HNO_3 concentrations at different locations: Sep — September 24-hr average; s — summer 24-hr average; a — annual 24-hr average. Results for Claremont in September 1985 were taken from Sickless at al. (1988); for Warren during the 1981/1982 period from Cadle (1985); for Tanbark Flat from Grosjean & Bytnerowicz (1993); for Shirley Meadow during the 1989 and 1990 summers from Bytnerowicz & Miller (1991); for Whitaker Forest during the 1988-1990 summers from Bytnerowicz & Riechers (in prep.); for Eastern Brook Lake during the 1985/1986 period from Miller & Walsh (1991); for Point Arena during the 1984 period from Roberts et al. (1988); for Smoky Mountains during the summer 1986 from Cadle & Mulawa (1988); and for Fortress Mountain during the 1985-1987 period from Legge & Krupa (1989)

DEPOSITION ESTIMATES

As ambient concentrations of nitrogenous pollutants increase, the deposition on plants also increases. Depositions of NO_3^- and NH_4^+ on surfaces of pine branches in the subalpine zone of the western Sierra Nevada were about 6 times higher than on the eastern side of the Sierra Nevada (Bytnerowicz et al. 1991, 1992). Similarly, deposition of these ions on ponderosa pine branches was much higher at Camp Paivika, the westernmost polluted area of the San Bernardino Mountains, than at Camp Osceola, the site located farthest away from the Los Angeles Basin (Fenn and Bytnerowicz 1993). This increase in deposition of NO_3^- reflects elevated concentrations of NO_2, HNO_3, and particulate NO_3^- on the western slopes of the Sierra Nevada and the San Bernardino Mountains. The increased surface deposition of NH_4^+ could be attributed to elevated concentrations of particulate NH_4^+ and NH_3 at those sites.

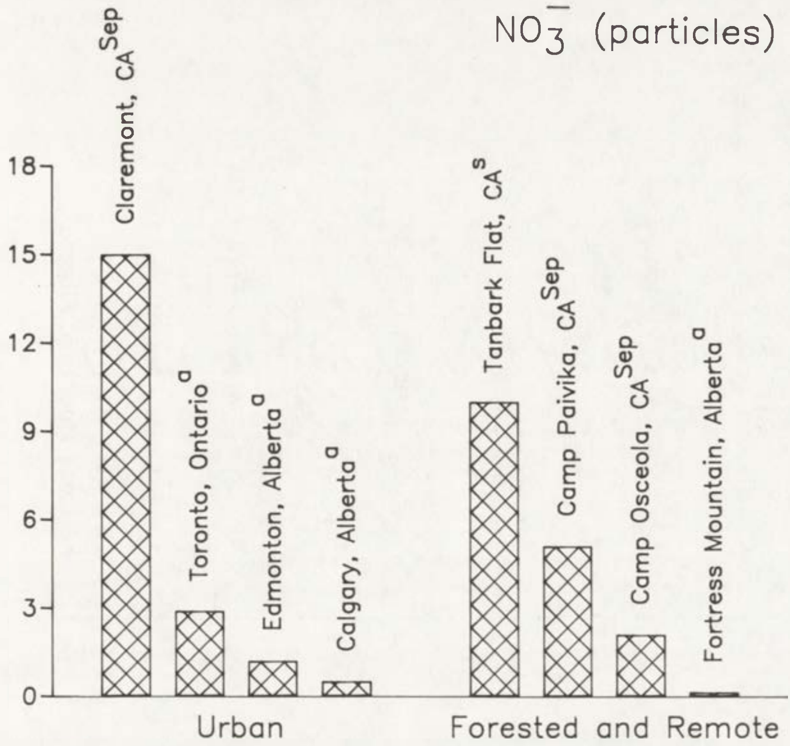

Fig. 4. Comparison of fine particulate NO_3^- concentrations at different locations: Sep — September 24-hr average; s — summer 24-hr average; a — annual 24-hr average. Results for Claremont during September 1985 were taken from Pierson & Brachaczek (1988); for Toronto, Edmonton and Calgary during the 1982/1983 period from Peake et al. (1988); for Tanbark Flat during the 1988-1991 summers from Grosjean & Bytnerowicz (1993); for Camp Paivika and Camp Osceola in September 1989 from Fenn & Bytnerowicz (1993); and for Fortress Mountain during the 1985-1987 period from Legge & Krupa (1989)

The carefully used branch washing technique seems to be a simple and reliable method for evaluating atmospheric dry deposition to plant surfaces (Lindberg et al. 1986; Bytnerowicz et al. 1987b). We have shown that dry deposition of ions to surrogate surfaces (nylon and paper filters) does not correlate with deposition occurring on branches of the studied pines (Bytnerowicz et al. 1991). However, accuracy of this method is affected by extraction of ions from foliage during the washing procedures, uptake of deposited substances by the interior of the foliage during the collection periods, resuspension and volatilization of the deposited particles, etc. (Hosker & Lindberg 1982). Dry atmospheric deposition can also be evaluated by throughfall analysis (Eaton et al. 1973). The same problems mentioned for the branch washing techniques complicate interpretation of the results obtained with this technique (Hosker & Lindberg 1982).

Dry deposition fluxes to plants can also be calculated by multiplying ambient concentrations of the individual pollutants by their deposition velocity, according to the following formula:

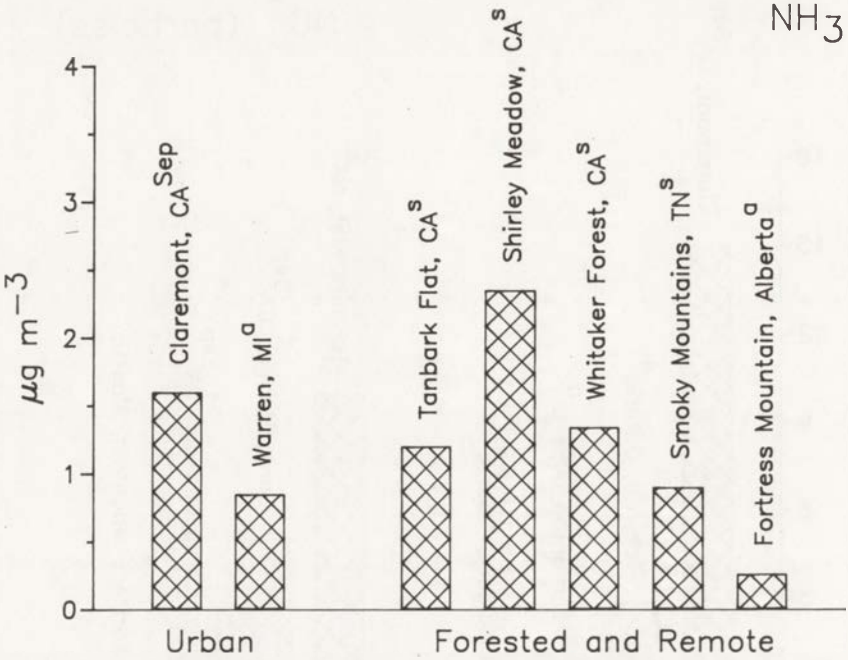

Fig. 5. Comparison of NH_3 concentrations at different locations: Sep — September 24-hr average; s — summer 24-hr average; a — annual 24-hr average. Petten, Holland, rural — 0.5 - 15 μg m^{-3}; Eastern England, rural — 05-5 μg m^{-3}. Results for Claremont for September 1985 were taken from Pierson & Brachaczek (1988); for Warren during the 1981/1982 period from Cadle (1985); for Tanbark Flat during the 1988 -1991 summers from Grosjean & Bytnerowicz (1993); for Shirley Meadow during the 1989 and 1990 summers from Bytnerowicz & Miller (1991); for Whitaker Forest during the 1988-1990 summers from Bytnerowicz & Riechers (in prep.); for Smoky Mountains during the 1986 summer from Cadle & Mulawa (1988); for Fortress Mountain during the 1985-1987 period from Legge & Krupa (1989), for Petten during the 1987 period from Keuken et al. (1988); and for eastern England in early 1980's from ApSimon et al. (1987)

$$F_d = c \times v_d$$

where F_d represents calculated dry deposition flux; c represents average ambient concentration of a pollutant; and v_d represents deposition velocity of a pollutant (Hosker and Lindberg 1982). This method, however, bears a high degree of uncertainty related particularly to a lack of reliable values of deposition velocity for different pollutants under given exposure conditions. Factors such as type of the surface to which deposition occurs, environmental conditions, stage of physiological activity of plants, etc., all affect the accuracy of this method. In addition, for most of the remote areas there is a lack of reliable data on pollutant concentrations. Some of the pollutants of interest (such as HNO_3) are very difficult to monitor and therefore the validity of the data sets is in question (Appel et al. 1988; Dasch et al. 1989). Considering that NH_3^- surface deposition may result from deposition of particulate NO_3^-, gaseous HNO_3, NO_2, PAN, and possibly also NO and HNO_2, one may imagine problems related to such calculations. Similarly, to calculate NH_4^+ surface deposition flux information on concentration and deposition velocity of particulate NH_4^+ and NH_3 would be required.

Because of these above-mentioned problems it appears that data on deposition fluxes obtained with branch washing may be more reliable. With some degree of uncertainty these results may be used for calculating total dry deposition to forest canopies. For open canopies in the California Sierra Nevada or San Bernardino Mountains we assumed that deposition fluxes determined for lower branches of trees could be also applied for other parts of tree crowns. Using information on total surface area of foliage in a given forest stand, a relatively simple calculation of total flux can be performed. An example of such an approach was a calculation of ionic fluxes to a subalpine forest of the Eastern Brook Lake of the eastern Sierra Nevada (Bytnerowicz et al. 1992). These calculations were made by extrapolation of dry deposition fluxes determined with the branch-washing technique and forest inventory data for this particular watershed gathered by Brown (1978) and Peterson et al. (1990). In our calculations of total dry deposition of N compounds to forest canopies we also took into consideration internal uptake of gaseous pollutants such as NO_2, NH_3, or HNO_3. For these calculations, the available information on ambient concentrations of these pollutants and literature values of deposition velocity were used (Taylor et al. 1988).

Table 1. Estimates of atmospheric N dry deposition at different locations

Location	Deposition ($kg\ ha^{-1}\ yr^{-1}$)	Method of measurement	Reference
Tanbark Flat, San Gabriel Mts, CA.	23	throughfall	Riggan et al. 1985
Camp Paivika, San Bernardino Mts, CA.	29	branch washing	Fenn & Bytnerowicz 1992
Camp Osceola, San Bernardino Mts, CA.	6	branch washing	Fenn & Bytnerowicz 1993
Santa Inez Mts, CA.	2	throughfall	Schlesinger et al. 1982
Sky Oaks Ranch, CA.	1.5	throughfall	Ellis et al. 1983
Emerald Lake, Sierra Nevada, CA.	2.4	branch washing	Bytnerowicz et al. 1991
Eastern Brook Lake, Sierra Nevada, CA.	0.4	branch washing	Bytnerowicz et al. 1992
Warren, MI	0.8	branch washing	Dasch 1986
Sweden	5 — 40	throughfall	Grennfelt & Hultberg 1986
Netherlands	115	throughfall	Draijers et al. 1989

Table 1 presents examples of calculated N dry deposition to forests in California mountains. For comparison, results for other locations in the eastern United States and Europe reported in the literature are also presented. Very high N deposition values for forests at the European sites resulted mainly from the deposition of ammonia released during various agricultural activities. It is difficult to judge the accuracy of the presented estimates.

CONCLUSIONS AND RECOMMENDATIONS

Dry atmospheric deposition should be taken into account when inputs of nitrogen and other nutrients to forest ecosystems are considered. In addition to the throughfall analysis, the branch-washing technique can be used for this purpose. This method seems to be especially attractive for open forest stands with good circulation of air masses.

Reliable data sets on fluxes of atmospheric ions to plant foliage, ambient concentrations of pollutants and their deposition velocities, and reliable forest inventory data with information on leaf area indices (LAI) can greatly improve our ability to calculate inputs of nutrients to forest ecosystems. Such calculations are essential for understanding the long-term effects of air pollutants on forest ecosystems.

REFERENCES

Aber J.D., Nadelhofer K.J., Steudler P. & Melillo J.M. 1989, Nitrogen saturation in northern forest ecosystems, *BioSci.*, 39: 378-386.

Allen G.E., Harrison R.M. & Wake M.T. 1988, A meso-scale study of the behavior of atmospheric ammonia and ammonium, *Atmos. Environ.*, 22: 1347-1353.

Appel B.R., Tokiwa Y., Kothny E.L., Wu R. & Povard V. 1988, Evaluation of procedures for measuring atmospheric nitric acid and ammonia, *Atmos. Environ.*, 22: 1565-1573.

ApSimon H.M., Krause M. & Bell J.N.B. 1987, Ammonia emissions and their role in acid deposition, *Atmos. Environ.*, 21: 1939-1946.

Brown J.K. 1978, Weight and density of crowns of Rocky Mountain conifers, USDA Forest Service Research Paper INT-197, January 1978, Intermountain Forest and Range Experiment Station, Ogden, UT.

Bytnerowicz A., Dawson P.J., Morrison C.L. & Poe M.P. 1991, Deposition of atmospheric ions to pine branches and surrogate surfaces in the vicinity of Emerald Lake watershed, Sequoia National Park, *Atmos. Environ.*, 25A: 2203-2210.

Bytnerowicz A., Dawson P.J., Morrison C.L. & Poe M.P. 1992, Atmospheric dry deposition on pines in the Eastern Brook Lake watershed, Sierra Nevada, California. *Atmos. Environ.*, 26A: 3195-3201.

Bytnerowicz A., & Miller P.R. 1991, Monitoring air pollution effects on forests in southern California mountains, Presented at the IUFRO and ICP-Forests workshop on monitoring, Prachatice, CSFR, 1991, 41-47.

Bytnerowicz A., Miller P.R. & Olszyk D.M. 1987b, Dry deposition of nitrate, ammonium and sulfate to a *Ceanothus crassifolius* canopy and surrogate surfaces, *Atmos. Environ.*, 21: 1749-1757.

Bytnerowicz A., Miller P.R., Olszyk D.M., Dawson D.M. & Fox P.J. 1987a, Gaseous and particulate air pollution in the San Gabriel Mountains of southern California, *Atmos. Environ.*, 21: 1805-1814.

Bytnerowicz A., & Riechers G. (in prep.), Gaseous and particulate air pollutants in two forest sites of the western Sierra Nevada, *Atmos.Environ.*

Cadle S.H. 1985, Seasonal variation in nitric acid, nitrate, strong aerosol acidity, and ammonia in an urban area, *Atmos. Environ.*, 19: 181-188.

Cadle S.H. & Mulawa P.A. 1988, Atmospheric summertime concentrations and estimated dry deposition rates of nitrogen and sulfur species at a Smoky Mountain site in North Carolina, Presented at the 81st Annual Meeting & Exhibition of the Air Pollution Control Association, Dallas, Texas, June 19-24, 1988, pre-print No. 88-119.3.

Dasch J.M. 1986, Measurement of dry deposition to vegetative surfaces, *Water Air Soil Pollut.*, 30: 205-210.

Dasch J.M., Cadle S.H., Kennedy K.G. & Mulawa P.A. 1989, Comparison of annular denuders and filter packs for atmospheric sampling, *Atmos. Environ.*, 23: 2775-2782.

Draijers G.P.J., Ivens W.P.M.F., Bos M.M. & Bleuten W. 1989, The contribution of ammonia emissions from agriculture to the deposition of acidifying and eutrophying compounds onto forests, *Environ. Pollut.*, 60: 55-66.

Eaton J.S., Likens G.E. & Bormann F.H. 1973, Throughfall and stemflow chemistry in a northern hardwood forest, *J. Ecology* 61: 495-508.

Ellis B.A., Verfaillie J.R. & Kummerow J. 1983, Nutrient gain from wet and dry atmospheric deposition and rainfall acidity in southern California chaparral, *Oecologia* 60: 118-121.

Farber R.J., Huang A.A., Bregman L.D., Mahoney R.L., Eatough D.J., Hansen L.D., Blumenthal D.L., Keifer W.S. & Allard D.W. 1982, The third dimension in the Los Angeles Basin, *Sci. Tot. Environ.*, 23: 345- 360.

Fenn M.E. & Bytnerowicz A. 1993, Dry deposition of nitrogen and sulfur to ponderosa pine and Jeffrey pine in the San Bernardino National Forest in southern California, *Environ. Pollut.*, in press.

Finlayson-Pitts B.J. & Pitts J.N.Jr. 1986, Atmospheric Chemistry: Fundamentals and Experimental Techniques, John Wiley & Sons, New York.

Grennfelt P. & Hultberg H. 1986, Effects of nitrogen deposition on the acidification of terrestrial and aquatic ecosystems, *Water Air Soil Pollut.*, 30: 945-963.

Grosjean D. 1983, Distribution of atmospheric nitrogenous pollutants at a Los Angeles area smog receptor site. *Environ. Sei. Technol.*, 17: 13-19.

Grosjean D. & Bytnerowicz A. 1993, Nitrogenous air pollutants at a southern California mountain forest smog receptor site, *Atmos. Environ.*, 27A: 483-492.

Hosker R.P. & Lindberg S.E. 1982, Review: atmospheric deposition and plant assimilation of gases and particles. *Atmos. Environ.*, 16: 889-910.

Keuken M.P., Schoonebeek C.A.M., van Wensveen-Louter A. & Slanina J. 1988, Simultaneous sampling of NH_3, HNO_3, HCl, SO_2 and H_2O_2 in ambient air by a wet annular denuder system, *Atmos. Environ.*, 22: 2541-2548.

Legge A.H. & Krupa S.V. 1989, Air quality at a high elevation, remote site in western Canada, Presented at the 82nd Annual Meeting & Exhibition of Air & Waste Management Association, Anaheim, California, June 25-30, 1989, Pre-print No. 89-133.5.

Lindberg S.E., Lovett G.M., Bondietti E.A. & Davidson C.I. 1984, Recent field studies of dry deposition to surfaces in plant canopies, Presented at the 77th Annual Meeting & Exhibition of the Air Pollution Control Association, San Francisco, California, June 24-29, 1984, Pre- print No. 84-108.5.

Lindberg S.E., Lovett G.M., Richter D.D. & Johnson D.W. 1986, Atmospheric deposition and canopy interactions of major ions in a forest, *Science*, 231: 141-145.

Marshall J.D. & Cadle S.H. 1989, Evidence for trans-cuticular uptake of HNO_3 vapor by foliage of eastern white pine (*Pinus strobus*), *Environ. Pollut.*, 60: 15-28.

Miller D.F. & Walsh P.A. 1991, Air quality and acidic deposition in the southeastern Sierra Nevada, Presented at the 84th Annual Meeting of the Air & Waste Management Association, Vancouver, Canada, June 16-21, 1991, Pre-print No. 91-59.3.

Miller P.R., McCutchan M.H. & Millican H.P. 1972, Oxidant air pollution in the Central Valley Sierra Nevada foothills and Mineral King Valley of California, *Atmos. Environ.*, 6: 623-633.

Nihlgard B. 1985, The ammonium hypothesis — an additional explanation to the forest dieback in Europe, *Ambio* 14: 2-8.

National Academy of Sciences 1977, Nitrogen Oxides. Committee on Medical and Biologic Effects of Environmental Pollutants, Washington D.C.

Peake E. & Legge A.H. 1987, Evaluation of methods used to collect air quality data at remote and rural sites in Alberta, Canada. Presented at the EPA/APCA Symposium on Measurements of Toxic and Related Air Pollutants, Research Triangle Park, North Carolina, May 3-6, 1987.

Peake E., MacLean M.A.& Sandhu H.S. 1988, Total inorganic nitrate (particulate nitrate and nitric acid) in the atmosphere of Edmonton, Alberta, Canada, *Atmos. Environ.*, 22: 2891-2893.

Peterson D.L., Arbaugh M.J., Robinson L.J. & Derderian B.R. 1990, Growth trends of white bark pine and lodgepole pine in a subalpine Sierra Nevada forest, California, U.S.A., *Arct. Alp. Res.*, 22: 233-243.

Pierson W.R. & Brachaczek W.W. 1988, Coarse- and fine-particulate atmospheric nitrate and HNO3 (g) in Claremont, California, during the 1985 nitrogen species method comparison study, *Atmos. Environ.*, 22: 1665-1668.

Possanzini M., Febo A. & Liberti A. 1983, New design of a high-performance denuder for the sampling of atmospheric pollutants, *Atmos. Environ.*, 17: 2605-2610.

Riggan P.J., Lockwood R.N. & Lopez E.N. 1985, Deposition and processing of airborne nitrogen pollutants in Mediterranean-type ecosystem of southern California, *Environ. Sci. Technol.*, 19: 781-789.

Roberts J.M., Langford A.O., Goldan P.D. & Fehsenfelt F.C. 1988, Ammonia measurements at Niwot Ridge, Colorado and Point Arena, California using the tungsten oxide denuder tube technique, *J. Atmos. Chem.*, 7: 137-152.

Runeckles V.C. & Palmer K. 1987, Pretreatment with nitrogen dioxide modifies plant response to ozone, *Atmos. Environ.*, 21: 717-719.

Schlesinger W.H., Gray J.T. & Gilliam F.S. 1982, Atmospheric deposition processes and their importance as sources of nutrients in a chaparral ecosystem of southern California, *Wat. Resour. Res.*, 18: 623-629.

Schulze E.-D., De Vries W., Hauhs M., Rosen K., Rasmussen L., Tamm C.- O. & Nilsson J. 1989, Critical loads for nitrogen deposition on forest ecosystems, *Water Air Soil Pollut.*, 48: 451-456.

Sickless J.E.II., Perrino C., Allegrini I., Febo A. & Possanzini M. 1988, Sampling and analysis of ambient air near Los Angeles using an annular denuder system. *Atmos. Environ.*, 22, 1619-1625.

South Coast Air Quality Management District 1985, El Monte, California. Unpublished.

Stohlgren T.J. & Parsons D.J. 1987, Variation of wet deposition chemistry in Sequoia National Park, California, *Atmos. Environ.*, 21: 1369-1374.

Taylor G.E.Jr., Hanson P.J. & Baldocchi D.D. 1988, Pollutant deposition to individual leaves and plant canopies: sites of regulation and relationship to injury, (in:) Heck W.W., Taylor O.C. & Tingey D.T. (eds.), *Assessment of Crop Loss from Air Pollutants*, pp. 227-257, Elsevier Applied Science, London.

Van Der Eerden, L.J., Dueck Th.A., Berdowski J.J.M., Greven H. & Van Dobben H.F. 1991, Influence of NH_3 and $(NH_4)_2SO_4$ on heathland vegetation, *Acta Bot. Neerl.*, 40: 281-296.

Waring R.H. & Schlesinger W.H. 1985, Forest Ecosystems — Concepts and Management, Academic Press, Inc., Orlando, Florida.

Wellburn A.R. 1990, Why are atmospheric oxides of nitrogen usually phytotoxic and not alternative fertilizers? *New Phytol.*, 115: 395-429.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:177-186, IGSO PAS, Warszawa

SPATIAL DISTRIBUTION Of SULPHUR AND NITROGEN CONTENT IN NEEDLES OF SCOTS PINE (*PINUS SILVESTRIS* L.) AS RELATED TO AIR POLLUTION AND TREE STANDS VITALITY IN POLAND

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Abstract: The aim of the investigation was to determine the relationship between air pollution by SO_2 and NO_x, sulphur and nitrogen content in Scots pine needles, and the vitality of tree stands in Poland. The spatial distribution of air pollution coincided to a large extent with sulphur content in needles and nitrogen/sulphur ratio (N/S). Higher air pollution was related to a greater total sulphur content in needles and to lower N/S ratio. The areas of eastern and northeastern Poland were less polluted than western and southwestern Poland. No relationship between air pollution, sulphur content in needles, N/S ratio, and tree stands vitality determined by a defoliation index has been found. These are introductory results of a much broader research program containing many more elements.

Key words: spatial distribution, pine needles, sulphur content, nitrogen content, forest vitality, Poland.

INTRODUCTION

The chemical composition of pine needles has been investigated for many years. Two conceptual approaches dominated. In the first, the content of elements in assimilation apparatus was correlated with the content of the same elements in the soil in an attempt to connect the balance of chemical elements in the soil that ensures nutritional optimum, with an appropriate chemical composition of assimilation apparatus. There is surely a relationship between the amount of accessible forms of elements in the soil and their content in assimilation apparatus (Puchalski & Prusinkiewicz 1975). This approach is connected also with hypotheses relating to damage of coniferous forests with a deficit of some elements in needles caused by soil changes under the impact of air pollution deposition (Rechfüess 1983; Hüttl 1985; Zötl & Hüttl 1986, 1989). In the second approach, the chemical composition of needles was connected with gaseous air pollution, considering that immediate contact with assimilation apparatus influences its chemical composition. This approach is linked with the use of plants as bioindicators of environmental pollution and threats to vegetation cover (Huttunen et al. 1985; Molski & Dmuchowski 1985, 1986, 1989, and many others).

The approach presented here is closer to the second variant; although, by relating S and N content to the tree vitality level, it takes into account the first approach in an indirect way. The results of S and N content in Scots pine needles presented here were related not only to air pollution deposit indices (SO_2 and NO_x) but also to the level of tree stand damage as expressed by their mean defoliation. The results discussed are a part of broader studies on the relationship between the chemical composition of Scots pine needles and the level of tree stand damage at the dimensional scale of Poland. They are of introductory character.

MATERIAL AND METHODS

The analysis has been done on the basis of data collected in the forest monitoring network. The spatial distribution of air pollution has been presented on the basis of mean indices of SO_2 and NO_x deposition from a 3-year monitoring period from 1989 to 1991, collected from a network of 1340 measurement points located in forest areas. The measurement has been done with a passive method (Amaya & Sugiura 1983) with the use of K_2CO_3 as the absorption substance, at 1-month exposition of sampling devices. The results were expressed in mg/m^2 24 h. The observations were divided into winter and summer seasons.

The vitality of tree stands has been evaluated according to a defoliation level determined yearly on 1496 permanent sample plots localized in pine, spruce, and fir stands as well as in oak, beech, and birch stands older than 40 years. Defoliation was determined in 5% grades that were then aggregated in 10% range classes (Manual on Methodologies and Criteria... 1989). Defoliation indices were calculated for each plot as weighted means, taking class number as the weight. All range of variability was divided into four groups ascribing to them a definite degree of damage (vitality).

Scots pine needles were collected on 300 permanent monitoring plots in autumn 1990. For each plot, three trees were selected from dominant tree stands. Twigs from the upper part of the crown (3-5th whorl) growing on the southern side were collected. The needles were classified into age classes: current-growth needles and previous-year-growth needles. The needles were dried in the laboratory at 50°C, minced to a dust, and closed in plastic containers. The total sulphur was measured with LECO SC-132 analyzer (Giesemann et al. 1991). Total nitrogen was colorimetrically measured with Technicon analyzer. The results were recalculated for dry mass content.

Maps were drawn with numerical methods with the ISOLIN program (Molski et al. 1987) on the Roland DPX 3300 plotter.

RESULTS AND DISCUSSION

Distribution of air pollution in Poland expressed as the mean SO_2 and NOx deposition index in 3 years, 1989-1991, classified by winter and summer, are presented on the maps (Fig. 1, 2). In the winter, SO_2 and NO_x air pollution was much greater than in the summer. Whereas in the summer season, the NOx air pollution index did not exceed 0.8 mg/m^2 24 h, in the winter, it exceeded 1.2 mg/m^2 24 h in the most polluted areas. Still greater differences between summer and winter seasons occurred in the case of SO_2 up to 16 mg/m^2 24 h and over 32 mg/m^2 24 h, respectively. The areas of western and southwestern Poland were characterized by air pollution much greater than that in the eastern and northeastern regions.

The spatial distribution of total sulphur content in Scots pine needles in Poland, based on the measurements of 300 plots, have been presented on maps (Fig. 3 — current-growth needles and previous-year-growth needles). Five zones of sulphur content in needles have been determined on the maps. Designation of additional zones with higher sulphur content was abandoned because of injuries to needles in trees growing in strong air pollution conditions (Godzik 1976; Godzik & Sassen 1978; Huttunen & Laine 1981; Huttunen et al. 1983). There were concerns that the results might be deformed when needles were partly dead. An increased dissolving of sulphur by air precipitation and "dilution" of sulphur by the dry mass of needles, a part of which was dead, could be the reason for such a deformation of results (Puchalski & Prusinkiewicz 1975).

The SO_2 air pollution occurred on the entire territory of Poland. Sulphur content in pine needles reflects spatial distribution of SO_2 deposition in Poland. The level called "normal" for Poland (Bytnerowicz et al. 1981/1982; Dmuchowski et al. 1981/1982, 1985; Huttunen & Tormalehto 1982; Mankowska 1983; Molski & Dmuchowski 1985, 1986) being equal to 0.07%, characteristic for unpolluted areas, did not occur at any measuring point. Areas of sulphur content in needles up to 0.09% have been shown in earlier publications for northeastern Poland (Molski & Dmuchowski 1986). At the present time, that zone does not occur, and the lowest values are measured to be as high as 0.1%. Previous-year-growth needles contained greater amounts of sulphur than the current-growth needles. The spatial distribution of SO_2 air pollution coincided to a large extent with the content of sulphur in needles. The highest SO_2 contents in air and total sulphur in pine needles occurred in western and southwestern Poland, while the lowest SO_2 contents occurred in eastern and northeastern Poland.

The N/S ratio in plants is often used as a measure for the sulphur status (De Kok 1990). The ratio of nitrogen to sulphur have been suggested as a potential indicator of exposure to SO_2 (Malcolm & Garforth 1977). At the large scale, within the range of pollution climates, this ratio is perhaps better used as an indicator of relative importance of sulphur and nitrogen components of atmospheric pollution (Cape et al. 1990). The values of N/S ratio for Poland have been presented on maps for the same sampling plots (Fig. 4

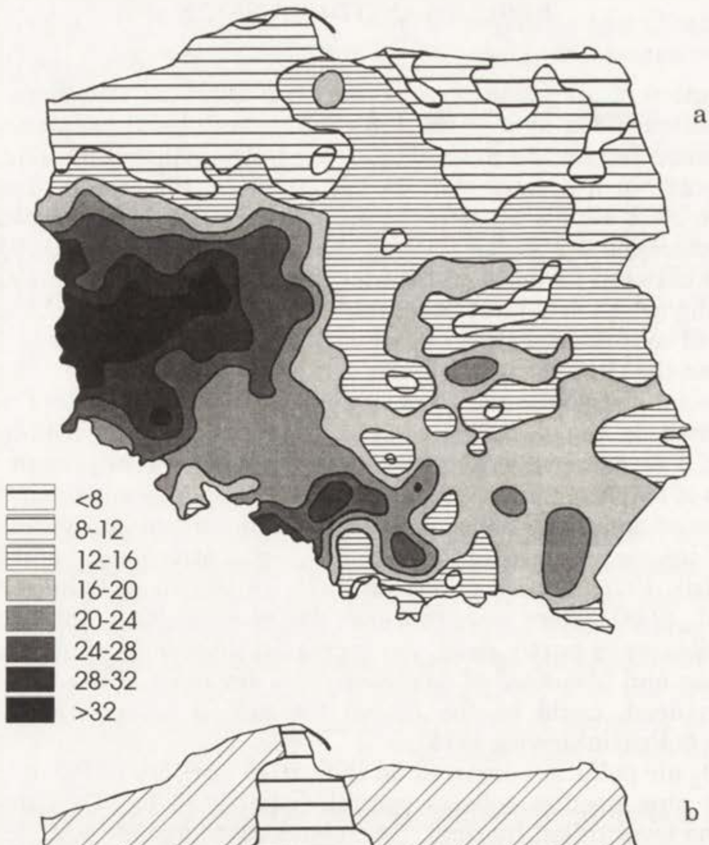

Fig. 1. SO_2 deposition index, average value for 1989-91period (mg/m^2 24 h)
a — winter, b —summer

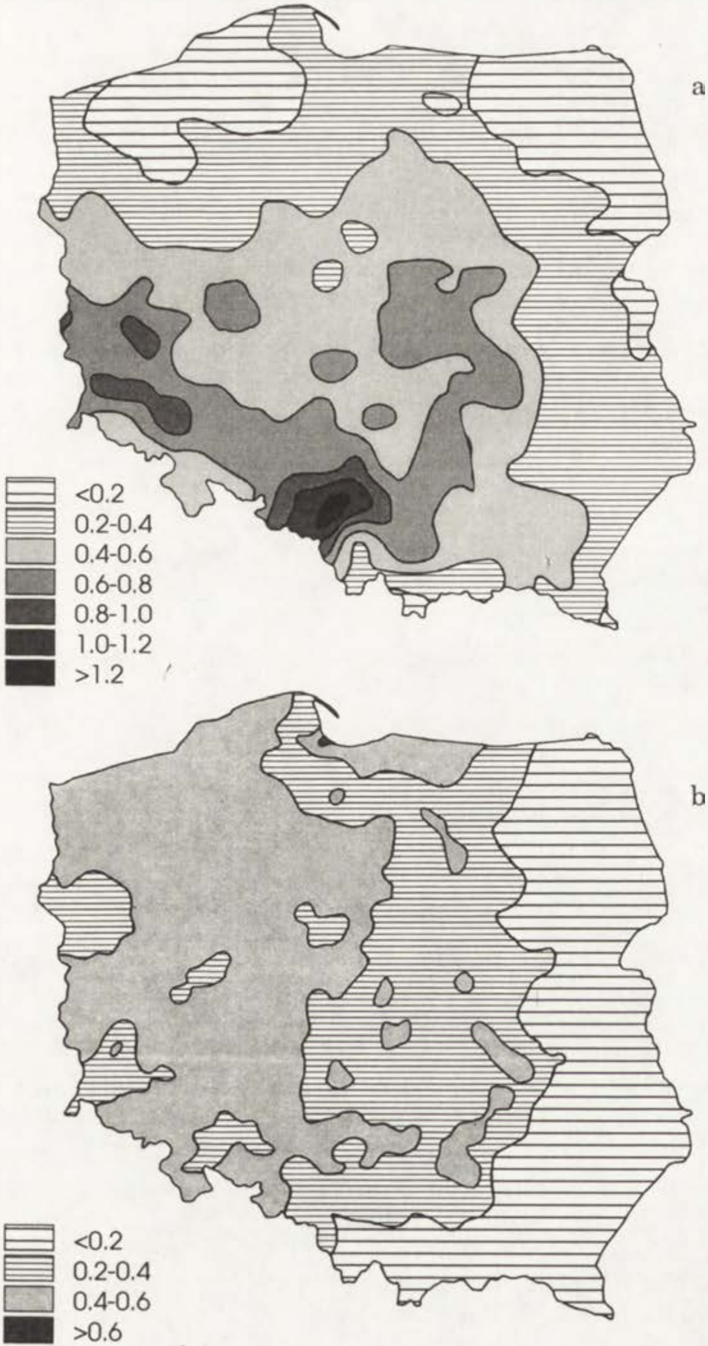

Fig. 2. NO_x deposition index, average value for 1989-91 period (mg/m^2 24 h)
a — winter, b —summer

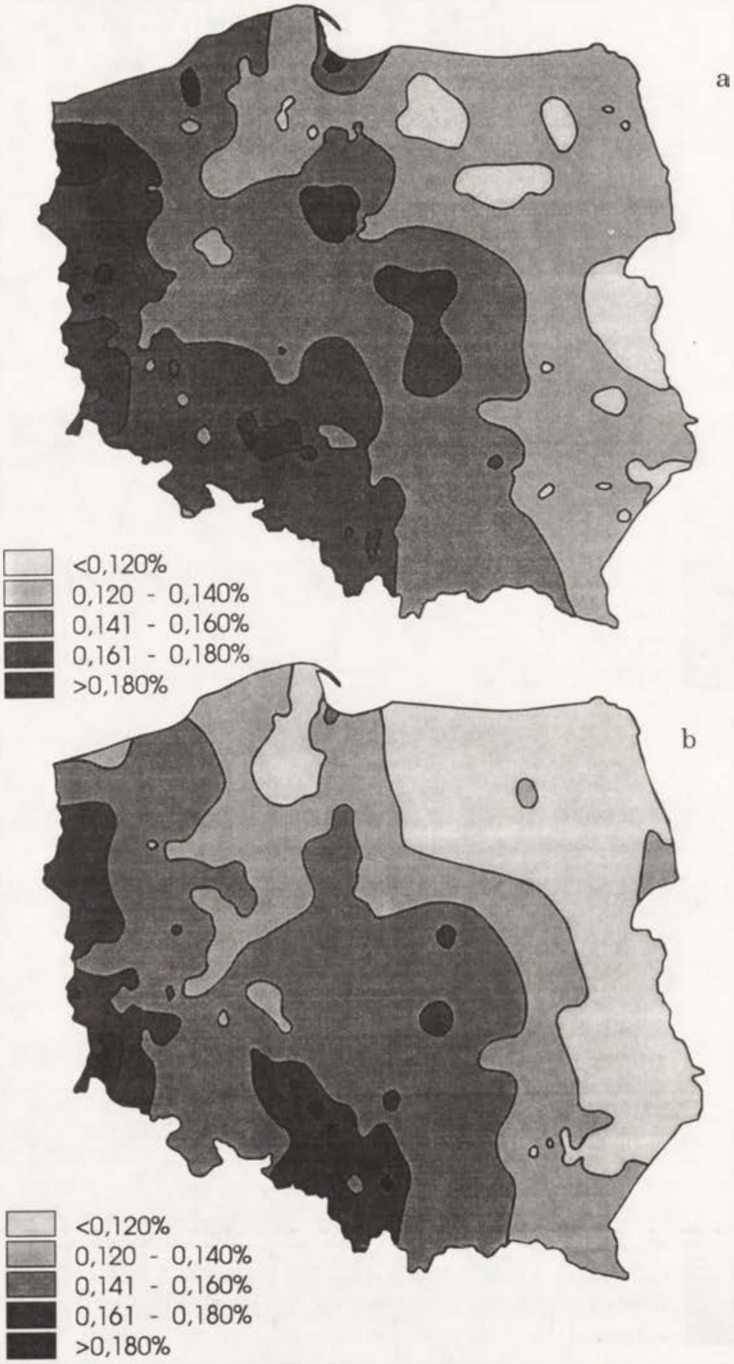

Fig. 3. Total sulphur content in Scots pine needles (% in d.m.)
a — current growth, b — previous-year growth

— current-growth needles and previous-year-growth needles), as for sulphur. The N/S ratio ranged in the interval from 8 to 16. The spatial picture on maps was approximately the reverse of that for sulphur content in needles. The N/S ratio for eastern regions was higher than that in the western part of the country. The statistical analysis (Table 1) proved that a strong correlation occurs between the contents of nitrogen and sulphur in the needles of both past and present growths. The problem of using N/S ratio in Poland as an index of pollution and threat to tree stands requires further studies.

The most extensive injuries to pine stands (Fig. 5), determined on the basis of differentiation of defoliation index, occurred in the southern part of the country. The less injured stands were found in the east and in the central belt. The spatial distribution of damage index and sulphur content in needles does not coincide with the entire area. The differences concern the Lubuska Land in particular, where injuries were light, and the content of sulphur in needles was high. This area, however, is characterized by favourable climatic conditions, i.e.; the 2-week longer vegetation period and higher mean air temperatures for both winter and summer (Wiszniewski 1973). This fact may positively impact the forest resistance to air pollution. The statistical analysis (Table 1) also has not proved a relationship between the index of injuries and sulphur content in needles. A very weak correlation 0.206 appeared only at the 0.05 significance level for sulphur content in current-growth needles.

Table 1. Correlation between sulphur and nitrogen in pine needles and defoliation of trees

Correlated values	Correlation coefficient	Significance of correlation for critical value of	
	R	R 0.05 = 0.194	R 0.01 = 0.254
Sulphur (needles 1) — defoliation	0.295	+	–
Sulphur (needles 2) — defoliation	0.190	–	–
Sulphur/nitrogen (needles 1)	0.435	+	+
Sulphur/nitrogen (needles 2)	0.361	+	+
Nitrogen/sulphur (1) — defoliation	0.028	–	–
Nitrogen/sulphur (2) — defoliation	0.049	–	–
— degrees of freedom	291		

Level of damage assessment and threats to forests should be based on various observations and measurements; e.g., determination of sulphur content in needles, search for injuries in assimilation apparatus, evaluation of active root biomass, increments and vitality of trees. A weak specificity of morphological damage features; i.e., their bounds with different kinds of acting pollutants and other stressing agents (drought, frost damage, diseases,

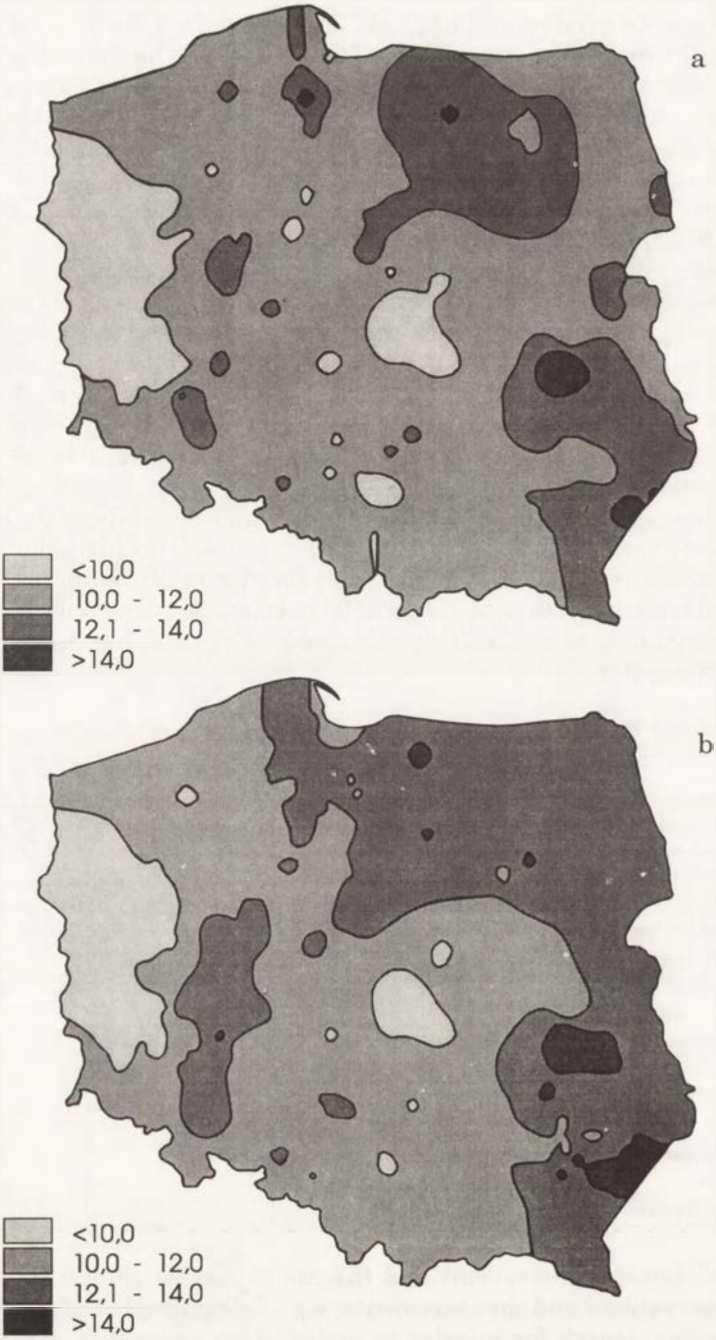

Fig. 4. The ratio of nitrogen to sulphur in Scots pine needles
a — current growth, b — previous-year growth

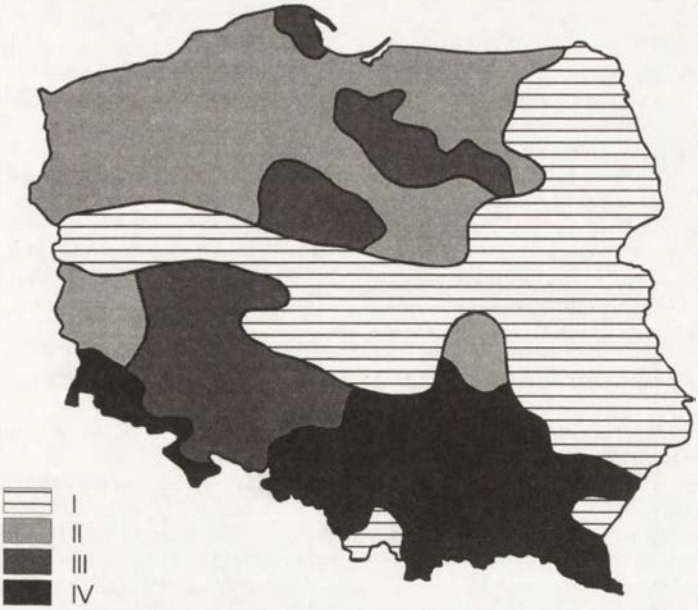

Fig. 5. Forest damage distribution in Poland in 1991
I — low damage; II — medium damage; III — high damage; and IV — very high damage

and pests) does not allow that they constitute the only criterion of SO_2 impact. On the contrary, the inference based only on assessment of sulphur content in plants and in the air is not sufficient because there is no direct relationship between the concentration and the degree of damage (Godzik 1989).

Our findings present only the fragment of a larger program. This stage of investigations is still too premature to draw more conclusions on a relationship between chemical composition of Scots pine needles, deposition of S and N air pollutants, and vitality of tree stands in Poland.

REFERENCES

Amaya K. & Sugiura K. 1983, A simple inexpensive and reliable method of measuring of nitrogen dioxide concentration in ambient air, *Environ. Protect. Engineer.*, 9:5-9.

Bytnerowicz A., Dmuchowski W. & Molski B. 1981/1982, Effect of Needle Harvest Time, Age of Needles and Scots Pine (*Pinus silvestris L.*), Trees on the Accumulation of Total Sulphur, *Roczn. Dendrol.*, 34:51- 68.

Cape J.N., Freer-Smith P.H., Paterson J.S., Parkinson J.A. & Wolfenden J. 1990, The nutritional status of *Picea abies* (*L.*) Karst. across Europe, and implications for “forest decline”, Trees B4:221-224.

De Kok L.J. 1990, Sulfur metabolism in Plants, (in:) Rennenberg H. et al. (eds), *Sulfur Nutrition and Sulfur Assimilation in Higher Plants*, pp. 111-130, SPB Academic Publishing, The Hague.

Dmuchowski W., Bytnerowicz A. & Molski B. 1981/1982, The influence of the boreal site on the accumulation of total sulphur in the pine needles, *Roczn. Dendrol.*, 34:69-77.

Dmuchowski W. & Molski B. 1985, The influence of the forest site and needles age on the process of sulphur, fluorine and some chosen metals accumulation in Scots pine needles on highly polluted and control areas, Proceedings of the IUFRO. S 2.09. Air

Pollution Symposium, XIII International Meeting of Specialists in Air Pollution Damages in Forests, Most (CSRS) 27.08.-1.09.1984:372-377.

Giesemann A., Herstein U. & Jager H.J. 1991, A rapid and simple method to determine organic and inorganic sulphur in plant samples, using an automated sulfur analyzer, *Angew. Bot.*, 65:352-358.

Godzik S. 1976, Pobieranie SO_2 z powietrza i rozmieszczenie S u niektórych gatunków drzew. Badania porównawcze, *Prace i Studia* 16.

Godzik S. & Sassen M.M.A. 1978, A scanning electron microscope examination of *Aesculus hippocastanum L.* leaves from control and air-polluted areas, *Environ. Pollut.*, 17:13-18.

Godzik S. 1989, Ostre i chroniczne uszkodzenia roślin oraz dopuszczalne w Polsce stężenia dwutlenku siarki, (in:) Białobok S. (ed.), *Życie drzew w skażonym środowisku* pp. 245-256, PWN, Warszawa.

Hüttl R.F. 1985, Neurtige Waldschaden und Nahrelementversorgung von Fichtenbestand in Südwestdeutschland, Thesis, Freiburger Bodenkündliche Abhandlungen 16, University Freiburg, FRG.

Huttunen S. & Laine K. 1981, The structure of pine needle surface (*Pinus silvestris* L.) and the deposition of air-borne pollutants, *Arch. Ochr. Srod.*, 2-4:29-38.

Huttunen S. & Tormalehto H. 1982, Air pollution resistance of some *Pinus silvestris* L. provenances, Aquilo, *Ser. Bot.*, 18: 1-9.

Huttunen S., Karhu M. & Laine K. 1983, Air pollution induced stress and its effects on the photosynthesis of *Pinus sylvestris L.* in Oulu, Aquilo, *Ser. Bot.*, 19:275-282.

Huttunen S., Laine K. & Torvela H. 1985, Seasonal sulphur contents of pine needles as indices of air pollution, *Ann. Bot. Fennici*, 22:343-359.

Malcolm D.C. & Garforth M.F. 1977, Sulphur : nitrogen ratio of conifer foliage in relation to atmospheric pollution with sulphur dioxide, *Plant and Soil* 47:89-102.

Mankowska B. 1983, The natural sulphur content in the leaves of forest trees, *Biologia* (Bratislava) 38:51-57.

Manual on Methodologies and Criteria for Harmonized Sampling, Assessment, Monitoring and Analysis of the Effects of Air Pollution on Forests. Hamburg/Geneva: Programme Co-ordinating Centres, UN-ECE 1986, revised 1989.

Molski B. & Dmuchowski W. 1985, Evaluation of air pollution pressure of forest and agricultural areas (mapping on macro regions scale) on the basis of sulphur and fluorine accumulation by the needles of Scots pine, Proceedings of the IUFRO S 2.09. Air Pollution Symposium, XIII International Meeting of Specialists in Air Pollution Damages in Forests. Most (CSRS) 27.08-1.09.1984:110-123.

Molski B.A. & Dmuchowski W. 1986, Effects of Acidification on Forests Natural Vegetation, Wild Animals and Insects. (in:) Schneider T. (ed.) *Acidification and its Policy Implications*, pp. 29-51, Elsevier, Amsterdam.

Molski B., Glebicki K. & Dmuchowski W. 1987, Data management computer system of air pollution impact on forests used in the Botanical Garden of the Polish Academy of Sciences and its relation to existing systems in Poland, (in:) Kariukstis L., Nilsson S. & Straszak A. (eds.), *Proceedings of the workshop, Forest decline and reproduction: regional and global consequences*, pp. 45-52, Kraków, Poland, 23-27 March, 1987.

Molski B. & Dmuchowski W. 1989, The comparison of environmental pollution in Northern Finland near Kevo and in Poland with the use of *Pinus sylvestris L.* as bioindicator, Rep. Kevo Subarctic Stat., 21, (in print).

Puchalski T. & Prusinkiewicz Z. 1975, *Ekologiczne podstawy siedliskoznawstwa leśnego*, PWRiL, Warszawa.

Rehfüess K.E. 1983, Walderkräukungen und Immisionen — eine Zwischenbilanz, *Allg. Forstl. Jahrb.,* 58:201-224.

Wiszniewski W. 1973, *Atlas klimatyczny Polski*, PPWK.

Zöttl H.W. &, Hüttl R.F. 1986, Nutrient Supply and Forest Decline in Southwest Germany, Water, *Air and Soil Pollution* 31:449-462.

Zöttl H.W.& Hüttl R.F. 1989. Nutrient deficiencies and forest decline, (in:) Bucher J.B. & Bucher-Wallin I. (eds.), *Air pollution and forest decline 1*: 189-193, EAFV, Birmensdorf.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:177-195, IGSO PAS, Warszawa

A COMPARISON OF AIR, SOIL, AND SPRUCE NEEDLE CHEMISTRY IN THE IZERSKIE AND BESKIDY MOUNTAINS

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Abstract: More than 90% of the forest area of the third injury class is located in southern Poland, along the border with the Czech Republic. This coincides roughly, according to model calculations, with the highest emission and deposition of sulphur dioxide in Poland. In Poland forest decline on a large scale has occurred in the Izerskie Mountains. No similar phenomenon has been found farther east, in the Beskidy Mountains. Concentration of total sulphur in spruce needles in compared areas is highest in the Izerskie Mountains samples, exceeding 0.32%. The sulphur concentration is in the range of 0.26% for the Beskidy Mountains samples. No differences of sulphur concentration has been found for needle samples taken from stands at 650 m and 1000 m elevations in the Beskidy area.

The yearly mean concentration of sulphur dioxide in the Izerskie Mountains for the period 1984 to 1989 is 24 micrograms m^{-3}, with the highest value for the year 1989 (45 micrograms m^{-3}). The yearly mean concentration of sulphur dioxide for the Beskidy region, depending on elevation and location, ranges from 12.8 to 34.7 micrograms m^{-3}.

No major differences in soil properties of samples from similar elevations of compared locations have been found. There are, however, differences in top soil properties depending on elevations. Climatic factor(s) seems to play an important role in those differences.

Key words: spruce needles, forest damage, air pollution, element content, Poland.

INTRODUCTION

Forest decline in the Czech Republic, eastern Germany, and the Izerskie Mountains in Poland has been declared as ecological disaster. In Poland over 10 000 ha of forest, mostly spruce stands in Izerskie Mountains, were cut down in the years 1980 to 1988. No similar forest decline has occurred in the Beskidy region and farther to the East. On both the Czech and Polish side of the border, an increase of forest injury has been noted in the Beskidy Mountains east of the Sudety Mountains. At higher elevations in the Silesian Beskidy Mountains, however, several tens of hectares of spruce stands have died (Skrzyczne and Barania Góra). According to recent large scale inventories of forest injury in Poland, over 90% of severe injury class III is found in southern part of Poland, along the border to the Czech Republic (Table 1 and Table 2).

Table 1. Forest area endangered by air pollution in southern Poland according to Administrative Districts in 1990*

Administrative District	Total area		Area endangered (ha) Class of injury		
	ha	%	I	II	III
Poland	1 089 297	16.0	824 993	232 783	31 521
Bielsko	26 181	30.9	16 976	9 205	-
Jelenia Góra	103 911	70.5	54 602	35 647	13 662
Katowice	162 026	99.2	66 499	82 482	13 045
Kraków	18 252	59.9	17 847	405	-
Opole	21 652	11.1	13 468	6 256	1 928
Wałbrzych	27 107	24.6	10 067	16 314	726
Total for above given administrative districts:					
ha	359 129	·	179 459	150309	29 361
%		33.0	21.7	64.6	93.1

Not listed are districts of Southern and Southeastern Poland, where forest injury due to air pollution has not been identified.

* Environment Protection 1991.

Table 2. Area of forest endangered by air pollution according to Forest Administrative Districts for Southern Poland in 1990*

Forest Administrative District	Total area		Class of injury		
	ha	%	I	II	III
Poland	1 089 297	16.0	82 499	232 783	31 521
Katowice	283 000	48.2	152 567	115 458	14 973
Kraków	35 991	21.8	34 986	1 005	-
Krosno	4 017	1.0	4 017	-	-
Wrocław	198 296	40.7	119 316	64 446	14 534
Zielona Góra	92 831	22.6	85 490	7 195	146
Total (ha)	614 135	·	396 376	188 104	29 653
(%)		56.4	48.0	80.8	94.1

* Environment Protection 1991.

In Poland, gradient in the severity of forest injury exists along the lines West-East and South-North. In the mountains, the phenomena of differentiated stands injury along an elevation gradient also exists. It does not mean that severely damaged forests are not to be found in other parts of Poland around some large emission sources e.g., Puławy Nitrogen Fertilizer Plant.

Sulphur dioxide emitted from large coal-fired power stations located in Czech Republic, Germany and Poland are responsible for the forest decline in the Izerskie Mountains. Until recently, however, few data concerning concentration of sulphur dioxide, nitrogen oxides have been available. No long lasting measurements of ozone concentration have been carried out.

It has been acknowledged that under extreme conditions, the critical concentration and load of pollutants causing adverse effects are decreasing. An example of these are recommendations of IUFRO and the UNECE Critical Level Programme (Convention ... 1990) for critical level of sulphur dioxide.

The aim of our study was to compare concentration of air pollutants and soil and spruce needle chemical composition of samples from areas of the Izerskie and Beskidy Mountains. In addition a limited number of samples from the Beskidy Mountains were taken at different elevations: the foot, middle, and top of a hill. Bulk deposition has been collected at two elevations, 650 and 940 m, and the amount of several elements analyzed.

The Izerskie Mountains site was chosen because of forest decline. The Beskidy sites as area of possible decline phenomena in the future, but at the present time it does not have a large scale forest damage.

MATERIAL AND METHODS

Air pollutants measurements at the Rozdroże Izerskie (Izerskie Mountains) were carried out by the Centre for Environmental Studies in Jelenia Góra (Ośrodek Badania i Kontroli Środowiska). West-Gaeke for sulphur dioxide and Salzman methods for nitrogen oxide concentration measurements were used.

In the Beskidy Mountains the Surface Active Monitoring (SAM) method was used for sulphur dioxide concentration measurements. More recently a volumetric method was used for air sampling, following measurements of sulphate concentration in 0.3% solution by ion chromatography.

To avoid diffusion of gaseous pollutants in bulk deposition, a small diameter tube between the funnel and polyethylene (PE) bottle was used.

Soil sampling and analysis were performed as recommended by of the Polish Soil Science Society.

One year spruce needles were taken from six trees growing at the stands edge, 4 to 5 m above the ground, from the southern part of the crowns. Total sulphur was determined turbidimetrically after digestion of fine grounded needles in calorimetric bomb. Cations were determined by atomic absorption method (AAS).

RESULTS AND DISCUSSION

AIR POLLUTION

The yearly mean concentration of sulphur dioxide in Izerskie Mountains area fluctuated from 16 micrograms m^{-3} in the year 1984 to 1985 to 45 micrograms m^{-3} in the year 1988 to 1989. An increase in both yearly mean values and maximum daily concentration has occurred after the major part of the forest in this area declined. No data on air pollutants concentration are available, however, for the period before 1984. During the whole measurement period, nitrogen oxides exceeded the sulphur dioxide concentration. Should sulphur dioxide be the major pollutant responsible for forest decline in the Izerskie Mountains, a significantly lower critical level of this pollutant must be accepted than has been recommended recently (Convention ... 1990). A 20 micrograms m^{-3} sulphur dioxide concentration for forest ecosystems has been proposed.

Critical level for nitrogen dioxide for all land use categories has been proposed to be 30 micrograms m^{-3} (Convention ... 1990). Concentration of nitrogen dioxide have not been measured, but this compound is usually at highest quantities among all other oxides of nitrogen.

A week of continuous measurements of sulphur dioxide and nitrogen dioxide carried out at the same locality in 1989 have shown a lower concentration of nitrogen dioxide, but a higher concentration of sulphur dioxide (joint measurement of the Swiss Federal Forestry Research Institute and the authors, unpublished). Credibility of the measurement data from the local institution remains to be tested.

Although different methods for determination of sulphur dioxide at the Izerskie Mountains and the Beskidy Mountains sites have been used, comparison is possible. A high correlation coefficient between these two methods allows acceptance of these data. A one week continuous measurement of at each location carried out by a team from the Federal Swiss Institute for Forestry has also given similar results (unpublished).

A key question on the cause of forest decline in this region remains as to what is the direct effect of air pollutants.

On the Beskidy Mountains sites only sulphur dioxide concentration were measured, using SAM procedure (Table 3). For the same time period, higher concentration were measured at the Salmopol site (940 m) if compared to the Brenna site (660 m). Such large differences are caused by significantly higher sulphur dioxide concentration during October to April at the higher elevation. This pattern may be a result of sulphur dioxide emissions from the village located in the valley. The sulphur dioxide concentration has fallen markedly at the Jałowiec site located about 30 km east of Salmopol site. Both are at the similar elevation.

Table 3. Concentration of SO_2 (micrograms m^{-3}) in the Beskidy Mountains at different elevation

Location and elevation	Concentration
Brenna, 665 m	18.62
Salmopol, 940 m	34.66
Jałowiec, 850 m	12.76

Mean concentration of sulphur dioxide at the Izerskie Mountains and the Beskidy Mountains sites does not differ significantly; forest health, however, differs. Results of one week of continuous measurements of sulphur dioxide concentration are similar to obtained by using the SAM method. Comparison to nitrogen dioxide and ozone concentration is not possible, because these pollutants were not measured there.

Studies are underway in the Beskidy area for better understanding of differences in forest health status and spatial distribution of air pollutants concentration and loads.

The highest mean concentration of aerosols and nitrogen oxides for the Izerskie Mountains site is for the year 1984 to 1985. Sulphur dioxide concentration was highest in the years 1988 to 1989. (Table 4). It does not coincide with the highest rate and degree of forest decline in this region.

At the same location, the pH of rainfall was in the range 2.2 to 7.4 in the years 1984 to 1985. Such fluctuation was, perhaps, because of periodically high deposition of alkaline particulate matter, emitted from coal-fired power stations in this region. Particulates emission control was not adequate at this time. An indirect support seems to be the aerosol concentration, also highest in this period (Table 4).

Table 4. Air pollution at Rozdroże Izerskie, the Izerskie Mountains. Mean value for the period 1984 to 1989 and peak 24 h concentration (micrograms m^{-3}). (OBIKS Jelenia Góra, 1990, unpublished)

	Concentration (Year)		
	Mean a^{-1}	Peak a^{-1}	Peak 24 h
Sulphur dioxide	24	45 (1989)	392 (1989)
Nitrogen oxides	32	47 (1985)	448 (1989)
Aerosols	59	45 (1985)	399 (1985)

No similar record of air pollutants concentration is available for other parts of Poland (outside urban and industrial areas). More recent measurements carried out at the Silesian Beskidy Mountains and the Jałowiec Rim, using SAM approach, are summarized in Table 3. The locations were chosen, based on calculations of air pollutants concentration along a West-East line.

NEEDLE ANALYSIS

Concentration of some elements in spruce needles from several locations in the Izerskie Mountains and the Beskidy Mountains is given in Table 5. A higher total sulphur concentration in needles from the Izerskie Mountains may reflect the air pollution situation caused by the transport of sulphur dioxide from coal fired power stations located in the Czech Republic, Germany, and Poland. In the Beskidy Mountains area sulphur dioxide seems to be of lower importance as compared to that in the Izerskie Mountains area. No data on sulphur dioxide concentration are available for the needle growth period (summer 1989 to early spring 1990) for both locations. Data for the period 1988 to 1989 for Rozdroże Izerskie, however, are the highest for whole time of measurement. One may speculate if this situation is similar for the year 1989 to 1990.

Table 5. Concentration (micrograms m^{-3}) of some elements in 1-year old Norway spruce needles from the Izerskie and Beskidy Mountains. Mean value of six trees, 1990

Sampling site	Concentration in needles					
	S(%)	Ca	Mg	Zn	Pb	Cd
Izerskie Mountains						
660 m	0.324	2178.7	435.2	16.0	1.80	0.16
Beskidy Mountains						
665 m	0.266	2744.5	560.5	32.2	2.77	0.48
1000 m	0.268	1676.6	442.9	27.2	2.06	0.25

No differences in total sulphur concentration in needles from lower and higher elevations in the Beskidy area were found, which does not correspond to average sulphur dioxide concentration determined for these locations (Table 3). Additional analysis are needed to explain this inconsistency. Sulphur concentration in spruce needles from both locations is from two to three times higher than that given as a natural one, and are similar to that determined in spruce needles from injured stands (Tesar & Temmlova 1981; Stefan 1982).

Concentration of calcium, magnesium, and zinc in needles from both locations are in the lower range of levels accepted as normal, or adequate (Gussone 1964; Hüttl & Zöttl 1986). Similar concentration of these elements has been found in some German forests (Krause & Prinz 1989). The concentration of magnesium in needles exceeds the level calculated as a deficient for photosynthetic capacity (Lange et al. 1989).

SOIL CHARACTERISTIC

Soil properties at both the Izerskie Mountains and the Beskidy Mountains sites are summarized in Tables 6 to 10. The most significant differences between top soils from lower and higher elevations are in the ratio C/N. This ratio is in the optimum in mineral soil horizons. It may indicate a slow decomposition of organic matter in top soil horizons at higher elevations. The pH of soils is within limits determined for spruce forest in these regions. Concentration of K, P, Mg and Ca are to be described as low.

Based on a comparison of soil properties in the Izerskie Mountains and Beskidy Mountains, there seems to be no strong argument for making the soil quality as the reason for forest decline in the Izerskie Mountains.

Table 6. Soil characteristic of the Beskidy Mountains location. Brenna (Wilczy Potok, 670 m, spruce stand)

Horizon	Depth	C org.	Org. mat.	N tot.	C/N	pH		Exchangeable mg/100 g of soil				Al^{+3} mg/100 g soil
	cm	%	%	%		H_2O	KCl	K	P	Mg	Ca	
AH	3-7	23.98	41.3	1.32	18.22	3.5	2.7	24.6	6.6	0.1	15.0	88.58
A1A2	7-17	6.64	11.4	0.58	11.61	3.3	2.8	4.1	0.8	0.8	3.0	52.15
A2B	17-31	2.52	4.3	0.26	9.58	3.8	3.3	4.7	0.6	6.8	0.4	37.83
B(B)	31-74	0.78	1.3	0.12	6.67	4.2	4.1	6.9	0.6	4.2	0.4	26.48
C	74-88	n.d.	n.d.	n.d.	n.d.	4.0	3.9	10.0	0.6	0.3	0.4	30.77

Table 7. Soil characteristics of the Beskidy Mountains location. Malinowy (Wierch), elevation 1000 m. Spruce stand

Horizon	Depth	C org.	Org. mat.	N tot.	C/N	pH		Exchangeable mg/100 g of soil				Al^{+3} mg/100 g soil
	cm	%	%	%		H_2O	KCl	K	P	Mg	Ca	
AF(H)	1-3	31.90	55.0	0.19	165.1	3.5	2.8	24.3	11.5	0.9	6.0	96.97
A1+m	3-7	11.50	19.8	0.78	14.7	3.3	2.6	13.2	6.9	0.8	1.6	48.47
A1A2	7-13	4.81	8.3	0.45	10.7	3.4	2.7	6.4	5.2	1.3	1.4	33.63
A2B	7-21	5.06	8.7	0.34	14.9	3.7	3.2	5.3	0.8	0.4	2.6	42.94
B(B)	21-63	2.93	5.0	0.24	12.4	4.3	4.0	2.4	1.0	6.8	1.0	34.24
BC	63-85	0.76	1.3	0.04	19.0	4.5	4.4	1.9	2.0	1.3	1.4	21.35

Table 8. Soil characteristics of the Izerskie Mountains location. Jakuszyce, Slope of Kamienna, close to the top, dead spruce stand

Horizon	Depth	C org.	Org. mat.	N tot.	C/N	pH		Exchangeable mg/100 g of soil				Al^{+3} mg/100 g soil
	cm	%	%	%		H_2O	KCl	K	P	Mg	Ca	
AH	4-10	17.52	30.2	0.16	106.2	3.5	2.8	20.9	6.0	1.3	1.6	73.84
A1	10-21	4.09	7.0	0.40	10.3	3.7	3.0	5.3	2.3	3.2	0.4	31.17
A2	21-25	2.63	4.5	0.40	6.6	3.4	2.9	5.8	1.5	0.4	0.4	30.36
B	25-70	2.05	3.5	0.34	5.9	3.9	3.5	5.3	0.8	3.7	1.6	29.64
W	70-	1.35	2.3	0.18	7.3	4.0	3.7	4.1	11.1	0.8	0.6	31.78

Table 9. Soil characteristic of the Izerskie Mountains location. Jakuszyce, existing spruce stand, middle of the Kamienna slope

Horizon	Depth	C org.	Org. mat.	N tot.	C/N	pH		Exchangeable mg/100 g of soil				Al^{+3} mg/100 g soil
	cm	%	%	%		H_2O	KCl	K	P	Mg	Ca	
AH	1-4	28.63	49.4	0.32	88.9	3.8	3.1	18.2	6.8	0.9	2.0	79.47
A1A2	4-12	2.87	4.9	0.20	14.5	3.5	3.0	6.9	1.0	1.7	0.4	86.84
A2B	12-38	2.44	4.2	0.21	11.4	4.1	3.9	4.1	5.0	2.2	0.4	30.04
B	38-55	0.96	1.6	0.10	9.7	4.2	3.9	3.0	0.3	1.8	3.0	29.33
BC	55-70	n.d.	n.d.	n.d.	n.d.	4.4	4.1	1.8	0.3	1.0	3.2	25.44

Table 10. Soil characteristic of the Izerskie Mountains location. Rozdroże Izerskie, existiing spruce stand

Hori-zon	Depth	C org.	Org. mat.	N tot.	C/N	pH		Exchangeable mg/100 g of soil				Al^{+3} mg/100g soil
	cm	%	%	%		H_2O	KCl	K	P	Mg	Ca	
AH	2-6	23.55	40.6	1.68	14.0	3.4	2.7	27.4	9.9	9.0	1.6	98.10
A1+2	6-14	1.33	2.3	0.27	4.9	3.8	3.5	4.1	9.5	1.9	0.4	28.00
A2(B)	14-27	3.22	5.5	0.42	7.6	3.2	2.8	5.8	1.5	0.8	0.4	35.88
B	27-76	0.52	0.9	0.01	40.0	4.4	4.3	5.3	5.8	0.1	2.4	22.48
C	76-80	n.d.	n.d.	n.d.	n.d.	4.2	4.1	5.8	1.5	2.7	0.6	30.46

CONCLUDING REMARKS

1. Concentration of sulphur dioxide and nitrogen dioxide (or nitrogen oxides) between the Izerskie Mountains and the Beskidy Mountains sites, do not differ markedly. At both localities they are close or higher than recently recommended critical levels for these pollutants. Short-term continuous measurements have shown higher peak concentration of sulphur dioxide at the Izerskie Mountains site.

2. In the Beskidy Mountains sites, higher concentration of sulphur dioxide has been measured at the higher elevation. Differences were much larger during the heating season as compared to the growing season. It is not clear, however, whether this is a local or more general phenomena.

3. Soil properties from the Izerskie Mountains and the Beskidy Mountains sites do not differ markedly. Ratio C/N in the top soil at higher elevations is very large. This may suggest a slow decomposition of organic matter.

4. Total sulphur concentration in spruce needles is the highest at the Izerskie Mountains site. No differences have been found between needles from lower and higher elevations in Beskidy Mountains. These results are not consistent with measurements of sulphur dioxide concentration data from different locations and elevations.

5. Low concentration of some macronutrients in the soil are reflected in their concentration in needles. Ca and Mg are in the lower levels recommended as sufficient.

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REFERENCES

Convention on Long-Range Transboundary Air Pollution 1990, Draft Manual on: 1. Methodologies and Criteria, and 2. Scientific Background Materials.

Gussone H.A. 1964, Faustzahlen für Düngung im Walde, BLV-Verlag, München.

Hüttl R.F. & Zöttl H.W. 1986, Diagnostische Düngungsversuche in geschädigten Nadelbaumbeständen Südwestdeutschlands, (in:) KfK-PEF IMA-Querschnittsseminar

"Restabilisierungsmassnahmen — Düngung": 3-14, Kernforschungszentrum Karlsruhe, 15-16.04.1986.

Krause G.H.M. & Prinz B. 1989, Experimentelle Untersuchungen der LIS zur Aufklärung möglicher Ursachen der neuartigen Waldschäden, LIS-Berichte 80, Landesanstalt für Immissionsschutz Nordrhein-Westfalen, Essen.

Lange O.L., Welkert R.M., Welder M., Gebel J. & Heber U. 1989, Photosynthese und Nährstoffversorgung von Fichten aus einem Waldschadensgebiet auf basenarmem Untergrund, *Allgem. Forst Zeitschr.*, 3: 55-64.

Environment Protection 1991, GUS (Main Statistics Office), Warszawa.

Stefan K. 1982, Darstellung der Immissions- und Ernährungssituation der Wälder im Raum Gailitz-Arnoldstein mit Hilfe chemischer Analysen von Fichtennadeln, (in:) Halbwachs G. (ed.), *Das immissionsökologische Projekt Arnoldstein, Verlag des Naturwissenschaftlichen Vereins für Kärnten*, Klagenfurt.

Tesar V. & Temmlova B. 1981, Content of Silicon and Sulphur in Spruce Needles as a Demonstration of an Accelerated Aging of the Organism by Action of Immissions, *Communicat. Inst. Forestalia Cechosloveniae* 12: 147-157.

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MAPPING AIR POLLUTION IN POLAND BY MEASURING HEAVY METAL CONCENTRATION IN MOSSES

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Abstract: Concentrations of heavy metals in *Pleurozium schreberi* (Brid.) Mittl., a common moss species, were used to indicate relative levels of air pollution by the heavy metals: cadmium (Cd), chromium (Cr), nickel (Ni), vanadium (V), copper (Cu), zinc (Zn), lead (Pb), and iron (Fe), in Poland. *Pleurozium* was sampled from 147 localities regularly distributed throughout the country. Differences were found in heavy metal levels in mosses representing particular localities, the greatest variations being related to Cd and Pb. Four contamination zones were distinguished in Poland according to the metal concentration values in mosses. The highest metal concentration was recorded in the mosses of southern Poland and the lowest recorded was in northern and eastern Poland. The contamination of the environment in Poland by heavy metals, determined by moss analysis, correlates well with the distribution of emission sources and with forest injury in the country. Moss contamination with heavy metal in Poland is higher than in Scandinavian countries.

Key words: spatial distribution, heavy metals, Poland, *Pleurozium schreberi* (Brid.) Mittl., Poland.

INTRODUCTION

Several studies have shown that mosses are an efficient accumulator of heavy metals (Tyler 1970, 1990; Grodzińska 1978; Masche 1981; Brown 1984). For this reason, mosses can serve as a tool for studies on the distribution of heavy metal deposition in local and nation-wide surveys.

Mosses are used in many countries for long-term monitoring of environmental contamination by heavy metals (Ruhling & Tyler 1971; Grodzińska 1978, 1990; Grodzińska et al. 1990; Folkeson 1979; Steinnes 1980; Thomas & Hermann 1980; Ruhling et al. 1987, 1992; Sarkela & Nuorteva 1987; Thoni & Hertz 1987).

Mosses have been used as an indicator of metallic environmental contamination for more than 20 years (Ruhling & Tyler 1969). Numerous national and regional surveys have shown that mosses give a very precise reflection of the atmospheric pollution status (Ruhling & Tyler 1971; Groet

1976; Grodzińska 1978, 1990; Folkeson 1979; Steinnes 1980; Gydesen et al. 1983). Ruhling et al. (1987) and Tyler (1990) demonstrated that heavy metal concentration in mosses (Cd, Ni, Cu, Pb, Zn, Fe) is clearly correlated ($r = 0.95$) with their level in precipitation. According to Ross (1990) for Cd, Cu, Fe, Pb, Zn, and V there are significant correlations between metal wet deposition as measured in bulk collectors and moss concentration values. Cr and Ni concentration levels in mosses, however, were not correlated with atmospheric deposition estimates. Therefore, Ross (1990) suggests estimating Cr and Ni deposition analyzing bulk estimates. For other metals, the choice of method (moss or gauge technique) depends on the goals of the experiment. Tyler (1990), in turn, is of the opinion that there is no reason to believe that the gauge data represent a better estimate of the true situation, and that differences might partly be because the geometry and surface properties of gauge and moss differ to an appreciable degree. Tyler (1990) still recommends the use of moss, especially feather moss (*Pleurozium*, *Hylocomium*) as a sensitive indicator of environmental contamination with heavy metals.

This paper presents the regional atmospheric deposition of heavy metals in Poland using mosses; to indicate the localization of heavy metal emission sources and to compare the results with similar investigations carried out in neighbouring countries.

MATERIAL AND METHOD

Samples of feather moss *Pleurozium schreberi* (Brid.) Mittl. were collected from 147 localities in Poland from May through September 1990. The samples were taken from openings in coniferous and mixed forests. The sampling sites were located at least 300 m from main roads and at least 100 m from any road. At each sampling site 10 subsamples were collected and mixed in the same bag.

The unwashed mosses were separated into green and brown parts. The green parts usually represented 2- to 3-year increments, whereas the brown parts were older (4 to 5 years). Samples were dried to constant weight at 85°C. Dry moss samples (green parts) of about 2.5 g each were subsequently wet-digested in concentrated nitric acid. The brown parts of the mosses were stored for further use.

Cd, Cr, Cu, Fe, Ni, Pb, Zn, and V levels were measured employing atomic absorption spectrophotometry (AAS) with atomization in an air acetylene flame.

The results of the metal content analyses and the coordinates of the sampling sites were computerized and displayed in the form of contour maps. This procedure involved the transformation of the data from the irregularly spaced sampling sites to a regular grid pattern. Poland was divided into 62 large squares (80 × 80 km); every large square was further divided into 100 basic squares (8 × 8 km). Localities where moss samples were collected are shown on the map (Fig. 1).

Maps were drawn by using the isolines method — ISOLIN (Dytczak et al. 1987; Molski et al. 1987). ISOLIN is a FORTRAN package generating and plotting contour lines. ISOLIN can generate contour lines from data regarding the value of a given function F (x, y) at irregularly distributed points. The package can approximate the specified data FORTRAN 77 and, as such, conforms to ANSI X 3.9 — 1978. The program was compiled with a Microsoft FORTRAN 77, version 3.30 computer.

The difference between metal concentration values in two areas with different patterns on the map may not be statistically significant. The maps are a graphic representation of a large data set.

RESULTS

Heavy metal concentrations in the moss (*Pleurozium schreberi*) vary greatly throughout Poland. Cd and Pb show the greatest concentrations, about 30-fold amplitude, Fe and Zn are somewhat lower (approximately 15-fold), whereas V, Cr, Ni, and Cu are characterized by the lowest (about 6- to 10-fold) amplitude (Table 1).

In view of such a wide differentiation of concentration values, several concentration classes were established for each element. And thus for Zn there were nine classes, for Fe — eight, for CD, Pb, and V — seven, for Cr and Cu — six, and for Ni — five. Territories wherein mosses accumulated metals in the amounts characteristic of a given class were marked on the map as separate zones. Eight maps illustrate the spatial distribution of Cd, Cr, Ni, V, Cu, Pb, Zn, and Fe concentration levels in mosses in Poland (Fig. 2-9).

The highest values were encountered in mosses collected in southern Poland. Concentrations decreased in north and northeastern Poland. Such a pattern was the most discernible for Cd, Cr, Pb, and Zn (Figs. 2, 3, 7, 8), and lesser for Ni, V, a nd Fe (Figs. 4, 5, 9). The distribution of the latter three elements is closely related to local emission sources (e.g., oil refineries and chemical factories). The distribution of Cu has a different pattern, being mostly restricted to the Copper Basin in west Poland (Fig. 6). The areas with the highest and the lowest heavy metal concentration values occupy a small percentage of Poland's area. More than 80% of Poland's territory falls into a medium zone of moss metal concentration (Fig. 2-9).

To present a more generalized picture of the environmental pollution with heavy metals, four zones were established in Poland; i.e., a relatively-clean, moderately-polluted, heavily-polluted, and very heavily-polluted zone (Table 1, Fig. 10). The borderline between the relatively clean and moderately-polluted zones is delineated by isolines of minimal levels of Fe, Cr, and Ni; the border between the moderately-polluted and heavily-polluted zones is set by isolines of minimal concentration values for Cd and Zn; whereas, the very

Table 1. Concentration of heavy metals (microgram d. wt) in green parts of *Pleurozium schreberi* in different pollution zones in Poland in 1990. Zones: A — relatively clean, B — moderately polluted, C — heavily polluted, D — very heavily polluted

Element	Pollution zones																			
	A					B					C					D				
	N	Mean (SD)	Median	Min.	Max.	N	Mean (SD)	Median	Min.	Max.	N	Mean (SD)	Median	Min	Max	N	Mean (SD)	Median	Min.	Max
Cd	43	0.33 (0.06)	0.33	0.2	0.41	55	0.41 (0.11)	0.41	0.19	0.77	42	0.81 (0.37)	0.74	0.28	1.77	7	2.36 (1.81)	1.14	0.90	5.20
Cr	43	1.5 (0.47)	1.5	0.97	3.98	55	2.5 (0.74)	2.4	1.2	5.0	42	3.0 (1.08)	2.8	1.8	6.6	7	5.6 (1.43)	5.6	3.5	8.0
Ni	43	1.7 (0.32)	1.7	1.0	2.8	55	2.6 (0.81)	2.4	1.4	5.8	42	2.9 (0.97)	2.7	1.5	6.3	7	4.1 (1.20)	3.8	2.9	6.3
V	43	4.1 (1.07)	3.8	2.4	7.9	55	5.2 (1.68)	4.8	1.7	9.8	41	5.9 (2.63)	5.3	2.6	15.0	7	10.1 (3.44)	9.7	6.2	16.8
Cu	43	7.4 (1.26)	7.3	4.9	9.8	55	11.7 (5.29)	10.2	5.6	28.6	42	11.1 (2.59)	10.5	7.0	19.1	7	14.7 (1.85)	14.1	12.8	18.0
Pb	43	15.2 (3.05)	15.2	8.0	25.7	55	24 (8.94)	21.8	12.5	66.1	42	38.8 (17.5)	33.0	15.2	79.0	7	114.2 (85.4)	57.3	48.1	269.4
Zn	43	46 (6.43)	46	33	65	54	55 (12)	52	33	87	42	79 (26)	68	49	142	7	206 (136.4	151	74	463
Fe	43	781 (385)	677	386	2883	55	1548 (583)	1402	650	2960	42	1696 (901)	1424	815	4926	7	4331 (1513	4333	2030	6828

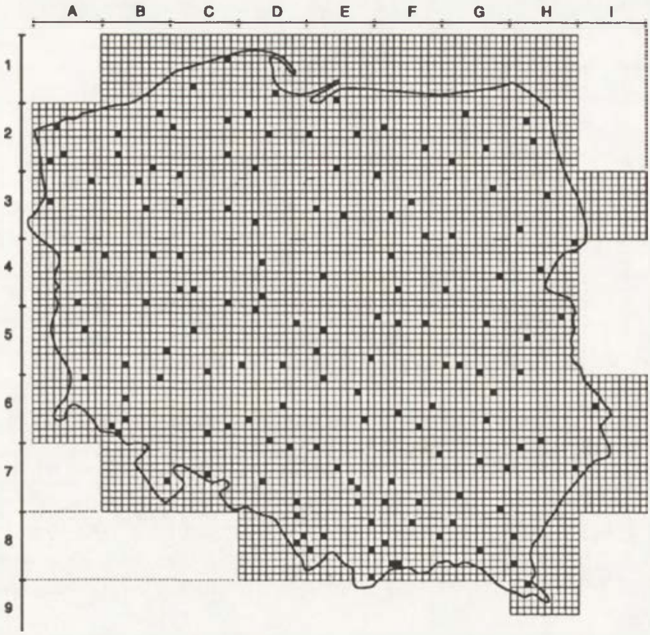

Fig 1. Sampling sites in Poland for moss of the species *Pleurozium schreberi*

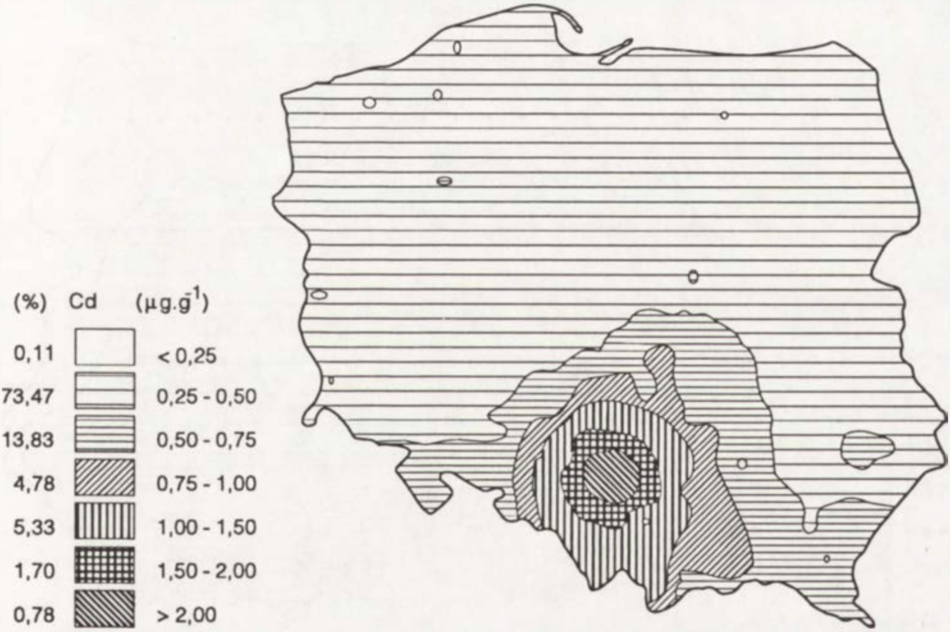

Fig. 2. Cd concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

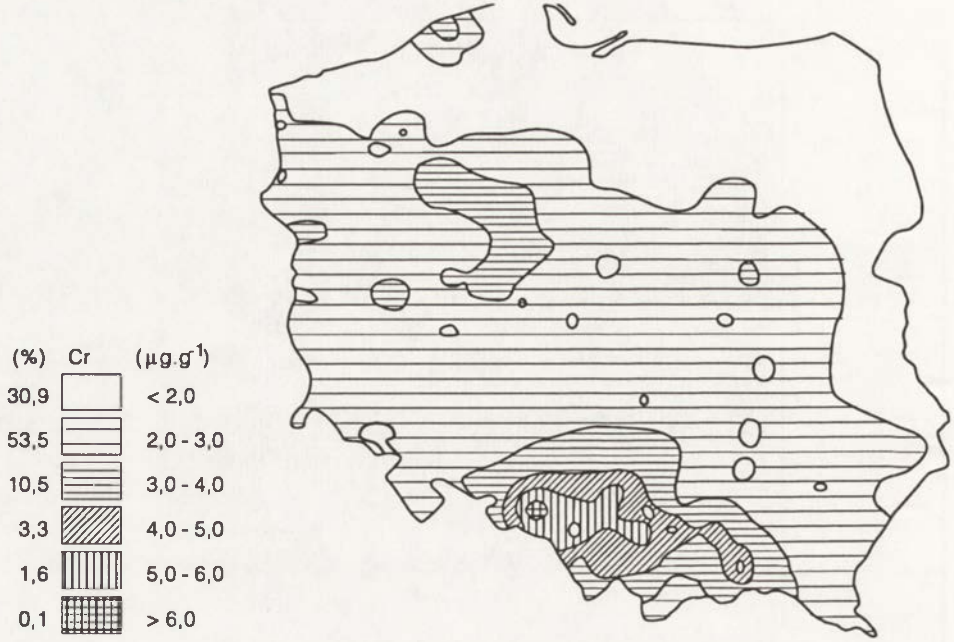

Fig. 3. Cr concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

Fig. 4. Ni concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

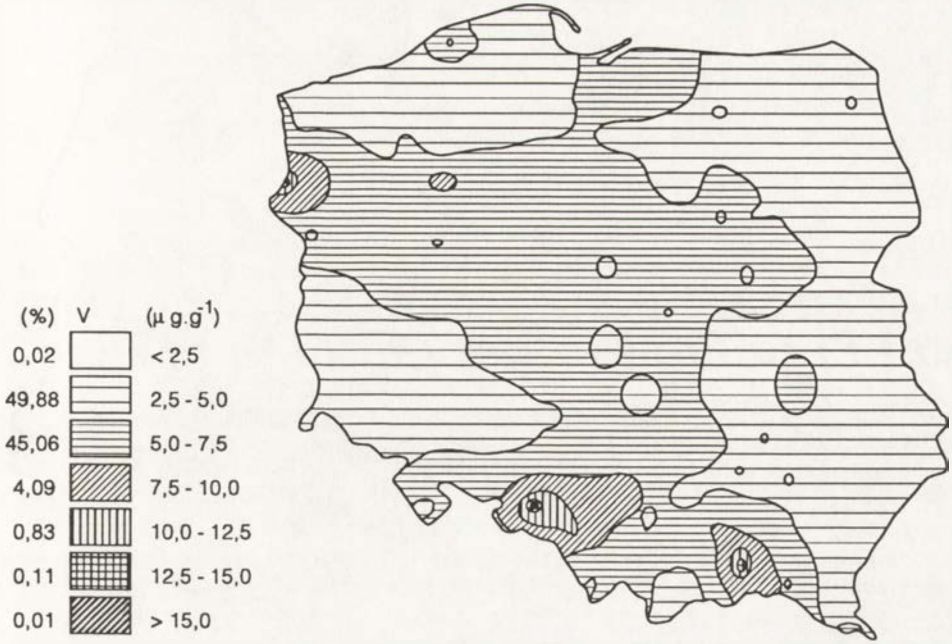

Fig. 5. V concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

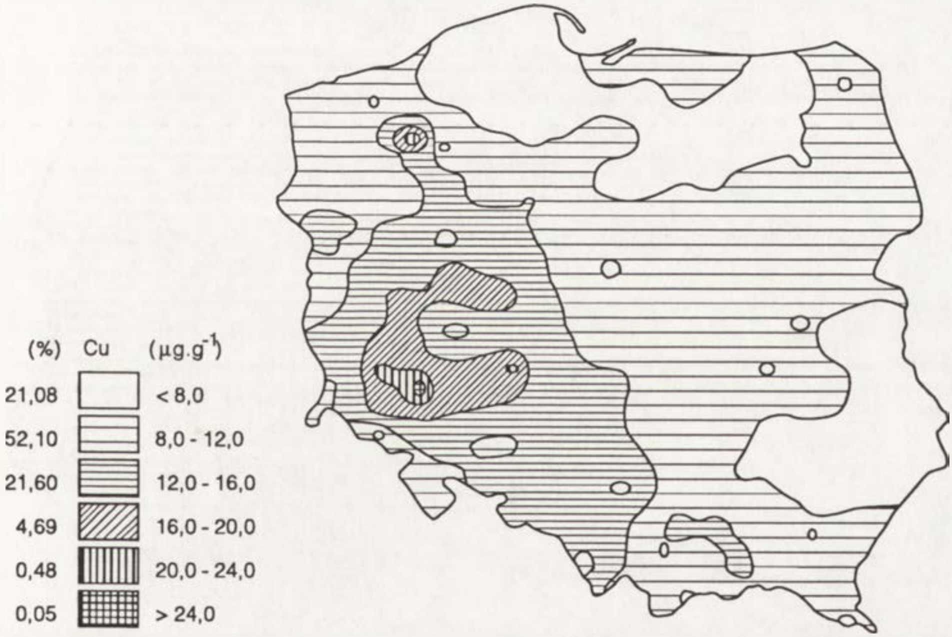

Fig. 6. Cu concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

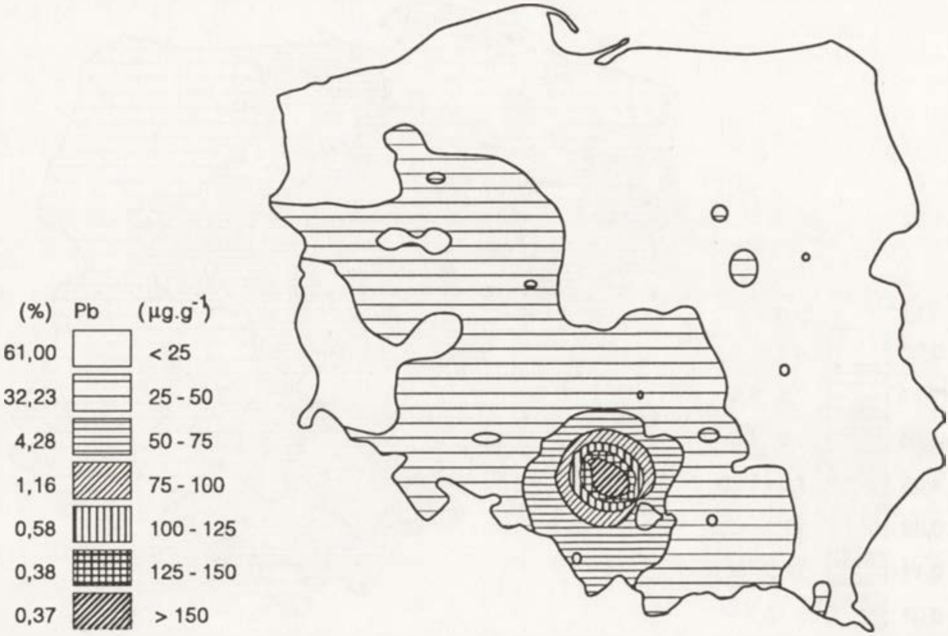

Fig. 7. Pb concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

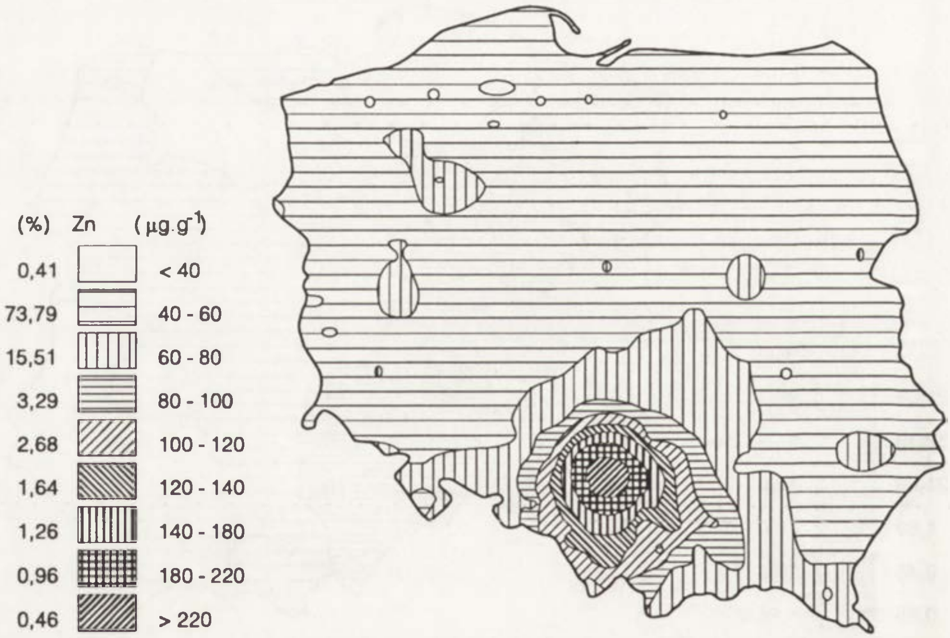

Fig. 8. Zn concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

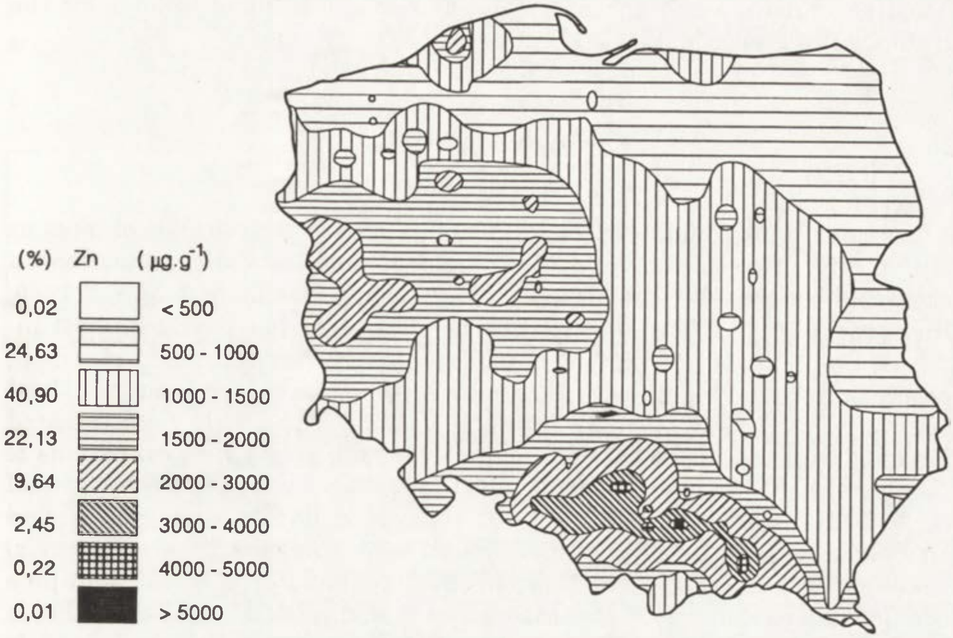

Fig. 9. Fe concentration values (mg g^{-1} dwt) in *Pleurozium schreberi* in Poland and percentage of the country area representing particular concentration classes

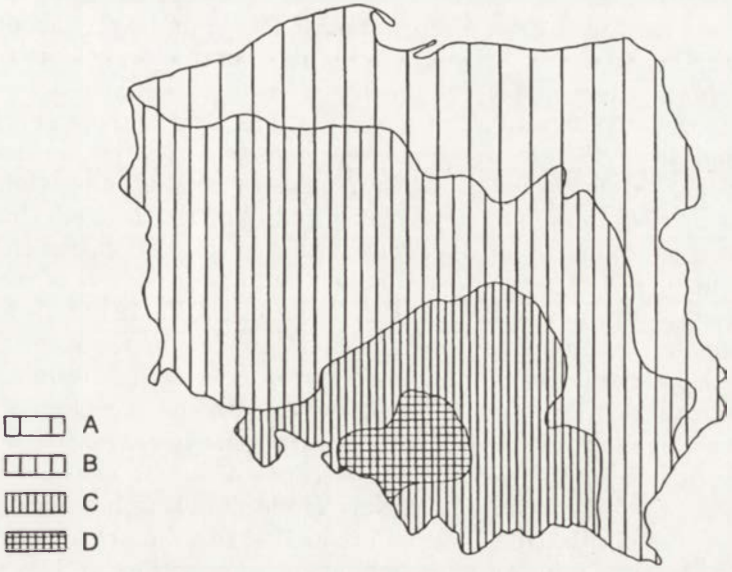

Fig. 10. Zones of heavy metal pollution in Poland defined by moss of the species *Pleurozium schreberi*. Zones: A — relatively clean, B — moderately polluted, C — heavily polluted, D — very heavily polluted

heavily-polluted zone has been established on the basis of isolines for the majority of metals (Cd, Pb, Zn, Fe, Cr, V).

DISCUSSION

The picture of contamination in Poland, achieved with the use of moss as an indicator, corresponds to the distribution of emission sources and areas of ecological hazard (Kassenberg & Rolewicz 1985; Kassenberg & Marek 1986; Kassenberg 1990; GUS 1990, 1991). Therefore, it is the southern, most industrialized part of Poland that is subjected to the heaviest dust deposition, additionally receiving metallic dust carried over the border from industrial centres located in Czech and Slovak Republics. The poorly industrialized areas — north and northeastern Poland — are, thus, the cleanest regions of the country. Pollution zones determined in this paper on the basis of metal content in mosses correspond to the zones delineated by Molski and Dmuchowski (1990) on the basis of metal values in pine (*Pinus sylvestris*) needles. Since mosses are a more effective accumulator of metal than pine needles, the concentration of these elements, and especially of Zn and Pb, is much higher. The contamination of mosses by heavy metals in Poland is much higher than in Scandinavian countries. Mosses from southern Poland contain four times more Fe than mosses in the southern part of Sweden, about three times more Cd and Pb, and about two times more V and Cr (Table 2). When northern Poland is compared with the areas in northern Sweden, it appears that the concentration of Pb, V, and Fe is about three times higher, Cd and Cr about two times higher, and the level of Zn and Ni is about 30% higher. Except for Fe, the levels of all the analyzed metals in mosses growing in northern Poland are almost identical to those of southern Scandinavian moss. There are no large industrial centers in northern Poland, nor are there any major urban agglomerations. On the other hand, in southern Sweden large industrial plants and cities are located. One could then expect a difference to occur between heavy metal concentration values in moss samples collected in the two areas. Yet, similar levels of metals in moss samples testify to similar metal deposition. In the 1970's and 1980's, heavy metal concentration values in mosses growing in southern Sweden were much higher than in the 1990's (Gydesen et al. 1983; Ruhling et al. 1987); approximating the present metal levels (with the exception of Fe) in southern, heavily industrialized Poland. The decrease in concentration levels for most metals in southern Sweden is because of better emission control legislation, better filter technique, closure of old polluting industrial plants — not because of decreased industrial production (Ruhling et al. 1987). The technological level of industry in Poland is much lower than in Sweden and, therefore, even in poorly industrialized regions there is relatively more metallic elements in the air than in southern Sweden. This is the reason for comparable concentration values of heavy metals in moss collected in northern Poland and southern Sweden.

Table 2. Median concentration of heavy metals (micrograms g^{-1} dwt) in green parts of *Pleurozium schreberi* in Poland and Sweden in 1990

Element	Poland		Sweden**	
	southern*	northern	southern	northern
Cd	0.84	0.33	0.31	0.14
Cr	3.0	1.5	1.6	0.8
Ni	2.7	1.7	1.7	1.3
V	6.0	3.8	3.1	1.3
Cu	11.0	7.3	6.2	4.6
Pb	40.4	15.2	14.9	5.3
Zn	74	46	48	35
Fe	1552	677	390	200

* southern Poland — C and D zones;
** Ruhling et. al., 1992

CONCLUSIONS

The correspondence between the distribution of emission sources and the level of heavy metals in mosses in various regions of Poland confirms the validity of mosses as an indicator of heavy metal environmental contamination. The results presented in this paper provide a basis for further studies of air pollution impact on ecosystem. In southern Poland (C and D zones; Fig. 10), such studies are being carried out by ecologists from the Institute of Botany, Polish Academy of Sciences in Kraków.

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REFERENCES

Brown D.H. 1984, Uptake of mineral elements and their use in pollution monitoring, (in:) Dyer A.F. & Duckett J.G. (eds.), *The Experimental Biology of Bryophytes*, pp.229-255, Academic Press, London.

Dytczak M., Lipiński D.M. & Wolszczak L. 1987, ISOLIN a map plotting package, Warsaw Technical University, Manuscript.

Folkeson L. 1979, Interspecies calibration of heavy-metal concentrations in nine mosses and lichens applicability to deposition measurements, *Water, Air and Soil Pollution* 11: 253-260.

Grodzińska K. 1978, Mosses as bioindicators of heavy metal pollution in Polish national parks, *Water, Air and Soil Pollution* 9: 83-97.

Grodzińska K. 1990, Long-term monitoring in the National Parks of Poland, (in:) Grodziński W., Cowling E.B. & Breymeyer A.J. (eds.), *Ecological Risks — Perpectives from Poland and the United States*, pp. 232-246, National Academy Press, Washington DC.

Grodzińska K., Szarek G. & Godzik B. 1990, Heavy metal deposition in Polish National Parks — changes during ten years, *Water, Air and Soil Pollution* 49: 409-19.

Groet S.S. 1976, Regional and local variations in heavy metal concentrations of bryophytes in the northeastern United States, *Oikos* 27: 445-56.

GUS (Main Statistical Office) 1990, Raport o stanie, zagrożeniu i ochronie środowiska 1990, Warszawa.

GUS (Main Statistical Office) 1991, Ochrona środowiska (Environmental Protection 1991), Warszawa.

Gydesen H., Pilegaard K., Rasmussen L. & Ruhling A. 1983, Moss analyses used as means of surveying the atmospheric heavy metal deposition in Sweden, Denmark and Greenland in 1980, *Bulletin SNVPM* 1670: 1-44.

Kassenberg A.T. 1990, Diagnosis of Environmental Protection Problems in Poland, (in:) Grodziński W., Cowling E.B. & Breymeyer A.J. (eds.), *Ecological Risks — Perpectives from Poland and the United States*, pp. 355-371, National Academy Press, Washington DC.

Kassenberg A. & Marek M.J. 1986, *Ekologiczne aspekty przestrzennego zagospodarowania kraju* (Ecological aspects of the spatial development of the country), 174p., Warszawa, PWN (State Scientific Publishers).

Kassenberg A. & Rolewicz C. 1985, Przestrzenna diagnoza ochrony środowiska w Polsce (Spatial diagnosis of environmental protection in Poland), Komitet Przestrzennego Zagospodarowania Kraju PAN, *Studia* 89:1-125, Warszawa PWN.

Maschke J. 1981, Mosse als Bioindikatoren von Schwermetall Immisionen, *Bryophytorum Bibliotheca* 22: 1-492.

Molski B., Glebicki C. & Dmuchowski W. 1987, Data management computer system of air pollution impact on forests used in the Botanical Garden of the Polish Academy of Sciences and its relation to existing systems in Poland, (in:) Kairinkstis L., Nilsson S. & Straszak A. (eds.), *Proceedings of the Workshop on Forest Decline and Reproduction: Regional and Global Consequences*, Kraków, Poland (23-27 March, 1987), IIASA, Laxenburg, Austria.

Molski B. & Dmuchowski W. 1990, Distribution and movement of selected elements in Poland using pine needles analysis, (in:) Grodziński W., Cowling E.B. & Breymeyer A.J. (eds.), *Ecological Risks — Perpectives from Poland and the United States*, pp. 215-231, National Academy Press, Washington DC.

Ross H.B. 1990, On the use of mosses (*Hylocomium splendens* and *Pleurozium schreberi*) for estimating atmospheric trace metal deposition, *Water, Air and Soil Pollution* 50: 63-76.

Ruhling A. & Tyler G. 1969, Ecology of heavy metals — a regional and historical study, *Botaniska Notiser* 122: 248-59.

Ruhling A. & Tyler G. 1971, Regional differences in the deposition of heavy metals over Scandinavia, *J. Applied Ecology* 8: 497-507.

Ruhling A., Rasmussen L., Pilegaard K., Makinen A. & Steinnes E. 1987, Survey of atmospheric heavy metal deposition in the Nordic countries in 1985 monitored by moss analyses, *Nord* 1987, 21: 1-44.

Ruhling A., Brumelis G., Goltsova N., Kvietkus K., Kubin E., Liiv S., Magnusson S., Makinen A., Pilegaard K., Rasmussen L., Sander E. & Steinnes E. 1992, Atmospheric heavy metal deposition in Northern Europe 1990, *Nord* 1992, 12: 1-41.

Sarkela M. & Nuorteva P. 1987, Levels of aluminium, iron, zinc, cadmium and mercury in some indicator plants growing in unpolluted Lapland, *Annales Botanici Fennici* 24: 301-05.

Steinnes E. 1980, Atmospheric deposition of heavy metals in Norway studied by the analysis of moss samples using neutron activation analysis and atomic absorption spectrometry, *Journal of Radioanalytical Chemistry* 58: 387-91.

Thomas W. & Herrmann R. 1980, Nachweiss von Chlorpestiziden, PCB, PCA und Schwermetallen mittels epiphytischer Moose als Biofilter entlang eines Profils durch Mitteleuropa, *Staub-Reinhalt. Luft* 40: 440-44.

Thoni L. & Hertz J. 1987, Moose als Biomonitoren fur die flachenhafte Abschatzung der Schwermetallbelastung in der Schweiz, *VDJ Berichte* 609, 755-63.

Tyler G. 1970, Moss analysis — a method for surveying heavy metal deposition, Proceedings of the Second International Clean Air Congress: 129-32, Washington DC.

Tyler G. 1990, Bryophytes and heavy metals: a literature review, *Botanical J. Linnean Society* 104: 231-53.

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HEAVY METALS IN FOREST LITTER: A CHEMICAL TIME-BOMB

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Abstract: Heavy metal accumulation in forest litter has been well documented. Heavy metal ions bond efficiently to the soil organic matter and are adsorbed on clay particles. Large parts of heavy metals are also incorporated into the cells of soil micro-organisms (fungal hyphae in particular). Thus, even in the areas of a low pollution-level, heavy metals can build up to high levels, with time, and eventually constitute a dangerous burden of potentially toxic substances in forest ecosystems. Under typical soil conditions, this burden can remain immobilized for a long time without visible signs of ecosystem degradation. In many forest ecosystems, however, especially those on naturally acidic soils, only a minor change in soil pH can rapidly mobilize a large proportion of accumulated heavy metals. This increases the concentration of bioavailable metals to the levels toxic to soil micro-organisms and plant roots. Disruption in decomposition processes, nutrient cycles, and root-fungi interact ions will occur as a result.

Key words: heavy metals, forest litter, accumulation, Poland.

INTRODUCTION

Heavy metals are well known for their ability to bond to the soil organic matter. High levels of some metals accumulated in peat soils were found in the industry-polluted regions (e.g., Livett 1988). An increasing concern with heavy metal contamination of terrestrial ecosystems have led to numerous studies which have proven that in forest ecosystems under the influence of industrial emissions accumulation of heavy metals occurs in a litter layer (e.g., Rühling & Tyler 1973; Berg et al. 1991). In recent studies, Berg et al. (1991), Laskowski and Berg (1993), and Laskowski et al. (1993a) show that some heavy metals increase in concentration during litter decomposition and also in forests unexposed to direct heavy metal pollution. Among heavy metals studied by Laskowski et al. (1993a) and Laskowski (1992), Fe, Zn, Pb, and Cd revealed a clear increase in concentration during litter decomposition in all forests studied (Figs. 1-4), despite the differences in forest and soil types and in the pollution situation. Three ecosystems were located at relatively unpolluted areas: oak-hornbeam forest (OH1) and two pine-beech stands (PB1 and PB2). The fourth ecosystem studied was the oak-hornbeam forest located in the vicinity of a large steel-mill (OH2). More details on these studies can be found in Laskowski et al. (1993a) and Laskowski and Berg (1993).

HEAVY METALS TOXICITY

According to our present knowledge, iron does not create any serious risk of toxicity to plants in a broad range of concentrations of up to 5% in soil (Kabata-Pendias & Pendias 1979). This level was not reached in decomposing litter, even in the area polluted by the steel-mill (Fig. 1). The effect of high iron concentrations on soil micro-organisms is not recognized. However, a high rate of iron accumulation observed in areas under industrial emissions can contribute to mobilization of other heavy metals accumulated in litter layer by saturating the soil/litter system with metal ions. With substantially lower concentrations in unpolluted ecosystems, iron still reveals a fast increase in concentration in the course of litter decomposition (3 to 9-fold during 2-3 years; Fig. 1).

In contrast to iron, zinc toxicity to plants and micro-organisms is well-recognized. Most plants exhibit metabolic disorders at concentrations of 100-400 microgram Zn g^{-1} soil (Kabata-Pendias & Pendias 1979, and the literature cited therein). Laskowski et al. (1993b) found a significant decrease in the respiration rate of litter treated with 1000 microgram Zn g^{-1} dwt on the third day after experimental treatment. The final concentrations of Zn in decomposing litter reached levels of ca. 170-500 microgram g^{-1} in older fractions (Fig. 2). In this case, the risk of direct zinc toxicity to plants and soil and litter organisms cannot be excluded.

Lead reached the levels of ca. 35-100 microgram g^{-1} dwt in older litter fractions (Fig. 3), and these levels do not seem to be toxic to plants (Kabata-Pendias & Pendias 1979). In our earlier experiments we did not find any decrease in the respiration rate of forest litter treated with a dose of lead as high as 500 microgram g^{-1} dwt. It can be concluded, thus, that at undisturbed forest stands the direct lead toxicity is unlikely. Additionally, lead is characterized by the high affinity to the soil organic fraction and clay minerals, being relatively immobile in most forest soils if not strongly acidic.

Natural levels of cadmium in soils of unpolluted regions can range from ca. 0.01-2 microgram g^{-1} (Kabata-Pendias & Pendias 1979). In the course of litter decomposition, cadmium concentration can increase ca. 2.5 to 4.3-fold during 2-3 years, reaching levels up to approximately 3 microgram g^{-1} at undisturbed sites (Fig. 4). Data on cadmium toxicity, although abundant, are frequently contradictory. Minimum concentrations toxic to plants were found to be as low as 0.01-5 microgram g^{-1} on a sandy soil (cf. Balsberg Pahlsson 1989). On the other hand, some plant species are not affected by concentra-

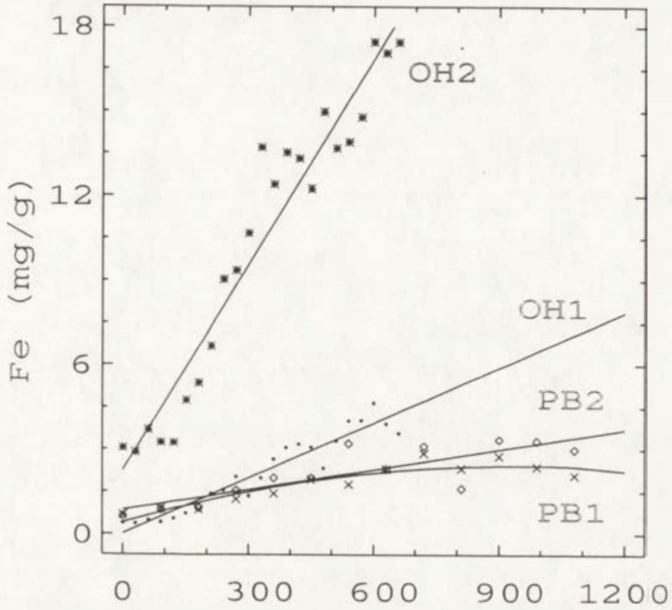

Fig. 1. Concentrations of iron in decomposing forest litter; all regressions significant at $P < 0.001$; symbols described in text

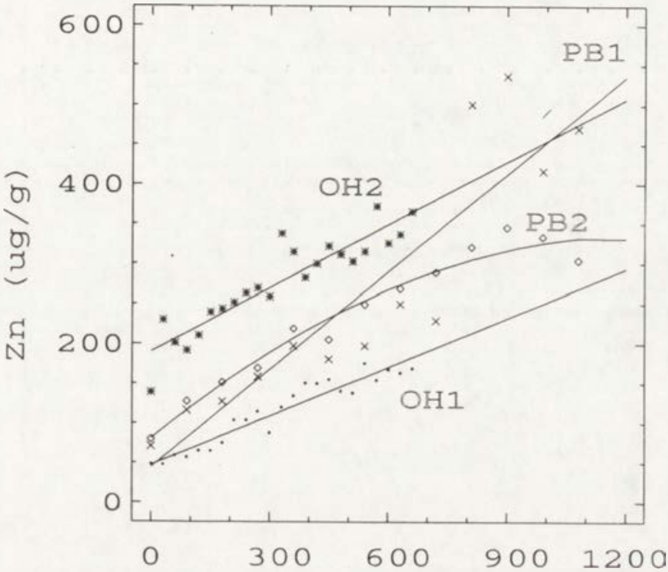

Fig. 2. Concentrations of zinc in decomposing forest litter; all regressions significant at $P < 0.001$; symbols described in text

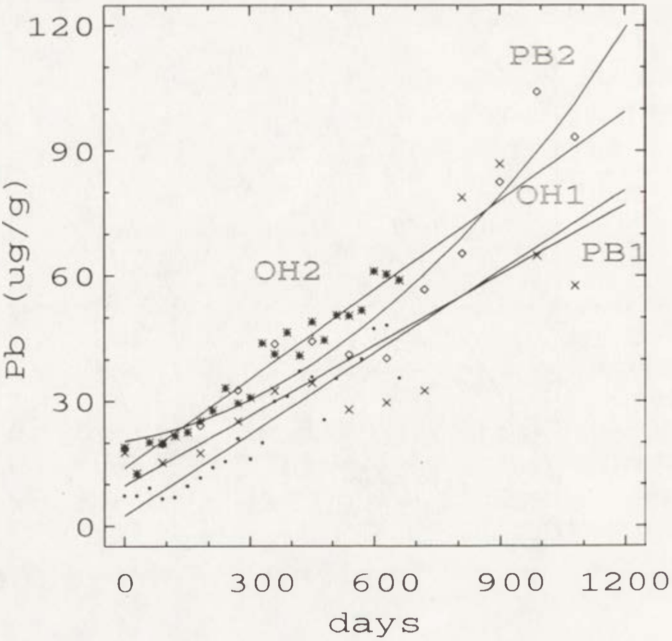

Fig. 3. Concentrations of lead in decomposing forest litter; all regressions significant at $P < 0.001$; symbols described in text

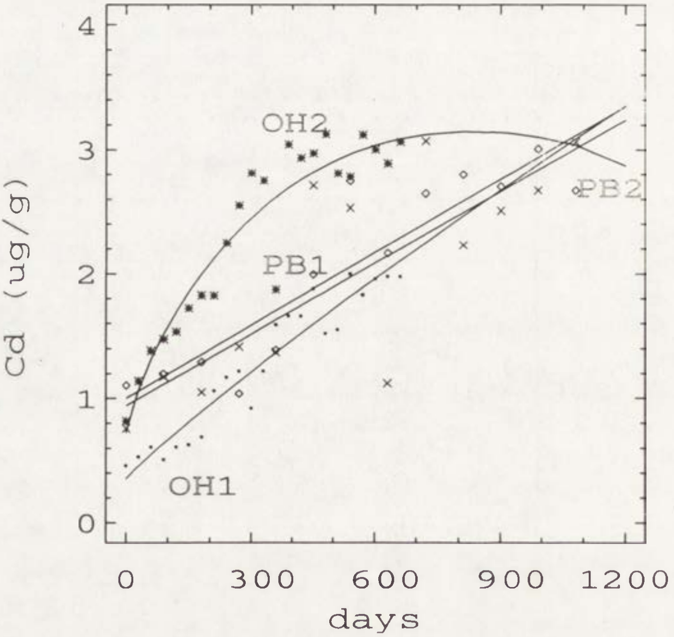

Fig. 4. Concentrations of cadmium in decomposing forest litter; OH1, OH2 and PB2 — $P < 0.001$; PB1 - $P < 0.01$; symbols described in text

tions up to ca. 600 microgram g^{-1} soil (Kabata-Pendias & Pendias 1979). Also the inhibitory effect of cadmium on litter decomposition and respiration rates have not been clearly defined. For instance, Bewley and Stotzky (1983) did not find any retardation of the respiration rate of soil treated with 1000 microgram Cd g^{-1} dwt.; while Chang and Broadbent (1981) showed a decrease in the respiration rate of the soil samples treated with 50 microgram g^{-1} dwt. Nevertheless, it seems that cadmium levels that were reached during the decomposition of unpolluted forest litters are too low to affect the functioning of the soil and litter system.

It has been shown in many studies that elevated levels of heavy metals in litter retard the decomposition rate (e.g., Rühling & Tyler 1973; Strojan 1978; Coughtrey et al. 1979; Killham & Wainwright 1981; Bengtsson et al. 1988; Grodziński et al. 1990). This effect is probably caused by the toxicity of heavy metal ions to decomposers (Babich & Stotzky 1974; Bengtsson & Rundgren 1984; Rühling et al.1984) and, thus, should be related to the soluble fraction of heavy metals rather than to their total concentration in soil and litter. Also, the toxicity to plants depends on heavy metal concentration in soil solution. This may be the reason for the discrepancy in data on heavy metal toxicity to plants and soil organisms.

HEAVY METALS MOBILITY

Generally, soils with a high content of clay minerals and organic matter can immobilize large amounts of heavy metal ions at approximately neutral pH. The metal burden can increase even in ecosystems not exposed to a heavy atmospheric pollution (Fig. 1-4) without affecting ecosystems' functions until no decrease in soil pH occurs. A drop in pH below ca. 6.0-5.5, however, induces a rapid increase in solubility of most heavy metals. For instance, Christensen (1984) found that decreasing pH by two units lowered the equilibrium isotherm for cadmium more than 75%,

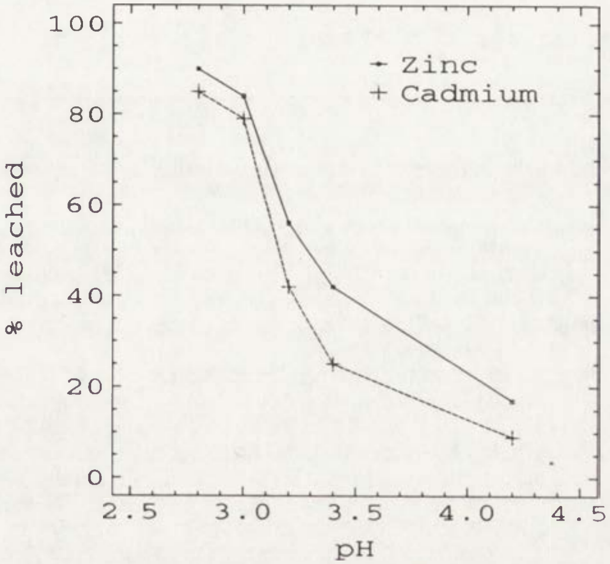

Fig. 5. Percent of total content of zinc and cadmium leached from soil at different pH of leaching solutions; data from Tyler (1978)

and Boekhold and Van der Zee (1992) proved that the effect of pH on the behaviour of Cd is the most important among soil factors. Kabata-Pendias and Pendias (1979) report zinc mobility in acid soils to be 10-fold greater than at pH > 6.4. In an experiment by Tyler (1978) less than 10% of the total amount of cadmium and less than 20% of the total amount of zinc was leached from soil with a leaching solution of pH = 4.2. Decreasing solution pH by one unit (to 3.2) resulted in leaching more than 40% of cadmium and above 55% of zinc (Fig. 5). Lead was clearly the least mobile metal and only ca. 10% was leached at pH = 2.8.

Christensen (1984) also identified another important mechanism triggering desorption of heavy metals (cadmium in that case) from soil: additions of zinc or calcium significantly increased the solubility of cadmium in soil solution. A similar effect could have been responsible also for the decrease in microbial activity of forest litter treated with cadmium and lead after the addition of calcium, magnesium, or potassium (Laskowski et al. 1993b).

As shown above, an increasing concentration of some heavy metals in litter can constitute a potentially dangerous burden for forest ecosystems, even if no signs of system malfunction are detectable at present. It seems that throughfall acidity is of primary importance as the factor potentially triggering heavy metal mobility in a soil/litter system. Another important factor, overlooked in many studies, is the dynamics of concentrations of some nontoxic elements (e.g., Ca, Mg, Na, K, Fe, Mn) in litter. These contribute substantially to the cation exchange capacity (CEC) of a soil/litter system and, by saturating the system, can increase the concentration of heavy metals in soil solution.

REFERENCES

Babich H. & Stotzky G. 1974, Air pollution and microbial ecology, *Crit. Rev. Environ. Control* 4: 353-421.

Balsberg Pahlsson A.-M. 1989, Toxicity of heavy metals (Zn, Cu, Cd, Pb) to vascular plants, *Water, Air, Soil Pollut.*, 47: 287-319.

Bengtsson G., Berden M. & Rundgren S. 1988, Influence of soil animals and metals on decomposition processes: a microcosm experiment, J. *Environ. Quality* 17: 113-119.

Bengtsson G. & Rundgren S. 1984, Ground-living invertebrates in metal-polluted forest soils, *Ambio* 13: 29-33.

Berg B., Ekbohm G., Söderström B. & Staaf H. 1991, Reduction of decomposition rates of Scots pine needle litter due to heavy-metal pollution, *Water, Air, Soil Pollut.* 59: 165-177.

Bewley R.J.F. & Stotzky G. 1983, Effects of cadmium and zinc on microbial activity; influence of clay minerals. Part I: Metals added individually, *The Sci. Total Environ.*, 31: 41-55.

Boekhold A.E. & Van der Zee S.E A.T.M. 1992, Contribution to the discussion on soil quality standards for the Dutch soil sanitation practice, *Abstracts of Eurosol: European Conference on Integrated Research for Soil and Sediment Protection and Remediation*: W 1-3, MECC, Maastricht, The Netherlands, 6-12 Sept. 1992.

Chang F.H. & Broadbent F.E. 1981, Influence of trace metals on carbon dioxide evolution from a Yolo soil, *Science* 132: 416-421.

Christensen T.H. 1984, Cadmium soil sorption at low concentrations: II. Reversibility, effect of changes in solute composition, and effect of soil aging, *Water, Air, Soil Pollut.*, 21: 115-125.

Coughtrey P.J., Jones C.H., Martin M.H. & Shales S.W. 1979, Litter accumulation in woodlands contaminated by Pb, Zn, Cd and Cu, *Oecologia* (Berl.) 39: 51-60.

Grodziński W., Greszta J., Laskowski R., Maryański M. & Rożen A. 1990, Effect of the chemical composition of industrial dusts on forest floor organic matter accumulation, *Water, Air, Soil Pollut.*, 53: 169-178.

Kabata-Pendias A. & Pendias H. 1979, Pierwiastki śladowe w środowisku biologicznym, 300 pp., Wydawnictwa Geologiczne, Warszawa,

Killham K. & Wainwright M. 1981, Deciduous leaf litter and cellulose decomposition in soil exposed to heavy atmospheric pollution, *Environ. Pollut.* 26: 70-85.

Laskowski R. 1992, Nutrient and heavy metal dynamics in decomposing forest litter, *Abstracts of Eurosol: European Conference on Integrated Research for Soil and Sediment Protection and Remediation*: W 4-17, MECC, Maastricht, The Netherlands, 6-12 Sept. 1992.

Laskowski R. & Berg B. 1993, Dynamics of some mineral nutrients and heavy metals in decomposing forest litter, *Scand. J. For. Res.*, in print.

Laskowski R., Maryański M. & Niklińska M. 1993a, Nutrient and heavy metal dynamics decomposing beech-pine litter, *Ekol pol.*, in print.

Laskowski R., Maryański M. & Niklińska M. 1993b, Effect of heavy metals and mineral nutrients on forest litter respiration rate, *Environ. Pollut.*, in print.

Livett E.A. 1988, Geochemical monitoring of atmospheric heavy metal pollution: theory and applications, (in:) Begon M., Fitter H., Ford E.D. & Macfadyen A. (eds.), *Advances in ecological research* Vol. 18: 65-177, Academic Press, London.

Rühling A., Baath E., Nordgren A. & Söderström B. 1984, Fungi in metal contaminated soil near the Gusum brass mill, Sweden, *Ambio* 13: 29-33.

Rühling A., Tyler G. 1973, Heavy metal pollution and decomposition of spruce needle litter, *Oikos* 24: 402-416.

Strojan C.L. 1978, Forest leaf litter decomposition in the vicinity of a zinc smelter, *Oecologia* (Berl.) 32: 203-212.

Tyler G. 1978, Leaching rates of heavy metal ions in forest soil, *Water, Air, Soil Pollut.* 9: 137-148.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:219-227, IGSO PAS, Warszawa

A BASIS FOR THE CLASSIFICATION OF BIOINDICATIVE METHODS: A PROPOSAL FOR DISCUSSION

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Abstract: Presented in this arcticle are possible criteria for the classification of the various methods of bioindication. Also presented are links between the criteria from different groups and — against this background — the bioindicative approaches applied most frequently.

Key words: bioindication, classification, evaluation research.

INTRODUCTION

Many dffferent definitions and classifications of bioindicators are encountered in the literature on the subject. Unfortunately, the majority of these are targetted very narowly and relate only to defined areas of bioindication. Encountered particularly frequently are classifications in relation to bioindications of the state of pollution of the environment, and first and foremost of the atmosphere (Grodziński & Yorks 1981; Arndt 1982; Knabe 1982; Martin & Coughtry 1982; Schubert 1982; Ten Hoten 1983; MacCarthy et al. 1989). In these classifications, attempts are made to use just a few classifying criteria to interpret the wide range of levels of organization of indicating objects (indicators) and objects being indicated. The usual effect of this is to leave the selected categories insufficiently well-defined. The classifications do not embrace the total variety of bioindicative approaches either. In particular, they take no accuunt of long-elaborated and oft-verified systems for the indication of conditions in the abiotic environment, on the basis of complex analysis of species composition and of the links between elements of an ecosystem (cf. Roo-Zielińska & Solon 1994).

According to the widest possible definition, bioindication is the process by which quantitative and/or qualitative characteristics of a living object (called a bioindicator) are used to define the state of a whole ecological system, and/or parameters of its biotic and abiotic components, including anthropogenic substances and impacts. This definition emerges from the general principles by which ecosystems function, and makes reference to the views presented many times in the literature (cf. e. g. Harwell et al. 1990).

It must be emphasized clearly that the above definition relates to concepts of indication and indicators that are already classical. It differs considerably from the approach promoted recently (ECE 1985; OECD 1991; UNSO 1992) under which an "indicator" is a parameter, or a value derived from observations and/or measurements, which describes the state of a phenomenon with a significance extending beyond that obtained directly from the observed properties (Proposal... 1991).

Bioindicative properties are possesed by living systems at various levels of organization. The huge diversity of features analysed is connected with this (Schubert 1982). The levels recognized most often are as follows (Steubing 1982):

— the subcellular and cellular levels (it is most often biochemical and physiological features that are studied);

— the levels of tissues and organs (it is most often biochemical, physiological, and anatomical features that are studied);

— the level of the organism (it is most often anatomical, morphological, and biorhythmic features that are studied);

— the level of the population or biocenosis (it is most often population, trophic, competitive and other autecological and synecological feature that are studied);

— the level of the landscape (it is spatial features that are studied most often).

However, it must be emphasized that not every method of using biological material in the evaluation of the state of the environment is fully within the framework of bioindication. A classic example might be the use of so-called "biosensors", i. e. fragments of the tissue of living organisms which are built into measuring apparatus (Auerbach 1989). This is a totally new technology which lies on the border between bioindication and measurement using apparatus, but is closer to the latter.

A REVIEW OF CRITERIA USED IN THE CLASSIFICATION OF BIOINDICATIVE METHODS

The criteria used in classifying methods must seek to reflect the great diversity of levels of organization in the living world which are used in bioindication, as well as the various relationships which each have their own properties. As bioindication is part of a wider class of research, i. e. evaluational research (Kostrowicki 1992), classifications of bioindicators cannot contradict classifications of methods of evaluation.

The criteria used in classification may be grouped into three main sections. The first of these refers to the character of the indicative object, the second to the object being indicated and the third to the process of bioindication itself and to the method by which results are presented. In the review below, the examples of the criteria in the various groups presented have been taken (with slight modification) from the paper by Kostrowicki (1992). They relate first and foremost to phytoindication, and are obviously not exhaustive.

I. Indicator (indicative object)

— fragment of a living organism;
— single individuals;
— one population;
— an aggregation of several populations (a trophic level, a layer, a competitive grouping, a chronocenosis, taxocenosis etc.);
— a community (phytocenosis or zoocenosis);
— a vegetation landscape.

II. Object being indicated

1. Kind of object being indicated

— the bioindicator itself;
— other living organisms;
— abiotic environmental factors;
— anthropogenic environmental factors (disturbance).

2. Complexity of the features being indicated

— one simple feature (e. g. the level of ozone in the atmosphere);
— one complex feature or a set of simple features (e. g. the level of pollution of the atmosphere);
— a set of features and complex characteristics of processes (e. g. the level of anthropogenic impact).

3. The subject of the indication

— structural properties;
— functional properties;
— systemic properties.

III. Indicative evaluation

1. Aim of the indication

— cognitive;
— utilitarian (including geo-ecological, social, economic and technical).

2. Direction of the indicative evaluation

— current;
— historical;
— prognostic.

3. The theoretical basis of the indication

— deductive basis (based on a cause-effect relationship and a known functional mechanisms);
— inductive basis (based on a correlative relationship).

4. The features measured

— kind of features measured, e. g. the characteristics of a population (phenology, age structure etc.), the characteristics of individuals (morphology, chemical composition etc.), spatial characteristics (bordering, contrast, diversity, evenness etc.).

— the categories of description of the features measuured (presence-absence, numerical representation, cover, frequency of occurence etc.).

5. The method of measurement

— absolute measurement;

— relative measurement (comparison with "normal state" or with the past);

— qualitative evaluation.

6. The kind of indication

— simple (measured variable is a direct measure of the phenomenon being indicated);

— complex (measured variable must be used on its own or with other measured variables must be used in a model of the phenomenon; the solution of the model is the measure of the phenomenon being indicated).

7. The range of the indication

— local;

— regional;

— supra-regional;

— independent of scale;

— aspatial.

8. The form in which results are presented

— descriptive;

— graphic (including cartographic and pictorial);

— symbolic (mathematical or logical).

Not included in the above review is a whole group of potential criteria for distinguishing and classifying indicative objects and methods of indication. This group comprises the characteristics of the so-called "quality" of the bioindicator and in particular its (a) sensitivity (relationship between signal and noise); (b) elasticity (rate of reaction and relaxation time); (c) natural (background) level of variability; and a number of other things. Also exluded is a quite important division into stress bioindicators (which provide information about something that has a direct influence on the environment) and response indicators (which show effects of the influence). The reason for this is that these concern the relationship between the indicative object and the object being indicated and may be defined on the basis of the main criteria presented previously.

LINKS BETWEEN PARTICULAR CRITERIA AND THE PLACE OF SOME TYPES OF BIOINDICATION IN THE SYSTEM OF CLASSIFICATION

The aforementioned criteria for the classification of indicative methods are only to some extend independent. From a formal point of view, it is possible to distinguish more than 300,000 types of bioindicative evaluation which differ in at least one of the classification criteria distinguished. However, in reality there are only between ten and 20 types.

Most convenient from pragmatic point of view would seem to be a double classification, which would bring together in one scheme the degree of structural and functional complexity of the indicative object (the levels of organization of living matter) and the level of complexity of the features being indicated. An example of such a classification scheme is presented in Table 1.

Table 1 Simplified scheme for the classification of phytoindicative methods

Indicated object	Bio-(phyto-)indicator						
	Parts of plants	Separate plants	Plant populations	Aggregation of few populations	Plant association	Vegetation landscape	?
Single factor	1		2	2	3		
Interrelated group of factors	4	5		6			
Anthropogenic influence as a whole			7	8		9	
Biodiversity					10	11	
Natural stand conditions		12			13	14	
Overall character of the area						15	

1 — Ozone evaluation on the basis of chemical and morphological changes in tissues (Cowling & Hueck 1989); 2 — Presence of elements and compounds (e.g. petroleum) on the basis of the presence of a given species or species aggregation; 3 — Trampling evaluation on the basis of changes in species composition (Kostrowicki 1981); 4 — Air pollution evaluation on the basis of tree bark chemistry (Grodzińska 1979); 5 — Air pollution evaluation on the basis of the concentration of heavy metals in plants (Grodzińska 1990); 6 — Air pollution evaluation on the basis of the spatial distribution of selected lichen species (Hawksworth & Rose 1970; Kiszka 1990); 7 — Qualitative evaluation of the anthropogenic changes in the habitat on the basis of the state (growth, defoliation, decolourization) of a chosen tree population; 8 — Evaluation of the anthropogenic deformation of the ecosystem on the basis of share of coenoelement groups (Kostrowicki 1972; Kostrowicki, Roo-Zielińska & Solon 1991); 9 — Evaluation of the anthropogenic deformation of the landscape on the basis of the synanthropization index (Kostrowicki, Plit & Solon 1988) or other indices connected with the hemeroby concept; 10 — Evaluation of the biodiversity (of different taxonomic groups) on the basis of the character and floristic composition of the ecosystem (Andrzejewski, Baranowski & Solon, in prep.); 11 — Evaluation of the overall biodiversity and possible changes in it on the basis of vegetation fragmentation in the landscape (Schonewald-Cox & Stohlgren 1989); 12 — Climate reconstruction on the basis of tree-ring growth (Reams 1989); 13 — Evaluation of habitat condition(s), e.g. — moisture, nitrogen content, pH, continentality, temperature, on the basis of the floristic composition according to Ellenberg's (1974) or Ramienskij's (Ramienskij et al. 1956) approaches (Roo-Zielińska & Solon 1988, 1990); 14 — Evaluation of the conditions of a natural habitat and its suitability for different form of management on the basis of the concept of potential vegetation (Kostrowicki & Wójcik 1972); 15 — Evaluation of the landscape dynamics on the basis of the spatial pattern of vegetation (Solon 1990)

The levels of complexity distinguished in the table for bioindicators are not fully discrete. They are connected with one another by various relationships resulting both from the essence of biological systems (e. g. monospecific tree stands in a forested area may be considered as either a defined population or a part of a metapopulation realized fully at the level of the landscape, or else as a structural and structure-creating part of the forest phytocenosis) and from the evaluational models defined in practice. In the latter case, it is only possible to use as bioindicators objects of a given level of organization (e. g. plant association), if there is knowledge of the mechanisms and use of relationships occurring at lower levels (e. g. plant populations). On the other hand, levels of organization immediately above (e. g. vegetation landscape) introduce limiting, border conditions far the functioning and practical usefulness of a bioindicator.

It is clear that a certain regularity emerges in the scheme presented above: the more complex the indicated object, the more often that indicators of higher levels of organization are used in its evaluation. This results from the general connection between the structural and functional complexity of the indicative object and the time needed for a reaction to occur after an external disturbance (Fig. 1). An increase in the structural and functional complexity of the indicative object leads to a situation in which conclusions concerning the indicated object are based most often upon correlative links (and not on cause and effect) and are expressed in rank or quality categories rather than in strictly quantitative ones.

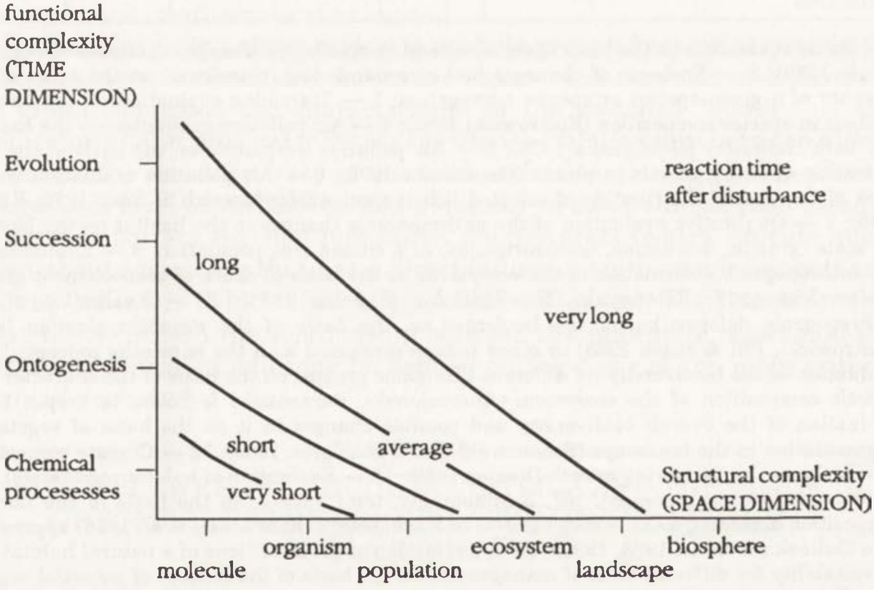

Fig. 1. Relationship between the structural complexity of an indicative object, its functional complexity and the time needed for reaction to some external disturbance

FINAL REMARKS

The bio-(phyto-)indicators presented in the classification scheme may be divided into two groups, which differ in relation to the object indicated, the method by which initial data are collected and the method by which results are processed. The first group includes bioindicators which define the general situation of the environment — and the directions of the processes taking place — in a general way. According to the classification adopted the majority of bioindicators in this group are at the levels of the plant community and vegetation landscape. They define (indicate) the so-called "conditional" and "positional" environmental factors of Van Wirdum (1981). The second group of bioindicators is used for the precise characterization of the state of selected components, and in particular the level of anthropogenic pollution. According to the classification adopted, all the bioindicators from this group represent lower levels of organization (mainly individual and populational). They most often have the character of accumulators defining (indicating) the so-called "environmental factors having direct impact" (Van Wirdum 1981).

The double classification presented here makes it easier to prepare — for the evaluation of any biotic and abiotic variables — a logical and cohesive bioindicative approach that constitutes a hierarchical, mutually-interlinked and complementary bioindicative system of evaluation, rather than a collection of independent methods. This may be drawn up in different ways according to need; e. g. a different set of bioindicators is used for Forest Health Monitoring and for the general evaluation of the state of the environment. Recently, Poland has seen interesting steps taken in this direction with the ongoing development of the System of Biological Indicators of the State of, and Changes in, the Environment (Projekt Systemu... 1993).

REFERENCES

Andrzejewski R., Baranowski M., Solon J. (in prep.), *Biodiversity evaluation with the help of the landscape pattern analysis.*

Arndt U. 1982, Comparability and standarization of bioindication processes, *Task for vegetation science* 7: 129-130.

Auerbach S. J. 1989, Monitoring the Environment in the 21st Century, Proc. 2nd US — USSR Symposium on Air Pollution Effects on Vegetation, 165-171.

Cowling E. B., Hueck W. H. 1989, Air Pollutants, Plants and Mechanisms of Interaction: A Historical Perspective, Proc. 2nd US — USSR Symposium on Air Pollution Effects on Vegetation, 65-70.

ECE 1985, Draft set of ECE environmental indicators, Conference of European Statisticians, 33 Plenary Session (CES/548/Add. 6/Rev. 1)

Ellenberg H. 1974, Zeigerwerte der Gefasspflanzen Mitteleuropas, Scr. Geobot. 9: 982 Göttingen.

Grodzińska K. 1979, Tree bark-sensitive biotest for environment acidification, *Environ. Intern.* 2: 173-176.

Grodzińska K. 1990, Long-term ecological monitoring in the National Parks of Poland, (in:)

Ecological Risks-Perspectives from Poland and United States, Eds.: Grodziński W., Cowling E. B., Breymeyer A. J. National Academy Press, Washington, D. C.

Grodziński W. , Yorks T. P. 1981, Species and ecosystem level bioindicators of airborne pollution: an analysis of two major studies, *Water Air Soil Pollut.*, 16: 33-53.

Harwell M. A., Harwell C. C., Weinstein D. A., Kelly J. R. 1990, Characterizing Ecosystem Responses to Stress, (in:) *Ecological Risks, Perspectives from Poland and the United States*, 91-115.

Hawksworth D. L., Rose F. 1970, Quantitative scale for estimating sulphur dioxide air pollution in England and Wales using epiphytic lichens, *Nature* 227, 145-148.

Kiszka J. 1990, Lichenoindykacja obszaru województwa krakowskiego (Lichen Indication on the Kraków Voivodship), *Studia Ośrodka Dokumentacji Fizjograficznej* 18: 201-212.

Kostrowicki A. S., 1972, Zagadnienia teoretyczne i metodyczne oceny synantropizacji szaty roślinnej (Theoretical and methodical problems in evaluation of the synanthropization of the plant cover), *Phytocoenosis* 1(3), 171-191.

Kostrowicki A. S. 1981, Metoda określania odporności roślin na uszkodzenia mechaniczne powstałe na skutek wydeptywania (The new method of evaluating the plant resistance to trampling), *Prace Geogr. IGiPZ PAN* 139: 40-67.

Kostrowicki A. S. 1992, System "Człowiek-Środowisko" w świetle teorii ocen (The "Man — Environment" System in the Light of the Theory of Evaluation), *Prace Geograficzne IGiPZ PAN* 156.

Kostrowicki A. S., Plit J., Solon J. 1988, Przekształcenie środowiska geograficznego (Changes in Geographical Environment), *Prace Geograficzne* 147: 108-115.

Kostrowicki A. S., Solon J., Roo-Zielińska E. 1991, Spatial differentiation of chory and gamy in vegetation landscape (Białowieża Case Study), *Phytocoenosis* 3 (N. S.), 101-109.

Kostrowicki A. S., Wójcik Z. 1972, Podstawy teoretyczne i metodyczne oceny warunków przyrodniczych przy pomocy wskaźników roślinnych (Theoretical and Methodical Foundations of Using Plant Indicators for Evaluation of Natural Environment), *Biul. KPZK PAN* 71:3-63.

Knabe W. 1982, Monitoring of air pollutants by wild life plants and plant exposure: Suitable bioindicators for different immissions types, *Task for vegetation science* 7: 59-72.

Martin M. H., Coughtrey P. J. 1982, Biological monitoring of heavy metal pollution — *Land and Air* — Applied Science Publ. London 11.

McCarthy J. F., Adams S. M., Jimenez B. D., Shugart L. R. 1989, Environmental Monitoring of Biological Markers in Animals and Plants, Air Pollution Effects on Vegetation, 187-196.

OECD 1991, Environmental indicators. A preliminary set, OECD, Paris.

Projekt systemu biologicznych wskaźników stanu i zmian środowiska: 1993, Etap II (The Project of the System of Biological Indicators of the State and Changes of the Natural Environment. Part II), Narodowa Fundacja Ochrony Środowiska, Warszawa.

Proposal for Environmental Indicators in Norway 1991, Report No. 1 from the Reference Group for Environmental Indicators appointed by the Ministry of Environment.

Ramienskij L. G., Cacenkin I. A., Cizikov O. N., Antipin N. A. 1956, *Ekologiceskaja ocenka kormovych ugodii po rastitielnomu pokrovu* (Ecological evaluation of grasslands on the basis of vegetation), Moskow.

Reams G. A. 1989, Dendrochronology and Spatial Analyses, Proc. 2nd US — USSR Symposium on Air Pollution Effects on Vegetation, 43-56.

Roo-Zielińska E., Solon J. 1988, Phytosociological typology and bioindicator values of plant communities as exemplified by meadows in the Nida Valley, *Documents Phytosociologiques* N. S. 11 :543-554.

Roo-Zielińska E., Solon J. 1990, Phytosociological typology and phytoindicative value of young oak and larch forest communities near Pińczów (S-Poland), Vegetatio 88: 67-78.

Roo-Zielińska E., Solon J. 1994, Geobotanical Indication as a Tool for Forest Monitoring, *Conference Papers IGiPZ PAN* 19: 229-244.

Schonewald-Cox C., Stohlgren T. J. 1987, Biological Diversity and Global Change: Habit

Fragmentation and Extinction, Proceedings of the Second US — USSR Symposium on: Air Pollution Effects on Vegetation, 217-224.

Schubert R. 1982, Selected plant bioindicators used to recognize air-pollution, *Task for vegetation science* 7:47-51.

Solon J. 1990, The spatial distribution of vegetation units as a result of habitat and synanthropization pattern — *Ekologia* (CSFR) 9: 4:383-393.

Steubing L. 1982, Problems of bioindication and the necessity of standarization, *Task for vegetation science* 7: 19-24.

Ten Hoten J. G. 1983, Biological indicators of air pollution, *Environ. Monit. Assessm.* 3: 257-261.

UNSO 1992, Note of environmental indicators, Inter-Governmental Working Group on the Advancement of Environment Statistics, Arusha, Tanzania, 17-21 February 1992.

Van Wirdum G. 1981, “Ecodivice”, First International Congress on Landscape Ecology, Veldhoven, April 1981.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:229-243, IGSO PAS, Warszawa

GEOBOTANICAL INDICATION AS A TOOL FOR FOREST MONITORING

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Abstract: We have characterised principles of geobotanical indication methods, that may be used as a tool in forest monitoring. Further, we have discussed the vegetation role as an indicator of present conditions and transformations of numerous elements of the natural environment, (especially climate and soils) occurring under the influence of anthropogenic influences and natural mechanisms. A few examples of possible applications of geobotanical indication methods for analysing changes of forest phytocoenoses and abiotic factors in time and space are presented.

Key words: forest monitoring, geobotanical indication, informative richness, degree of naturalness, gamy, chory, Poland.

THEORETICAL AND METHODOLOGICAL PRINCIPLES OF GEOBOTANICAL INDICATION

Geobotanical indication is one of several sections of the widely understood concept of bioindication (Solon 1994). It differs from other sections by the specific concept of indicating objects and theoretical principles. Geobotanical indication clearly results from the concepts of geosystem and ecosystem.

The geosystem is an entity comprising various mutually influencing entities of lower order and of varying degree of integration. It is composed of components of different degrees of durability; e.g., components that undergo transformations only to a small extent, such as geological substrates and labile ones changing quickly in time. Such components especially include water relations, soils, animals, and vegetation cover. The durability of components influences their mutual subordination; to climate and land relief are subordinated water, soils, and vegetation as well as animals. These factors shape the local climate too.

It should be remembered, however, that each of the subordinated components also exerts its influence on directing factors, thus modifying their conditions and regulating processes taking place in them.

From the hierarchic ordering of geocomponents enables us to determine the limiting influence exerted by directing factors on directed factors. The durability and repeatability of relations occurring between components is a basis for indicative methods for evaluation of the landscape and its elements.

Kostrowicki (1976) has analyzed connections between 124 attributes (physical, chemical, and functional) of five subsystems: atmosphere (26 attributes), hydrosphere (28 attributes), lithosphere (30 attributes), pedosphere (17 attributes), and biosphere (23 attributes). On this basis he has presented the degree of dependence between various components and their indicative possibilities. The data analysis shows that the biosphere (including vegetation) has the highest ability of indicating the condition and dynamics of other components.

The vegetation cover is thus a sensitive and easily changing component of both the geosystem and the ecosystem, as it enables us to determine the functional character of the given system and transformations which it undergoes. Both the flora (plant species) and vegetation (plant community level) are characterised by specific properties that enables the determination of those components of the natural environment with which they are ecologically connected. "Each plant or plant association represents a perfect reflection of those conditions in which it is living" (Clements 1920).

The basic ideas applied in geobotanical indication are:

— An indicating object (indicator);

— An indicated object, that we can learn, measure, and assess with the help of indicators;

— Indication field, i.e. the precisely determined system (structural, spatial) that is the subject of interest.

In geobotanical phytoindication the main indicator is the plant community: i.e., spontaneously established multispecies (more seldom a single species) structural and spatial system of higher plants of varied complexity degree. The indicative elements of that system, sometimes called elementary indicators, are populations of higher plants constituting the given system. Further, the indicators' elements are attributes: i.e., properties characterising populations of various species occurring in a community, such as numbers, vitality, health condition, etc. Hence, in the case of geobotanical indication, we are faced with at least a three-grade hierarchical system of indicators: community, population and attributes of that population. These indices combined, characterise the properties of the plant community as a complex indicator.

Elementary attributes taken into consideration in geobotanical phytoindication are the following:

— Morphoanatomical attributes such as life forms, habitat of plant, vitality, shaping of organs, etc.;

— Demographic attributes such as type of pollination, seed dispersal, ability to germination, etc.;

— Geoecological attributes such as phytosociological, ecological, phytogeographical, and genetic belonging, relation to human activities, sensitivity to anthropopressure etc.;

— Physiological attributes such as relation to various elements, chemical compounds, various types of radiation, etc.;

— Utility attributes such as food value, toxicity, aesthetical value, as well as the role of biologically active compunds emitted to the environment.

Phytosociology makes use of elaborated methods for describing phytocoenoses and types of communities (Matuszkiewicz 1981). Its basis is composed of the floristic and ecological characteristics of vegetation stands that represent the given type of community and are recorded in the form of a phytosociological record. It contains the following basic information concerning the given vegetation stand:

— Species composition;

— Cover; i.e. the area share of various species (in %);

— Layer character; i.e., the structural attributes of the community concerning its vertical structure. Most frequently distinguished is the layer of trees (a), shrubs (b), herbs (c), and the ground level (d). It is desirable to provide the average height of the given layer;

— Coverage; i.e., percent of area covered by all plants constituting the given layer.

The phytosociological record contains supplementary information, that includes date of vegetation description, the precise situation with a description of location in land relief (slope, exposition) and, frequently a description of the soil profile.

Phytosociological records constitute a basic preliminary material that allows us to determine the numerical values of bioindicative indices. The phytoindicative analysis based on phytosociological records taken at the same time, but in different places, enables us to evaluate the current differentiation of space and typological vegetation units. On the other hand, long-term geobotanical and indicative studies on permanent observation areas are intended for evaluating the dynamics of vegetation and environmental factors, including the intensity of anthropogenic activity.

Current research in the field of geobotanical indication is developing in the following directions (Kostrowicki, Roo-Zielińska & Solon 1992):

— Autoindication; i.e., the evaluation of the condition and changes of the vegetation itself through its detailed and directed analysis. It enables us, among other things, to evaluate the anthropogenic deviation, resistance to external influence, and way ecological systems function.

— Pedoindication; i.e., the evaluation of the condition and transformations of the soils and their usefulness for various economic sectors.

— Hydroindication includes two separate sections: (a) indication of open water and (b) indication of shallow levels. Its purpose is to evaluate changes in the chemical composition of water, degree of its pollution and possible directions for land reclamation and use.

— Thermoindication; i.e., the evaluation of microclimate and local climate properties, including such variables as the influx of radiation energy to the biologically active layer and mean effective temperatures of the vegetation period.

— Lithoindication; i.e., the determination of the physical and chemical structure of the lithological substrate.

— Chemoindication; i.e., the evaluation of the contents of various substances in the environment as well as in live plants. Such type of studies are widely executed in the world and mainly concern three problems: (1) indication of chemical pollution in the environment; (2) indication of cumulative and detoxicative properties of various plant species and plant communities; (3) indication of deposits of useful minerals through vegetation indices. Currently significant development has taken place in the research field on how to indicate the pollution level on the basis of accummulation of various elements in plants. Already numerous species-accumulators of pollution have been distinguished, particularly for heavy metals (Grodzińska 1978), and standard methods have been elaborated for collection of plant material and for its chemical analysis. However, due to the specific treatment of plant species separately from their ecological background, the latter type of indication does not belong to the group of classical geobotanical methods.

— Sanoindication; i.e., the evaluation of health and recreational properties of natural and secondary plant communities, as well as of food products and medical products obtained from them.

— Landscape phytoindication is aimed at evaluating the structure, functioning, and deformation and degradation level of the landscape. This direction is of fundamental importance in the evaluation of consequences of any type of activities, such as in recultivation and landscape shaping, spatial planning, etc.

The above classification of geobotanical indication directions has analytical character and has its basis on various indicated object. We could thus apply this analytical approach using a more synthetic division, such as the following indications: agricultural, meadow, water, urban, forest, etc. The latter indication is the subject of this paper.

THE PLACE OF GEOBOTANICAL INDICATION IN FOREST MONITORING

In the past, approaches toward forest monitoring have been focused on the analysis and evaluation of the character and degree of tree stand damage which results from environmental pollution and other anthropogenic factors. The analysis and evaluation of other (abiotic and biotic) components of the forest ecosystem were not considered or used as additional characteristic of the study plots. Only in some cases was a detailed analysis of the remaining components a basis for determining the degree of similarity between the selected study plots.

In the past, forest monitoring has concentrated only on the production and on the economic aspect, and has not taken into consideration ecological, landscape, and social aspects.

It seems that such a narrow approach of the forest monitoring range is not appropriate for two reasons. First, it often happens that it is not the tree stand that is the most valuable component of a forest, but rather the genetic quota of rare species, biocenotic relations, landscape, recreational, and protective values. Such views on values of forest ecosystems are closely connected with the concept of protecting the biodiversity and the programme "Sustainable Biosphere" (Lubchenco et al. 1991). In such a case a comprehensive analysis and evaluation of connections is indispensable. In numerous cases geobotanical indication is the most suitable tool for that purpose.

Second, even when limiting the range of forest monitoring to tree stands only, geobotanical measures may be useful for the following:

— Selection and evaluation of homogeneity (similarity) of the monitoring areas;

— Evaluation of the condition of a dynamic forest ecosystem in order to evaluate the suitability of the given tree stand to monitoring needs;

— Evaluation of tree-stand quality within the ecosystem;

— Early detection of long-term trends of deviations in forest ecosystems, which until now were not disclosed in tree stand changes;

— Supplying of additional information indispensable for correct construction of models of tree stand reactions (and of the whole ecosystem) to various types of stresses and disturbances.

ADVANTAGES AND DISADVANTAGES OF APPLYING GEOBOTANICAL INDICES IN FOREST MONITORING

The significance of geobotanical indication as a method for evaluating the vegetation itself and its environmental conditions is based on the fact that it estimates environmental variables from the position of a system of coexisting, interdependent organisms. The specimen, the population or the phytocoenosis is being limited not only by abiotic and anthropogenic factors, but also by internal system interactions. Such interactions would be, for example, allelopathic, influence by microorganisms, phytophages, and zoophages, as well as mechanical pressure by neighbours, and rate of nutrient release from organic matter, landscape, etc. Such influences define the ecological framework of permissible life possibilities of species coexisting in nature. Those frameworks are usually more narrow than actual amplitudes of potential life possibilities, such as defined in laboratory tests.

Geobotanical indication methods and technologies only in some cases may be applied for evaluating temporary conditions and transformations taking place in a period shorter than one vegetation period. The majority of indicative methods do not take into consideration temporary biocenotic changes but rather relatively permanent long-term transformations of the ecosystem and the phytocoenoses. This is difficult, because one must wait at least a full year for the first results.

Another limitation of the aplicability of bioindicative methods is that they directly define the condition and changes only of those attributes which are ecologically significant for the given group of organisms. The evaluation of other, less important environmental properties, on the other hand, may progress in an indirect way. An advantage of the majority of bioindicative methods is the rapidity of application and low price, as basically they do not require any complicated measurement equipment.

SELECTED EXAMPLES OF GEOBOTANICAL MEASURES USEFUL IN FOREST MONITORING

Within the concept of geobotanical indication, methods making use of species scales and landscape scales are particularly useful for forest monitoring. The majority of existing approaches based on species scales may be divided into two groups. The first group embraces autoindicative indices; e.g., describing and characterizing the condition of vegetation itself and also indirectly processes leading to that condition. The second group is composed of indices characterizing the abiotic environmental condition: e.g., insolation, temperature, degree of continentalism, humidity, acidity, nitrogen contents, humus contents, and soil granulation. Such evaluations, apart from the floristic composition of communities (phytosociological records), require lists of diagnostic attributes of species.

A separate category of indicative measures, infrequently used for the needs of forest monitoring, is composed of indices reflecting the spatial differentiation of vegetation. The initial material for defining such measures is a detailed map of the existing vegetation and a map of the potential vegetation, supplemented by field studies and values of selected indices calculated on the basis of floristic composition of various stands.

AUTOINDICATION WITH THE UTILIZATION OF SPECIES SCALES

(a) Index of informative richness

This index describes the degree of the structure complexity of a given stand, and also indirectly the relative primary productivity of the given phytocoenosis. It is calculated using the the following formula (Kostrowicki 1972; Roo-Zielińska 1982):

$$Zi_{og} = Zi_a + Zi_b + Zi_c + Zi_d$$

in which: Zi_{og} is general informative content; Zi_a is informative content of the tree layer; Zi_b is informative content of the shrubs layer; Zi_c is informative content of the herbs layer; Zi_d is informative content of the ground layer.

For each layer the index of informative richness has the form:

$$Zia...d = \frac{h[0.5(g^2 + g)^{dom} * p^{dom} + (g^{tow} * p^{tow}) + (g^{spor} * p^{spor})]}{100}$$

where: h is the average height of layer (in cm); g is the number of species; p is the total cover of each group of species (dom, tow, spor); *dom* is the subscript for dominating species with cover > = 5%; *tow* is the subscript for accompanying species with cover up to 5%; *spor* is the subscript for sporadic species with cover up to 0.1%.

In the classical form the above index allows us to quantify the degree of complexity in the structure of a given phytocoenosis, which is highly useful in the preliminary stage of selection and comparison of study points. It also allows to determine the degree of community transformation due to man. After minor modifications this index may be applied also for evaluating the role of various groups of species (systematic, phytosociological, and ecological) in the structure of a given phytocoenosis. Particularly, it is being used for a quantitative evaluation of the share of anthropophytes (i.e., species accompanying man) in communities constituting a given spatial system (Roo-Zielińska 1982). In the case of appropriately dense observation grid and isolinear representation, such a system shows clearly the sources and routes of spreading degradational anthropogenic influences (Fig. 1).

(b) Measure of degree of naturalness

This measure is based on the determination of the share of so-called alien species for a given phytocoenosis. The floristic composition of each stand qualified to be a defined syntaxonomical unit is constituted by (1) a characteristic combination of species; i.e., species characteristic for the association, alliance, order, and class, species distinguishing the unit and those accompanying species which are characterized by the highest durability and similar ecological requirements, and (2) accidental species connected with other syntaxons.

Species included in the characteristic combination of species and those accompanying species with ecological requirements in compliance with the community character may be acknowledged as species proper to a given phytocoenose.

Species characteristic for syntaxons alien to the given community and accidental species of an ecological character deviating from the given type of community, create a group of alien species. They indicate the degree and direction of deviation from the approved syntaxonomic model taking place in the plant stand. A measure of compliance of the given plant stand with the model is constituted by the share of alien species in the floristical composi-

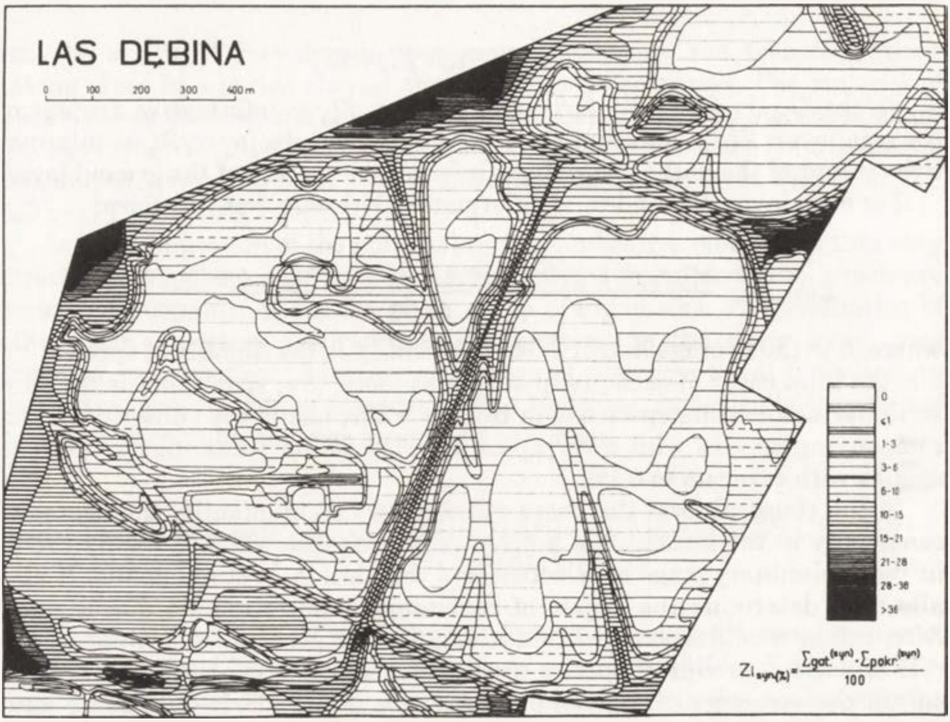


Fig. 1. The informative richness of anthropophytes in the herb layer of the Dębina Forest near the Pińczów town (Kostrowicki 1972)

tion. The smaller is the number and cover of alien species, the more close to the typical condition is the given community.

(c) Indices of gamy and chory

A specific measure of phytocoenoses structure is the dominating type of pollination (gamy) including anemogamy, entomogamy, autogamy, etc. Another measure of phytocoenoses is the type of seed dispersal (chory), including anemochory, barochory, autochory, zoochory, etc. These indices are evaluated quantitatively through their percentage of cover of the herb layer of species with a defined type of gamy and chory.

In most cases there is a relationship between the syntaxonomical type of vegetation and its chory and, to a smaller extent, gamy characteristics. This does not mean that phytocoenons that are syntaxonomically closed are always similar from the point of view of prevailing chory and gamy types. These connections are modified by external influences; e.g., a type of forest management, that is visible when comparing protected and utilized parts of the same area.

The structure of chory and gamy may be interpreted as an index of qualitative and quantitative character of small fauna, especially entomofauna. It is also suggested that because of their lability, chory and gamy can indicate the presence and differentiation of external phenomena influencing phytocoenoses of the same syntaxonomic kind.

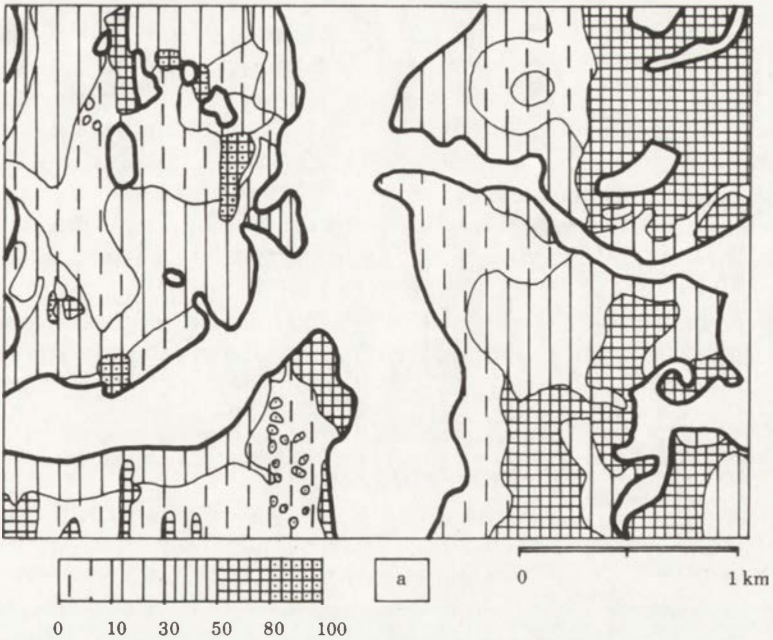


Fig. 2. The percentage of anemogamic species in *Tilio-Carpinetum* forests of the fragment of the Białowieża Forest. a — communities other than *Tilio-Carpinetum* (Kostrowicki, Roo-Zielińska & Solon 1991)

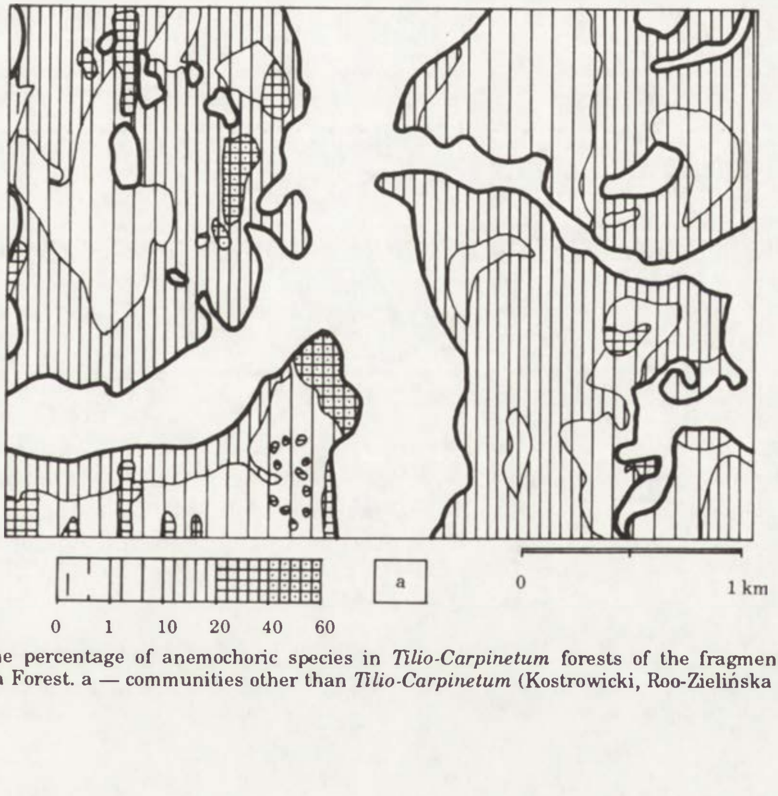


Fig. 3. The percentage of anemochoric species in *Tilio-Carpinetum* forests of the fragment of the Białowieża Forest. a — communities other than *Tilio-Carpinetum* (Kostrowicki, Roo-Zielińska & Solon 1991)

In the presented example (Fig. 2, Fig. 3) originating from the Białowieża National Park and its protection zone (Kostrowicki, Roo-Zielińska & Solon 1991) there was a differentiation in the share of anemogamic and anemochoric species in different development stages and habitat forms of oak-hornbeam forest (*Tilio-Carpinetum*). The forest of the type *Tilio-Carpinetum calamagrostietosum* growing in the National Park area is characterised by an absolute dominance of anemogamy and chory mixed, but the same subassociation growing in managed part of forest is characterised by the lack of dominant chory and gamy types. *Tilio-Carpinetum typicum* in managed forests is characterised by the dominance of entomogamy and chory mixed, but in the National Park anemogamy and entomogamy are codominant. Other forms of *Tilio-Carpinetum* forests (*T.-C. corydaletosum*, *caricetosum*, and *polytrichetosum*) are characterised by the lack of dominant chory and gamy types.

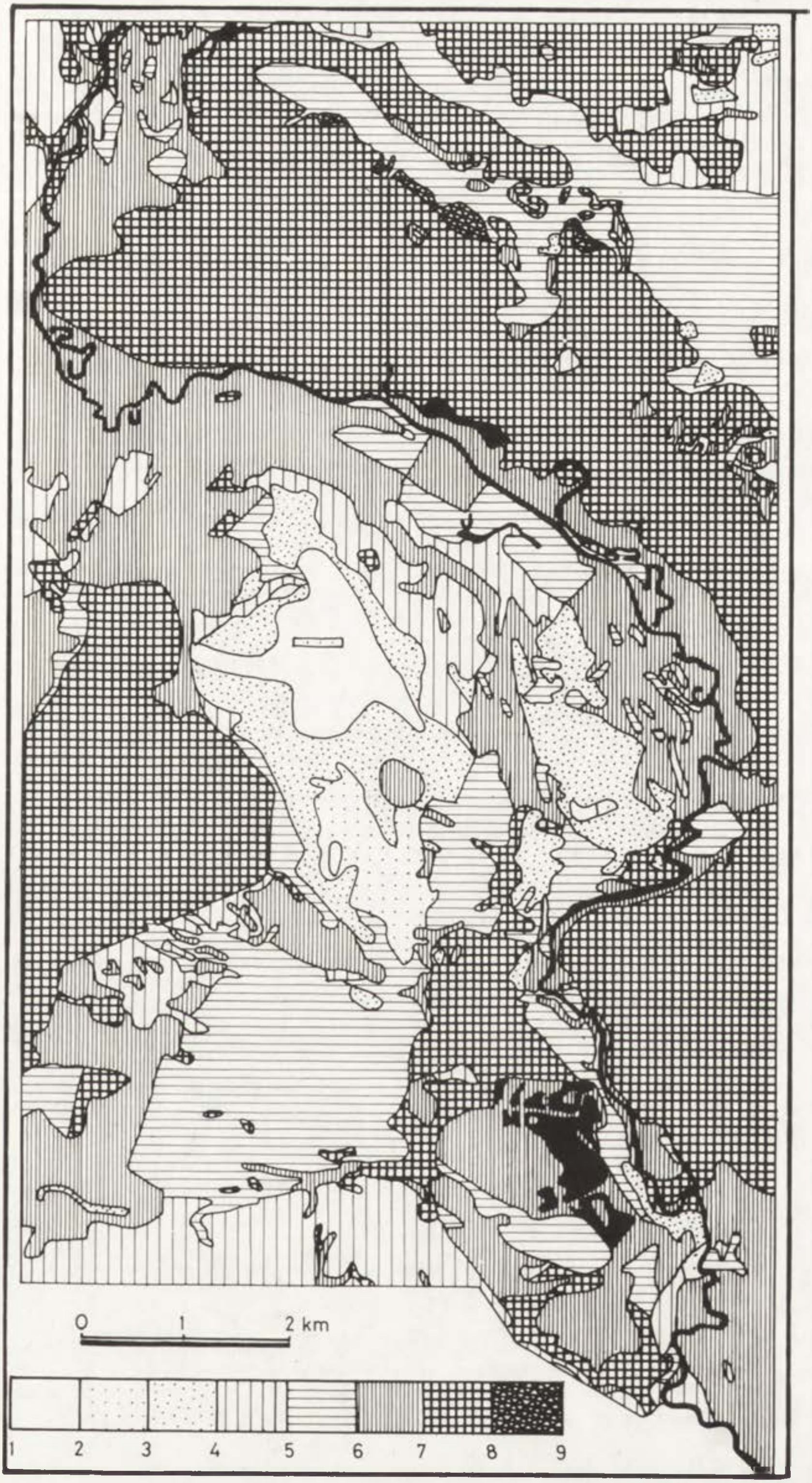
(d) Evaluation of the degree of succession

This method belongs to the group of qualitative methods, but in an indirect way it makes use of species scales and analyses of processes. It enables us to make an evaluation of each vegetation stand from the point of view of its distance from the climax stage. This is all the more important because reactions of a given tree stand to stress and disturbance do not depend exclusively on the tree stand's absolute age, but also on the development stage of the whole plant community. Recently a comprehensive review of criteria and means of distinguishing successive stages was presented by Faliński (1990).

INDICATION OF ABIOTIC ENVIRONMENTAL CONDITIONS WITH THE USE OF SPECIES SCALES

Indication of an abiotic environment is particularly useful in forest monitoring of the regional level and in monitoring of unstabilized (nonclimax) systems. It has, on the other hand, a lower significance and supplies significantly less interesting data for large-area monitoring, including the whole country or even a part of a continent. In observations on a regional level the most useful indications of the local differentiation are those of the climate (thermoindication) and of soils (pedoindication) (Fig. 4). The comparison of a tree stand map and a map of phytosociological differentiation of actual vegetation with bioindicative maps, enables us to make a precise determination of the internal differentiation of abiotic conditions of various

Fig. 4. Soil acidity in the Dębina Forest near the Pińczów town evaluated with the use of geobotanical indication;
1-3 — very acid soils, 3-5 — acid soils, 5-7 — weakly acid soils, 7-9 — neutral soils, 9-10 — basic soils (Roo-Zielińska in print)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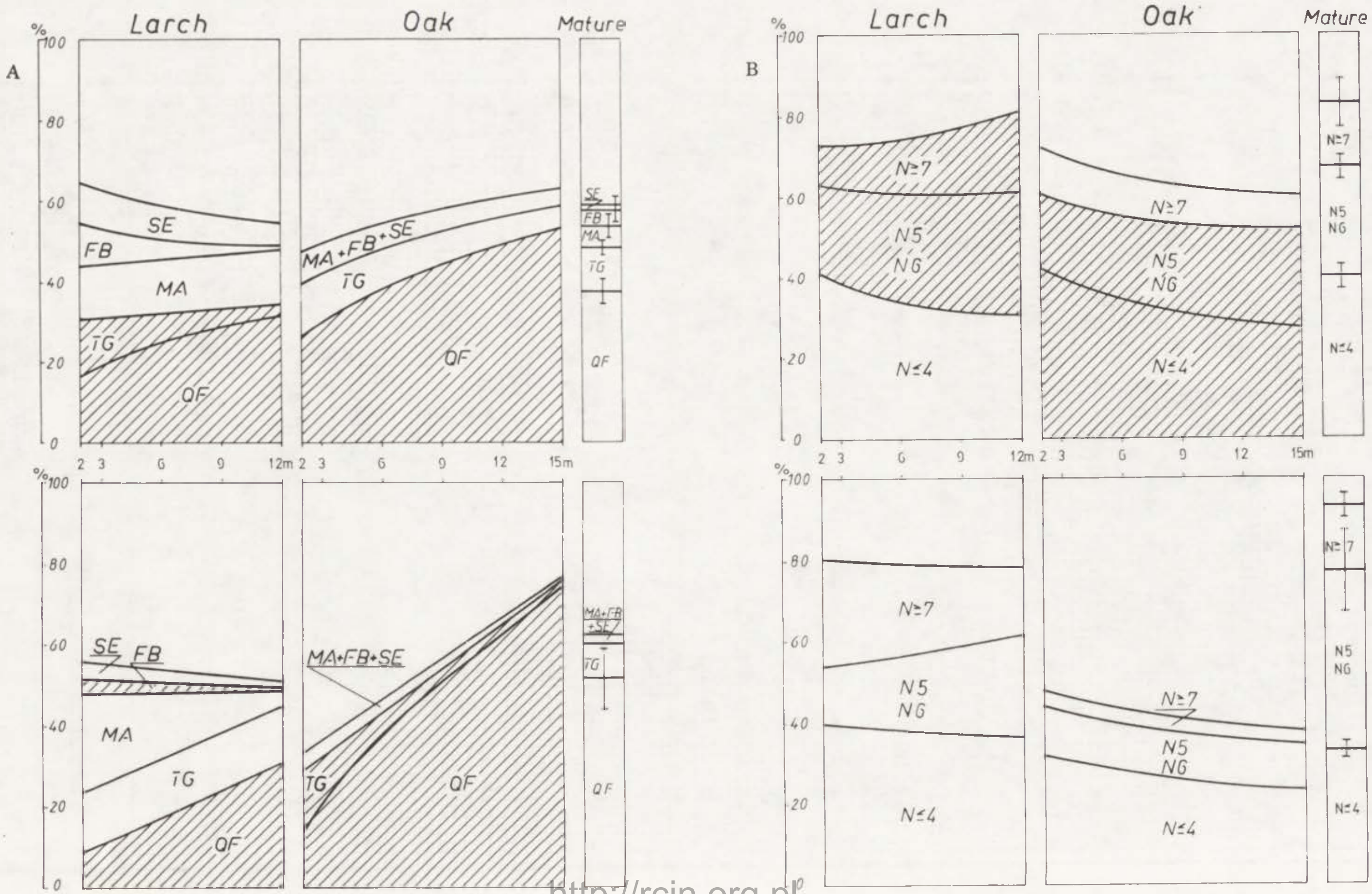
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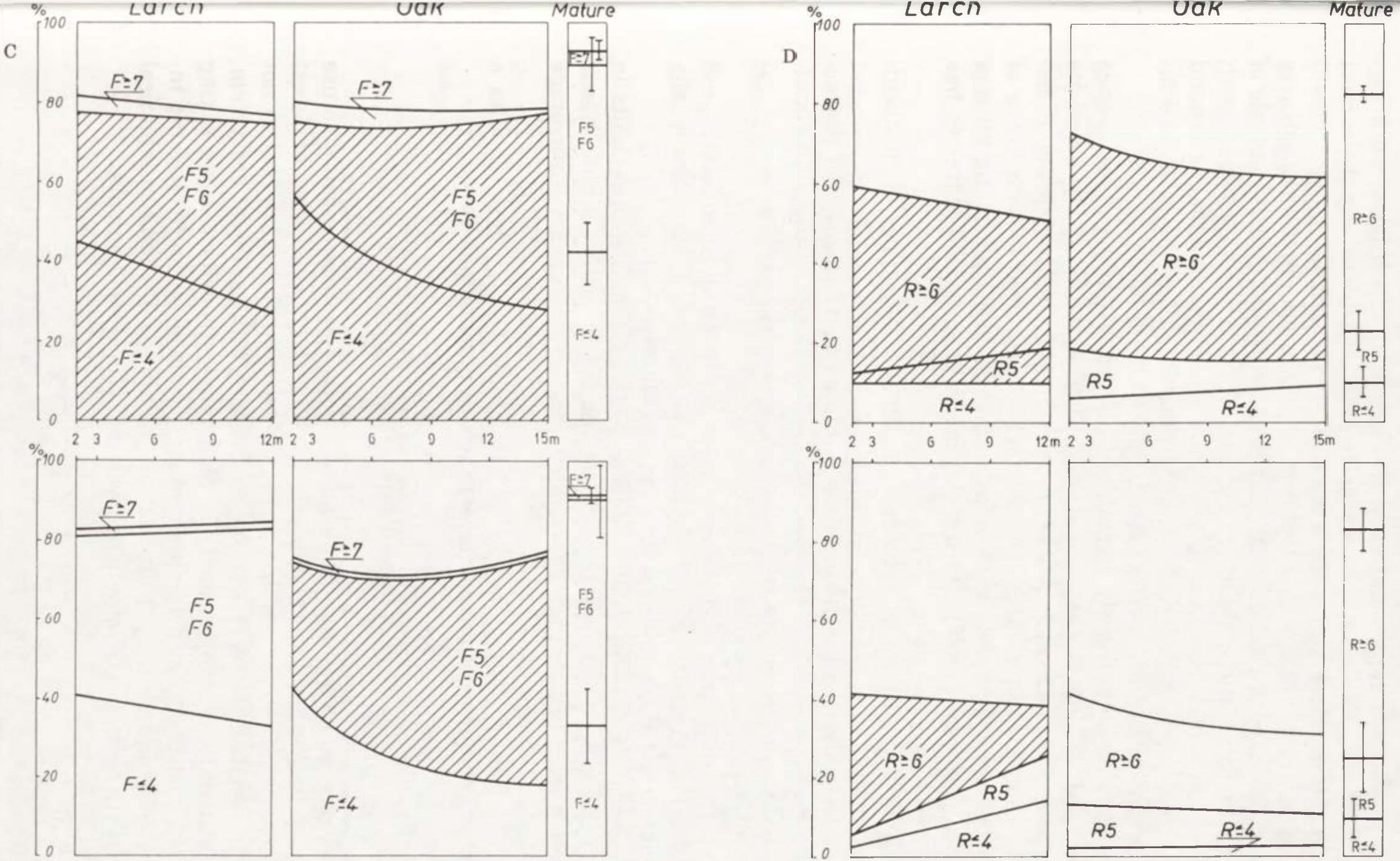

Fig. 5. Changes in: number of species from different syntaxonomical classes (A), demands for nitrogen contents in soil (B), soil moisture (C), and soil acidity (D) of the larch and oak monocultures in the Dębina Forest near the Pińczów town. SE — *Secalietea* class; FB — *Festuco-Brometea* class; MA — *Molinio-Arrhenatheretea* class; TG — *Trifolio-Geranietea* class; QF — *Querco-Fagetea* class. hatched area — changes with the highest (a ≤ 0.001) statistical significance

forest types, which is rapid, and even simultaneous. Such basic work significantly facilitates the later indentification of factors disturbing the correct functioning of forest ecosystems (stress and other disturbances).

The real character of the development of plantations and monocultures may also be analyzed with the use of geobotanical indication. An example of such an approach is the elaboration conducted for differently ageed larch plantations (*Larix decidua*) and oak (*Quercus robur*) planted on the ground of a former oak-hornbeam forest (*Tilio-Carpinetum*) near the town of Pińczów in southern Poland (Roo-Zielińska & Solon 1990).

In this study, young, freshly established plantations of both tree species clearly differed in both the floristic composition of the herb layer and its ecological character. However, with the stand aging, and with an undisturbed development, a gradual changes took place, making both types of monocultures more similar to each other and to previously existing mature oak-hornbeam forest (Fig. 5). During the development similar trends has been observed as the following:

— An increasing share of species common for both types of monocultures;

— A statistically significant increase in number and in cover of characteristic species for deciduous forests of the *Querco-Fagetea* class, and simultaneously a decrease in species from other phytosociological classes;

— An increasing share of shade-seeking species;

— An increasing share of species of an oceanic (Atlantic) character;

— A decreasing share of xerophylous species and a statistically significant increasing in the role of species typical for fresh soils;

— A general decreasing share of species with extremal requirements in relation to the majority of climatic and edaphic factors with a simultaneous gradual increasing in the area, share, and number of species with average requirements.

A repetition every few years of a detailed indicative analysis enables a quick evaluation of development processes of thickets and pole forest.

FINAL REMARKS

In the overview we have shown several selected examples of how to use geobotanical indication for an analysis of spatial changeability of forest phytocoenoses and habitat conditions. Remember that the above indices not only comprehensively characterize the condition of a given forest ecosystem, but also constitute a perfect analysis of dynamic transformations taking place in the vegetation and its environment, caused by anthropogenic influences (land reclamation, pollution of air and soils, and mechanical destruction of vegetation cover, etc.) as well as natural mechanisms.

REFERENCES

Clements F.E. 1920, Plant indicators, the relation of plant communities to process and practice, 290 p., Carnegie Inst. Publ, Washington.

Faliński J.B. 1990, *Kartografia geobotaniczna* Cz. II (Geobotanic Cartography Part II), 283 p., PPWK, Warszawa.

Grodzińska K. 1978, Mosses as a bioindicators of heavy metal pollution in Polish National Parks, *Water, Air, and Soil Pollution* 9: 83-97.

Kostrowicki A.S. 1972, Zagadnienia teoretyczne i metodyczne oceny synantropizacji szaty roślinnej (Theoretical and methodical problems in evaluation of the synanthropization of the plant cover), *Phytocoenosis* 1.3: 171-191.

Kostrowicki A.S. 1976, A system-based approach to research concerning the geographical environment, *Geographia Polonica* 33: 27-37.

Kostrowicki A.S., Roo-Zielińska E. & Solon J. 1991, Spatial differentiation of chory and gamy in vegetation landscape (Białowieża case study), *Phytocoenosis* 3 (N.S.), *Supplementum Cartographiae Geobotanicae* 2: 101-109.

Kostrowicki A.S., Roo-Zielińska E. & Solon J. 1992, Ocena stanu i przekształceń środowiska na podstawie wskaźników geobotanicznych (The evaluation of the environment on the basis of geobotanical indices), (in:) *Projekt systemu biologicznych wskaźników stanu i zmian środowiska*: 1-23, Narodowa Fundacja Ochrony Środowiska, Warszawa.

Lubchenco J., Olson A.M., Brubaker L.B., Carpenter S.R., Holland M.M., Hubbell S.P., Levin S.A., MacMahon J.A., Matson P.A., Melillo J.M., Mooney H.A., Peterson C.H., Pulliam H.R., Real L.A., Regal P.J. & Risser P.G. 1991, The Sustainable Biosphere Initiative: An Ecological Research Agenda, *Ecology* 72, 2, 371-412.

Matuszkiewicz W. 1981, *Przewodnik do oznaczania zbiorowisk roślinnych Polski* (The Guide for Determination of Polish Plant Communities), 298 p., PWN, Warszawa.

Roo-Zielińska E. 1982, Struktura geobotaniczna i jej ekologiczno-siedliskowe uwarunkowania terenu przyszłych osiedli mieszkaniowych w Białołęce Dworskiej w Warszawie (The geobotanical structure and its ecological conditions of a future housing estate area in Białołęka Dworska in Warsaw) 403-422 p, *Człowiek i Środowisko* 6 (3-4), Warszawa.

Roo-Zielińska E., in print, Ekologiczne zróżnicowanie roślinności rzeczywistej — analiza fitoindykacyjna (Ecological differentiation of the actual vegetation — the phytoindicative analysis), *Dokumentacja Geograficzna IGiPZ PAN*.

Roo-Zielińska E. & Solon J. 1990, Phytosociological typology and phytoindicator value of young oak and larch forest communities near Pinczów (southern Poland), *Vegetatio* 88: 67-78.

Solon J. 1994, A basis for the classification of bioindicative methods; A proposal for discussion, *Conference Papers IGiPZ PAN* 19:219-227.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
Conference Papers 19:245-254, IGSO PAS, Warszawa

DENDROCHRONOLOGICAL DATA APPLICATIONS AT FOREST MONITORING SYSTEM

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Abstract: Annual tree-ring width is one of the most acceptable indicators for ecological monitoring needs. Changes in annual tree-ring increments may be treated not only as an indicator of the anthropogenic pressure but also of growth and productivity dynamics of tree stands. When studying anthropogenic dynamics of injured stands, it is important to know the rates of growth, productivity, etc, in "normal" stress-free conditions. The growth model for Scots pine stands of different density for the most widely spread pine forest type (*Pinetum pleurosiosum*) was developed based on tree growth and mortality data from the "normal" (control) areas. Investigation of injured stands shows that anthropogenic changes of different indicators and parameters in a polluted environment are rather closely related and correspond well with the age changes of stands. The growth model of the injured stands was developed using a model of the natural dynamics of pine stands and data of anthropogenic changes of annual ring width.

Key words: dendrochronology, forest monitoring, Scots pine, Lithuania.

INTRODUCTION

Forests of the European continent basically consist of the even-aged stands in a different stage of succession after felling and fires. Pine stands are widely spread and one of the most sensitive to environmental pollution; therefore, they are the most important forest monitoring objects.

Assessment of anthropogenic changes of various physical, chemical, and biological indicators on the background of its natural quasi-periodical fluctuations is a difficult problem. Particular difficulties arise in the case of low level chronical environmental pollution on a regional scale.

Real possibilities of anthropogenical changes assessment depend on characteristics of monitored indicators, such as:

— sensitivity of indicators to anthropogenical influence;
— spatial and temporal variability of indicators.

METHODS

Methods and indicators must have a high priority to allow use of retrospective information for a sufficiently long period. Often erroneous conclusions may be obtained with accurate but short-term data.

Many investigators have pointed out that annual tree increment (width of annual tree rings) is one of the most acceptable indicators for ecological monitoring needs. Despite its rather low sensitivity, the method provides important long-term series information.

In order to be used as a quantitative assessment of tree increment decrease, caused by the environmental pollution, the method has been developed by comparing increment indices of injured and healthy stands (Bitvinskas 1974; Liepa 1980). In this case, the accuracy of assessment is subjective and depends on the successfulness of healthy or so called “control” stand choice. The method was improved during the last decade and its objectivity improved (Liepa 1980). The control stand method may be used successfully in areas with a well-expressed pollution gradient.

In the case of a comparatively low level of chronic environmental pollution on a regional scale, the choice of “control” stands is very difficult. Methods, based on the quantitative analysis of tree ring- series of injured stands and dependence of the width of annual rings from exogenous and endogenous factors, are most promising (Philips et al. 1977; Cook 1987). The value of these methods depend on the level of our knowledge in the scope of causes of natural ring-series fluctuations.

The dependence of annual tree-ring width on various climatic factors was the principal goal of dendroclimatological investigations. Our investigations show that the correlation coefficient between different climatic factors and tree-ring width is not very high and usually does not exeed 0.3-0.4.

RESULTS AND DISCUSSION

Our investigations show that the temperatures of late winter (February), early spring (March, April), and late summer (August) of the current year, and the temperatures of the autumn months of the past year (September and October) strongly affect the growth of pines in Lithuania.

The effect of precipitation is less essential than the effect of temperature (Fig. 1). The closest relations were found between annual tree increment and precipitation of winter (January and February) and summer (June and July).

Climate response models are usually considered as the linear response models. In climatic conditions, far from optimal, such simplifications seem acceptable. Shelford (1913) shows that deficiency of heat energy and moisture, similarly a surplus of heat energy and moisture limit activity (growth) of live organisms. Numerous experiments show that the so called curves of tolerance are best approximates by the curve of the type:

$$Y = e^{a + bx - cx^2} \tag{1}$$

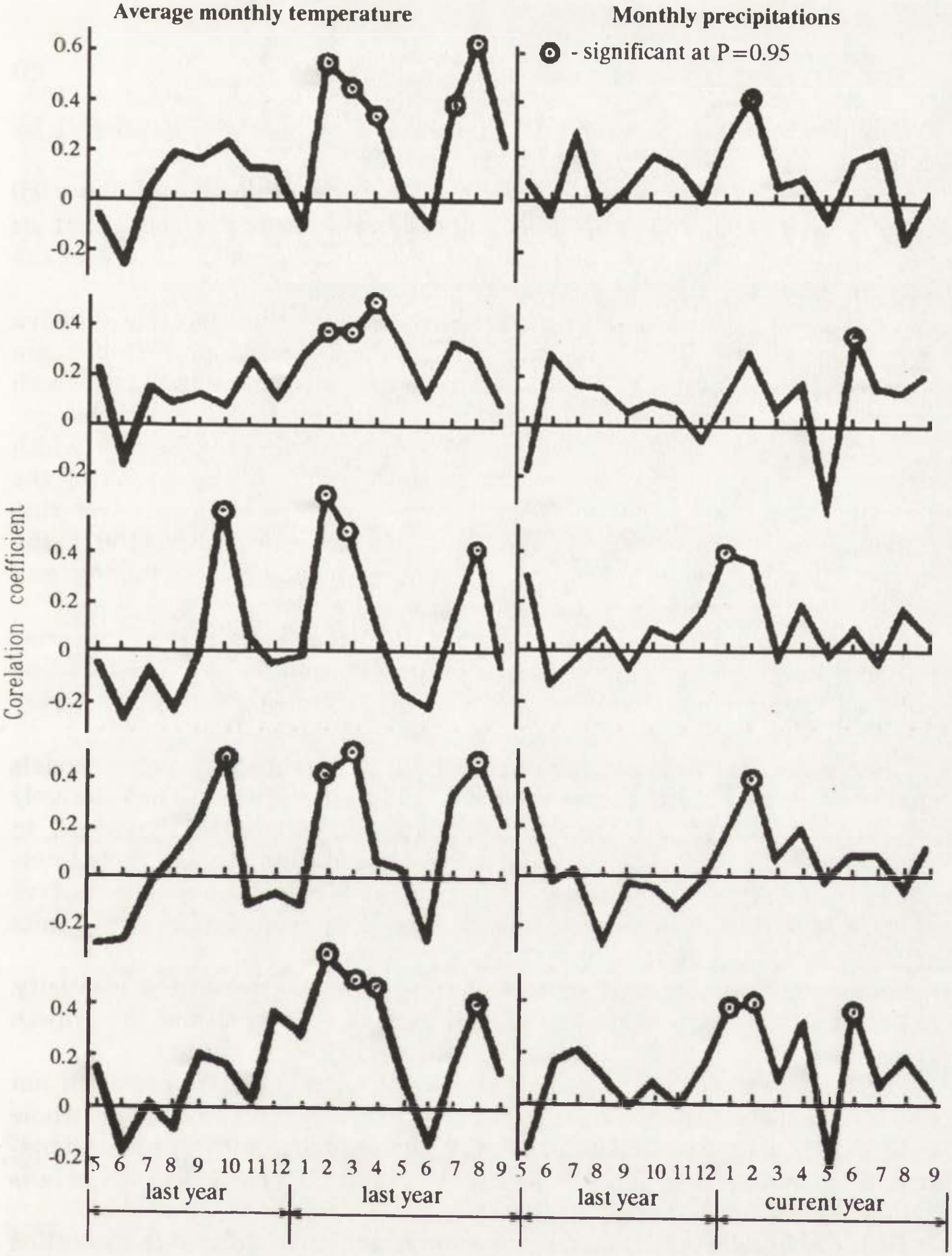

Fig. 1. Correlation coefficient between increment indices and climatic indicators

or after a logarithmic transformation:

$$\ln Y = a + bx - cx^2 \tag{2}$$

and in a multivariate case we have

$$\ln Yj = a_0 + \left[\sum \left(b_i x_{ij} - c_i x_{ij}{}^2 \right) \right] \tag{3}$$

The theoretical background of these relationships was developed by Fomin (1985).

As a rule, three to four factors prove to be statistically significant (P = 0.95) and for one-half of these, square numbers are statistically significant as well. This type of climate-response model usually accounts for 40-70% of the tree-ring series variance, while their standard error is 7-10%.

Actual and estimated data of tree-ring series for moderately (Jonava region) and slightly (Kazlu-Ruda region) damaged Scots pine stands are given in Figure 2. In the 1970's, we could see that increment decrease, which cannot be explained by the influence of climate factors, had begun to change.

Our investigations show, that the closeness of climate-tree-ring width relations also depends on the length of time series. If the length of the tree-ring series exceeds 40 to 50 years, the closeness of climate-tree-ring relations usually decreases. As mentioned by Schweingruber (1987), the reaction of trees on external factors is changing in the process of aging, and possibly it is the reason for the phenomena noted above.

According to our investigations the 30- to 50-year length tree-ring series are most acceptable for climate response models used for the forest decline studies. The resolving possibilities of this statistical methodology is not very high but it allows detection at less than a 10% increment decrease.

From our point of view, resolving possibilities of climate-response models could be improved in the future if we can find how to estimate qualitatively the consequences of well-known regularities of population dynamics, in which all live organisms are striving for the equilibrium state in their interactions with environmental factors. Under these homeostatic conditions, tree response is not always adequate to influence of external factors, and limits the possibilities of statistical methods.

Considering such characteristics of the system as resiliency, elasticity, etc., more complex investigations of endogenous regularities of the growth process and its relations with exogenous factors are necessary.

For ecologic monitoring needs it is necessary to gather information not only about anthropogenic changes of one indicator, but about the whole stand growth and productivity as well. While studying anthropogenic dynamics of injured stands, it is important to know the "norm", which means normal growth, normal productivity, etc.

Forest science carefully developed growth tables (models) of the so called "normal stands." These models must reflect the growth of the even-aged stands of maximum productivity (full stocking). The last investigations, how-

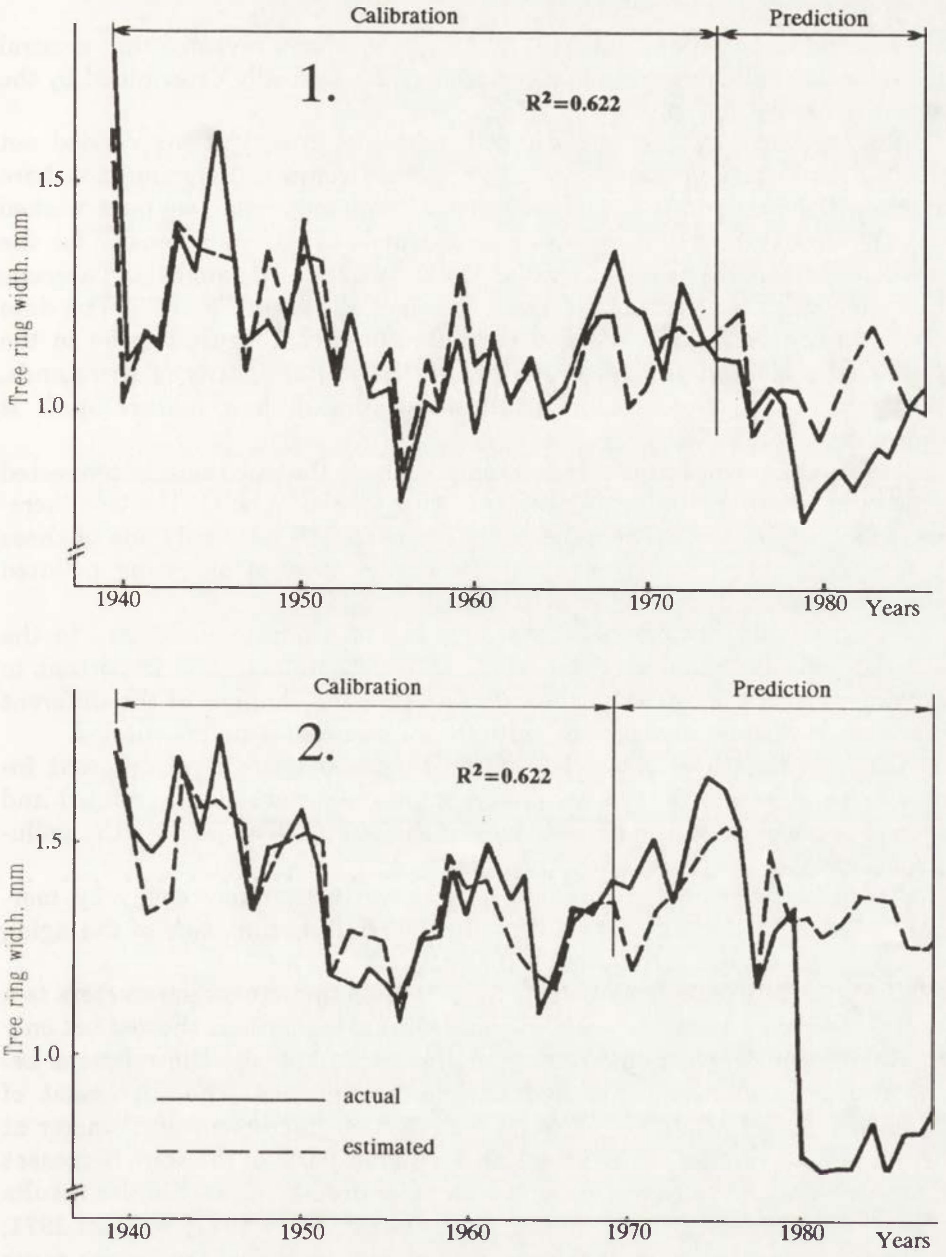

Fig. 2. Actual and estimated Scots pine tree rings: 1 — Slightly damaged stand in the Kazlu-Ruda region; 2 — Heavily damaged stand in the Jonava region

ever, showed that growth tables of normal stands do not reflect growth of real stands but represent a limit, which the stands achieve only once or several times during their lifetimes, and cannot constantly grow in these extreme conditions (Kuzmichiov 1977). Also, it has been revealed that natural dynamics of stands growing in a certain site are basically determined by the stand's primary density.

On the basis of trees growth and mortality investigations carried out during the last 15 years in specially protected zones of Berezina biosphere reserve (Belarus) and Aukstaitija National Park (Lithuania), we have worked out the growth model of the Scots pine stands of different density for the most important type — *Pinetum pleurosiosum*. Dynamics of average diameter, density of trees, and basal area are shown in Figure 3. The data show that the growth of the stands differs greatly from that given in the yield tables of normal stands. The higher the initial density of the stands, the quicker the stands achieve full stocking, and their mature stock is reduced.

Investigations of injured growth stands show, that two closely connected processes take part under the influence of the pollutants: (1) the tree increment decreases, and (2) tree mortality increases. Usually only one of these processes is taken into account in the methodology of assessing polluted environmental influence on growth stands.

Essential difficulties arise from changes of separate indicators to the antropogenical dynamics of the whole stand. Therefore, it is important to have a general concept that allows connecting the changes of the different parameters of individuals (trees) with the changes of all stands studied.

Our investigations show that anthropogenical changes of different indicators and parameters in a polluted environment are closely related and correspond well with the age changes of the stands. The heavier the pollution, the faster the process of stand aging.

Aging of trees and stands can be evaluated relatively easily by morphological indicators, despite a fact that internal mechanisms of the aging process of plants are not studied sufficiently.

Decrease of the increments by different stem and crown parameters is a characteristic symptom of aging in trees. Our investigations showed not only the increment decrease in polluted environments but also the relations between changing increments and various parameters. The increment of height decreases relatively more intensively than increment of diameter at breast height; the radial increment at the higher parts of the stem decreases faster than at the bottom parts of the stem, or breast height. Similar results also were obtained by other investigators (Lux & Stein 1977; Wentzel 1971; Lorenz & Eckstein 1988). It is well known that analogical tendencies occur with the aging of trees in noninjured stands.

Linear increment of the branches decreases most intensively in the higher part of the crown of injured trees. Most heavy growth depression is observed at the leader. The crowns of the injured trees become blunt or dry-topped similar to the crowns of overaged trees.

The mortality process in injured stands includes mostly thin and sup-

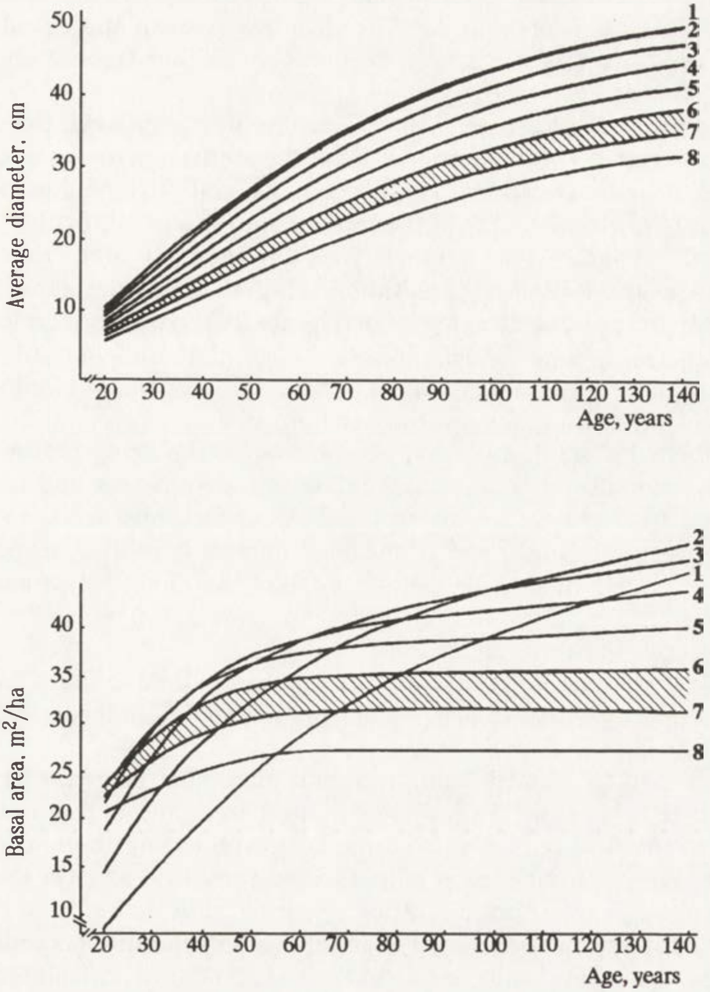

Fig. 3. Natural dynamics of Scots pine stands with various initial density

pressed trees. The heavier the pollution, the more intensive mortality occurs, and more thick stands of trees die. With age increase, an analogical deplacement of a self-thining process toward relatively thicker trees is observed in noninjured stands.

It is necessary to note that with an increase in injury level, the closeness of relations between various parameters of the stands decreases and entropy of the system increases in overaged stands as well. This makes the investigations and growth modeling of the injured stands more difficult.

Other investigators who studied tree development and other live organisms under the influence of pollution (Maurin 1986) also came to a conclusion that the process of aging is accelerated. Apparently acceleration of the aging process is a non specific reaction of biota to unfavourable external influence. According to Leopold (1964), plant aging is one of plant's adaptation mechanisms to an unfavourable environment.

Our principal conclusion is that acceleration of the aging process of trees and stands (decrease of increment by different parameters and increase of mortality) occurs to be rather interrelated. An opportunity arises to estimate the anthropogenic changes and to model dynamics of injured stands on the basis of information about the decline of one of the quantitative parameters of trees. For this purpose, annual radial increments of trees is one of the most prospective indicators.

We have developed a growth model for injured stands that is based on a model of natural dynamics of pine stands and data on anthropogenical changes of annual-ring width.

We have used the relative annual radial increment decrease as an additional input to this model. This was estimated according to the methodology presented in the first part of this paper, or by simulating the anthropogenic influence as the constant rate of annual increment decrease. On the basis of regressive dependence of annual radial age increment, taken from the model of natural dynamics of Scots pine stands, and information on radial increments of the damaged stands, biological age of stands was calculated.

Dynamics of all other parameters of damaged stands were calculated using a model of natural Scots pine stand dynamics, putting in the biological age of damaged stands for each annual step of modeling.

Figure 4 shows the dynamics of damaged Scots pine stands for three simulated cases: (1) slight influence — annual anthropogenic decrease of tree-ring width equals 0.5%; (2) middle influence — equals 3%; and (3) heavy influence — equals 10%. Thus an average diameter of injured stands is increasing faster than that of healthy stands. This phenomena is a consequence of the principal regularity of tree mortality process for damaged stands. As mentioned above, the process of stand injury includes mostly thinning and growth suppression of trees.

All the basic tendencies calculated by the model are similar to the data of long-term field investigations of injured stands, and confirm the acceleration

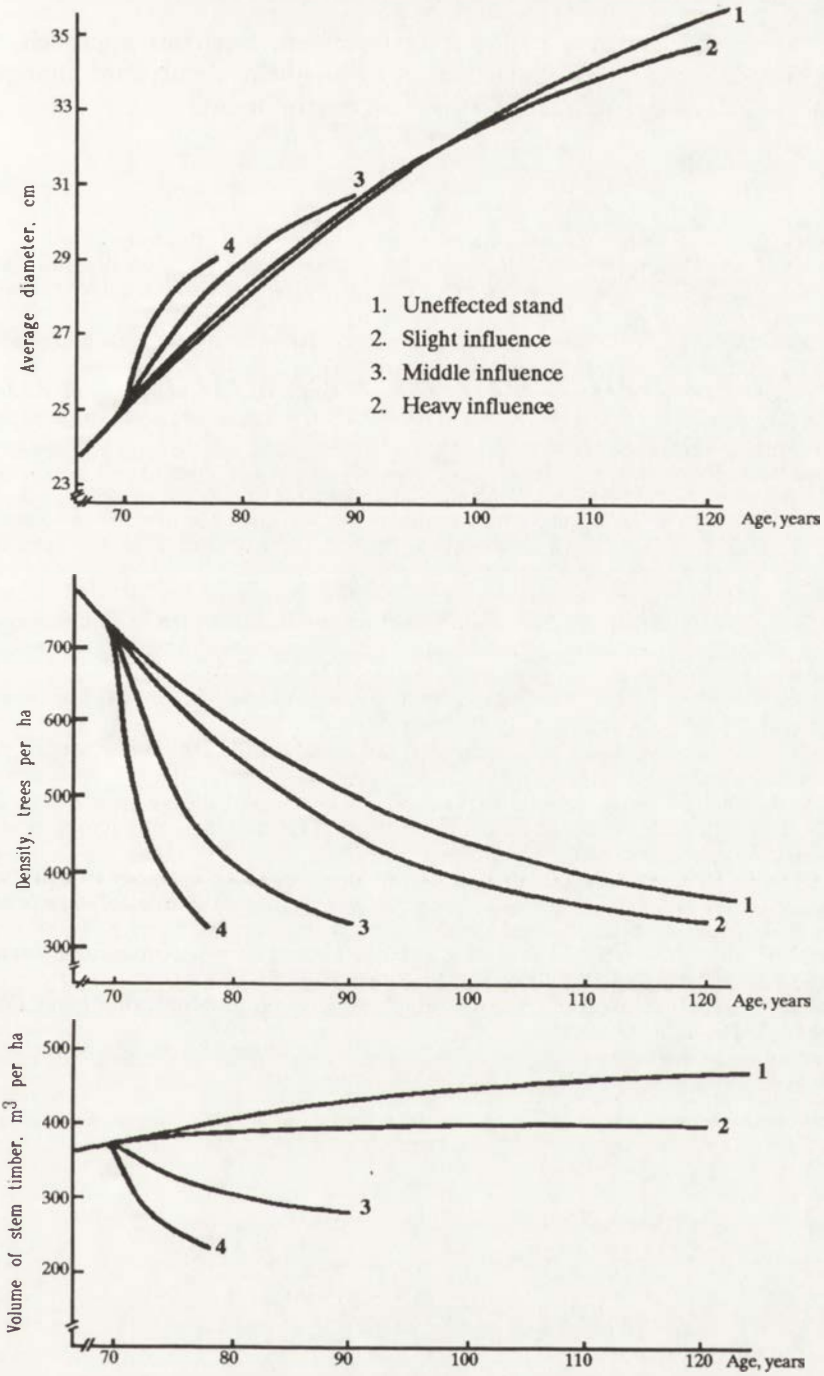

Fig. 4. Dynamics of damaged Scots pine stands

of the aging process in a polluted environment. Such an approach, with limited initial data, allows information to be given about total changes of stands' productivity dynamics in a polluted environment.

REFERENCES

Bitvinskas T.T. 1974, Dendroklimaticeskie issledovania, 220 p., Gidrometeoizdat.

Buligin N.E. & Dovgulevitsch Z.N. 1981, O matematiceskom modelirovanii meteofenologiceskich sviazei u dreviesnych rastienii v prognosticeskich celach, *Ekologia i zascita lesa* 6: 19-21.

Cook E.R. 1987, The use of climatic response models of rings in the analysis and prediction of forest decline, (in:) *Methods of dendrochronology*, 1: 269-276, Warsaw.

Fomin B. 1985, Teoreticeskie predposylki kontrolia fonovych antropogennych vozdeistvij na prirodnyje ekosystemy, (in:) *Problemy fonovovo monitoringa sostojanija prirodnoj sredy*, pp. 69-78, Leningrad.

Gortinskij G.B. & Evdokimov W.N. 1981, Sposob ocenki kompleksnogo vliania temperaturi i osadkov na prirost derevev, *Ekologia i zascita lesa* 6: 16-19.

Kuzmichiov W.W. 1977, Zakonomiernosti rosta drevostoev, 160p., Nauka, Novosibirsk.

Liepa I.J. 1980, Edinaia programma reakcjii drevostoia na vlianie faktorov vozdieistva, Modelirovanie i prognoz v ekologii 44-67, Riga.

Leopold A. 1964, Plant growth and development, 490 p., New York.

Lorenz M. & Eckstein D. 1988, Wachstumsreaktion von Eizelbaumen in Douglasien-Fichten und Kieferbestanden norddeuschen Walds-Schadengebieten, Forst und Holzwirt., 43.1: 8-12.

Lux H. & Stein G. 1977, Die Forstlichen Immisionschadgebiete im Lee des Ballungsraumes Halle und Leipzig, *Hercynia* 14.4: 413-421.

Maurin A. 1986, Temporalnost kak integralnyj pokazatel trenda sostoiania lesnych ekosistem, Monitoring lesnych ekosistem 21-22, Kaunas.

Philips A.O., Shelly J.M. & Burkhardt H.E. 1977, Eastern White Pine growth retardation by fluctuating air pollutant levels: interaction of rainfall, age and symptom expression, *Phytopatologia* 67.6: 721-725.

Schweingruber F.H. 1987, Potentials and limitations of dendrochronology in pollution research, (in:) *Proceedings of the international symposium on Ecological aspects of treering analysis*, pp. 344-352, New York.

Shelford V.E. 1913, The reaction of certain animals to gradients of evaporating power and air. A study in experimental ecology, *Biological Bul.*, 79-120.

Wentzel K.F. 1971, Habitus-Änderung der Waldbäume durch Luftverunreinigung, *Forstarchiv* 42: 165-172.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
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CLIMATIC STATES OF FOREST ECOSYSTEMS DYNAMICS

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Abstract: The analysis of the climatic determination of the modern occurrence of forest plants has enabled us to present a hypothesis that plant species showing similar ecological requirements need to be dependent on different climatic limiting factors in their distribution and evolution for a successful coexistence. And phylogenetically different species can exhibit similar patterns of relations with the climate owing to limited possibilities of adaptation. As a result of an extensive literature review and collected pollen materials, the data base "PALEO" was created. All factors creating a pattern of connection with the climate can be differentiated into three groups, which are conventionally named: limiting factors, controlling factors and indifferent variables. The dimensionality of the phase space of an area of specific forest ecosystems (both taiga and broad-leaved) determines their present life. Objects of studies are *Picea abies* (L.) Karst., *Alnus incana* (L.) Moench., *Carpinus betulus* L., *Ulmus carpinifolia* Rupp. ex G. Suckow, *Quercus robur* L., etc.

Key words: limiting factors, models, information theory, climate, forest types, Belarus.

INTRODUCTION

In order to recognize the anthropogenous component of the forest ecosystems dynamics, we must proceed from "climatic standard" as the main element of monitoring. By dynamics, we mean hologenetic transformations of the forest ecosystems rather than succession changes. The complexity of the system "climate" consists of a multidimensional pattern. Climatic states of forest ecosystems can be described by an infinite number of variables, each of them having a physical meaning. However, the redundancy of information increases the reliability of the presentation of the climate as a system, but simultaneously deteriorates chances to realize it by analyzing the forest ecosystems dynamics. This paper deals with problems of the climatic standard of forest ecosystem's hologenetic dynamics and determination of the most informative climatic variables for monitoring. These problems require a solution of one more question concerned with the heredity endowment of former forest states to modern forest ecosystems.

The curent state of forest ecosystems is a result of superimposing and interaction of the "internal" and "external" memories of the systems and of the contemporaneous conditions effect. The internal memory of forest ecosystems reflecting their autochtonous development is described in detail in literature, while data about the external memory connected with an ability of systems to memorize former states and those arising in response to different external changes are practically absent. As a result of an extensive literature review and collected pollen materials (more than 300 sections), the data base "PALEO", including three main blocks: GEOPALEO, DEPS, TAX have been created. Block GEOPALEO presents section number and name, geographical coordinates, data about the source of information and author, as well as some additional information about the object. Block "DEPS" deals with the sediment type, number of layers and samples in the sections, absolute and relative time, thickness of deposits, and sampling depth.

Block "TAX" describes the taxon pollen percentage in samples, depending on their location in the section and the absolute age. On the base of "PALEO" data block, isolinear and vectorial phytochorological maps of the principal forest-forming trees have been constructed, the migration ways and time, and flora concentration centres have been determined.

The paleophytochorological analysis based on spore-pollen diagrams gives only a partial solution of the "heredity" problem and tentatively establishes stages (migration, transformation, and succession) of forest ecosystems formation in the Late Pleistocene-Holocene time. This confirms to a large extent Sukachev's idea about the endo-exogeneous dynamics of forest communities.

Nevertheless, the deficiency of microanalysis, carried out on the taxon level can be successfully supplemented with macroanalysis (on the community level), which enables determination of the rules of the forest ecosystems transformation within the East-European Plain in the Holocene. Analysis of the material permits spatial and chronological isomorphism of present ecosystems' transformations on the genus level and, partly, on the species level. The cluster analysis has resulted in the determination of the periods with relatively stable and unstable structure type of forest ecosystems.

These periods generally agree with the formerly established stages of the vegetation cover formation on the paleophytochronological level of generalization.

METHODS

Examination of corresponding maps of separate time cuts and peculiarities of the forest ecosystems-type structure for stationary and nonstationary regimes gives an opportunity to state a hypothesis on the modern situation of stationarity degree. An idea about relatively stationary transformations of forest ecosystems in the modern period coordinated with climatic changes was a result of our investigations.

The development (evolution) and distribution of forest ecosystems depend on climatic factors, the number of limiting factors being small. To recognize the determining role of climate a complete description of the system “climate” using known indicators is needed. During the investigation of the behaviour of systems with numerous mutually dependent parameters (climate is such a system), however, the necessity for their reduction arises. Some methods of the information theory (Kastler 1960) have been used for resolving this problem. The above methods, in some cases, permit establishment of better logical correlations on the basis of available data of parameters. Standardized coefficients of the correlation between the characteristics have been calculated from a formula (Puzachenko & Skulkin 1981):

$$K(X,Y) = \frac{2^{T(X,Y)} - 1}{2^{H(\min\{X,Y\})} - 1} \times 100\%$$

where: T(X,Y) is the informational measure of correlation, bit; H(min{X, Y}) is the minimal uncertainty of one from two parameters.

In the case of close correlation between two climatic parameters, one of them with a large entropy (which characterizes the measure of spatial diversity) has been selected for further analyses.

It appears that because of reduction of information, 37 characteristics (of 127 initial variables) are sufficient for a complete description of the system “climate” (error is 5%).

The dimension of the phase space of a specific area of forest ecosystems (both taiga and broad-leaved) determines their present life (Kozharinov 1989). Objects of studies are *Picea abies* (L.) Karst., *Alnus incana* (L.) Moench., *Carpinus betulus* L., *Ulmus carpinifolia* Rupp. ex G.Suckow, *Quercus robur* L., etc.

RESULTS

A number of limiting factors was small, and forest ecosystems are indifferent to most of the climatic factors. Moreover, all the factors creating a pattern of connection with the climate can be differentiated into three groups, which are conventionally named limiting factors, controlling factors, and indifferent variables (Table 1). A group of limiting factors includes those which determine the distribution and evolution of plants and plant communities, a group of controlling factors involves those that govern the evolution of plants and their communities and are responsible for the general habit, growing, flowering, and fruiting periods, productive capacity of plant communities, etc.

For coniferous communities, limiting factors involve total temperature above 10°C, mean air temperature in May, and number of days per year with relative humidity exceeding 80%. Controlling factors include mean air temperatures in

April and June, mean air temperatures of the warm period of the year, total-year evaporation, and moistening coefficient of the warm period.

Table 1. Critical periods in the evolution and distribution of forest plants (fragments)

Plant species	Limiting factors		Controlling factors	Critical periods	
	Eliminators	Compensators		Phenophase	Ontogeny
Picea abies (L.) Karst.	Total T > 10°C May temperature Number of day with relative humidity > 80%	Snow cover depth	April temperature June temperature Temperature of WP Evaporation Moistening of WP	Flowering	Maturity
Quercus robur L.	January temperature Number of thawing days	Snow cover depth. Number of days with snow cover	Number of days FW Temperature of CP December temperature Total T < -50°C	Winter rest period Begining of vegetation	Juvenile phase

Limiting factors for oak forests are mean air temperatures in January, number of thawing days during the cold period, and depth of snow cover. The last feature has a compensation effect upon spreading and evolution of oak forests. Controlling factors of oak forests are mean temperatures of the cold period, mean December temperatures, total-year temperature below -5° C, and duration of foggy weather period.

According to the position and azimuth orientation of a geographic boundary, limiting and controlling factors can be interchanged, which is due to both regional pattern of the hydrothermal field of the territory, and the time of the area colonization.

The analysis of the climatic determination of the modern occurrence of forest plants have enabled us to establish an hypothesis that plant species showing similar ecological requirements need to be dependent on different climatic limiting factors in their distribution and evolution for a successful coexistence. Phylogenetically different species, however, can exhibit similar patterns of relations with the climate owing to limited possibilities of adaptation (Table 1). Phytochorologically, forest ecosystems areas are dominated by one or another forest-forming species. The analysis of a mosaic pattern of forest ecosystems in the hydrothermal fields of the East-European Plain territory enable us to distinguish limiting factors, which are similar to the features responsible for the species areal range as a whole (Fig. 1).

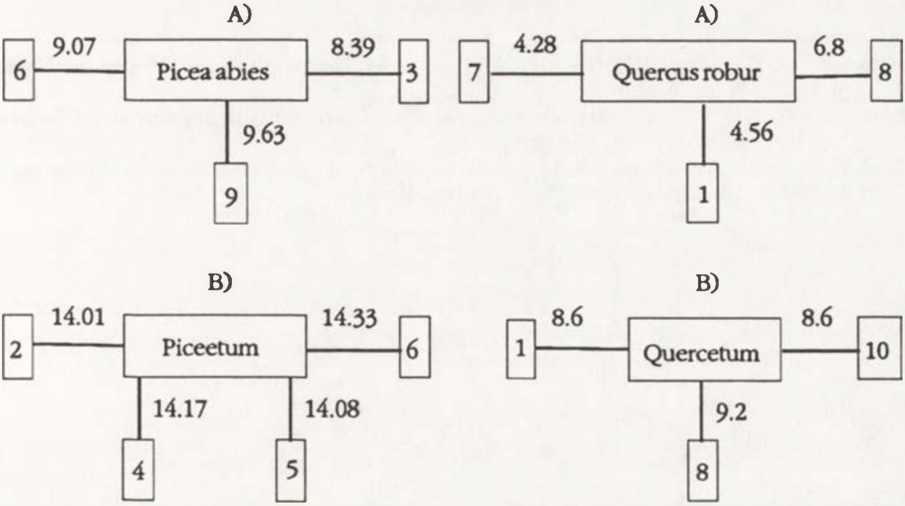

Fig. 1. Graph showing relationship between plant population occurrence (A) and forest ecosystems (B) and climatic limiting factors: (1) January air temperatures; (2) April air temperatures; (3) May air temperatures; (4) mean year temperatures; (5) absolute minimum temperatures; (6) total temperatures above 10°C; (7) average depth of snow cover; (8) number of thawing days in winter; (9) number of days with relative humidity higher than 80%; and (10) number of foggy days

CONCLUSIONS

The relationship of forest plants and their communities to climatic limiting factors has an effect on their behaviour, especially in peripheral parts of areas. The studies show that the most important signs of dynamic trends of evolution and forest ecosystems distribution in the mixed-forest zone are the pattern of relationship and the probability of occurrence in plant populations relative to climatic limiting factors, ecotopic diversity of the area, life form of the plant and its geography, the vitality and evolution cycle of vegetation near its occurrence limits, number and type of plant population "islands" and their regional reference and ecological identity. It was revealed by analysis that the taiga forest ecosystems are at the present time in the stage of natural decrease in their areas, whereas broad-leaved forest ecosystems evidently show a tendency to expand.

The elaborated method of statistical description of ecological niches makes it possible to determine a number of factors of the normal, natural evolution of forest ecosystems distribution and provides a possibility for their studies when developing the climate monitoring of forest ecosystems.

REFERENCES

Kastler G. 1960, Principles of the information theory, (in:) *Information theory in the biology*, pp. 9-53, Moscow.

Kozharinov A. 1989, Climatochorological analysis of forest plant population of Belarus, 176 p., *Nauka i tekhnica*, Minsk.

Puzachenco, Ju.G. & Skulkin V.S. 1981, The structure of the forest zone vegetation in the USSR. Systematic analysis, 276p., *Nauka*, Moscow.

J. Solon, E. Roo-Zielińska, A. Bytnerowicz (eds.),
Climate and Atmospheric Deposition Studies in Forests,
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LOSS OF NEEDLES IN RELATION TO THE BIOSOCIOLOGICAL POSITION OF TREES IN SPRUCE ECOSYSTEMS

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Abstract: In the northwestern Slovakia, 60 sample trees of different biosociological position were analyzed. Whereas needle loss in dominant trees was 46.0%, needle loss with codominant, partially codominant, suppressed, and undertopping trees was 48.2%; 62.5%; 68.4%; and 89.2%, respectively. While the dominant and codominant trees of good biosociological positions had approximately one-half needle biomass in the upper vertical thirds of the crowns, the trees of the worst biosociological position in the ecosystems had 68.8% to 90.4% of needle biomass concentrated in the upper vertical thirds of their crowns. The worse the biosociological position of the tree, the faster and more intensive was the reaction to stress caused by emissions, demonstrated by needle loss biomass. The worse the biosociological position of a tree, the more needle loss biomass occurs in lower and central parts of crowns leaving needle biomass concentrated in the upper parts of the crowns.

Key words: tree biosociological position, norway spruce, needle loss, Slovakia.

INTRODUCTION

At the beginning of the 1980's, the problems of damaged forests became serious in Slovakia. First, oak forests in the southern parts began to die; but now, the most important problems in the spruce forests (both natural and seminatural) occur in the northern part of Slovakia. Here a third generation of man-made spruce forests grow on sites of natural mixed beech, spruce, and fir. Environmental pollution affects the forests in northern Slovakia so intensively, especially under certain meteorological situations, that many forests at an elevation of 700 m to 1000 m above sea level are badly damaged, and their production is getting lower and lower.

SCOPE OF STUDY

In the northwestern part of the country, we studied the forests on four sample plots situated on the slopes exposed to the prevailing winds in the Beskydy Mountains. The sample plots were in different gradients of damages caused by pollutant emissions. In these forests we studied defoliation, reduction of the leaf area index (LAI), changes in crown architecture, and biomass production. For these reasons, we analyzed 60 sample trees of different biosociological position.

The studied forests were 65- to 85-years-old and were situated at the elevation of 720 m to 910 m above sea level.

Our research goal was to learn how trees of different biosociological positions in forests react to needle loss. In our study, we used the well-known Kraft's classification scale.

RESULTS AND DISCUSSION

Needle loss was studied in August 1987 to 1991. Needle loss increased at that time. For example, in 1987 the needle loss at Sample Plot I, II, and III was 48.9%; 46.7%, and 47.9%, respectively. In 1988, it was 55.5%; 54.9%, and 53.3% on average; and in 1989, 55.8%; 57.9%, and 55.4% on average. In 1990 and 1991, the needle loss was smaller.

Generally, the smallest needle loss was found in dominant trees in three sample plots. The lower the biosociological position in the ecosystem, the higher the needle loss. Table 1 shows the situation for Sample Plot III.

Table 1. Needle loss for spruce trees at Sample Plot III

Kraft's tree class	Number of trees per 1 ha	Mean needle loss	Standard deviation
1	148	46.0	33.48
2	133	48.2	31.94
3	61	62.5	26.10
4	66	68.4	19.18
5	31	89.2	9.85

In these three sample plots, needle loss varied from 37.2% (first tree class) to 98.9% (fifth tree class) in 1987 to 1991.

In Sample Plot IV, needle loss obviously was less pronounced. For example in 1989, trees of first class had a needle loss of 26.4% on average, whereas trees in the fifth tree class had a needle loss of 73.7% on average. For dominant, codominant, and partially codominant trees (in the first, second, and third class trees on the Kraft scale), 6-year-old needles were found in the upper third of the crowns in almost all sample trees; 7- and 8-year-old needles were found only on the upper thirds of the crowns of four dominant sample trees. A complete number of needles was found only on the 2- to 4-year-old twigs in trees of first, second, and third tree classes. The older twigs had needle loss from 50% to 80%.

In the upper thirds of trees in the fourth and fifth tree classes, only 2- to

4-year-old twigs with needles were found. A complete number of needles, however, was found only on 1- and 2-year-old twigs.

Differences between sample trees of different biosociological positions were non-significant in the central third of the crown. Generally, a complete number of needles was found on 1-, 2-, 3- and, occasionally, 4-year-old twigs. Older twigs were found only on trees of first and second tree classes (up to 6-years-old), but the needle loss was 30% to 95%.

In the lower thirds of the crowns of trees of all tree classes, there were only 1- to 4-year-old twigs with needles, but the complete number of needles was only on the 1-year-old twigs. The differences in the loss of needles from twigs with living needles between trees of different biosociological positions were not significant.

The total amount of needle biomass and its distribution in the crown space of sample trees of different biosociological positions was also studied. After weighing the branches of the respective thirds of crowns (i.e., living branches with the diameter of 1.5 cm and less), testing samples in the laboratory, and stating the rate between needle and branch biomass in weight units, we could evaluate how needle biomass was distributed in the upper, central, and lower thirds of living crowns of trees with different tree classes.

Table 2 shows that the dominant and codominant trees in sample plot III had about 50% of needle biomass in the upper thirds, whereas in central thirds only about 1/3 of the total amount of the needle biomass. The lower thirds of the crowns of dominant and codominant trees contained only about 16% to 17% of needle biomass. For trees in the third, fourth, and fifth Kraft tree class scale, the greatest part of needle biomass was concentrated in the upper thirds of crowns (68.8% to 90.4%), with small parts of needle biomass in the central and lower thirds.

Table 2. Differentiation of needle biomass within crowns of sample trees at Sample Plot III

Kraft's tree class	Percentage of needle biomass in:		
	crown thirds (%)		
	upper	central	lower
1	48.2	35.0	16.8
2	52.0	31.8	16.2
3	68.8	22.6	11.4
4	84.7	10.9	4.4
5	90.4	7.6	2.0

We can state that the biosociological position of a tree in the forest ecosystem is an important factor. Trees react to poor growing conditions (including air pollution stress) according to their position in the ecosystem. Of course, their present position, vitality and health status, depend on previous growth conditions. The biosociological position of trees plays an important role in the complete scale of phenomena caused by environmental pollution of the forest ecosystems of our country.

CONCLUSIONS

Comparing the above results with information showing the amount of needle biomass in "healthy" or less healthy forest ecosystems in our country, we can state the following:

— The worse the biosociological position of a tree in the ecosystem, the faster and more intensive is the reaction to stress caused by air pollution deposition, demonstrated by loss of the needle biomass;

— The worse the biosociological position of a tree in the ecosystem, the more intensive is the loss of needle biomass in the lower and central parts of crowns;

— The worse the biosociological position of a tree in the ecosystem, the larger the part of needle biomass is concentrated in the upper parts of crowns;

— Differences are insignificant among dominant, codominant, and partially codominant trees when compared with the persistence of needles in the upper thirds of crowns;

— Differences are significant among trees of different biosociological positions, when compared with the longevity of needles in central and lower thirds of crowns;

— Needle biomass (loss of needles) and its distribution in crowns of trees with different biosociological positions can be used as a characteristic indicator of the health state of the forest.

FINAL REMARKS

It is worthwhile to emphasize that defoliation or needle loss is not the only and most significant indicator of the level of health state of our forest tree species.

It should be mentioned that another method was also used during the field work in which 6-year-old branches were taken from the top part of the crowns and then fully analyzed. We could not find any significant differences in needle loss between the trees of different biosociological positions in the same forest ecosystem. On the other hand, the average values of needle loss obtained from certain forest ecosystems were valuable when comparing two or more forest ecosystems.

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NUMERICAL TERRAIN MODEL AS A BASE FOR FOREST ENVIRONMENTAL RESEARCH IN THE RANGE OF FOREST DISTRICT AND WHOLE COUNTRY

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Abstract: Methods used at the Department of Forest Management and Geodesy, Warsaw Agricultural University, for establishing the numerical model of the terrain surface and GIS are presented in this paper. The numerical model of the terrain surface (also called numeric terrain model [NTM]) describes vertical configuration of the terrain. It is defined as a series of properly chosen terrain surface points (with coordinates x, y, z) and interpolation algorithms enabling reproduction of the surface in defined space. The NTM can be built by making use of various professional software packages. The Department of Forest Management and Geodesy uses the SCOP system which is widely used in Germany and Austria. The SCOP system is composed of software packages (developed for various computers and operating systems) which serve to build the NTM and to process the data. The Department of Forest Management and Geodesy use the PC ARC/INFO version 3.4 D system to build the Geographical Information System (GIS). It has been assumed that research on diversity and spatial structure of forest complexes can be rationalized by the use of so called grid data bases. The size and location of basic fields should be according to the SINUS system. Research on 15 forests stand characteristics was carried out in Rogów Forest Experimental Station Site (Popień Forest). The relation field (according to SINUS system) was diversified: 31.25 m × 31.25 m (P-7), 62.5 m × 62.5 m (P-6), 125 m × 125 m (P-5), 250 m × 250 m (P-4), 500 m × 500 m (P-3). Indices from the evaluated data were entropy, Szyrmer coefficient "z," and autocorrelation coefficient. The optimum fields for this research are fields P-7 and P-6. The proposed method can be applied to diversity evaluation and diversity comparison of different objects. Interpretation of the results can deliver valuable information to ecologists, specialists in silviculture, topology, and resource management.

Key words: GIS, numerical terrain model, SINUS system, Poland.

WHAT IS THE NUMERICAL TERRAIN MODEL?

Information on the extent of degradation of environment is essential for protecting and managing natural resources. Information distribution substantially improved after the creation of computerized spatial information systems (SIS) which made collection, computing, storage, and access to spatial information possible. Spatial information is information about position, geometric properties, and spatial relations of objects that can be identified in relation to the Earth (Gadzicki 1990). The numerical model of the terrain surface, also called numeric terrain model (NTM), describes the vertical configuration of terrain and is the base for many spatial information systems. Sometimes NTM is considered to be an independent information system. NTM is defined as a series of properly chosen terrain surface points (with coordinates x, y, z) and interpolation algorithms enabling reproduction of the surface in defined space.

Information about vertical configuration of the terrain should be used in different activities carried on in forest enterprises as well as in forest research (Olenderek & Korpetta 1992; Piekarski et al. 1992). Terrain relief, as a factor forming forest communities, is taken into consideration in forest management, silviculture, phytosociology, pedology, and forest climatology. The NTM of the areas affected by erosion processes can have a special importance. In such cases, the NTM allows forecasting of the scope and range of erosion processes and finding effective methods of protection against this unfavorable phenomenon (Ehgartner et al. 1988; Stechauner & Ehgarten 1988). The NTM is very helpful in analysis of storm damages, avalanches, spatial distribution of pollution and ecological risk mapping (Belina 1992; Bayer et al. 1992; Doringer and Schwarz 1992; Centralblatt ... 1991).

The NTM can be applied also to engineering terrain management; e.g., designing roads and strip roads, hydraulic objects, etc. It can also serve as a source of information for orthophotomapping and stereoorthophotomapping. These maps should be the basic forest maps for mountain and submountain regions in the future.

CHARACTERISTICS OF UTILIZED NTM AND GIS SOFTWARE PACKAGES

The NTM can be built making use of various professional software packages. The Department of Forest Management and Geodesy uses the SCOP system which has been widely used in Germany and Austria.

The research on implementation of the SCOP system to forestry has been taken up within the HEXAGONALE program coordinated by the Institute of Photogrammetry in Vienna.

The SCOP system is composed of software packages (developed for various computers and operating systems) that build the NTM process data. The system began as a result of cooperation between Photogrammetry Departments of Technical Universities in Vienna and Stuttgart; its development started in 1972 and is ongoing. Utilizing algorithms interpolation, NTM's can be built exactly by means of the SCOP system, which makes the NTM useful for large-scale exact elaborations (Duren 1992; Hochstoger 1989). SCOP modules make it possible to correct data base preparation for NTM creation, interpolation, and further processing (Waldhausl & Molnar 1991).

The system provides the possibility of contour line interpolation (including the terrain skeleton lines), altitude calculation of points of known level coordinates, setting the vertical longitudinal and transversal cross-sections, and building the numerical model of slopes and slope zones delimitation. The system also provides the possibility of setting vectors illustrating the slope direction, making perspective drawings (in axonometric and central projection), and mono plotting (changing of picture coordinates for terrain coordinates).

The SCOP allows building NTM's by aggregating two basic models and makes solid-bounded volume calculation by these two models possible. The SCOP also allows to generate terrain visibility (lighting) maps from various basic points that enable insolation zone simulation according to season and the time-of-day.

Because of the features described above, the SCOP is a suitable tool for forest and landscape research. The system becomes versatile for spatial research after connection with the Geographical Information System (GIS).

Department of Forest Management and Geodesy uses the PC ARC/INFO version 3.4 D system. This is a software package for building the GIS. The basic version is assigned to computers called workstations running under a UNIX operating system. The software producer also adopted it for microcomputers running under the DOS operating system so that the GIS can be built especially for Poland's microcomputers and to be compatible with the IBM PC standard. A simplified version of the ARC/INFO system is called PC ARC/INFO and is widespread today in the 3.4 D version.

The PC ARC/INFO system contains six program blocks for spatial data base and thematic data base creation; these blocks are topological construction structures, interactive output of data, preparation and final edition of maps, spatial analysis (e.g., analysis of network systems), spatial data selection according to attributes value, and data conversion to design an assisting system (including data conversion from the ERDAS grid system, and conversion to and from the computer-aided design system AUTOCAD).

Program packages PC ARC/INFO allow users to create their own applications using macro instructions and programs written in Simple Macro Language (SML).

Promotion of this software package by the ESRI in Poland and the presence of the official dealer (NEOKART) designated to organize training courses for system users, allows one to hope that ARC/INFO and PC ARC/INFO will be widely used by decision making centers and design offices utilizing spatial information systems.

Using the PC ARC/INFO and SCOP systems, the successful trial of full integration of the two systems was undertaken (Hochstoger et al. 1992).

A tool for versatile forest environmental analysis in three-dimensional space at different detail levels — from forest complex to forest superintendency to the whole country — was achieved.

NTM AS A FOREST ENVIRONMENTAL RESEARCH BACKGROUND IN FOREST SUPERINTENDENCY SCALE

Forest environmental research has intensified in past years all over the world (Wilson & Peter 1988). It encompasses not only the quantity of nature elements existing in certain areas, but also their relations and evolution processes. This is not a static system; it changes in time, being affected by various internal and external factors.

It is assumed that research on this system will deliver better knowledge of ecosystems and allow humans to influence in full consciousness the processes occurring in the ecosystems. The research must be carried on with reference to terrain configuration so the NTM can definitely improve it.

It was assumed that research on diversity and spatial structure of forest complexes can be rationalized by the use of so called grid data bases (Kamińska 1992). It was proposed to cover the forest complex with a net of basic fields of shape similar to a trapezoid. The size and location of basic fields should be according to the SINUS system (Ciołkosz, ed. 1990).

Each elementary field in this system has three functions. These functions are the following:

— A geometric figure surface;
— A data carrier;
— An identifier of phenomena spatial location.

We omit the technical side of grid data base creation in geometric and thematic meaning. The ARC/INFO and SCOP systems were used. The NTM was created according to the accepted basic field configuration for each grid mesh.

Forest inventory data was based on 15 stand characteristics that were registered in the ARC/INFO system. The experiment was carried out in Rogów Forest Experimental Station Site (Popień Forest). The relation field (according to the SINUS system) was diversified: 31.25 m × 31.25 m (P-7), 62.5 m × 62.5 m (P-6), 125 m × 125 m (P-5), 250 m × 250 m (P-4), 500 m × 500 m (P-3). The remaining data bases were used for qualification of spatial diversity of stand characteristics. Dependence of spatial diversity on the basic field area was evaluated. Entropy (Pierce 1967), Szyrmer coefficient "z" (Szyrmer 1987), and autocorrelation coefficient (Robinson et al. 1988) were the diversity measures.

Entropy is the measure of diversity, disorder, and uncertainty of a system. It increases with the number of information and freedom of choice increase, and decreases when freedom of choice and degree of randomness decrease. It is equal to 0 for an identical characteristic value in the entire set.

Coefficient "z" enables calculation of spatial diversity degree of phenomena defined with indices. It is a result of ratio values of all possible pairs of set elements; i.e., spatial units composing the studied object. It assumes values in the interval $0 < Z < 1$. $Z = 0$ means that the phenomenon value is constant in all units. Z close to 1 means diversity close to maximum; diversification is high when $Z = 0.5$.

Correlation examined in one of the sets is called autocorrelation. Characteristic value in an elementary field is compared to values in other fields located some distances off and in certain directions. Autocorrelation coefficient r assumes values <-1;1>. It is indeterminate for the constant value of characteristics in the entire space. The spatial diversity degree of a phenomenon decreases as the autocorrelation coefficient increases.

The diversity is evaluated in relation to stand characteristics, terrain relief, and surface created by an upper layer of crowns defined by the SCOP system. Tables 1, 2, 3, and 4 exemplify the results. The work is continued. Optimum fields are fields for this kind of research are P-7 and P-6 (Table 5).

Table 1. Diversity coefficient (entropy) of selected elements of the Popień Forest complex

Characteristic	Grid				
	P-7	P-6	P-5	P-4	P-3
Type of forest site	1.77	1.75	1.63	1.53	0.86
Species	1.23	1.29	0.93	0.97	0
Stand density	2.64	2.64	2.63	2.47	1.95

Table 2. Diversity coefficient (Szyrmer's) of selected elements of the Popień forest complex

Characteristic	Grid				
	P-7	P-6	P-5	P-4	P-3
Volume	0.311	0.313	0.311	0.350	0.251
Number of trees	0.383	0.390	0.386	0.414	0.371

Table 3. Diversity coefficient (autocorrelation) of selected elements of the Popień forest complex

Characteristic	Grid				
	P-7	P-6	P-5	P-4	P-3
Height	0.880	0.749	0.584	0.330	0.215
DBH	0.888	0.769	0.587	0.407	0.089

Table 4. Diversity coefficient for NTM and upper layer of crowns of the Popień forest complex

Characteristic Coefficient	Terrain		Upper layer of crowns	
	Slope	Exposure	Slope	Exposure
Z	0.341	0.548	0.390	0.570
r	0.626	0.370	0.437	0.324

Table 5. Mean errors of selected elements of the Popień forest complex for different basic fields of the grid

	Real Values	P-7	P-6	P-5	P-4	P-3
Area (ha)	168.33	168.55	168.14	168.75	169.75	175.00
Border length (m)	5185	6187	6273	6000	6000	6000
Number of subcompartments	50	50	47	36	16	7
Mean error of subcompartments area estimation (ha)	-	0.29	0.48	1.22	3.24	5.77

The proposed method can be applied to diversity evaluation and to diversity comparison of different objects. Interpretation of results can deliver valuable information to ecologists, specialists in silviculture, topology, and resource management.

Interrelations of spatial diversity coefficient of different stand characteristics in forest complexes can be used for the evaluation of those complexes. Changes in interrelations can indicate tendencies of complex development and effects of the management system.

An NTM created on the basic field, P-6, can be used to scale build numerical site maps from 1:5000 to 1:25000 utilized for planning at the stand, forest complex, and district and forest district level.

The proposed method is being implemented to the Rogów Forest District and the Kampinos National Park. These two units will serve as proving grounds in further research on geographical information systems and cartographic modelling application with use of, among other things, the MAP ALGEBRA rules (Tomlin 1990).

NUMERICAL TERRAIN MODEL AND NUMERICAL MAP OF NATURAL FOREST REGIONALIZATION IN EVALUATION OF FOREST CONDITIONS AND CHANGES IN POLAND

The research on environmental changes, including forest environment, can be done on the superintendency level and the entire country level as well. The process of observation and measurement of particular environmental elements and collected data analysis of substantial activities directed to degradation prevention is called environmental monitoring. Information about environmental quality comes from the fixed measurement stations and periodic field investigation. Remote sensing can play an important role in the observation and evaluation of human environmental activity. Remote sensing is, after all, "the set of methods allowing identification of objects and phenomenon arising on the Earth's surface and definition of their structure and condition from aerial and satellite photographs" (Poławski 1991; Kraus 1991).

Spatial information systems are supplied by remotely-sensed data in addition to information gained from cartographic materials and terrain measurements. The SINUS, developed at the Institute of Geodesy and Cartography, belongs to such spatial information systems. It is a basic system for registering and researching environmental changes used by GRID Warszawa. SINUS can be used for environmental risks mapping (Critical Loads/Levels concept) within the United Nations Economic Commission for Europe (UN ECE) Convention on Long-Range Transboundary Air Pollution (LRTAP) — (Koble & Smiatek 1992).

The grid database of the SINUS system can be applied to the evaluation of conditions and changes of forest environment on an entire country level. Supplemented with the NTM, the SINUS grid data base can be used to generate numerical maps for forest sites. Maps are being created by the Swiss method (Brzeziecki 1992). The method uses a mathematic model for simulation occurrence of forest site types based on various parameters of physical-geographic environment. Such maps can be built with the use of a model "forest community-environmental condition" if there are suitable data to map the terrain. The Swiss method uses the following data:

— Numerical terrain model, grid 250 m × 250 m;
— Numerical climatic map;
— Numerical soil use map.

There are different forest topology rules in Poland. In order to use the Swiss method for our forest conditions, we would need modifications and adaptations to obligatory topology principles. An NTM for the entire country must be created first, with SINUS system P-4 field (250 m × 250 m) as a base.

Mapping "critical load levels" and preparation of an exact numerical terrain surface model for the entire country will be realized in the near future. Actually the NTM has been built by the Department of Forest Management and Geodesy on the basis of a geographical map and SCOP system. With a PC ARC/INFO system numerical map of the natural forest, regionalization has been generated by digitizing country borders on the base of maps in the scale 1:100 000 and natural lands, provinces, and mesoregion borders on the base of maps in the scale of 1:200 000. In the INFO part of the system, tens of mesoregions characteristics have been registered. Integration of the numerical country terrain model and numerical maps of natural forest regionalization allows us to define new characteristics and new relations among forest environmental elements within the mesoregions.

These two data bases were supplemented with numerically registered administrative borders of forest superintendencies, regional boards of state forests, as well as communes and provinces. The data bases are suitable for the following:

— generation of various maps; e.g., windbreak and snowbreak danger (Zajączkowski 1991);
— presentation and analysis of large-scale inventory results;

— presentation and analysis of forest monitoring results;

— presentation of different kinds of natural, economic and social phenomena concerning forestry on a global scale in cases where terrain relief and natural forest conditions play an important role.

CONCLUSIONS

1. Spatial information systems and NTM's should be used in widely understood forest environmental monitoring in Poland.
2. Grid database can be a ground for information collection and processing, and for biodiversity research at the forest complex level, forest district level, and country level.
3. NTM parameters are used on great-scale elaboration (forest district level) as well as small-scale elaboration (country level), and should conform to a grid thematic base. Forest environmental analysis must take into account the terrain relief because it is a substantial element of this environment.

REFERENCES

Bayer I., Fischer E. & Weihrich D. 1992, GIS als Instrument zur Durchführung einer ökologischen Riskoanalyse — ein metodischer Beitrag zur Umweltverträglichkeitsstudie, *Salzburger Geographische Materialen* 18.

Belina G. 1992, Modelierung der raumlichen Verteilung von Klimaelementen im Land Salzburg, *Salzburger Geographische Materialen* 18.

Brzeziecki B. 1992, Numerical map of forest sites (in Polish), Materiały Sympozjum "Urządzanie lasu — stan i perspektywy rozwoju", 11-12 czerwca, Instytut Badawczy Leśnictwa, Warszawa.

Centralblatt fur das gesamte Fortstwesen 1991, Heft 1/2.

Ciołkosz A. (ed.) 1990, Natural environment information system (in Polish), Wydawnictwa SGGW, Warszawa.

Doringer G. & Schwarz M. 1992, Ökologische Risikoanalyse am Beispiel des Konfliktbereiches Grundwasser, *Salzburger Geographische Materialen* 18.

Duren U. 1992, Methoden zum Aufbau eines DGM hocher Genauigkeit in Wordrhein, *Westfalen Leipziger Bildmesstage*: 20.01-22.01.

Ehgartner M., Kalliany R. & Stechauner A. 1988, Bodenerosionsgefährdungskarten als Planungsgrundlage in der Flurbereinigung, Vermessung, Photogrametrie, Kulturtechnik 1.

Gadzicki J. 1990, Spatial information system (in Polish), PPWK, Warszawa-Wrocław.

Hochstoger F. 1989, Ein Beitrag zur Anwendung und Visualisierung digitaler Gelandemodelle, *Geowiss. Mittt.*, 34.

Hochstoger F., Kanonier J. & Korpetta D. 1992, Verknupfung von ARC/INFO und SCOP für Aufgabenstellungen in der Land- und Fortwirtschaft, *Salzburger Geographische Materialen* 18.

Kamińska G. 1992, Grid data model in forest complexes spatial structure studies (in Polish), Katedra Urządzania Lasu i Geodezji Leśnej SGGW, Warszawa.

Koble R. & Smiatek G. 1992, Datenbedarf und Datenverarbeitung in der kritischer Luftbelastungen. *Geo-Information Systeme* 3.

Kraus K. 1991, Welche Umweltparameter kann man mit Photogrammetrie und Fernerkundung erfassen. *Zeitschrift fur Vermessungswessen* 8/9.

Olenderek H. & Korpetta D. 1992, Possibilities of use of spatial information systems at forest superintendency level (in Polish), *Materiały Sympozjum "Numerical methods in forestry."* Politechnika Warszawska.

Piekarski E., Korpetta D.& Olenderek H. 1992, Photogrammetry and spatial information systems in forest management in Polish conditions (in Polish), *Materiały Sympozjum "Urządzanie lasu — stan i perspektywy rozwoju"*, 11-12 czerwca, Instytut Badawczy Leśnictwa, Warszawa.

Pierce J.R. 1967, Symbole, sygnały i szumy, PWN, Warszawa.

Poławski Z.F. 1991, Remote sensing in environmental monitoring (in Polish), Biuletyn Informacyjny Branżowego Ośrodka Informacji Naukowej Technicznej i Ekonomicznej Geodezji i Kartografii 36: 2-3.

Robinson A., Sale R. & Morrison J. 1988, Podstawy Kartografii, PWN, Warszawa.

Stechauner A. & Ehgartner M. 1988, Praktische Möglichkeiten für Bewerung der Bodenerosion in Österreich, OzfVuPh., 2.

Szyrmer J.H. 1987, Spatial diversity measurement methods (in Polish), *Przegląd Geograficzny* 59.4, PWN, Warszawa.

Tomlin C.D. 1990, Geographic Information Systems and Cartographic Modelling, Prentice Hall, Englewood Cliffs, N.J.

Waldhausl P. & Molnar L. 1991, Programmsystem SCOP — zur Erstellung, Wartung und Anwendung DGM, Produktinformation, Wien.

Wilson E.G. & Peter F.M. 1988, Biodiversity. National Academy Press, Washington.

Zajączkowski J. 1991, Forest resistance to harmful impact of wind and snow (in Polish), Wydawnictwo Świat, Warszawa.

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