FORSTLICHE SCHRIFTENREIHE
UNIVERSITÄT FÜR BODENKULTUR, WIEN

Band 10

E. FÜHRER UND R. BERGER
(HRSG.)

EFERN
EUROPEAN FOREST
ECOSYSTEM RESEARCH
NETWORK

PROCEEDINGS
OF THE
1ST PLENARY MEETING
19.–22. OCTOBER 1996, VIENNA

ÖSTERR. GES. F. WALDÖKOSYSTEMFORSCHUNG
UND EXPERIMENTELLE BAUMFORSCHUNG
UNIVERSITÄT FÜR BODENKULTUR
AUGUST 1997

Führer E. und R. Berger (Hrsg.); 1997: Tagungsbericht des 1. EFERN-Plenarmeetings vom 19. – 22. Oktober 1996 in Wien.

Forstliche Schriftenreihe, Univ. f. Bodenkultur, Wien; Band 10, 94 S.; Verleger: Österreichische Gesellschaft für Waldökosystemforschung und Experimentelle Baumforschung, Universität für Bodenkultur, Wien. ISBN 3-900865-09-4.

Kurzfassung: Zukünftige Schwerpunkte in der Waldökosystem Forschung war Rahmenthema der 1. Plenartagung der EU-Concerted Action "European Forest Ecosystem Research Network" (EFERN) in Wien, im Oktober 1996. Es erfolgte ein erster Gedankenaustausch für eine der Hauptaufgaben von EFERN, die Erstellung eines kommentierten Katalogs von Forschungsthemen, deren vordringliche Bearbeitung empfohlen wird. In diesem Band werden die überarbeiteten und ergänzten Referate veröffentlicht. Die Beiträge umfassen Problempunkte im Verständnis von Waldökosystemen zur Vorhersage von Primärproduktion und zur Nachhaltigkeit in "man-made" Wäldern, die Bedeutung von Aspekten der Waldhygiene, Restauration degradierter Waldökosysteme, Spontan-Aufforstung von Brachland, die Bedeutung von Auwald-Ökosystemen, Auswirkungen von Forschungsergebnissen auf die Forstpolitik und Probleme bei der Umsetzung von theoretischen Kenntnissen in praktische Anwendbarkeit.
STICHWÖRTER: EFERN, Schwerpunkte in der Waldökosystem Forschung, Europa.

Führer E. and R. Berger (Eds.); 1997: Proceedings of the 1st EFERN-plenary meeting held October 19th – 22nd 1996 in Vienna.

Forstliche Schriftenreihe, Univ. f. Bodenkultur, Wien; Vol. 10, 94 p.; Published by the Austrian Society for Forest Ecosystem Research and Experimental Tree Research at the BOKU-University Vienna. ISBN 3-900865-09-4.

Abstract: Towards focusing forest ecosystem research was subject of the first plenary meeting of the EU-Concerted Action "European Forest Ecosystem Research Network" (EFERN) in Vienna in October, 1996. This meeting promoted the first exchange of ideas for a main task of the EFERN, the writing of an annotated catalogue of research topics (CATRES) which are urgently recommended for future investigation. In this volume the revised and extended papers presented at the meeting are published. The contributions cover critical points in forest ecosystem understanding determining the predictability of primary production and the sustainability of man-made forests, implications of forest health aspects, restoration of degraded forest ecosystems, spontaneous afforestation of fallow land, floodplain forest ecosystems, ecological research implications of forest policy and problems of transfer of theoretical knowledge into practical applicability.
KEYWORDS: EFERN, focusing forest ecosystem research, Europe.

EFERN

EUROPEAN FOREST
ECOSYSTEM RESEARCH
NETWORK

http://efern.boku.ac.at

EFERN is a pan-European network initiative with the aim to promote co-ordination of forest ecosystem research and to improve communication among scientists working in that field.

The objective of EFERN is in line with the Resolution No.6 of the Ministerial Conference on the Protection of Forests in Europe, held 1990 in Strasbourg (S6). The Concerted Action is funded by the EC.

- The technical core of the network is a European wide database of projects, institutions and scientists relating to forest ecosystem research.
- The EFERN-team will issue a catalogue (CATRES) of research topics which are recommended for urgent action.
- An important perspective is to encourage and organise interdisciplinary research programs and transnational co-operations.
- The contributions in these proceedings are also available at the EFERN-Homepage.

CONTENTS

EFERN S6 - ITS IDENTITY AND INTENTS

Erwin FÜHRER
Institute of Forest Entomology, Pathology & Protection
University of Agricultural Sciences, Vienna, Hasenauerstrasse 38, A-1190 Wien, Austria

Forest dieback and the forest decline syndrome in the eighties made people aware of the preciousness of woodlands and the limited understanding of forest ecosystem processes. Forced by public concern politicians started joint activities 'on the protection of forests in Europe'. Ministerial conferences, held in Straßbourg (1990) and Helsinki (1993), resulted in agreements on a pan-European cooperation programme, furtherly known as the 'Helsinki Process'. Its central goal is to ensure and to improve the productivity and stability of forests in Europe by socio-economic and environmental reasons. The keynote is 'sustainable forest management'.

The line of the 'Helsinki Process' is defined in detail in the *'Helsinki Resolutions'* (Ministerial Conference Helsinki, 1993). The resolutions *H1* (General Guidelines for the Sustainable Management Forests in Europe), *H2* (General Guidelines for the Conservation of the Biodiversity of European Forests) and *H4* (Strategies for a Process of Long-term Adaptation of forests in Europe to Climate Change) claim actions, which must be based on a profound understanding of forest ecosystem processes. As there are conspicuous gaps in this understanding, networks for ecosystem research must be promoted, according to *Straßbourg Resolution S6.* Considering the goals of the *Helsinki Resolutions*, as expressed in the 'General Guidelines', the intimate entanglement between political postulates on one hand and progress in forest ecosystem understanding by research on the other becomes evident. In other words: Success or failure of a new era in forestry (sustainable management) depends to a high degree on the progress, which can be achieved in forest ecosystem research and on the ability of forest scientists to articulate their knowledge in the language of practical foresters.

Straßbourg Resolution 6 (Resolution S6) takes this fact into account and claims the setup of a *European Network for Research on Forest Ecosystems* (von Weissenberg et al., 1993). With reference to national and international research activities in the past and present (Sienkiewicz & Starr, 1993), the scientific efforts in Europe should be closer linked and better coordinated, thus yielding an 'Added European Value'. In fact, *Resolution S6* could be an important incentive for forest scientists, under the assumption, that the promotion of forest ecosystem research will not remain as empty declaration of intent in European gouvernments.

Due to the commitment of *Resolution S6*, a working group has been constituted (Sienkiewicz & Führer, 1995) as an EU-Concerted Action (FAIR 1-PL95-0883), entitled *'European Network for Research on Forest Ecosystems - Resolution S6' (EFERN S6).* The objectives of the action are: (1) the setup of a communication and information system including a project database, (2) the elaboration of an annotated catalogue of research subjects with high priority in the sense of the *Helsinki*

Resolutions and (3) the arrangement of new interdisciplinary and multinational cooperations in research.

A central goal of *EFERN S6* is the elaboration of an *'annotated Catalogue of Research Subjects with high Priority'.* That is identical with the setup of a thematical framework for research on forest ecosystems. The framework must be adjusted to the problems of sustainable forest management in a changing environment and it must take into account the diversity of problems caused by regional differences in European forestry. The work of *EFERN S6* determines the further development of forest ecology sciences - a great challenge and responsibility for those scientists, which are involved in that work.

The working out of the 'cataloge' demands from all *EFERN S6* participants (1) special care, (2) farsightedness of mind, (3) the giving up of sectoral thinking, (4) the overall view on the complex problems in forest ecosystem research and (5) the realistic assessment of the own scientific domain within the complete system. The objective of the *EFERN* project is not to push own thematic interests, but to define important and hitherto neglected or poory understood aspects of forest ecology.

The *EFERN S6* team is undergoing this task, willing to fulfill the political commitment, to preserve the principles of science and to deserve the confidence of the scientific community. The wide spectrum of scientific expertise and the presence of all European regions in the *EFERN S6* group will unify theortical and applied, national and regional aspects of forest ecosystem research.

Resolution S6 demands *...'the definition of a few priority research subjects particularly important for the protection of forests, and object of coordination within this network...'.* This statement deserves a few comments:

(1) The *a priori* thematical selection of only a few research subjects is politically plausible. However, a selection may exclude other subjects from funds on national and European level. That provokes mistrust and worry among the scientific community. The selecion process therefore requires special care and transparency. It must be governed by scientific principles, functionality and objectivity.

(2) *Resolution S6* expresses that the definition and investigation of *...'a few priority research subjects'...* covers the demands, made on scientists in the 'General Guidelines' of the *Helsinki Resolutions.* That opinion mirrors a very simple way of looking at problems. If forest ecosystem research is expected to contribute essentially to the solution of such complex problems, as immanent in the action programme 'Protection of Forests in Europe', we need a comprehensive concept instead of *...'a few priority research subjects'....* A comprehensive concept must (1) be adjusted to the burning practical problems in forest management, and it must (2) take into account the diversification of ecosystemic principles, which act in the extremly diverse European forest ecosystems. The creation of such a concept requires the scientific experience of all forest ecosystem related scientific disciplines. That fact may reassure those colleagues, who worry that their specific domaine may be excluded by the selection process. All competent voices and all reasonable arguments will be considered in the conceptional work.

(3) Although quantitatively insufficient, the phrase, cited above describes an important qualitative aspect of the expected research activities. Research subjects have to be found, which are *'....particularly important for the protection of forests....'*. That is the clear commitment to focus forest ecosystem research on applied aspects. Since forest ecosystem researchers are conscious of the socio-economic position of their scientific discipline, they generally have no problems to accept the 'applied' intents of *Resolution S6.* Nevertheless it is necessary to underline this qualitative dimension, because it determines the selection and the conceptual process. The question 'What is important for the protection of forests?' arises. The question may be considered from the practical view, which is outlined in the 'General Guidelines' of the *Helsinki Resolutions*: All knowledge about forest ecosystems is concerned, enabling foresters to manage forests sustainably under manifold circumstances and to maintain or improve their productivity, biodiversity and stability, to prevent damage caused by abiotic, biotic or anthropogenic factors, and to trigger their long-term adaptation to climatic changes. With reference to this 'overall umbrella' it must be asked, which subject in ecosystem research could be excluded from a relevant research concept? Consequently the selection of only a few priority research subjects, which merely are focused to applied aspects, will lead to unsatisfactory results. On the other hand, the theoretical approach, which is important as the applied one, will not ensure practically applicable results within an acceptable period of time. Both points of view must be linked in order to achieve a comprehensive research concept.

This process has been initiated on the first *EFERN S6* Plenary Meeting held on October 20 - 22 1996 in Vienna, when selected topics were dealt with by oral presentation and extensive discussion.The papers, which were presented at this meeting, are compiled in this brochure. Ideas and suggestions, expressed during and after the meeting, were collected and later on subjected to the critical analysis by the co-ordinative committee of *EFERN S6.* This work resulted in a concept entitled '*Thematical Framework for a Catalogue of Topics Concerning Forest Ecosystem Research in Europe (CATRES)'* (see this brochure). It will be scope and guideline for further *EFERN S6* work, particularly determining the directions, where forest ecosystem research will be advised to develop in future. Developing this catalogue 'CATRES' is an exciting challenge to the *EFERN S6* group, to be mastered until 1998. The 2nd Plenary Meeting in fall 1997 will be crucial for the success of this enterprise.

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CRITICAL POINTS IN FOREST ECOSYSTEM UNDERSTANDING DETERMINING THE PREDICTABILITY OF PRIMARY PRODUCTION

Folke O. ANDERSSON, Göran I. ÅGREN, George R. GOBRAN and Leif HALLBÄCKEN

Section of Systems Ecology, Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences, PO Box 7072, S-750 07 Uppsala, Sweden

ABSTRACT

The paper reviews some recent development in forest ecosystem ecology, relevant for the understanding, utilization, and management of the forests. In the introduction definitions used in ecology are discussed. In order to avoid misunderstandings definitions are important. This paper is focused on a limited part of ecosystem ecology, viz. primary production.

The strength of a science depends on the depth of its theory or theories. A theory for primary production, based on mineral cycling and the interaction plant/soil, is discussed in terms of a carbon-nitrogen model. The need for simplicity is emphasized. New concepts valid for the ecosystem level are important to derive. The model is presented by giving an example from a field experiment with nitrogen addition, accelerated acidification, and liming. Primary production is discussed in relation to nitrogen, phosphorous and potassium.

Possible causes for deviations in the results are discussed. Among other things the adequacy of current soil chemistry founded on bulk soil samples is discussed. Recent findings indicate that the root-near environment deviates from bulk soil properties. This deviation may be important in order to obtain a better nutritional linkage between plant and soil. Results from a field experiment where water and nutritional conditions have been manipulated are given as a base for the discussion.

INTRODUCTION

Ecology is a young science. As such it has weaknesses and strengths. The paradigm or scientific base of the discipline has been much debated (Peters 1991). Often there is a confusion in the debate depending on less clear definitions. Ecology has many facets. Usually ecology can be related to different biological organization levels: organism, population, community and ecosystem. From this follows a possible division into autecology and synecology. Ecology can also be defined according to type of organisms involved - such as animals, plants, microbes, or according to media - terrestrial, fresh-water, marine. We will in the following focus on ecosystem ecology or still more limited *forest ecosystem ecology*. Our focus is then structure, function and regulation of the forest. The functioning is characterized by flows of energy and matter, such as carbon, water and minerals. The ecosystem can be understood in terms of transformations, fluxes and accumulation of matter.

In this paper we deal with a limited part of ecosystem ecology - primary production or forest growth. A main concern is then the linking of primary production to biogeochemical cycling. Soil/plant relationships play a major role. A review of the development of the area is given by Tamm (1995).

The aim of the paper is to review some recent development in ecosystem ecology relevant for understanding of forest ecosystems, their utilization, and management. The focus is biogeochemical relationships and forest growth. Special attention is also given to the importance of the root-near environment in order to have relevant soil chemistry data for adequate predictions.

IS THERE AN ECOSYSTEM THEORY?

The strength of a science depends on the depth of its theory or theories. According to Ågren and Bosatta (1996 b) "a theory is a set of concepts (the language) linked by mathematics (the tool) used to analyze specific problems by being translated through models". Terrestrial ecosystem ecology can claim to a have a number of relevant theories, each with its specific focus. If we emphasize structural aspects of the ecosystem there is a theory of forest dynamics founded on the gap theory (Shugart 1984). The focus chosen in this paper, the linking of forest growth with biogeochemical cycling, concentrates on element interactions in the forest ecosystems (Vitousek et al. 1988). Ågren and Bosatta (1996 b) has developed a theory for such interactions, mathematical formulations of which permit identifying properties relevant at the ecosystem level. Such properties can be nutrient productivity (Ågren 1983, Ågren and Bosatta 1996 b) and organic matter "quality" of which the latter provides a bridge between vegetation and soil (Ågren and Bosatta 1996 a).

MAXWELL'S DEMON - ON MODELS AND MODELING

Maxwell's demon is a well-known character in physics. For a long time it intrigued the physicists and seemed to upset the second law of thermodynamics. This demon controls an opening between two boxes, where one initially is filled with a gas and the other one empty. Every time a gas molecule with a speed exceeding the average speed of the gas molecules approaches the opening, the demon lets it through and every time a slow gas molecule tries to slip through the demon stops it. Eventually this would lead to a separation of the gas into a hot and a cold part, contrary to the second law of thermodynamics. For a long time, the accepted solution to this problem was the assumption that the demon needs energy to gather information about the velocity of the gas molecules and this information gathering would cost more than what was gained by the separation of the gas. This solution has been questioned. Today it is suggested that the demon's problem is not the gathering of information, but rather how to get rid of the excess information.

The story of the Maxwell's demon has parallels to problems that ecosystem research is facing. How do we get rid of all the excess information that is coming from physiological and biogeochemical studies of components and processes of the ecosystems? Ecosystem models are many times complex (Ågren et al. 1980; van Oene and Ågren 1995). For example, modeling of plant growth in the ecosystem is often given a plant physiological approach with leaf gas exchange as the base. This leads to problems of scaling up in time and space from the leaf level to the whole tree. An ecosystem based model should have a more aggregated base, such as the nitrogen productivity which describes the ability of a unit of nitrogen in the leaves/needles to form plant biomass (Ågren 1996).

THE FARABOL EXPERIMENT - AN ILLUSTRATION OF A CARBON/NITROGEN THEORY

We will here use the theory by Ågren and Bosatta (1996b) to construct a model of the carbon-nitrogen-phosphorous cycling in the Farabol field experiment (Andersson et al. 1995), where tree production has been investigated together with biogeochemical components: deposition, leaching, weathering and inventories of tree and soil compartments of different mineral nutrients.

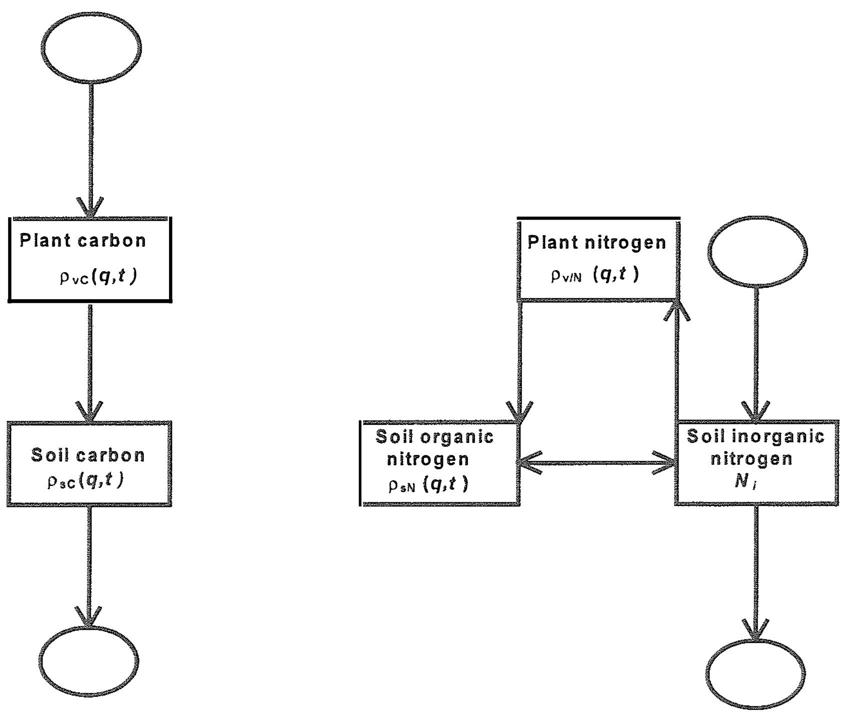

Figure 1: Schematic representation of a terrestrial ecosystem. The circles stand for external sink and sources. From: Ågren and Bosatta (1996b)

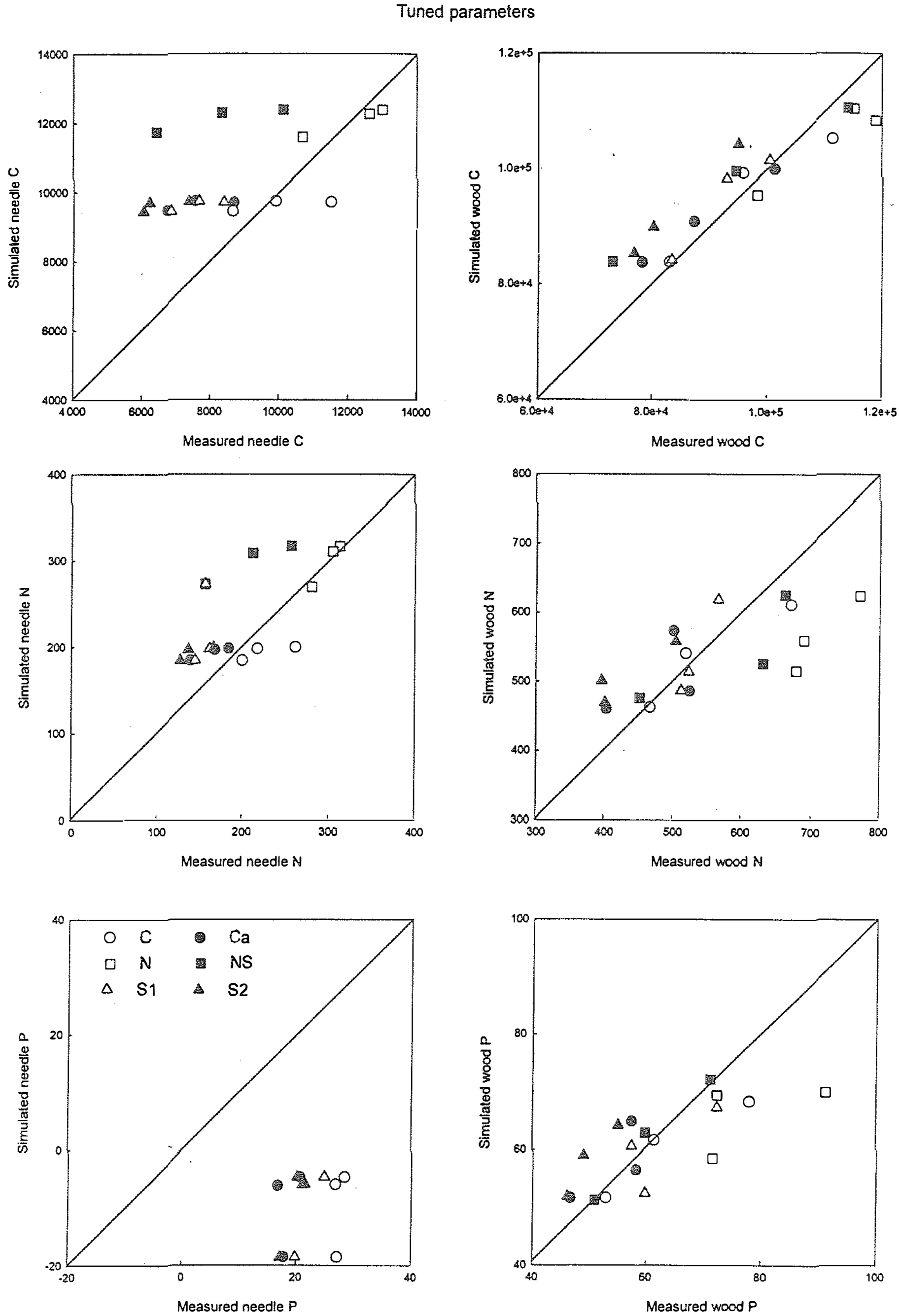

Figure 2: Measured and simulated carbon, nitrogen, and phosphorous content in needle and wood biomass compartments in the Farabol field experiment, SE Sweden C - control, N - nitrogen addition 600 kg N ha^{-1}, S1 and S2 - 600 and 1 200 kg S ha^{-1} respectively, NS1 - combination of N and S1, Ca - 6 000 kg $CaCO_3$ ha^{-1}.

The basic interactions between carbon and nitrogen (phosphorous behaves similarly to nitrogen) are shown in Fig. 1. However, all biomass compartments are divided into a needle and a woody (everything but needles) compartment to account for the large differences in turnover times (Fig. 2). Needle growth is proportional to the amount of nitrogen in the needles (nitrogen productivity) and wood growth proportional to needle biomass. Phosphorous has no effect on tree growth and tree phosphorous amounts are recorded only for mass balance purposes. Mortality of needles and wood is a constant annual fraction of the biomass. Wood has constant concentration of nitrogen and phosphorous whereas needle nitrogen and phosphorous depends on the balance between uptake and losses as a result of mortality (with a constant concentration). Since we are only dealing with a short-term experiment (15 years) in a system that initially should be not far from steady-state, we neglect changes in soil organic matter quality and assume that mineralization rates can be treated as constants for each component. Immobilization of nitrogen during decomposition is, however, dependent on the availability of inorganic nitrogen such that the retention of fertilizer nitrogen can be accounted for. Phosphorous immobilization is, on the other hand, assumed to occur at a constant decomposer phosphorous concentration. A constant fraction of the soil inorganic nitrogen is annually leached. Inorganic inputs and outputs of phosphorous are not included. A complete model description is given in the Appendix.

Parameter values are the same for all plots in the treatment except the turnover rates of soil organic matter, which differ between blocks to account for observed differences in amounts of humus. Each plot is initialized individually to give the initially observed amounts of elements in trees and soil. In nitrogen fertilized plots, inorganic nitrogen was added as in the experiment. In addition, an annual nitrogen deposition of 10 kg ha^{-1} was added.

The experiment was carried out in a 80 year old spruce forest in SE Sweden during 15 years (Andersson et al. 1995). It had a factorial design with three replicates and containing the following treatments: Nitrogen addition (N - 600 kg N (urea) ha^{-1}), accelerated acidification (S1 and S2 - 600 and 1 200 kg S (sulfur powder) ha^{-1}), Nitrogen addition and acidification (NS1 - 600 kg N and 600 kg S ha^{-1}), and liming (Ca - 6 000 kg calcium carbonate ha^{-1}).

The results of the simulation of the experiment are shown in Fig. 2. Needle carbon is reasonably well simulated for the treatments not containing sulfur. The simulations of sulfur treatments overestimate considerably needle production. Since needle uptake of nitrogen mostly agrees with observation, we can conclude that the model indicates that the effect of the sulfur treatments is to decrease the efficiency with which the trees can use their nitrogen resources. Wood carbon is well predicted for all treatment despite its dependence on erroneously estimated needle biomes. However, the initial wood carbon weighs heavily in the predictions and prevents errors in the predictions of growth over the experimental period to show up. The underestimation of wood nitrogen in the nitrogen-only treatment can be a result of the assumption of a constant wood nitrogen concentration. Simulated phosphorous uptake by woody tissues agree well.

The large discrepancy in simulated needle phosphorous is, of course, a consequence of the manner in which this variable is calculated. Since only organic phosphorous pools have been included in the model, we interpret the difference between simulation and observation as a measure of the phosphorous supply from inorganic sources. The total increment of phosphorous in the tree biomass during the experimental period, averaged over all treatments, is 30 kg ha^{-1}, which is comparable to the error in needle phosphorous. The contribution from inorganic phosphorous sources to tree growth must, therefore, considerable in this ecosystem.

A possible contributing error is that the soil properties and nutrient availability changes over short distances. The root near environment deviates in many respects, which will be discussed in the following section.

SOIL ENVIRONMENT AND SOIL/PLANT RELATIONSHIPS

Recently, Gobran and Clegg (1996) presented a conceptual model for nutrient availability in the mineral soil-root system (Fig.3). The model focuses on dynamic feedback processes between plant roots and the surrounding soil materials to illustrate the soil response to environmental stresses. The root and its associated organisms maintain a higher level of nutrient availability in the rhizophere than in the bulk soil. According to the conceptual model, dynamic linkages exist between three soil fractions: bulk soil, rhizosphere soil (Rhizo) and soil root interface (SRI). This is accomplished by the release, transport and accumulation of soil organic matter and reactive inorganic compounds in the SRI and rhizosphere. The interaction between soil, micro-organisms and roots creates a mutually supportive system that can raise nutrient availability by increasing moisture content, mineralization and enriching the pool of exchange sites.

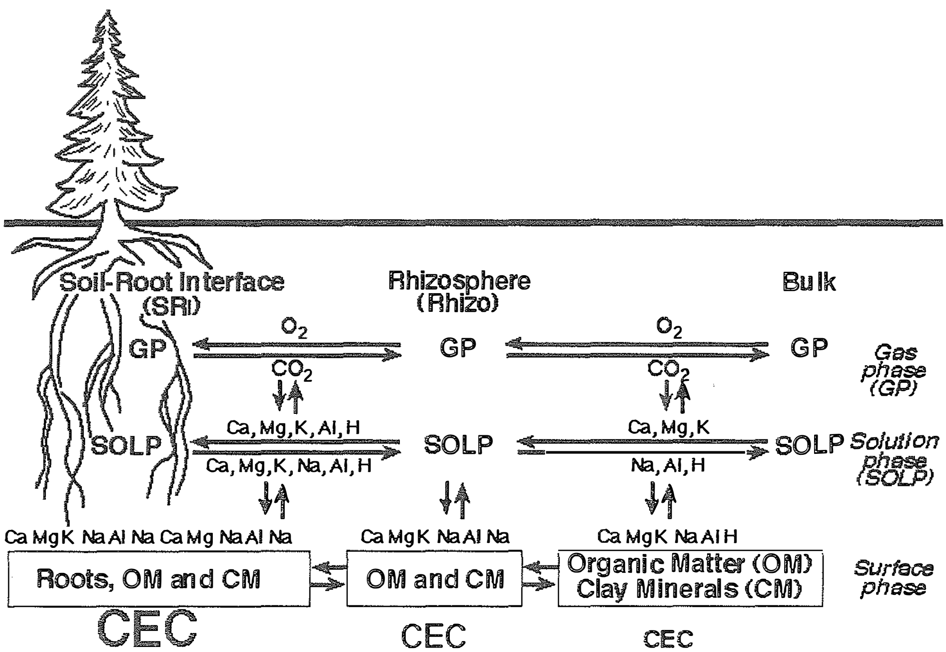

Figure 3: A conceptual model for the nutrient availability in the mineral soil-root system. From: Gobran and Clegg (1996).

The arrows in Fig. 3 represent the three major transport mechanism between the soil fractions and phases; mass flow, diffusion and biological transport by mycorrhiza and fine roots. The surface phase of the bulk soil with the largest volume of the soil body, is represented by a large box, yet it has a lower charge per unit mass, thus a lower cation exchange capacity (CEC) than the rhizosphere and SRI. In contrast, the rhizosphere and SRI represent a smaller fraction of the soil body but have larger CEC due to higher organic matter (OM), clay mineral and amorphous oxide content (CM). The organic matter component probably differs from the bulk soil since it may comprise of a higher proportion of easily mineralized and reactive root material, exudates, mycorrhizae and other associated micro-organisms. Gobran and Clegg (1996) hypothesized that organic matter in the rhizosphere and SRI is the most dynamic part of the system since it acts as both a source and a sink for elements, is involved in weathering and fuels biological reactions. Accordingly, CEC follows the same trend as organic matter content, increasing from the bulk soil to the SRI.

A series of studies encompassing a range of field observation from hydrologically and chemically manipulated forests support the conceptual model (Gobran and Clegg 1996; Clegg and Gobran 1997; Clegg et al. 1997; Courchesne and Gobran 1997). In these studies soil samples were taken from the "Skogaby experiment" situated in SW Sweden (Nilsson and Wiklund 1992). The field experiment has the following treatments: control (0 - no treatment), drought (D - 66 % of the throughfall was prevented from reaching the ground during the growing season), irrigation (I - water was added to prevent water storage deficits >20 mm during the growing season), and addition of ammonium sulfate (NS - 100 kg N ha^{-1} and 114 kg S ha^{-1} in three portions during each growing season). The site supports a Norway spruce (*Picea abies* (L.) Karst.) stand, planted in 1966. The soil is a Haplic podzol (FAO-UNESCO 1988) with a silty loam texture throughout the profile. Separation of the soil fractions was conducted by carefully removing all roots by hand from the field-moist mineral soil, which then was passed through a 2 mm mesh to give the bulk fraction (Bulk). The remaining fine roots (<2 mm) and soil were gently shaken for on minute in a plastic container to separate the soil aggregates 0.5 - 5 mm) from the roots to give the rhizosphere fraction (Rhizo). The remaining fine roots and adhering soil (<2 mm) was called the soil-root interface fraction (SRI) or also the rhizoplane (SSSA 1997).

Analyses showed differences among the three soil fractions, especially the properties of the SRI. The major results were the following (Tab.1):

- Generally, exchangeable base cations (EBC) as well as soluble cations (BC) increased in this order Bulk<Rhizo<SRI. Similarly, the titratable acidity (TA)followed the same order, but pH in KCl was rather weak in reflecting these changes (Gobran and Bosatta 1988).
- The increase in acidity in the rhizosphere and SRI tended to be offset by the increase in base cations. This is indicated, for example, by the increased calcium aluminum balance (CAB) and base saturation (BS) following the same order Bulk<Rhizo<SRI.
- Correlation of OM to chemical composition in the horizontal plane (i.e. soil fractions) was more pronounced than in the vertical plane (i.e. horizons).

Table 1: Chemical characteristics of the soil fractions bulk soil (Bulk), rhizosphere (Rhizo) and soil-root-interface (SRI) in the E horizon, the bleached layer, from control plots of the Skogaby field experiment. Means followed by different letters are significantly different at the 5% level. From: Gobran and Clegg (1996).

	Bulk	Rhizo	SRI
Organic matter (%)	9.80^c	23.03^b	87.60^a
pH (KCl)	3.96^a	3.87^a	3.57^a
Total acidity, ($cmol_c\ kg^{-1}$)	4.08^b	10.23^b	35.48^a
Al ($cmol_c\ kg^{-1}$)	2.41^b	6.06^b	20.60^a
BC ($cmol_c\ kg^{-1}$)	0.10^c	0.46^b	2.03^a
Exchangeable base cations EBC($cmol_c\ kg^{-1}$)	0.33^b	1.93^b	11.35^a
Cation exchange capacity, ECEC ($cmol_c\ kg^{-1}$)	4.41^c	12.16^b	46.78^a
El. Conductivity, (mS^{-1})	9.64^b	17.99^b	36.25^a
Base saturation, BS (%)	7.47^c	16.13^b	24.56^a
Calcium aluminum balance, CAB	-1.35^b	-1.20^b	-0.80^a

Moreover, the clay mineralogy of the clay-sized particles of both the fractions was determined by X-ray diffraction (Courchesne and Gobran 1997). Their results pointed toward an accelerated degradation of mineral structures in the rhizosphere zone. The depletion of weatherable minerals and the concomitant preferential accumulation of weathering products (Al_0 and Fe_0) close to root surfaces (Fig. 4) indicate that the weathering regime was stimulated by root activity.

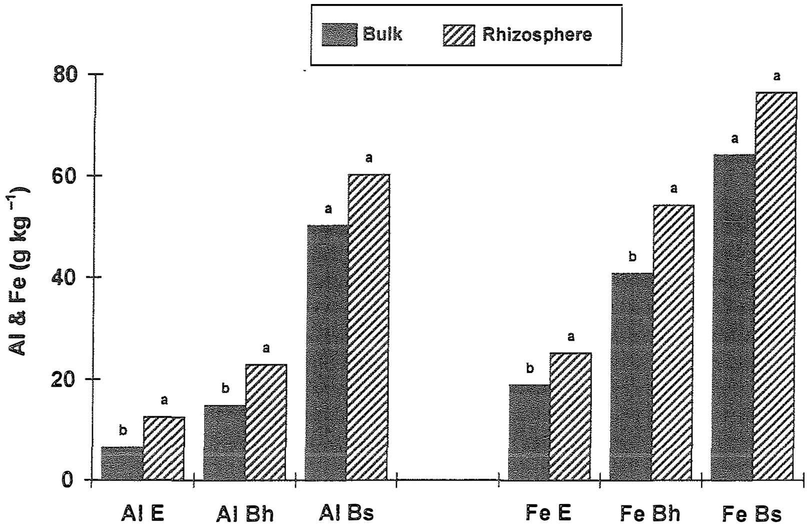

Figure 4: Al_o and Fe_o in the bulk and rhizophere soil fractions of the three mineral soil horizons E, Bh and Bs in the Skogsby experiment, SW Sweden. From: Chorchesne and Gobran (1997).

These observations lead to the conclusion that the chemical conditions of the rhizosphere may be more favorable for biological activity and nutrient uptake than in the bulk soil. For example, CAB that reflects the degree to which growth can be supported or hindered increased in the same order. Therefor, interpreting potential of plant growth based on bulk soil chemistry, e.g. CAB, will vary if the information is derived from the SRI and the rhizosphere fractions (Gobran et al. 199Xa). They showed that CAB was positively associated with tree growth. Fig. 5 illustrates the different trends of CAB values in three mineral soil horizons of the Skogaby experiment mentioned earlier. They also found that a threshold CAB of one exists, corresponding to the calcium aluminum ratio (CAR) of 0.1 (Zöttl and Mies 1983).

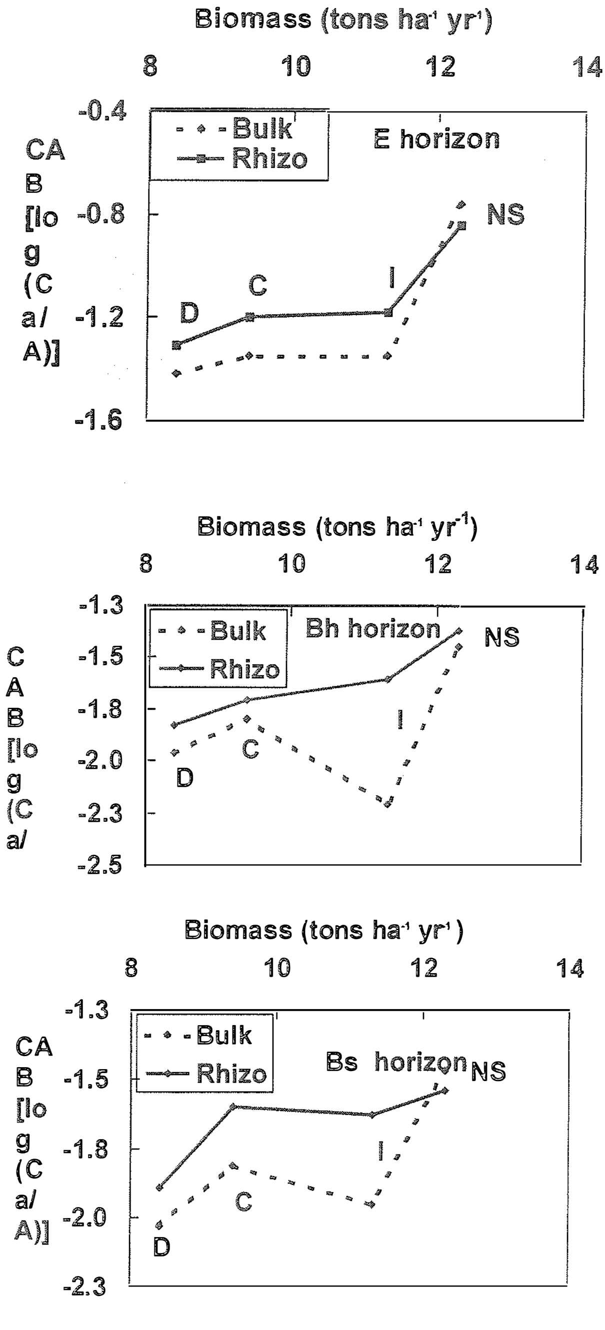

Figure 5: Calcium aluminum balance (CAB) and tree above-ground biomass production in tons ha^{-1} yr^{-1} in the Skogaby experiment, SW Sweden for the bulk soil (broken line) and the rhizosphere (continuous line) of the mineral horizons E, Bh and Bs. The treatments are: C - control, D - drought, I - irrigation, and NS addition of ammonium sulfate. From: Gobran et al. (199Xa).

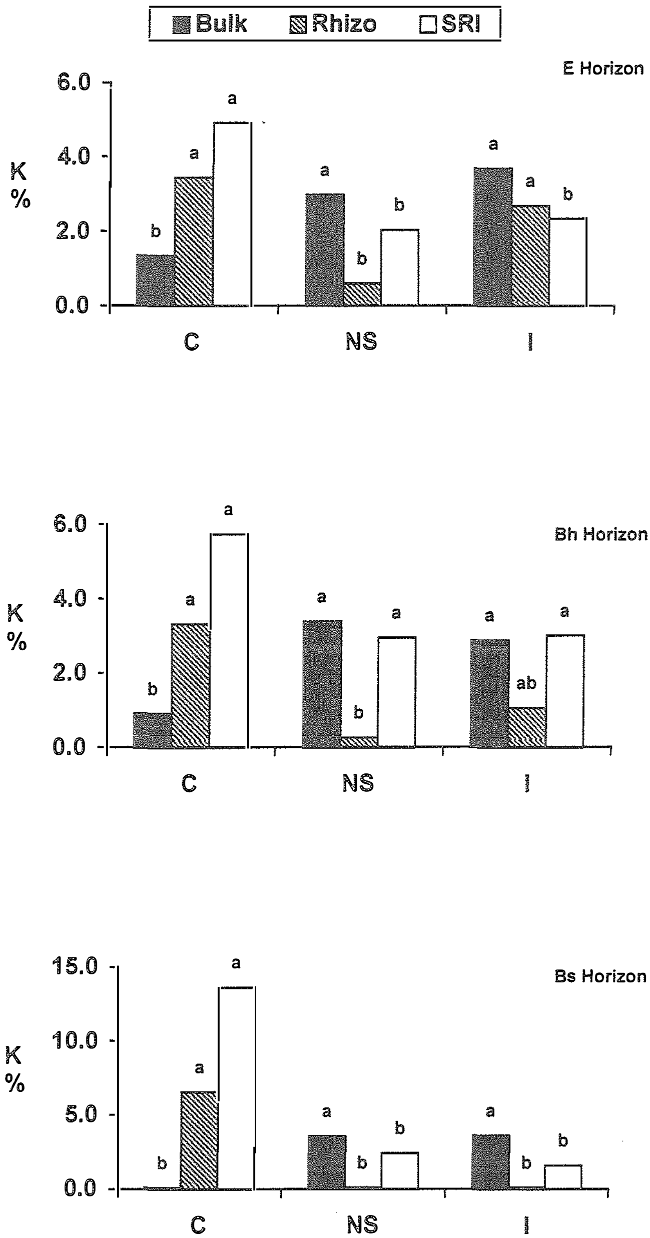

Figure 6: K % in the bulk soil, rhizosphere and soil-root-interface fractions of the mineral soil horizons E, Bh and E in the Skogaby experiment, SW Sweden. The result refre to control (C), ammonium sulfate (NS) and irrigation (I) treatments. From: Clegg et al. (1997)-

This study (Gobran et al. 199Xa) demonstrates that analyses of rhizosphere samples provide more useful information on ecosystem changes following perturbations than bulk soil chemistry alone. Additionally, Gobran et al. (199Xb) presented a case in which they link increased nutrient demands due to stimulated tree growth and rhizosphere chemistry. Rapid growth could deplete nutrients from the rhizosphere when processes can not keep pace with high demand, particularly if additional nutrient supply is mediated by weathering. The effect of rapid growth was investigated in the treatments of C, NS and I (see above). The NS and I caused significant growth increases of 31% and 20%, respectively, within the first three years of application (Nilsson and Wiklund 1992). Since soil mineralogy (Curchesne and Gobran 1997) showed that the weatherable K-bearing minerals were scarce leaving only feldspars, potassium in the soil presented here as an example. Exchangeable K and K saturation (K% = K/CEC) had similar trends within the soil fractions and horizons. Fig-.6 presents only data on K% and shows that in the control K% increased in the order Bulk<Rhizo<SRI, and that the trend was consistent with soil depth (E,Bh and Bs horizons). However, due to the treatments, NS and I, the trend in K% with soil fraction was reversed, SRI<Rhizo<Bulk. The reversal in K% and K content was attributed to rapid tree growth and demand and that the depletion of K was most seen in the rhizosphere compared to the bulk soil. Normally, such a large depletion of K would have been missed if only bulk soil information was used to link tree growth to soil chemistry.

CONCLUSIONS

The paper has dealt with a limited part of ecosystem ecology - the primary production as related to biogeochemical cycling. A theory with the aim of looking for simplicity was presented. In order to obtain models useful for understanding and predictions it is essential to derive expressions of properties, which can be related to the ecosystem level. The nutrient productivity and quality factor of the organic matter are such examples. The results presented deals with a limited time perspective, 10 - 20 years. A longer time will require consideration of mineralization and in particular weathering. The need for a deeper understanding of the rhizosphere complex for obtaining a better link between plant/tree and plant nutrition has clearly been demonstrated.

Advances in ecosystem ecology will depend on good experimentation. Clearly formulated hypotheses are needed as a base for well designed field experiments. Field experiments take time and are therefor costly. It is essential to capitalize on existing experiments as far as possible. There are special reasons to invest in existing experiments as well as using existing data. New questions and hypotheses will require new experiments. Also these will require a sufficient time in order to yield results which are relevant for the behavior of the forest with functioning feed-back mechanisms.

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APPENDIX

MODEL DESCRIPTION

State variables

C_L	Leaf carbon	kg ha^{-1}
N_L	Leaf nitrogen	kg ha^{-1}
P_L	Leaf phosphorous	kg ha^{-1}
C_W	Wood carbon	kg ha^{-1}
N_W	Wood nitrogen	kg ha^{-1}
P_W	Wood phosphorous	kg ha^{-1}
Cs_L	Soil leaf carbon	kg ha^{-1}
Ns_L	Soil leaf nitrogen	kg ha^{-1}
Ps_L	Soil leaf phosphorous	kg ha^{-1}
Cs_W	Soil wood carbon	kg ha^{-1}
Ns_W	Soil wood nitrogen	kg ha^{-1}
Ps_W	Soil wood phosphorous	kg ha^{-1}

Exogenous variables

D_N	Nitrogen deposition	kg ha^{-1}yr^{-1}
t	Time	yr

Parameters

a	Maximum nitrogen productivity	13.87	(kg C) (kg N)$^{-1}$yr^{-1}
b	Decrease in nitrogen productivity	0.00047	ha kg^{-1}yr^{-1}
e_0	Decomposer efficiency	0.25	-
f_C	Decomposer carbon concentration	0.5	-
f_{N0}	Reference decomposer nitrogen concentration	0.042	-
f_P	Decomposer phosphorous concentration	0.0042	-
k_W	Wood growth per unit needle	0.327	yr^{-1}
r_{NL}	Nitrogen concentration in needle litter	0.011	(kg N) (kg C)$^{-1}$
r_{NW}	Nitrogen concentration in wood	0.0056	(kg N) (kg C)$^{-1}$
r_{PL}	Phosphorous concentration in needle litter	0.0064	(kg P) (kg C)$^{-1}$
r_{PW}	Phosphorous concentration in wood	0.0064	(kg P) (kg C)$^{-1}$
u_L	Decomposer growth rate on needle litter	0.135, 0.116, 0.060	yr^{-1}
u_W	Decomposer growth rate on wood litter	0.0081, 0.0070, 0.0036	yr^{-1}
Δf_N	Change in f_N with inorganic nitrogen	0.004	yr
λ_F	Fraction of added nitrogen retained in the system	0.9	-
λ_N	Fraction of inorganic nitrogen not leached	0.9	-
λ_P	Fraction of inorganic phosphorous not leached	1	-
μ_L	Mortality of needles	0.205	yr^{-1}
μ_W	Mortality of wood	0.010	yr^{-1}

(Values for decomposer growth rates are for blocks I, II, and III, respectively)

Model equations

The equations describe the change from time t to t+1. All variables on the right-hand side are to be evaluated at time t.

$$\Delta C_L = (A - BC_L)N_L - \mu_L C_L$$

$$\Delta N_L = U_N - R_{NW}K_W C_L - R_{NL}\mu_L C_L$$

$$\Delta R_L = U_P - R_{PW}K_W C_L - R_{PL}\mu_L C_L$$

$$\Delta C_W = K_W C_L - \mu_W C_W$$

$$\Delta N_W = R_{NW}(K_W C_L - \mu_W C_W)$$

$$\Delta C_W = R_{PW}(K_W C_L - \mu_W C_W)$$

$$\Delta C_{SL} = - K_{CL}C_{SL} + \mu_L C_L$$

$$\Delta N_{SL} = - K_{NL}N_{SL} + R_{NC}K_{NL}C_{SL} + R_{NL}\mu_L C_L$$

$$\Delta R_{SL} = - K_{PL}P_{SL} + R_{PC}K_{PL}C_{SL} + R_{PL}\mu_L C_L$$

$$\Delta C_{SW} = - K_{CW} C_{SW} + \mu_W C_W$$

$$\Delta N_{SW} = - K_{NW} N_{SW} + R_{PC}K_{PW}C_{SW} + R_{PW}\mu_W C_W$$

$$U_N = \lambda_N(\lambda_F D_N + k_{NL}N_{SL} - r_{Nc}k_{NL}C_{SL} + k_{SW}N_{SW} - r_{Nc}K_{NW}C_{SW})$$

$$U_P = \lambda_P(D_P + k_{PL}P_{SL} - r_{Pc}k_{PL}C_{SL} + k_{SW}P_{SW} - r_{Pc}k_{PW}C_{SW})$$

$$f_N = f_{NO} + \Delta f_N(D_N - 10)$$

$$k_{Ci} = f_C \frac{1-e_0}{e_0} u_i, \quad i = L, W$$

$$k_{Ni} = k_{Pi} = f_C \frac{u_i}{e_0}, \quad i = L, W$$

$$r_{jc} = e_0 \frac{f_j}{f_C}, \quad j = N, P$$

COMMENTS

Simon Hodge

Can we restrict our consideration of "critical points in forest ecosystem understanding" only to ecosystem processes. What about the equally complex and important aspects of ecosystem structure and composition?

Answer: Today there is a major goal within forestry - a sustainable use of the forest resources. In the Forest Act of Sweden this is today expressed as an equal consideration of production aspects and aspects on other uses. The biodiversity issues have here a leading position. With this statement it is obvious that to consider production aspects alone is not sufficient.

In the presentation it was mentioned that we have different theories for different purposes. The Gap-theory was mentioned as an example when dealing with vegetation dynamics and effects of a changing environment. For practical purposes it was felt essential to limit the presentation to one area, which also is seen in the revised title.

The "what is an ecosystem" - questions can become a philosophical debate. However, it is important to consider and qualify the scale in this thinking. To some organisms a fallen log is an ecosystem, to others a landscape or many km^2 is an ecosystem. To a hydrologist the catchment might be considered the ecosystem; to a botanist distinct vegetation community might be considered the ecosystem.

Answer (comment to comment): Ecosystems do exist. Some common basic criteria are required. However, the delimitation in nature is best done by the user, who has her or his specific purposes to fulfill.

Reinhard Hüttl

More precise determinations of research gaps and needs are required. Examples: properties of the rhizosphere, importance soil organic matter for different soil processes, nutritional related soil/plant interactions.

Answer: Agree. However the listing of gaps and needs ought to be done out from specified objectives and hypotheses.

Deficiencies in modeling approaches?

Answer: The experience of modeling or use of models is that many times the difficulties are underestimated. It may be easy to construct a model for a specific purpose, but it is very easy to run into complexity. This is difficult and many times the "biological" problems are treated to superficially. Often there is also a lack of data. A rule could be "that a model should not be more complicated than you understand and can see the details in the model"

When should simplification in modeling be used?

Answer: The reply to this question is to some extent given in the answer to the previous question. A further illustration is given by Ågren (Nitrogen productivity or photosynthesis minus respiration to calculate plant growth. Oikos 76:529-535), who compared two different ways of calculating tree growth from physiological measurements and ecosystem based measurements. This is an example of simplification and a way to avoid scaling up from leaf to tree and stand.

Which are the appropriate ecosystem concepts and why?

Answer: See the same question under Simon Hodge.

Prof. Kilian

Comment: Weathering is an important and mostly unknown factor in nutrition and soil condition studies. But for budgets we need the weathering rate of the bulk soil, as the pattern of rhizosphere changes with root growth and reaches every part of the soil. Soil analyses of are therefor relevant as follows: for intensity: rhizosphere and root contact zone; for budgets: bulk soil.

Helfried Oswald

Comments: Nutrient cycling is one of the basic aspects of tree growth and "sustainability". The fine root compartment is very difficult to study and therefor it is often considered as a "black box". Weathering needs to be investigated with an adequate methodology.

An efficient model of nutrient cycling require a water balance in order to establish fluxes o water and nutrients.

A neglected area in the study of he carbon cycle is the soil organic matter.

All scientists involved in investigations of these and similar areas need to compare their methods in order to increase comparability.

Fergal Mulloy

The argument concerning the increased activity in the region of the rhizosphere is interesting and is a subject for continued study. However is there a common interest in this matter in other countries?

The importance of myccorhiza is clearly linked, but not mentioned!

Answer: The area attracts today an increased interest in several countries. Several research projects are underway.

The myccorhiza is definitely a part of the story. Recently it has been documented in Holland and Sweden that the mycorrhiza produces small wholes in gravel and stones, which means that there is a direct and active contact between these components. Probably there can be direct exchanges leading to increased acidity formation and release of elements available for uptake.

Ingino M Emmer

How can parameters of growth mosels, which include soil processes be translated into information that generally is available to forest management? How to obtain relevant information for site-orientated forestry and how to act when there is a lack of sophisticated soil data?

Answer: It is usually difficult to use one and the same tool or model for different purposes. A suitable solution would be to have a number of representative forests, which are thoroughly investigated and where proper information is available for detailed models. Combined with these is a net of likewise representative forests, where less intensive information is available. This will make generalizations possible.

ECOLOGICAL RESEARCH IMPLICATIONS OF AN ENVIRONMENTALLY INFLUENCED FOREST POLICY IN CENTRAL EUROPE

Reinhard F. HÜTTL and B. Uwe SCHNEIDER

Brandenburg Technical University Cottbus
Chair of Soil Protection and Recultivation

Introduction and background

Intending to determine forest damage caused by air pollution impacts for the last fifteen years simple parameters or simplified models for assessing and/or monitoring the vitality (health) status of forests have been applied and the results were used as a basis of an environmentally influenced forest policy throughout Europe. Particularly the visual evaluation of tree defoliation and crown transparency was and still is utilised to describe the development of forest vitality. However, the findings of these europeanwide surveys are rather confusing since decline and revitalisation phenomena frequently occurred in the same general areas or were observed in adjacent or comparable regions although site/stand conditions and deposition regimes would not reveal significant differences. Examples for such contradictory results of the above mentioned surveys on the health status of German forests are reflected in Table 1 and in Figures 1 and 2.

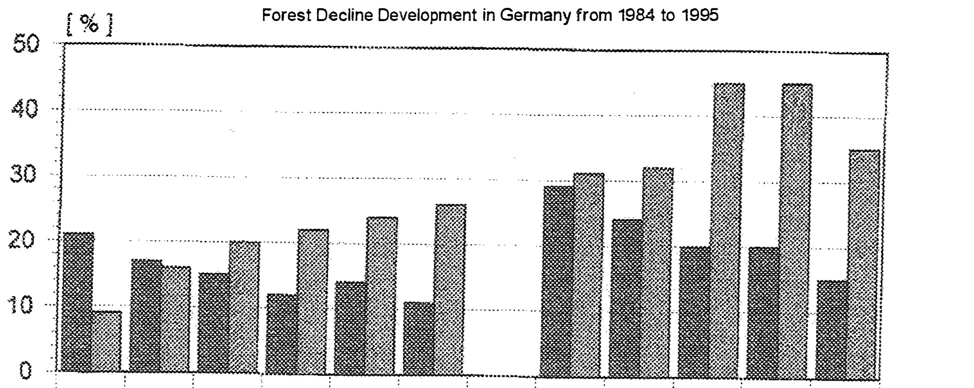
Table 1: Percentage of trees with visible decline symptoms for damage classes 2 (moderate) to 4 (severe) detailed for German states between 1984 and 1995:

Country	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Bremen	n.d.	21	42	25	13	20	5	13	10	13	15	12
Hamburg	11	26	30	24	15	14	16	17	17	14	15	15
Niedersachsen	9	10	11	8	10	13	17	10	13	16	17	17
Nordrhein-Westf.	11	10	11	16	10	10	13	11	16	16	15	14
Schleswig-Holstein	12	10	13	23	18	18	15	15	13	16	18	20
Northwest Germany	***10***	***10***	***11***	***13***	***11***	***12***	***15***	***11***	***14***	***16***	***16***	***16***
Berlin	8	14	28	22	25	23	13	29	14	25	21	18
Brandenburg	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	24	33	25	17	18	14
Mecklenburg-Vorp.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	40	49	43	30	11	10
Sachsen	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	25	27	21	24	25	17
Sachsen-Anhalt	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	52	34	32	33	18	21
Thüringen	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	34	50	54	50	45	39
East Germany	***n.d.***	***n.d.***	***n.d.***	***n.d.***	***n.d.***	***n.d.***	***36***	***38***	***34***	***29***	***23***	***20***
Baden-Württbg.	24	27	33	21	17	20	19	17	24	31	26	27
Bayern	26	28	26	21	18	18	n.d.	30	32	22	30	23
Hessen	9	12	19	19	17	17	19	29	33	35	38	40
Rheinland-Pfalz	8	9	8	9	10	19	10	2	13	14	21	19
Saarland	7	10	11	17	19	15	n.d.	17	18	21	18	23
South Germany	***20***	***22***	***22***	***19***	***17***	***17***	***n.d.***	***24***	***27***	***25***	***29***	***26***

n.d. = not determined (cf. Hüttl et al. 1997)

When looking at these data it becomes obvious that no sound conclusions can be drawn from neither the development trend over time nor the current vitality status. Therefore, it appears doubtful that such simplifying evaluation models are a sound basis for formulating a comprehensive environmentally oriented forest policy.

Figure 1

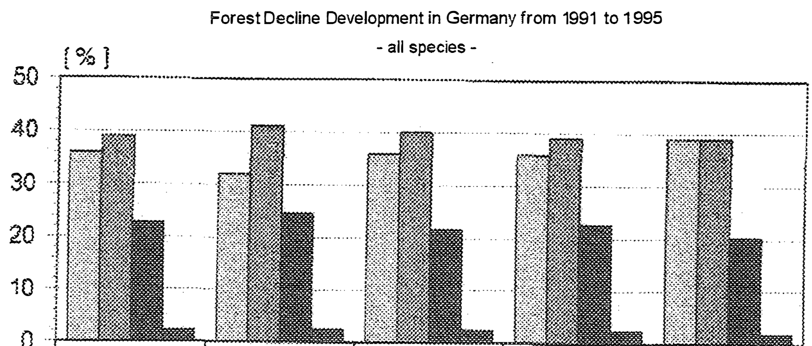


	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Pine	21	17	15	12	14	11	k.A.	29	24	20	20	15
Oak	9	16	20	22	24	26	k.A.	31	32	45	45	35

Damage classes 2 - 4; in %

(cf. Hüttl et al., 1997)

Figure 2



	1991	1992	1993	1994	1995
0	36	32	36	36	39
1	39	41	40	39	39
2	22,7	24,5	21,6	22,7	20,3
3 + 4	2,2	2,5	2,4	2,3	1,7

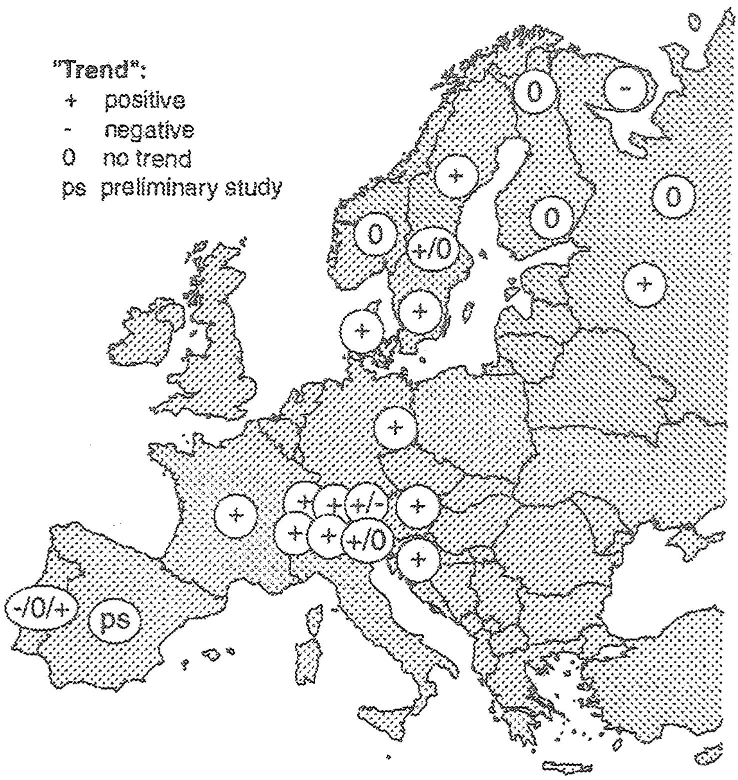
(cf. Hüttl et al., 1997)

Apparently such simplified approaches not based on sufficient scientific evidence tend to neglect the complexity of cause-effect-relationships that may affect the health status of trees or forests over time and in space. Site history, forest management practices, species selection, soil quality, climatic variations, biotic infestations and other factors may influence the vitality status of forest ecosystems on both the long and the short term and on both the local and the regional scale. Hence, reaction patterns of forest stands within a region and also much smaller areas may vary largely. This knowledge has to be taken into account when considering the large impact such results may have on the public opinion and/or the policy level.

Forest growth in Europe

A comprehensive report recently submitted by the European Forest Research Institute based on 22 case studies in 12 European countries elaborated by 43 scientists along with other findings indicates that European forests have probably never been growing faster than over the last 3 to 4 decades (Fig. 3 - 8a-d; Spiecker et al. 1996). These observations suggest a general improvement of site indices, yields and increments for nearly all permanent observation plots

Figure 3: Map showing the locations and summarised results of the studies



In general during this time period the growing stock of Europe´s forests has increased by over 40 %. Nevertheless the public and the official opinion assumes that air pollution is still <u>the</u> major thread to the vitality of our forests. Facing the fact of a frequently improved site productivity it becomes evident that the forest decline discussion in its current form lacks sound (and casewise) analysis of the causal relationships regarding forest stand/ecosystem development under changing environmental conditions.

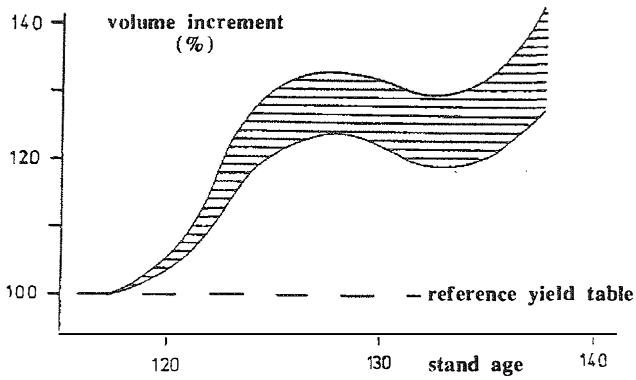


Figure 4: Stand volume increment in percent of the standardised yield table increment for a damaged spruce stand in the forest district Garmisch-Partenkirchen in the Bavarian Alps (Röhle 1987). Indicated is the volume increment (100% level). The upper border line of the hatched sector indicates increment loss calculated according to the table developed by von Guttenberg (1915), the lower line denotes loss according to the table by Assmann/Franz (1963). (cf. Spiecker et al., 1996)

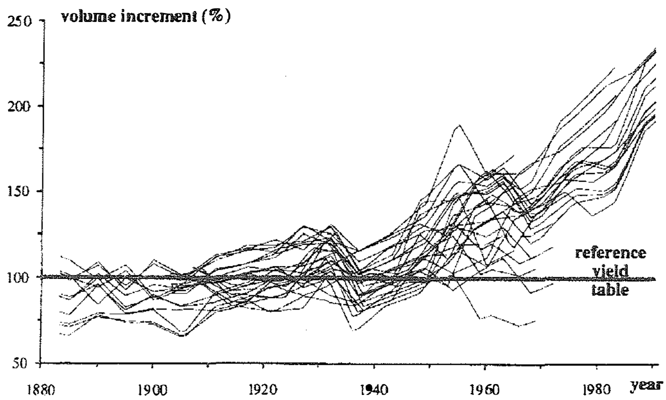


Figure 5: Development of the volume increment on 26 sample plots of the permanent experimental areas Denklingen, Eglharting, Ottobeuren and Sachsenried, compared to the yield table by Assmann/Franz (1963) over the calendar year (Röhle 1994). (cf. Spiecker et al., 1996)

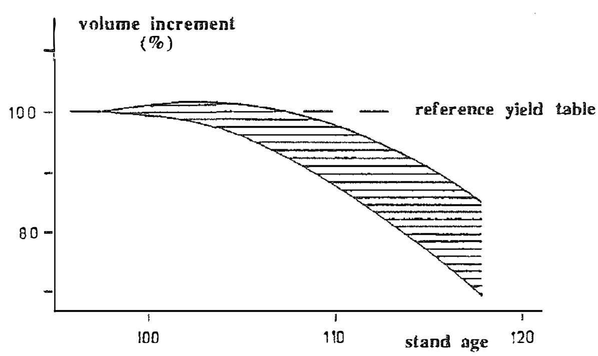
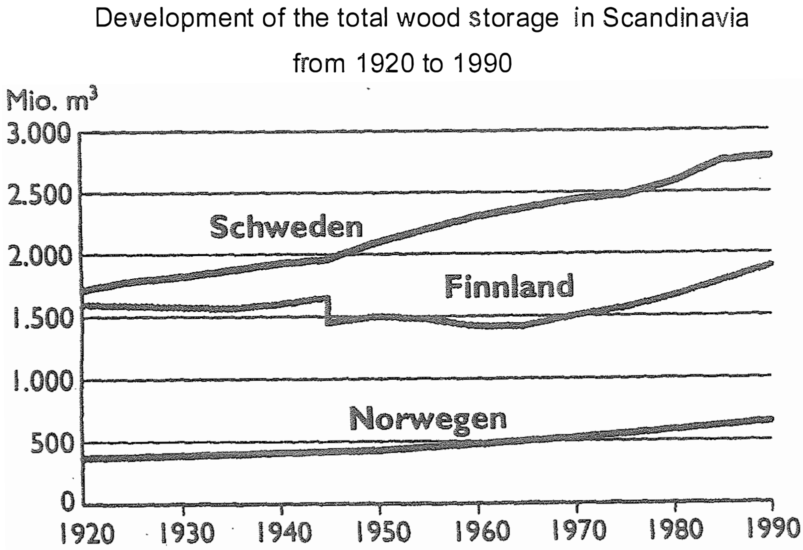


Figure 6: Development of annual volume increment of damaged spruce stands in the Bavarian forest district Bodenmais compared to the yield table (according to Röhle 1987). Given is the volume increment (100% level). The upper border line of the hatched sector indicates increment loss calculated according to the table by von Guttenberg (1915); the lower border line indicates loss calculated according to the table by Assmann/Franz (1963). (cf. Spiecker et al., 1996)

Figure 7:



(Anonymus, 1996)

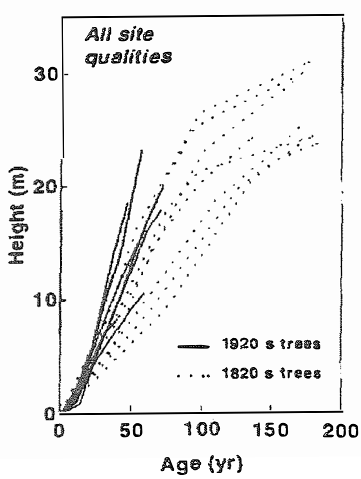


Figure 8a: Stem analysis curves of all sample trees in *Pinar de Valsain* Forest

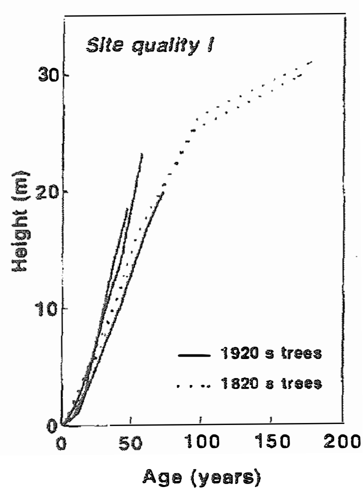


Figure 8b: Stem analysis curves of site quality I trees in *Pinar de Valsain Forest*

(cf. Spiecker et al., 1996)

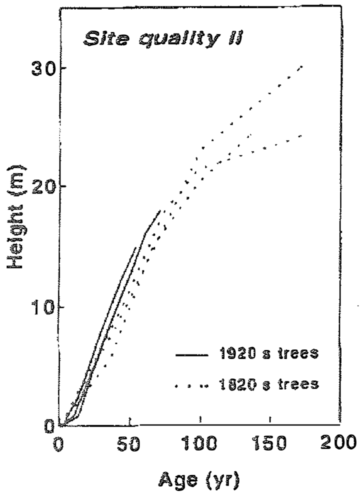


Figure 8c: Stem analysis curves of site dominant trees in *Pinar de Valsain Forest*

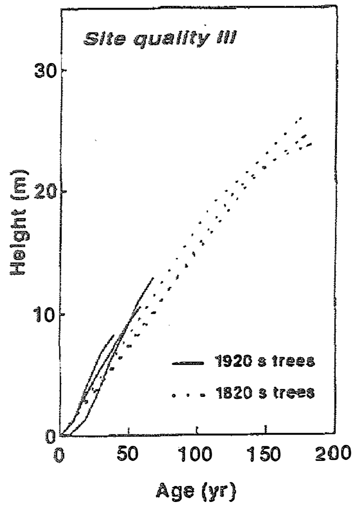


Figure 8d: Stem analysis curves of site. quality II quality III dominant trees in *Pinar de Valsain Forest* (cf. Spiecker et al., 1996)

Forests and changes in atmospheric chemistry

Recently an ecosystem study in comparable pine stands located along a deposition gradient in eastern Germany was conducted (Hüttl et al., 1996).

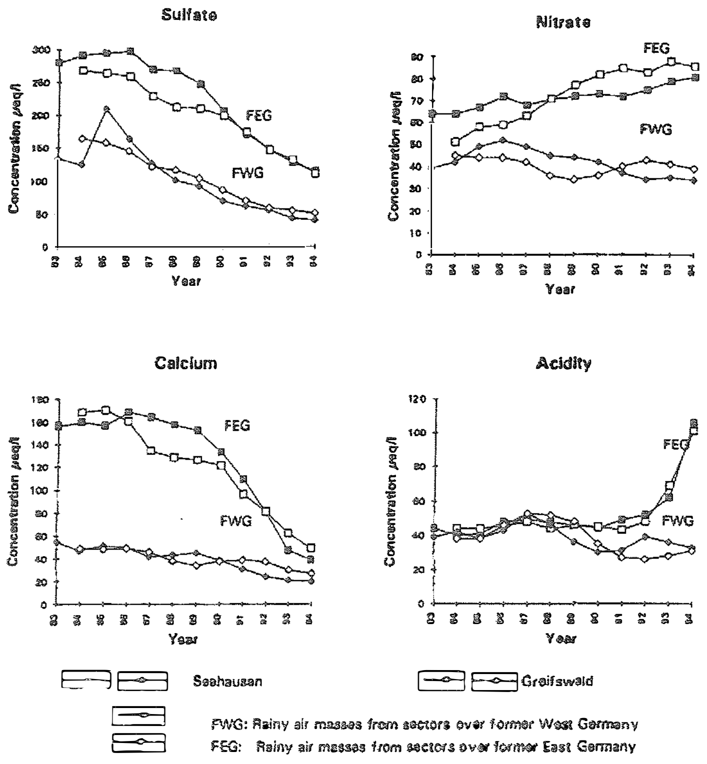


Figure 9: Temporal development of major ions in precipitation samples at representative observation sites (Seehausen, Greifswald) of former East Germany(cf. Marquardt & Brüggemann, 1996)

The unification of the Federal Republic of Germany lead to dramatic structural changes in the new federal states. Over decades industrial emissions formed a distinct pattern of acidification, alkalinization and eutrophication effects in terrestrial ecosystems. The discontinuation or modernisation of industrial and power plants since 1989/90 resulted in intensive reductions of pollutant emissions, particularly of alkaline dust and sulphur dioxide (SO_2). But as a net result, acidity in precipitation increased rapidly as alkaline dust containing buffer capacity decreased much faster than acid forming precursors such as SO_2 and NO_x. This development was illustrated by Marquardt and Brüggemann (1996) through investigating rain precipitation chemistry at representative sites in eastern Germany. As can be seen from Figure 9 in precipitation stemming from clouds formed over the territory of eastern Germany, particularly Ca, and, to a lesser extent, also SO_4 decreased significantly since unification, whereas no such changes occurred for precipitation of clouds transported to East Germany from West Germany. At the same time, NO_3 concentration in precipitation originating from clouds built over East Germany showed a slight increase whereas precipitation samples from clouds formed over West Germany reflected no changes. Hence, total acidity increased in rainfall clouds formed over East Germany and slightly decreased for those translocated from West Germany to East Germany.

To better understand the effects of such changes in atmospheric chemistry on terrestrial ecosystems since 1993 studies on soil chemistry as well as water and element cycling of three 40- to 60-year-old Scots pine stands along an air pollutant deposition gradient were conducted (Fig. 10). With respect to the reductions in emissions the study can be seen as a "roof experiment without a roof". Actual S- and N-deposition is elevated at two sites (25 kg S $ha^{-1}yr^{-1}$, 20 kg N $ha^{-1}yr^{-1}$) compared to the background site. Input rates of basic cations, especially Ca, showed a decreasing trend along the gradient.

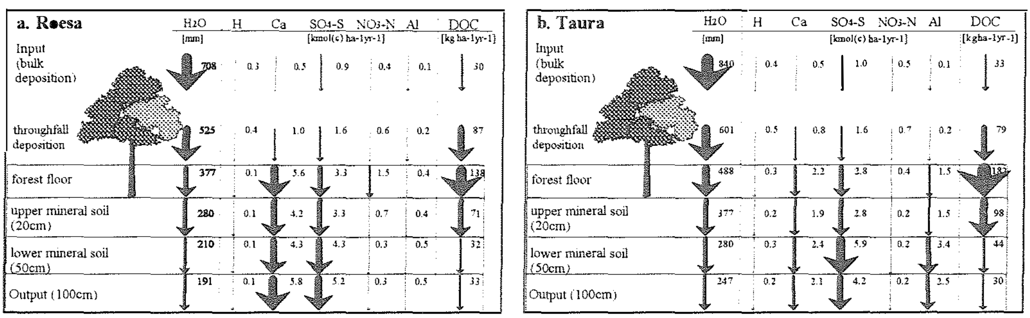
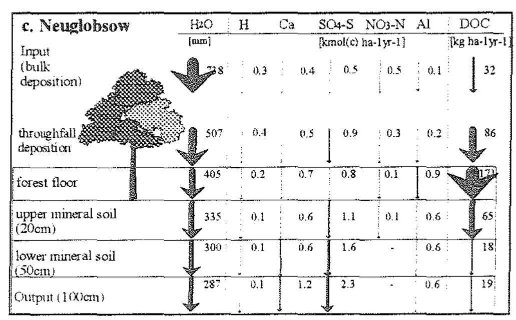


Figure 10: Annual water and element fluxes of the three Scots pine ecosystems
a. Roesa (former heavy deposition)
b. Taura (former moderate deposition)
c. Neuglobsow (background)
(mean values for the period October 1993 to October 1995)



(from Schaaf, 1997)

The analysis of soil solution contents clearly reflects the different deposition regimes of the past with high concentrations of Ca and SO_4 at the highly and moderately impacted sites (Roesa, Taura) and drastically decreasing values along the deposition gradient. With respect to soil and soil solution chemistry the site affected by high SO_2 pollution but lower alkaline dust input rates during the past (Taura) showed the most severe symptoms of accelerated sub-soil acidification. The element budgets indicate a significant release from stores of previous deposition and from buffering/transformation processes, especially for base cations, sulphur, and, partly aluminium. These results underline that elevated levels of SO_4 in the soil solution may persist long after deposition has decreased. Apparently, all three ecosystems are accumulating nitrogen, an observation that still lacks adequate explanation.

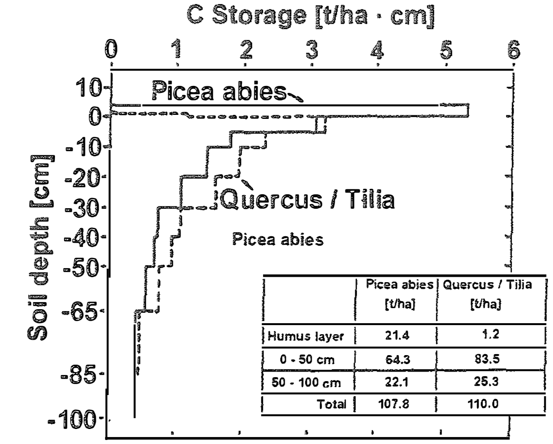
From this study it became obvious, that the response of forest ecosystems to changes of atmospheric deposition regimes requires a comprehensive analysis. With regard to the practised vitality classification system this example also illustrates that in the future, diagnostic systems have to be based on a more comprehensive scientific approach to guarantee an adequate interpretation of ecosystem development/behaviour. From this approach a permanent gain in knowledge and for methodological improvement can be expected.

Forests and management

Only little information exists of the long term impact of forest management practices on site quality. Results of Kreutzer (1981) and Glatzel (1991) indicate that the effects of forest conversion from deciduous to coniferous stands in the past and the nutrient export from soils in the course of forest exploitation (e.g. clear-cutting, litter-raking) may by far exceed the negative consequences of atmogenic deposition loads as known from high and middle elevation sites of mountainous areas in central Europe.

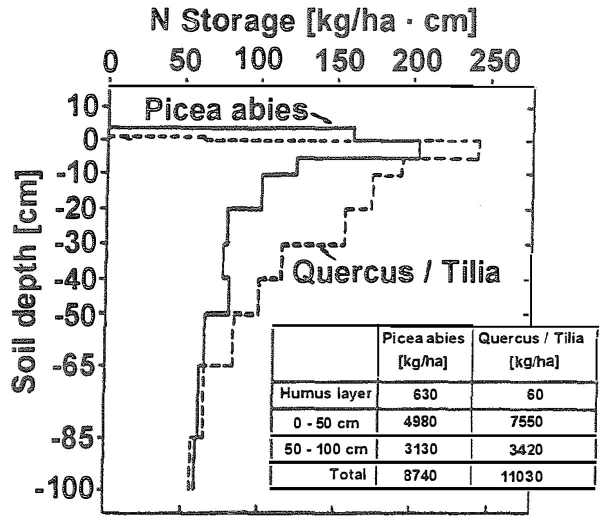
Kreutzer (1981) investigated soil changes caused by two generations of Norway spruce stands planted on a site formerly occupied with Quercus and Tilia species. This species change caused a change of the C storage in the soil profile down to 1 m depth (Fig. 11). There was an accumulation of C in the humus layer and a distinct reduction in the upper soil horizons (down to 65 cm) of this para-brown earth developed from tertiary sediments covered with loess. However, no large losses of C had occurred over this time period. There was also a change in the N storage with a pronounced N increase in the humus layer (Fig. 12). A significant loss of N had occurred in the upper mineral soil (0 - 50 cm). No changes were found in the subsoil. Overall a remarkable loss of N from the ecosystem was detected. This was confirmed by the measurement of NO_3 leaching losses (Fig. 13).

A comparison of the NO_3-concentration in the seepage water of the converted stand to the control stand with the natural species composition revealed much larger loss rates for the Norway spruce ecosystem. This is probably related to the prevailing decomposition and nitrification of organic matter stemming from the former deciduous forest with a much deeper rooting system compared to the shallowly rooting Norway spruce stand. In addition to the large N storage the present system receives a relatively high atmospheric N input (30-40 kg ha^{-1} yr^{-1}). This remarkable effect related to the change of deeper rooting deciduous tree species to shallow rooting Norway spruce was also found by Feger (1993).



	Picea abies [t/ha]	Quercus / Tilia [t/ha]
Humus layer	21.4	1.2
0 - 50 cm	64.3	83.5
50 - 100 cm	22.1	25.3
Total	107.8	110.0

Figure 11: C storage ($t*ha^{-1}* cm^{-1}$; 1 m soil depth) after 2 generations of Norway spruce as compared to the control stand stocked with the natural deciduous forest that was not converted into Norway spruce plantation; from Kreutzer, 1981.



	Picea abies [kg/ha]	Quercus / Tilia [kg/ha]
Humus layer	630	60
0 - 50 cm	4980	7550
50 - 100 cm	3130	3420
Total	8740	11030

Figure 12: N storage ($t*ha^{-1}* cm^{-1}$; 1 m soil depth) after 2 generations of Norway spruce as compared to the control stand stocked with the natural deciduous forest that was not converted into Norway spruce plantation; from Kreutzer, 1981.

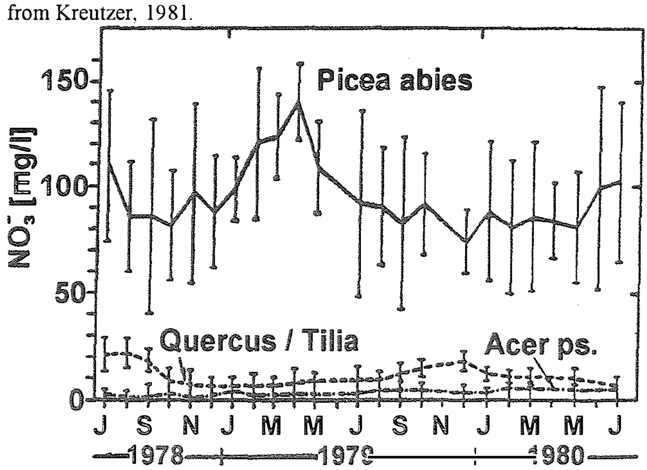


Figure 13: NO_3-concentrations in the seepage water underneath the main rooting zone of the Norway spruce stand as compared to the control stand stocked with the natural deciduous tree species. For further comparison a neighbouring maple (Acer pseudoplatanus) stand is shown; the observation period was July 1978 to July 1980; from Kreutzer, 1981.

These research results emphasize the need of forest re-conversion to more natural forest vegetation types for various forest areas in Europe. However, sound concepts how to convert generally pure coniferous stands into mixed (deciduous) stands are still missing. This is also true for afforestations on abandoned land.

Glatzel (1991) has demonstrated the detrimental effects of continuous litter raking on site properties. In this study a significant net loss of nutrients paralleled by a decline of the acid neutralisation capacity (ANC) was found (Tab. 2). Also whole tree cutting may significantly contribute to the loss of nutrients from managed forest ecosystems and, hence, to a reduction of ANC (Fig. 14).

Element/ANC	Dimension	Range
Nitrogen	kg N ha^{-1} yr^{-1}	10 - 50
Phosphorus	kg P ha^{-1} yr^{-1}	2 - 4
Potassium	kg K ha^{-1} yr^{-1}	12 - 25
Calcium	kg Ca ha^{-1} yr^{-1}	15 - >40
Magnesium	kg Mg ha^{-1} yr^{-1}	3 - >10
Acid neutralising capacity	kmol ha^{-1} yr^{-1}	2.4 - >5

Table 2: Loss of nutrients and ANC (Acid Neutralising Capacity) from forest ecosystems due to litter raking (range depending on tree species, site properties, and raking frequency, from Glatzel, 1991)

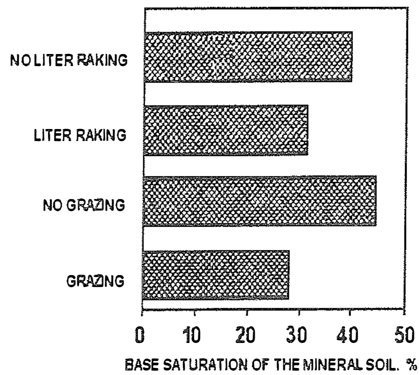
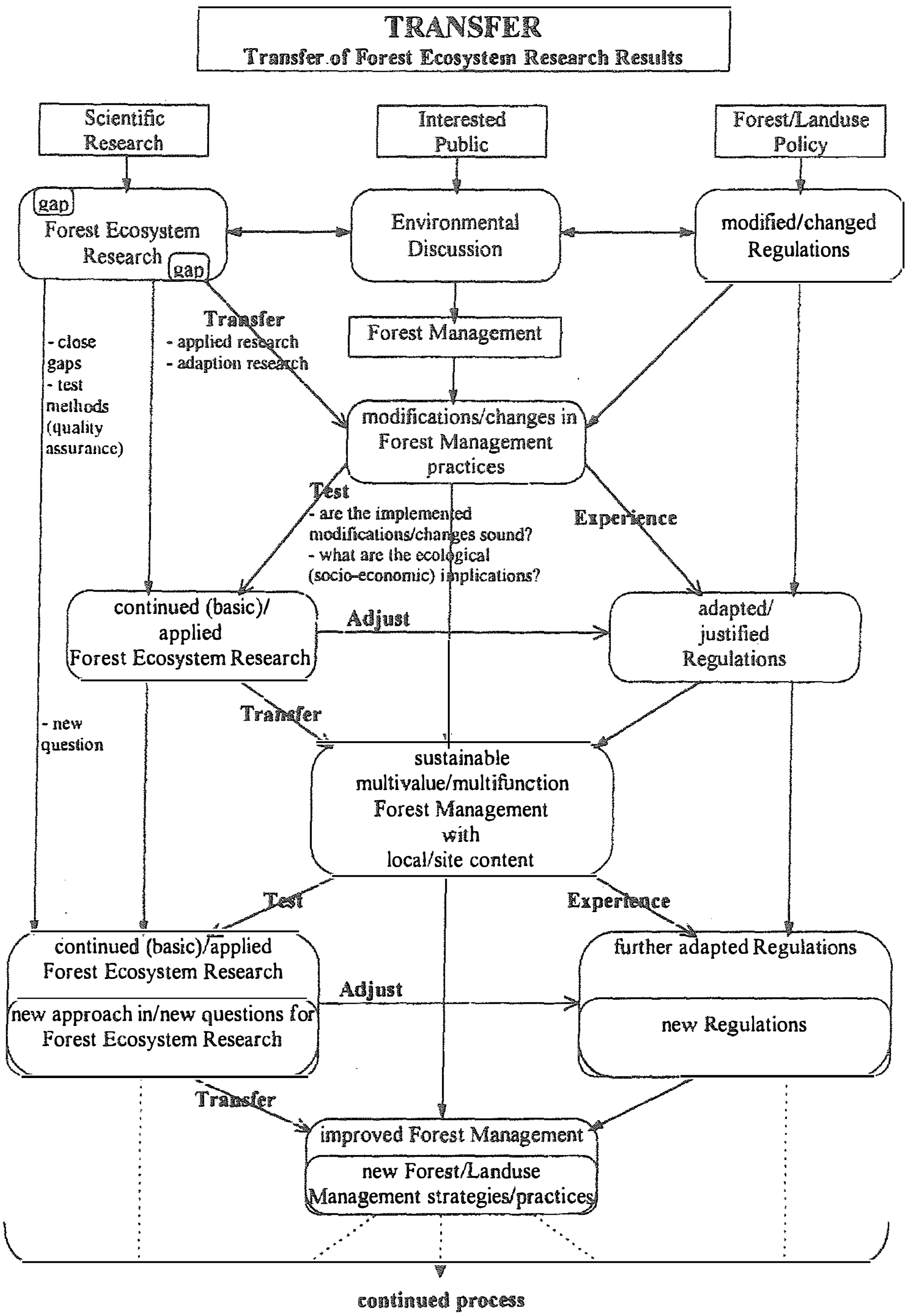


Figure 14: Base saturation of forest soils on silicate parent material in Tyrol/Austria as influenced by litter raking and grazing; from Glatzel (1991)

Forests and policy

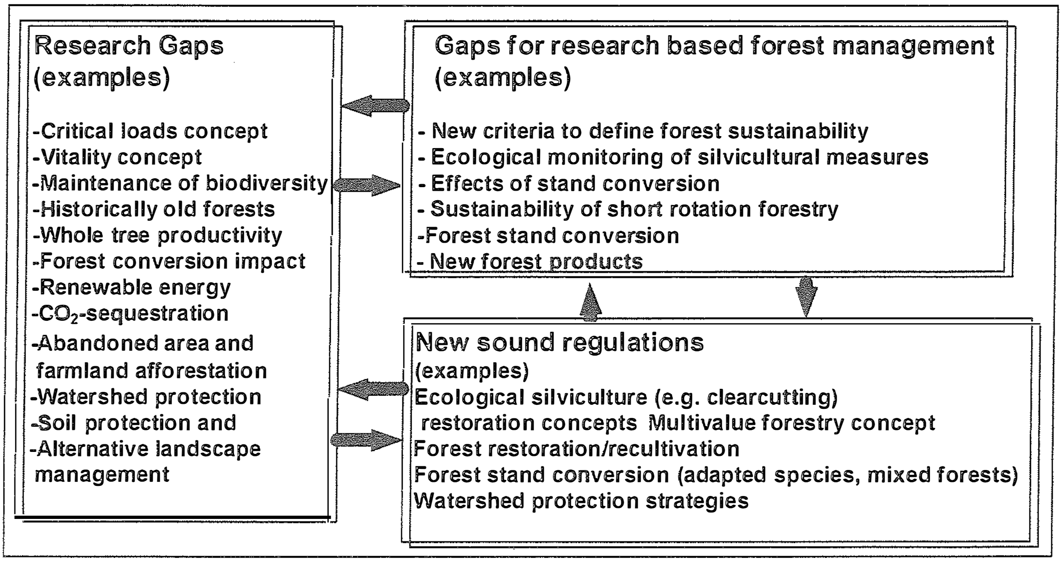
The few above mentioned and arbitrarily chosen examples (cf. also Hüttl 1991) indicate that the present environmentally influenced forest policy in Europe is not based on a comprehensive understanding of the functioning of forest ecosystems. Criteria established so far proved to be inadequate to support a sound forest policy. Therefore, the existing research results have to be critically reviewed, and research needs (i.e gaps in knowledge) have to be defined accordingly. Future research work should put more emphasis on the synthesis of available data, results and experiences, should elaborate their relevance for the policy level and above all should be dedicated to transfer generalised research results into forest management. In this context four major sectors involved in the "forest discussion" may be distinguished a) the forest ecosystem research community, b) the forest management group, c) the policy making institutions, and d) the interested public including the media. The present environmentally oriented discussion related to a sustainable development including the need for multifunctional stable forests will only be constructive when a continuous transfer of knowledge and information is guaranteed. Therefore, an adequate procedure to transfer knowledge from the ecosystem research level to all groups involved is needed to finally facilitate a sound forest policy as well as a sustainable and multifunctional forest management. To fulfill the relevant requirements for this discussion process, gaps in knowledge and in the intersectorial communication have to be identified and eventually closed. The following aspects may be formulated to promote a scientifically sound forest research policy (Fig. 15):

Figure 15: The "Transfer" - concept



When transferring existing knowledge into practical forest measures (e.g. conversion, regeneration, short rotation forestry) the effects of such implementation have to be monitored using scientific methods. To achieve this goal more efforts have to be focused on adaptation/applied research (Fig. 16).

Figure 16: Research - management - regulations



The listed examples of research gaps indicate that also the traditional forest education concept has to be adapted to these new needs. Since the economic function of forests has become less important the traditional forest management has to develop a broader perspective of forestry in the context of alternative land use systems on a landscape level and has to take into account the interrelationship between different land use systems to integrate the requirements that come along with protection goals (particularly groundwater), biodiversity, and other social and economic demands of the public (e.g. sustainable development).

In conclusion a re-orientation of the forest sector is recommended in order to satisfy present and future needs:

- Policy making in the forest sector has to be based on a better understanding of forest ecosystem functioning;
- The transformation of advanced scientific information into sound regulations has to be improved;
- Knowledge on forest ecosystem functioning generated so far has to be reviewed and generalised, and transferred to the forest management level;
- Forest policy making requires an effective on-line communication with the forest ecosystem science community;
- The transfer of information into the public has to be improved and intensified;
- Research gaps related to forest management have to be identified by forest practicians and transferred to the forest science sector;

- Gaps in fundamental knowledge of forest ecosystem functioning have to be identified by the science community and eventually closed;
- The traditional forest science and education concept has to be re-oriented towards a land use system landscape oriented scope.

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ECOLOGICAL SUSTAINABILITY OF MAN-MADE FORESTS.

Helfried OSWALD
Directeur de Recherche (em.)
Chargé de Mission
Institut National de la Recherche Agronomique (INRA)
Unité de Recherches Forestières Méditerranéennes
Avignon, France

INTRODUCTION

Regarding first at the world situation, plantation forestry has become a world-wide fact and an economic necessity for many countries. The increasing population density and the greater demands for natural resources (food, water, energy, wood, fibre, etc.) but also the growing interest for a cleaner environment, for the preservation of natural landscapes, including forests, for the conservation of biodiversity as well as for space for recreation, make the need for man-made plantations increasingly more apparent. These trends also justify that greater attention has to be paid to ecological sustainability in forest ecosystem management and in natural resource management and land-use in general.

Concerning European countries, most of their forests are today man-made forests established during the last two centuries. There are only a few, more or less undisturbed, natural or sub-natural forest ecosystems which still subsist, especially in boreal and mountain regions, and most of them are already legally protected or will it be in the near future.

In some regions of Europe management of forests reaches back as far as to the Roman Empire and treatment regimes, especially coppice and different forms of coppice with standards, were already in common use (Huffel, 1926). These treatment regimes are still applied today in many broadleaved forests and coppices of evergreen and deciduous oaks and are of environmental as well as of economical importance in the Mediterranean region of Europe.

GENERAL DEFINITIONS

To avoid eventual misunderstanding, and before going into details and citing a few examples, it might be appropriate, to indicate definitions of a few employed common terms, notions or concepts.

Ecosystem

The term « **Ecosystem** » has been first used by Tansley (1935), and Evans (1956) gives the following definition : « in its fundamental aspects, an ecosystem involves the circulation, transformation, and accumulation of energy and matter through the medium of living things and their activities ».

Thus defined, an ecosystem comprises the full range of biotic systems beyond the population level but its spatial and temporal boundaries are arbitrary. Once, the artificial boundaries of a particular ecosystem are identified, it is possible to refer to that ecosystem as if it had spatial and temporal limits. Such a system can be studied or managed with certain precautions, i. e. the monitoring of all the inputs and outputs across the boundaries of the system. This facilitates the understanding of the function of the system (Lugo, 1995).

The same author (Lugo, 1995) also defined **« ecosystem management »** as « using holistic analysis to guide [the management of] lands and water for products, services and the conservation of biodiversity ». Excluding explicitly from the analysis the atmospheric system, where we generally cannot directly intervene, except through the reduction of pollutant emissions, he considers the conservation of biodiversity as an ecological constraint ensuring the sustainability of management actions for the production of goods and services.

Sustainability

In forestry, the term **« sustainability »** was, until recently, essentially used for « sustained yield of timber or woody products » and it sometimes also connoted the indefinite maintenance of the site productivity potential.

Today, the notion of « sustainability » is used through an ecological approach with much broader perspectives and the concept of **« sustainable forest management »**, not only concerns the « sustainable » production (steady flow) of woody products, it also includes non-wood products and a wide range of environmental services, as the conservation of soil and water, the preservation of animal and plant genetic diversity, as well as major socio-economic aspects (F.A.O., 1994).

Thus, the Ministerial Conference on the Protection of Forests in Europe, Helsinki, 16-17 June 1993, in its « Resolution H1 », defined **sustainable management of forests** for the first time on the high political level as follows :

« Sustainable management means the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economical and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems » (Helsinki Resolutions, 1994).

Biodiversity

The conservation of **« biodiversity »** is considered today as a major and integrating part of sustainable forest management. But, as biodiversity can concern different levels of appreciation i. e. populations, individuals and genes, several, often quite diverging, definitions are used.

Approaches to measuring biological diversity, should therefore not only consider the number of all kinds of species (trees, animals, insects, microbes, etc.) existing aboveground or underground at a specific location. The assessment of biodiversity of a given ecosystem should use appropriate scaling and equally take into account the various spatial patterns and the temporal succession stages, as well as their dynamics.

Site and forest site productivity :

The term « **site** » is used to describe the sum of environmental conditions (biotic, edaphic, topographic and climate conditions, including atmospheric composition) existing at a particular location. **Forest site productivity** is defined as the woody biomass production potential of a given site. It is generally limited to the wood production potential of a site for a given tree species, provenance or forest type. Volume, basal area or height may serve as an indicator of site productivity (Spiecker, 1996).

Forest plantation systems

The term exclusively refers to man-made forests, generally aimed at the production of wood and woody products as a renewable resource. These man-made forests are often connoted as « artificial » and opposed to « natural forests ».

There are many different management systems and treatment regimes, including monoclonal or multi-clonal plantations of poplars or eucalypts, treated as high forest or as coppice, mono-specific plantations of various fast growing conifer species producing wood of industrial quality, and, last not least, plantations of very valuable and genetically improved broadleaved species, as wild cherries, walnuts, oaks and many others, treated as mono-specific or even mixed high forest, and using intensive silvicultural measures for high-quality timber production.

These forest stands are generally even-aged as their first generation has been established by planting or sowing, but their renewal can often be obtained through natural regeneration by seed. For many broadleaved species (eucalypts, oaks, poplars, etc.) renewal can also be obtained by coppicing.

Disturbances

All forest ecosystems, as well man-made as natural ones, are subject to **natural or human induced disturbances** as fire, insect pests, diseases, storms, etc. which can occur more or less periodically but which are generally difficult to predict. In this context, different forest management practices must also be considered as human induced disturbances which can produce positive as well as negative effects on the ecosystem. Furthermore, it has to be mentioned, that the renewal of many natural forest ecosystems depends largely on disturbances as fire, windfall or others. Disturbances play also an important role in the dynamics of succession.

Exotic or introduced species

Many man-made forests have been established with **« exotic « species** chosen either for their superior growth potential or their technological wood quality, but often also for their adaptation to specific site conditions. There are many examples from European countries where **« exotic » species** have been introduced with great success.

Thus, Douglas fir (*Pseudotsuga menziesii*), Sitka spruce (*Picea sitchensis*), Austrian black pine (*Pinus nigra ssp. nigricans var. austriaca*), Atlas cedar (*Cedrus atlantica)*, black locust (*Robinia pseudoacacia*), North American poplars and red oaks and many others, have already been grown now in several European countries over more than one or two rotation periods. Their genetic variation, their ecophysiology, their site requirements, their growth characteristics and their silvicultural treatments as well as their potential enemies are now well known and they can be considered as well adapted species to many different sites where they were introduced. Genetic selection and breeding have also largely contributed to the success of these species.

Many of these species contribute significantly to the production of quality timber and other woody products, and subsequently to the economic development of the local forestry sector. Species, as Austrian black pine, have been used with success a century ago for restoration of extremely degraded sites in the Alps and these stands still play today an important role as protection forests. Others, as Lodgepole pine (*Pinus contorta*), have been introduced on specific sites (peatland), where native species won't prosper.

Nevertheless, the use of « exotic » species is considered negatively by supporters of a « silviculture close to nature ». This rises the question : What should we consider as an « exotic » species ? Has a species to be considered as « exotic » when it has been introduced on convenient sites only a few hundred kilometres outside of its more or less clearly established or definable « natural range »? e. g. Norway spruce (*Picea abies*) in the Massif Central of France, Austrian black pine in the Central and Western Alps, etc. Should a species like evergreen cypress (*Cupressus sempervirens*), probably introduced and cultivated since more than 2000 years in South-western Europe, be considered as an exotic species ? There will probably be no clear answers, but if we use for a given species the notion of **« potential range »** besides **« natural range »**, many fruitless discussions could than be avoided.

EXAMPLES

European experience over several centuries has shown that even mono-specific man-made forest ecosystems, composed of native as well as of introduced species, can be maintained in a healthy and stable state and provide the desired goods and services. Let us take two examples for illustration.

The Maritime pine (*Pinus pinaster* Ait.) forests in the Landes of Gascony (France).

The « Landes of Gascony » constitute a natural region situated in the Southwest of France. The region has the form of a triangle, approximately limited in the Northeast by the Garonne river from its mouth to the town of Agen, in the Southwest from Agen to the town of Bayonne and in the West by the Atlantic Ocean. The thus delimited region comprises parts of the following administrative units (« département ») : « Landes » (40), « Gironde » (33) and « Lot-et-Garonne » (47).

The climate is generally temperate with little seasonal variations (mean annual temperature is about 12.5 °C), the annual precipitation (700 to 1200 mm) is regularly distributed all over the year, but climatic gradients from the coast to the interior and from North to South can be observed.

The following four major site types, ranged by increasing site productivity, can be distinguished : The « dunes » along the coast (approximately 10 % of total area); The « lande sèche » (dryland type) with *Calluna vulgaris* (25 %); The « lande humide » (wetlands) with *Molinia coerulea* (40 %), the « lande mésophile » (mesophylic type) with *Pteridium aquilinum* (25 %).

Poor sandy soils prevail all over the region and the dominant soil types in the « landes » are different types of podzols with more or less important layers of hardpans at variable depth. The whole region is flat, except the recent and ancient coastal dunes, and drainage of the wetland-type is absolutely necessary.

Maritime pine has a wide natural range which is divided into two different regions : The western Mediterranean region (north-western Italy, South of France, Southeast and South of Spain, Morocco, Algeria and Tunisia), and, the south-western European region along the Atlantic ocean (Southwest of France, Northern Portugal, Northwest of Spain). Several intraspecific races, especially an Atlantic and a Mediterranean one, and many different provenances have been distinguished and their particular characteristics (ecology, growth, wood quality, etc.) have been described.

The species is a fast growing and highly productive which can grow and prosper on very poor acid soils. As a pioneer species, natural regeneration, especially after fire, can be obtained. Maritime pine has also been successfully introduced in other regions of France - the total area of Maritime pine forests in France is about 1.3 millions ha - as well as in South Africa, Australia and New Zealand.

At the end of the 18th century, extensive grazing and frequent, human induced fires as well as wild fires, had reduced the forests of the region to about 100 000 hectares, mostly composed of dissociated woodlots of Maritime pine and, on better sites along small rivers, of native oak species as *Quercus toza*, *Q. robur* and *Q. suber.*

Along the 250 km of the coast, the sand dunes steadily moved inward and agricultural land and even villages had to be abandoned. The stabilisation of the dunes, already initiated in 1780, and their afforestation with Maritime pine, started in 1810 and was more or less achieved in 1862, creating about 110 000 ha of mostly state owned coastal forests. As the marine beach erosion is still ongoing, special stabilisation measures must continuously be applied along the shore in order to protect the coastal dune forests. These forests, which are not very productive, play today an important role for protection and recreation and their conservation requires special management and silvicultural methods. In these forests natural regeneration can now often be obtained.

Between 1857 and 1875 the drainage of the unproductive and even unhealthy wetlands allowed the establishment of about 600 000 ha of essentially private

Maritime pine forests. But the afforestation effort by private land owners, interrupted only during World War I, continued steadily and at the beginning of World War II, 1 100 000 ha of forests, of which about 90 % were composed of Maritime pine, covered about 77 % of the region.

Concerning the ownership, it must be emphasised, that about 84 % of the forests are private property, ranging from a few hectares to a few thousands of hectares, and only 16 % are public forests (10 % community forest, 6 % state forest), managed by the « Office National des Forêts » (State Forest Service).

Until World War I, resin tapping was the main production objective but declined steadily until the early fifties, when it was nearly abandoned. To maximise resin production, the stands were heavily thinned during the last third of their rotation and wood quality, due to resin tapping, was rather poor.

Since the late sixties, quite important changes in land-use occur and forest lands, on convenient sites in the wetlands, and about 100 000 ha have already been converted into irrigated agricultural land, especially for corn and, more recently, for vegetable growing. That tendency seems to continue as about 1 300 ha of forests have been converted to other land-uses in 1990.

Maritime pine forests still cover today about 1 million hectares in the region and their socio-economic impact is vital for the region and of great importance for the whole country. Since the early fifties new and important wood industries (saw mills, pulp and paper mills, furniture factories, etc.) as well as forest enterprises were progressively established. These industries employ about 30 000 peoples and transform an important proportion of the local annual harvest, thus creating about 3 3 billion francs of added value each year (Arbez & al., 1990).

Simultaneously, the traditional silvicultural practices are progressively replaced by new intensive sivicultural methods largely based on steadily forthcoming new research results concerning genetic improvement, nutrients and water, growth and yield, biotic and abiotic pests and disturbances, as well as the rational use of new and powerful machinery for drainage, cultivation and harvesting.

These new, very intensive and site specific silvicultural practices are characterised by a high degree of mechanisation from establishment to harvesting. Tools as yield tables, growth models, site classification systems and silvicultural guidelines have been published, facilitating the choice of the most ecologically and economically convenient methods (Chaperon, 1986; AFOCEL, 1994; Chollet, 1996).

Until 1990, about 85 % of the stands were established by direct row-seeding (2.5 kg/ha) using modern terrain-crossing agricultural machinery. Nowadays, planting with machines of 1000 to 1250 trees/ha concerns about 40 % of the annual stand establishment and is generally reserved for genetically improved plants of high quality and only on better sites. Fertilisation with phosphorous at the establishment is absolutely necessary on the wetland and mesophilic site type. Weed control uses mechanical cultivation and herbicides; 1 to 2 pre-commercial thinnings and 2 pruning operations (up to 3.0 m and to 5.6 m) are strongly recommended. Three commercial thinnings reduce the number of trees to the final stand density of 250 to 300 trees/ha.

These Maritime pine forests are generally managed as mono-specifc and even-aged high forest for the production of a high proportion of timber of good quality with rotations varying now from 40 to 60 years. Their total annual production, including ingrowth, can be actually (1990) evaluated at about 13.5 million m^3 and the annually harvested volume at about 5.8 million m^3, composed of 70 % timber and 30 % industrial wood. The 3 successive forest inventories of the « Inventaire Forestier National » (National Forest Inventory) showed an important increase of the mean annual current increment, including ingrowth, during the last 30 years.

4.7 m^3/ha/year in 1962
7.3 m^3/ha/year in 1977
9.0 m^3/ha/year in 1987

That progressive increase is essentially due to the evolution of silvicultural practices and genetic improvement and, only partially, to structural changes in age classes. A further increase up to 14.0 m^3/ha/year could be expected at the beginning of the 2nd millennium, mainly due to the faster growth of the genetically improved varieties.

It is quite obvious that these big mono-specific forests are particularly exposed to many natural and human induced disturbances. Three major disturbances must be especially mentioned. Until the early fifties, fire was the most important danger. Between 1940 and 1950 about 300 000 ha of forest were destroyed by many important fires of different origins and over 100 people, essentially fire fighters, were killed. As a consequence, an efficient system for forest fire prevention, detection and suppression has progressively been developed for the whole region. The spatial distribution of ages classes and the efficient weed and shrub control recommended in the new silvicultural practices, contribute also significantly to reduce the fire hazard.

A second important hazard concerns extremely low temperatures which occur periodically. Thus, in January 1985, temperatures below -20°C have been observed in several weather stations, killing the trees on about 20 000 ha and causing frost damage on further 130 000 ha. These damaged and weakened trees subsequently suffered or were killed by the outbreak of heavy bark beetle attacks. Thus a total of 60 000 ha had to be clearcut in the two following years. Fortunately it has been clearly demonstrated that the majority, about 95 %, of the frost damaged stands has been established after the 1940-1950 fires with imported seed from the Iberian peninsula, whereas stands on the same sites and of the same age, which were established with local and/or improved seed sources, showed a much better frost resistance and also recovered quickly (Le Tacon & al., 1994).

A third hazard concerns biotic agents. Quite important outbreaks of the processionnary caterpillar (*Thaumetopoea pityocampa*) are periodically observed, generally in a 6 years cycle. Damage by primary pest insects (*Dyorictria sylvestrella, Hylobius abietis, etc.)* can occur to some extend and secondary pest insects, as *Pissodes notatus, Orthotomicus erosus,* etc. can cause dieback on weakened trees after frost, drought, defoliation, etc. Thus, mortality affected 10 000 ha between 1989 and 1991 after a heavy defoliation by the processionnary caterpillar (100 000 ha) and very dry summers, followed by barkbeetle outbreaks (Bouhot-Leduc & Levy, 1994). Several other biotic (fungi, etc.) and abiotic (drought, wind, etc.) agents can locally play a minor role.

It has also to be mentioned here, that *Matsucoccus feytaudi*, a scale insect, which has initiated, since the late fifties, the dieback by subsequent barkbeetle attacks, of nearly all the older stands of Maritime pine (120 000 ha), in the forests situated East of the Rhone river in the Southeast of France, is endemic in the « Landes of Gascony », but it causes no damage there (Riom, 1994).

Today, an efficient monitoring system, based on frequent terrestrial, airborne and satellite observations, allows to predict insect outbreaks and to follow closely the state of health and the evolution of forest cover and land-use (Barthod, 1994a). Furthermore, efficient biological and/or chemical treatments are now available and allow the prevention and the control of major insect pests.

In comparison with the situation at the end of the 18th century, biodiversity of flora and fauna has significantly increased in the region. Efforts to create a still greater diversity of forest species remain limited due to the prevailing site conditions and the private land ownership. Nevertheless, stands of natural oak species are preserved whenever it is possible, the genetic diversity of Maritime pine is steadily increased and site tolerant broadleaved species, as American red oaks (*Quercus borealis, Q. palustris*), are locally introduced. All kinds of wildlife developed rapidly and roe deer and red deer populations have now to be closely managed to avoid damage (Guibert, 1992).

The actual management regime has to be maintained as well as for biological constraints, - Maritime pine is not a shade-tolerant species - as for economical reasons. But the appropriate choice of size and age of the management units and their spatial distribution as well as the diversification of silvicultural practices can contribute to the improvement of biodiversity and of the perception of the landscape.

In spite of the fact that the landscape of that flat and very poorly populated region with its huge pine forests remains inevitably rather monotonous, tens of thousands of tourists daily frequent during the summer season the beaches, the more recently developed resorts and the forests. They also come the whole year over to the forests and lakes for fishing, hunting, hiking and gathering of edible mushrooms or for any other kind of recreation. Today, tourism also contributes significantly to the regional economy.

Taking into account the size of these forests and their regional and even national socio-economic importance, the existing particular site conditions, the industrial potential and the private ownership, it is quite obvious, that these artificial forest ecosystems, which must be considered in a more or less arrested succession stage, have to be maintained in a state which assures their multiple functions.

Major problems concern the impact of intensive silvicultural practices as well as of other land-use systems, e. g. irrigated agriculture, on the long-term maintenance of site productivity, the maintenance of stability and health of the forests and, last not least, the maintenance of the environmental functions. This can only be achieved by a better understanding of the functioning of these ecosystems.

Since more than 3 decades, these forests have served as an open research laboratory for multi-disciplinary research, involving the major French research organisations in co-operation with other countries. Many important results have been obtained and are already transferred into practise.

Ongoing and foreseen basic and applied research concerns the soil-plant-atmospheric interactions in general (cycling of major nutrients, resources and quality of water), the genetic improvement of Maritime pine through selection and breeding for adaptation and/or resistance against biotic and abiotic agents, for vigour and wood quality (pole straightness), the validation of tree growth models and their transfer to practise and the elaboration of process-based models, the monitoring of insect pests as well as micro-economic studies. The main objective of all these R & D efforts aims at the development of ecological sustainable management practices for forests as well as for other land-uses in order to fulfil their ecological, economical and social functions.

Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests in France.

The first douglas fir trees have been introduced in private parks of France in 1842 and the first plantations have been established by private forest owners as early as 1880. A few of these stands still exist. After World War II, the encouraging results of the already existing plantations and governmental incentives for afforestation produced a steadily growing interest for the species.

Forest research progressively provided useful first information concerning the choice of convenient provenances - the first provenance trial in France was established in 1941 - , the site requirements of the species, growth and yield, wood quality and specific silvicultural practices (spacing, thinning, pruning, etc.). Similar afforestation trends with Douglas fir were observed in several European countries as Germany, the United Kingdom, Italy, Belgium, Ireland, Denmark and Portugal.

From the mid-sixties and still to today, Douglas fir is the most planted species in France and the annually planted area of about 10 000 ha, equalises that of Norway spruce (*Picea abies*). In 1980 the total area where Douglas fir is the dominant species has been estimated at about 220 000 ha with the maximum mean annual increment ranging between 16 and 21 m^3/ha/year (Bouchon, 1984). The same author (Bouchon, 1995) calculated an estimation for 1993 of about 375 000 ha. Thus, France is today the country with the greatest area of Douglas fir outside of its natural range.

The success of that species is essentially due to its high production potential, the outstanding technological quality of its wood, its adaptation to a wide range of site conditions and, last not least, its apparent resistance against biotic and abiotic agents. (I.D.F., 1981; Oswald & Pardé, 1984; Aussenac & Oswald, 1986; C.T.B.A., 1986).

Douglas fir can be considered as a rather plastic species concerning its site requirements. It has its growth optimum in regions with a more temperate climate and equally distributed annual precipitation between 700 and 1200 mm, but provenances from California (USA) can also support summer drought (Birot & Ferrandes, 1972). It grows on a wide range of soils but stability is reduced on hydromorphic soils and on very compact clay soils, growth is very low on shallow and/or calcareous soils and fertilisation with phosphor is necessary on podzols.

Douglas fir is a very fast growing and, besides Sitka spruce, one of the most productive species in Europe. Stands, at an age of 60 years, with top heights of 40 m, with a standing volume of more than 1 000 m3/ha and with a mean annual increment of about 25 m3/ha/year, can often be found on good sites.

The species reacts quickly and positively to intensive silvicultural practices and a large ring width doesn't notably alter the mechanical resistance of its wood (Riou-Nivert, 1989), which is of outstanding technological quality, allowing a wide range of utilisation (plywood, joinery, carpentry, pulp, etc.).

Douglas fir is resistant to low winter temperatures (-25°C) and late frost damage can be avoided by the choice of late-flushing provenances. It is planted from the sea level up to an altitude of about 1 100 m. At higher altitudes, its growth potential is reduced and equals those of Norway spruce and Silver fir (*Abies alba*) which are than preferred. Although Douglas fir reduces its growth on wind exposed sites, but its penetrating root system, the mechanical resistance of its wood and the flexibility of its branches, confers an excellent resistance against storms and snow-break. At the time being, no serious damage from insect pests or pathogens has been recorded.

The potential area of Douglas fir in France is very important. The majority of the plantations is situated in the Northeast (Beaujolais, Morvan), the Northwest (Limousin) and the Southwest (Cevennes) of the French Central Massif, in Brittany, in Normandy and also in the Northeast of France.

Most of the stands, which are generally of small size, were progressively established by small private land owners on abandoned agricultural land or replacing small farm woodlots of poor broadleaved coppices or degraded Scotch pine (*Pinus silvestris*) stands. Therefore, the temporal and spatial structure of Douglas fir forests presents a much greater diversity than those of Maritime pin in the « Landes of Gascony ». Furthermore, although most of the stands are mono-specific and even-aged, an understory of broadleaved trees and of shrub species is often maintained in older, heavily thinned stands. In some regions, Douglas fir as the main species has also been mixed with Grand fir (*Abies grandis*) or Norway spruce.

Genetic improvement through selection and breeding, the establishment of seed orchards and the certification of North American and French seed sources provide now the choice of a wide range of improved and site specific seed (C.E.M.A.G.E.F. & D.E.R.F., 1992).

Based on results from spacing and thinning experiments and growth and yield studies (Oswald, 1984; De Champs, 1990), new intensive silvicultural practices have been developed and guide-lines have been published (De Champs & Demarcq, 1996). In the near future, tree growth models will allow the simulation and validation of a wide range of possible silvicultural treatments for different production goals (Ottorini, 1995).

Douglas fir silviculture is actually characterised by initial plantation densities ranging between 800 and 1 600 trees (1 200) per hectare, pruning of about 200 crop trees and 3 to 6 thinnings; rotations vary between 40 and 70 years. Although natural regeneration can be obtained on many sites, it is still only occasionally practised due to a lack of scientific knowledge and practical experience.

Ongoing ecosystem research is focused on the long-term maintenance of the site productivity potential (nutrient and carbon cycling over whole rotations), the continuous genetic improvement (seed orchards with improved varieties, etc.), the validation of tree growth models, development and transfer to forest management of ecological sustainable silvicultural methods which will ensure the different production goals and environmental functions of the mostly small private owned Douglas fir forests.

It must also be emphasised, that Douglas fir stands established with site adapted well chosen and genetically improved planting material, are not only the most productive forests, but they are still today amongst the healthiest and most stable forests in France.

FOREST MANAGEMENT SYSTEMS, SILVICULTURAL TREATMENTS AND OPERATIONAL EFFICIENCY

The requirements for operational efficiency are generally large-scale, mechanised, simple and uniform methods of management and silvicultural treatment and these may be in conflict with the environmental values, which tend to be favoured by more small-scale complex and diverse methods (Holmes, 1978).

Most of the European man-made forest ecosystems are managed as even-aged and more or less mono-specific high forests by the clear-felling or the shelterwood system. These quite simple management systems, can easily be applied to many important forest tree species, conifers as well as broadleaves. Their operational efficiency depends largely on the size of the treatment (management) unit (Bol & Leek, 1984).

On the opposite, the single tree selection and the group selection system, which generally use natural regeneration, can only be applied to a limited number of tree species in pure or mixed, uneven-aged or even-aged stands. They have a much lower operational efficiency and they also need intensive management and specific silvicultural knowledge and skill.

However, within each of these systems exists a wide range of well known and practised variants concerning the size and shape of the treatment units, their degree of mixture and their spatial and temporal distribution patterns. For the final choice of a specific system Minkler (1974) states : « it's usually best to determine first the systems which are biologically viable and then decide which one will best fulfil the environmental, social and commodity value desired ». A reasonable and sensitive compromise has to be found by choosing management systems and silvicultural treatments appropriate to each particular situation.

These man-made plantation forests should therefore not be considered as mere commercial production forests, because most of them are already or will be managed in the future in a sustainable way as multiple-use forests and assume many other important functions.

RESEARCH NEEDS

During the past 30 years important progress in forest research in general and in forest ecosystem research in particular has already been achieved, and basic and applied research results have been adapted and successfully transferred to forest managers for sustained forest ecosystem management.

However, we must be very precautious when we want to generalise research results obtained in different countries for a given species on a particular site and under the prevailing climatic condition, and then apply them in other regions with different edaphic and/or climatic conditions or for different species. That doesn't mean that results are dubious, but differences in methodologies, in data analysis and interpretation can sometimes produce diverging results.

Most of the forest ecosystem research in Europe has been concentrated on mono-specific and even-aged stands of a few important forest tree species as Norway spruce, Scotch pine and beech, and, occasionally, Maritime pine, Douglas fir and Sitka spruce. There are still many research needs for ecosystems of tree species typical for the Alps or for the Mediterranean region, as well as for uneven-aged and/or mixed stands.

Key problems, common to most man-made forest ecosystem, are the long-term maintenance of the site productivity potential, the maintenance of stability and health and the maintenance of the ecological, economical and social functions. This can only be achieved by a better understanding of the functioning of these ecosystems taking into account the multiple interactions between management systems, sivicultural practices, genetic improvement, site conditions, etc. Thus, there are still many research needs for the future.

Concerning the long-term maintenance of the site productivity potential, research should be focused on the cycling and balance of major mineral nutrients, carbon and water over whole rotations. Special attention should be paid to the comparison of methodologies for measurement and analysis, and also to the root system which is very difficult to investigate.

New approaches in modelling of tree growth should be based on individual tree growth models allowing the modelling and simulation of the above-ground spatial distribution of the tree components (leaves, branches, wood (ring width, quality)) not only in even-aged, mono-specific stands but also in uneven-aged and in mixed stands. Furthermore, the validation of these models and their possible integration into process-based models, which need still to be refined, can only be achieved through a close co-operation between ecologists, foresters and model designers.

Concerning the maintenance of stability and health of the forests in general, the already existing European monitoring network provides very useful and permanent information about the state of health of the European forests. It is the task of the local authorities to take the necessary measures concerning the management of disturbances and to indicate existing gaps of basic knowledge and the priority of new research needs.

Concerning the maintenance of the ecological, economical and social functions of man-made forests, research needs are generally specific for a region and/or for a forest and must be addressed in each particular context. It has to be pointed out, that appropriate scaling should be recognised as a major problem in ecological research.

The main objective of all these R & D efforts must be the development of ecological sustainable management practices for forests as well as for other land-uses in order to fulfil their ecological, economical and social functions.

In the end, it will be the forest manager or forest owner who has to decide whether his objectives or methods are satisfactory or should be changed. The scientists in each country must help ensure that his decisions are based on knowledge and balanced judgement rather than on folklore or prejudice (Holmes, 1978).

CONCLUSION

Man-made forests will continue to play a major role in many European countries and managed as multiple_use forests. Though, in many places the cost-efficient production of wood of industrial quality will remain the main objective, **« sustainable forest management »,** as defined in the Helsinki Resolution H 1 and specified in follow-up seminars, will progressively be applied to many forests in France (M.A.P.A.-D.E.R.F., 1994), as well as in other European countries.

Let us conclude with some phrases pronounced by G. D. Holmes as an introduction to the IUFRO-Division 1 Meeting on « The ecology of even-aged forest plantations », held in Edinburgh, UK, 7-19 Sept. 1978.

« It has sometimes been suggested that there is a fundamental difference in outlook on ecological matters between the foresters responsible for managing traditional, semi-natural, uneven-aged forests and those responsible for man-made plantations. I do not believe this to be so, and any differences there may be tend to reflect differences in objectives of management rather than differences to awareness or sensitivity on ecological questions ».

« A sound knowledge of the forest ecosystem is obviously important in all circumstances and especially so for even-aged plantations. Furthermore, it needs to be stressed that new knowledge must be translated into terms which mean something to forest managers. In particular, if there are undesirable features, the manager needs to know what these are and why they are undesirable in terms of

productivity (e. g. site degradation, hazards to health, etc.), and environmental values (e. g. water, nature conservation and landscape) » (Holmes, 1978).

ACKNOWLEDGEMENT

I would like to express my thanks to the participants of the 1° EFERN S6 Plenary Meeting who contributed to the discussions at the meeting and made many useful written suggestions.

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IMPLICATIONS OF 'FOREST HEALTH' ASPECTS ON FOREST ECOSYSTEM RESEARCH

Erwin FÜHRER
Institut für Forstentomologie, Forstpathologie & Forstschutz
Universität für Bodenkultur WienHasenauerstrasse 38, A-1190 Wien, Austria

ABSTRACT

Epidemics of pest organisms in forest ecosystems are the manifestation of imbalances in consumer food chains. Their prevention through forest management practices must be based on knowledge of the ecosystemic roots of pest outbreaks. Distinguishing between the 'predisposing' and 'inciting' factors triggering epidemics can prove useful in gaining a better understanding of biotically induced forest damage. To evaluate the risk of pest outbreaks, the 'predisposing potential' of the abiotic circumstances, the vegetation, and the 'incitement potential' of the pest populations must each be considered separately. This is briefly exemplified by means of spruce bark beetles and oak defoliators, respectively, which represent epidemically different types of pests. Although both are herbivores, their integration into the respective food chains differs in many aspects; therefore, their functional position in the causative complex of 'predisposition' and 'incitement' is different. Due to this functional divergence, the traits of forest ecosystems or system compartments, that are relevant for balanced population dynamics, may be diverse. Their recognition and evaluation are essential components of the assessment and avoidance of risks in the course of forest management. Hence, the ecosystemic sources of biotically caused damage have to be adequately considered in forest ecosystem research.

Keywords: forest ecosystem research, pest organisms, epidemics, predisposition, risk assessment

INTRODUCTION

The main function of forest ecosystem research, as expressed by the Strasbourg / Helsinki Resolutions (Min. Conf. 1993), is to provide a sound ecological base to protect and manage forests on a sustainable basis. Throughout most of Europe, the protection and sustainable management of forests are closely inter-related. Except in limited areas such as 'Natural Reserves' or 'National Parks', where forest ecosystems are relatively free of human intervention, natural forest development is not allowed to run its course, but is in one way or another determined by socio-economic expectations. From the anthropogenic view a functional forest ecosystem should lead to welcome results, e.g. a certain yield of timber, reliable protection against soil erosion or groundwater pollution, or a sustainable supply of recreationally valuable landscape. In this sense, forest management steers ecosystemic processes toward a predetermined conceptual goal. Increasingly sophisticated forest management takes into account more and more functional aspects of forest structure and successional events.

Trends or single events in the forest ecosystem causing the management concept to fail, are regarded as detrimental. 'Forest protection', has been an integral part of 'forest management' from its first beginning; it must heal or - better - prevent forest damage. In light of ecosystem management expectations, forest damage is the manifestation of 'ecosystemic malfunctions'. Thus, every phenomenon of forest disease - ranging from windthrow to pollution effects, from pest epidemics to symptoms of forest decline - has its ecosystemic roots. Due to the great diversity of forest diseases, we must assume that their ecosystemic roots are diverse as well, and, rather specific.

Since forest management should adequately take into account aspects of forest protection, a fundamental understanding of the ecosystemic roots of forest diseases, epidemics and damage is necessary. Dealing with difficult or even extreme site conditions, with the rehabilitation of degraded forest ecosystems, or with commercial timber production, forest managers must be able to assess the current risks as well as to predict forthcoming risks of damage. This is impossible when there is only a rudimentary understanding of the functional relations between the system's components. Important relations include those between: physical and chemical site factors, vegetative diversity and species composition and structure, eco-physiology and stress-physiology of the trees, tree-herbivore interactions, quality and dynamics of pest populations, the regulatory potential of antagonistic organisms on pest populations - and the effects of human intervention on the system.

In view of the requirements for an ecologically successful and sustainable forest management and of the required security of forest ecosystem rehabilitation, forest ecosystem research is faced with a lot of unsolved scientific questions. Looking at the variety of important forest pathologies and of the agents involved, high priority must be given to efforts tracing the responsible causes back to their ecosystemic 'malfuctional' roots. Due to the different types of relevant disease phenomena, this view may result in a new thematical diversification of forest ecosystem research. This should be demonstrated and further explained in the following paragraphs.

THE PRINCIPLE OF 'PREDISPOSITION AND INCITEMENT'

Apparent forest diseases, like injuries to individual trees, stands or sites, should be usually understood as the result of interactions between at least two factors. Frequently more than two are involved, but their functions differ. Forest Pathology distinguishes between 'predisposing' and 'inciting' causative factors. A 'predisposing factor' raises the susceptibility of a target system (organism or ecosystem) to potentially damaging influences. The 'inciting factor' means that force, which causes the manifestation of the disease. The effectiveness of this proximate causal agent depends on its 'potency' in relation to the predisposing conditions of the target organism. Generally, only the nature of the 'inciting' influence is recognized, while the 'predisposing factors' remain obscure.

The 'decline spiral' proposed by Manion (1981) has its basis in the principle of 'predisposition and incitement'. Even if this model cannot be generalized in detail, it impressively demonstrates the wide range of ecosystemic processes involved in generating acute forest diseases. Manion's 'decline spiral' also shows that different degrees of susceptibility to a single 'inciting factor' may stem from the synergy of several 'predisposing' factors. This generalized principle, however, manifests itself through a diversity of cause and effect chains when specific cases/types of forest diseases are examined. Particularly, the role of pest organisms, in a pathological context, is much more diverse than indicated by the 'decline spiral'. This should be illustrated in the following examples.

The spruce bark beetle *Ips typographus* L.

Spruce bark beetles (Coleoptera, Scolytidae), have once again caused tremendous damage to the spruce forests (*Picea abies* Karsten) of Central Europe (Krehan 1996; Führer 1996); their epidemiology seems to conform with Manion's 'decline spiral'. The 'inciting factor' *Ips typographus* infests host tree populations, which are highly weakened, i.e. predisposed to successful beetle attack. But lethally successful attacks are not limited to moribund host plants. Further, weakened host trees can recover, if their episodical weakness does not coincide with the flight period of a high density population of the bark beetle.

The relation between 'predisposition' of the host tree population and 'incitement potential' of the insect population is much more complicated than can be expressed by Fig. 1. As shown in this scheme, the relevant 'integrated' qualities of the associated partners (host tree and herbivore), i. e. 'predisposition' and 'incitement potential', are interdependent to a certain degree, but each as well subjected to its own regulatory processes.

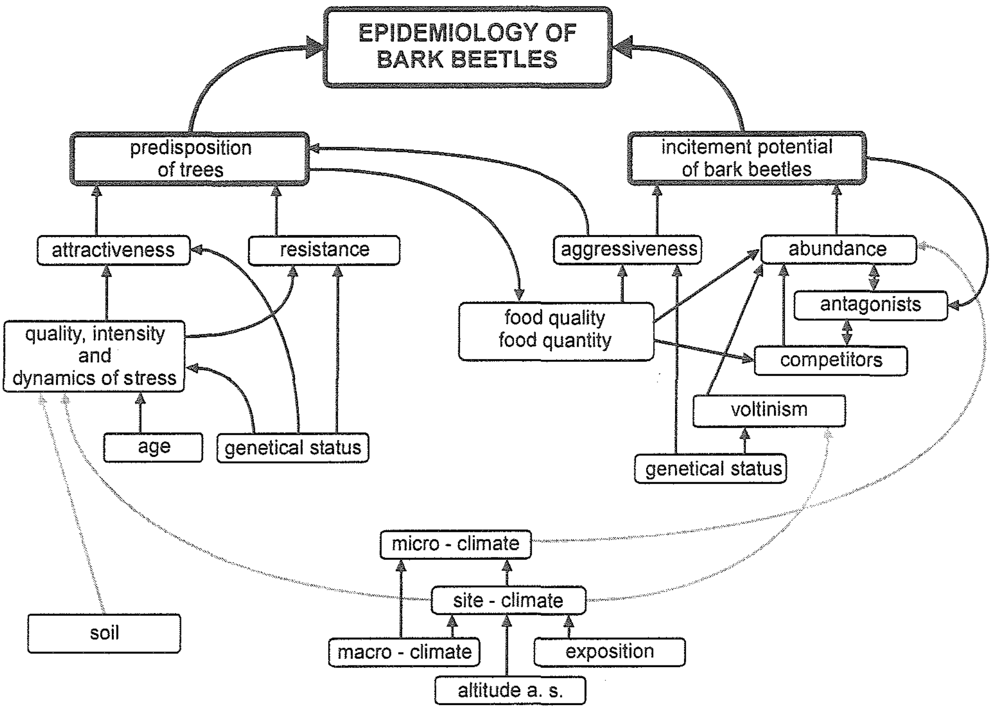


Figure 1: Simplified survey of factors involved in the epidemiology of bark beetles and oftheir functional position in the host tree - herbivore interaction.

Site factors, such as climate, operate on both host tree and herbivore, but generally have contrasting effects. When drought and high temperature cause severe stress to host trees (functioning as 'predisposing factors'), they, at the same time, promote the development and growth of beetle populations by allowing additional generations (thus enhancing the 'incitement potential').

In addition to the food plant-herbivore relationship, other elements in this system determine the interaction between the herbivore population and the host tree population (Fig 1). The relevant traits of host trees depend on their genetic make-up and age, which also influence their ecophysiological response to environmental stress. Site conditions, additionally, modify the effects of environmental stress on the host tree. In Norway spruce stands, soil properties may highly increase the likelihood of a climatically induced, predisposed state, to the benefit of spruce bark beetles. Shallow, acidic soils (or other edaphic factors) prevent trees from rooting in deeper soil horizons, and thus enhance the risk of windthrow and susceptibility to drought. Susceptibility to drought is enhanced in different ways: (1) The mechanical strain on the root systems by wind pressure causes excessive rupturing of fine roots, thus resulting in a persistant water stress in those trees not felled by the wind. (2) Superficial soil horizons are more frequently exposed to drought periods than deeper ones; insufficient water supply enhancing water stress is more likely. (3) Strong acidification in combination with water deficiency results in reversible episodes of extreme acidification (Ulrich & Matzner, 1983), thus mobilizing toxic Al^{+++} ions and damaging fine roots and mykorrhiza; water and nutrient uptake is considerably disturbed.

The phenomenon of tree susceptibility to bark beetle attack has stimulated a large number of investigations. The defense mechanisms of trees are multiple in nature, including structural and chemical components as well as constitutional and inducible strategies, directed against the insect and its associated blue-stain fungi. Christiansen et al. (1987) offered a theory explaining how various stress factors could weaken the defense mechanisms in the stem phloem, which are based on both past growth processes and the products of secondary metabolism (e.g. terpenes, phenolics). Stress factors, affecting the carbon budget of trees, reduce the available energy, which is necessary for a quick defense response against invading organisms. Energy deficiency in the phloem can be caused by a limitation of photosynthesis and by transport disturbance of photosynthetates, which in turn may be caused by drought effects of different origin, nutrient imbalance (Mg deficiency), competition for light, damaged foliage, defoliation, or general crown thinning.

Waring & Pitman (1983) proposed that, due to the tree's vital 'interests', assimilated carbon is invested, in order of priority, to: (1) buds, (2) roots, (3) storage, (4) growth in girth and (5) defense mechanisms. Consequently, only trees enjoying unlimited photosynthesis would develop a strong defense system. This disagrees in part with hypotheses explaining the differentiated, alternative investment of assimilates into plant growth and resistance (Lorio 1988). Lorio proposes that abundant supply with all required growth resources would provide the investment of a major proportion of net assimilates into plant growth, but only a small investment into defense mechanisms (products of secondary metabolism). This would explain the lack of plant resistance under luxuriant growth conditions, as observed in many agricultural systems. Limited supply of essential growth resources (nutrients, water etc.) would result in a proportionate limitation of growth, but surplus assimilates would flow into secondary plant metabolism, thus strengthening the defense system of the plant. Many examples of plants developing more secondary metabolites, under poor growth conditions, seem to support this hypothesis.

Due to the incomplete knowledge of the factors and processes operating at the plant-herbivore interface, it is quite difficult to uncover the pathways through which tree susceptibility to a few pest organisms may be determined by ecosystemic conditions. More knowledge on this issue would raise new distinct questions to the botanist, concerning the ecophysiological background of plant traits essential for the plant-herbivore association. In retracing the causal chain, processes at the soil-plant interface appear to be important, such as the effects of the atmosphere on plants and soil. It should be possible to elucidate these links in forest ecosystems, to the degree necessary to more accuratly evaluate the predisposing role of the various elements involved. This would enable us to assess the probable effects of human intervention or changing growth conditions on the respective host tree-pest interactions.

Considering insect populations, the factors determining the 'incitement potential' are partly related to, and partly independent of, the host tree. Quantitative and qualitative criteria of the food supply, in part, influence both the abundance and individual 'aggressiveness' of pest beetles. 'Aggressiveness', defined as the appetence and ability to breed in relatively 'vigorous' host trees, has a genetic basis and is modified by nutritional and environmental factors. 'Abundance' is clearly governed by the supply of suitable food (e.g. the situation after a windfall), but its dynamics can be essentially influenced by abiotic site factors (temperature sums), interspecific competition, and antagonists (predators, parasitoids, pathogens) (Thalenhorst 1958; Coeln et al. 1996). Thus, site conditions, stand structure, and factors determining the biodiversity of the forest ecosystem contribute considerably to the 'incitement potential' of a bark beetle population.

Pest organisms in the 'oak decline syndrome'

The hostplant - herbivore interactions

The phenomenon of oak decline is alarming in many European countries, and there are several divergent hypotheses offered for its explanation (Schlag 1994; Wulf & Kehr 1996). Two groups of factors are regularly mentioned: climatic disturbances and pest organisms. The conclusions of an interdisciplinary study (Hager & Grossmann 1996) assign the genesis of visible symptoms, or even the lethal progress of oak diseases, to the synergy of predisposing influences causing latent injury, and inciting factors causing acute damage. Unfavourable soil conditions, latent water stress, and insufficient adaptation of tree genotypes to the site are assumed to operate continuously or periodically over years or decades, thus progressively raising the susceptibility for acute stressors. When episodes of extreme weather conditions, i.e. drought in combination with heat or cold, are affecting predisposed trees, synergic effects cause a physiological crisis by acutely hindering hydrologic and metabolic processes in the plant. This is followed by a path to either recovery or mortality depending on whether there are repeated episodes of extreme weather or a lethal pest attack.

This concept views pest organisms as acting at the end of the causal chain, in full agreement with Manion's 'decline spiral'. Proximate causes of mortality are ascribed to fungal root diseases (*Armillaria* spp., *Phytophthora* sp.) or herbivorous (xylophagous) insects (*Agrilus* spp., Cerambycidae, *Scolytus intricatus* etc.) (Hartmann 1996, Blaschke & Jung 1996, Schopf 1992, Varga 1987). However, pest organisms obviously don't need to be involved in the exitus of the tree, mortality also may occur due to a physiological collapse caused by hydrologic and metabolic disturbance. The function of these fungi and insects in the lethal course of the oak disease(s) is ambiguous and may differ, locally.

In addition to this complex of detrimental influences, defoliation of oaks by insects (Lepidoptera) or mildew fungi is frequently observed. Evaluating their causal contribution seems difficult because such pest outbreaks are more common and have also occurred independently of the oak-decline syndrome (Wulf & Berendes 1996). Lobinger & Skatulla (1996) demonstrated that the timing of a complete defoliation within the vegetative period is important, and that repeated defoliation within one season, caused by a succession of different pest species, may be lethal.

The main effect of defoliation is the reduction or (reversible) loss of the photosynthetic ability of the tree. Hence, defoliators injure the basic metabolic function of the host plant, where it is vulnerable by the direct or indirect effect of other factors. As a central result of reduced photosynthesis, disturbances in the carbon budget occur, which also can be triggered by water / nutrient stress. In this respect, defoliators and abiotic stressors are functionally comparable, and probably exert stress on the host tree, synergetically. Disturbing the carbon budget also induces ecophysiological changes in the fine roots and mycorrhiza system, thus increasing stress. This also affects the stem phloem, reducing hardiness to cold (Thomas & Blank 1996). Following cold episodes can further enhance the effects of drought. At the end of the decline process the xylophagous insects and pathogenic fungi get their chance. The defoliators, however, stand at the beginning of the pathological sequence, ranking among the predisposing factors (Fig. 2).

If defoliators are considered important initiators of the 'decline spiral' in oaks, the ecosystemic links generating their epidemics should be carefully examined. The most common species are the oak tortrices (Tortricidae), winter moths (Geometridae) and the gypsy moth (Lymantriidae). Although they all are spring feeders, oak tortrix and winter moths must hatch simultaneously with the flushing of the host tree, whereas the gypsy moth is more flexible. Therefore, their population dynamics is significantly influenced by the genetic status of the host tree population (Schütte 1957), since differences in flushing time of individual trees result in the hatching of the young and sensitive insect larvae with varying qualities of the young, developing foliage (Feeny 1970). This is less critical for the gypsy moth. Although it can be assumed that the nutritional quality of oak foliage differs between individuals or oak species, independent of its developmental stage, there exists little information in literature. Little is also known about how physiological stress of the host tree may influence the nutritional quality of the foliage. However, at least in the oak tortrix and the winter moths, stress-induced nutritional effects on the insect's population dynamics are expected to be less striking than that exerted by genetically determined, differing bud-burst timing. Hence, the role that the host plant plays in the mortality of larval defoliators seems to be more influenced by the plant's genetic makeup than ecophysiological condition. Future investigations should address this possibility.

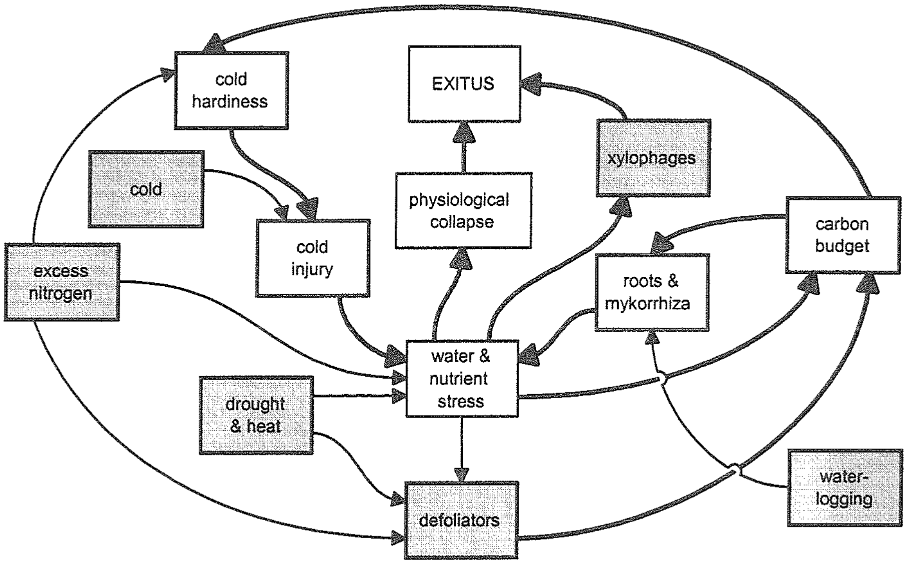


Figure 2: Position and contributions of defoliating and xylophagous insects, respectively, in the eco-physiological oak decline cycle.

The herbivore - natural enemy interaction

Another important complex of influences on the abundance of defoliator populations are their natural enemies (predators, parasitoids, pathogens). It is assumed that these organisms, in the absence of epidemic outbreaks, are able to regulate the population density of their prey (or host) in a density-dependent fashion. When epidemics occur, this regulatory potential has failed. Why?

Climbing to the next higher trophic level in the consumer food chain, the zoophagous (entomophagous) organisms, one is faced with a new scale of diversity of biological taxa: predatory mammals, birds, arthropods; parasitic insects and nematodes; pathogenic protozoa, bacteria, fungi and viruses; and most of them with a remarkable richness of species. There also is a rich diversity of life-history characteristics and synecological adaptations to the prey/host species, due to the organization and biological requirements of the individual type of natural enemies and species. There also are various types of epidemiological interactions between the populations of the herbivore and its natural enemies. In spite of this tremendous diversity, particular knowledge about the natural enemy complexes of some important forest pests is available. To develop biological control methods for individual insect species the natural enemy complex of the pest has been analyzed in detail, even considering the relative regulatory potential of single antagonist species. Winter moths and the gypsy moth are well documented examples (Sechser

1970; Bathon 1993). To take these success stories one step further, it would be necessary to uncover the ecological prerequisites of the natural enemies, to achieve an efficient long-term suppression of defoliator outbreaks in oak forests.

In the course of long-term fluctuation of defoliator population densities the dominance spectrum of natural enemies usually changes significantly. It is a common feature of such associations that a herbivore population is regulated by one set of antagonists at its endemic level and another set during epidemic outbreaks. In the endemic phase, well adapted host-specific parasitoids are usually dominant, while during epidemics rather unspecific parasitoids and predators dominate. At the culmination of the outbreak, pathogens (polyhedra viruses, fungi) frequently cause high mortality, thus reducing the pest population to its endemic level. The regulatory 'key species' in these successive phases of herbivore fluctuation may differ in different localities, but nevertheless are very similar in their behavioral patterns and life-history characteristics (Zwölfer 1963; Fuester et al. 1983; Maier 1995; Hoch & Schopf 1995; Zubrik & Novotny 1996). Of particular interest are those natural enemies which regulate the defoliator population on the endemic level, and specific attention must be paid to the circumstances under which the defoliator escapes this regulation.

Effective regulation is only possible if the relevant natural enemies are continuously and sufficiently supplied in the inhabited forest ecosystem with all the requisites they need for their existence. There also are demands for a special meso- and microclimate, which must be met by the site and the stand structure. There are as well specific requirements for complementary food sources (flowering herbs, honeydew producers etc.) and, in certain cases, intermediate host species. All this must be supplied by the available vegetation if it is lacking on the host tree of the defoliator. It becomes evident that the site conditions, the species composition of the vegetation, and the structure of the tree stand basically determine the habitat conditions of the natural enemies. Thus, there are opportunities to manipulate natural enemies by silvicultural means, provided we know their essential needs (Schimitschek 1969; Pschorn-Walcher 1977).

Tri-trophic hostplant - herbivore - parasitoid/pathogen interactions

In order to maintain the regulatory ability of the specialized natural enemies it is also essential that the target population is continuously available. During the endemic phase, host density is generally low. Potent regulators compensate for this fact with specific searching abilities, longevity etc.. Nevertheless, these compensatory behaviours are limited, and at extremly low host densities the situation may become criticle for the natural enemy. The risk of the host density falling below a criticle level for the natural enemy grows with the magnitude of population fluctuations and with a decrease in the equilibrium density of the host population. It is assumed that a host escapes regulation when its population falls below a criticle density, even if all other needs of the natural enemy are satisfied in its environment. Therefore, it is advisable to keep defoliator densities at moderate levels and avoid inducing high fluctuations in density caused by other ecological factors (e.g. coincidence-related cyclic changes in the food supply induced by genetic uniformity of the host tree population) (Führer 1985).

ECOSYSTEM-BASED ASSESSMENT AND AVOIDANCE OF RISKS

Due to this background it appears very promising to develop concepts for ecosystem-based management of defoliator populations in oak forests. The situation in conifer forests looks analogous because, similarly, regulation of population density by natural enemies is much more significant in defoliators than in xylophagous insects. The central objective of ecosystem-based preventive pest management is to establish well-balanced food chains. Targets of such management concepts are multitrophic systems, in which either the qualitative dynamics of the host tree or the regulatory potential of the natural enemies may play the major role in the determination of the pest density. Accordingly, the 'key factors', open to manipulation in an ecosystemic context, and that could achieve stabilization of the pest population, will differ.

Referring to the *Ips* example, the risk of a spruce forest being damaged or even completely destroyed by a single insect species depends on the constellation and dynamics of those circumstances in the ecosystem, which, either, determine the 'predisposition' of the tree population or influence the 'incitement potential' of the herbivore population. Secondary spruce forests in Central Europe tend to provide both prerequisites for bark beetle epidemics, simultaneously, thus greatly increasing the risk of disastrous outbreaks. This may be similar in many semi-natural spruce forests, where the management history has triggered a change in tree species composition in favour of Norway spruce and a degradation of the site. Forestry is therefore commited by strong legislative regulations to apply operations of 'forest hygiene' regularly and continuously, in order to hold bark beetle populations to an artificially low 'incitement potential'. This strategy is very expensive and for this reason, increasingly neglected. Hence, it is totally unsuitable for every kind of extensive forest management which must be primarily based on ecosystemic self-regulation. The very possibility of renunciating the 'hygienic routine' would have direct economic benefits, to say nothing of the economic and environmental advantages of more stabile forests. In order to achieve reliable diagnoses as well as to assess and avoid the risk of damage by bark beetles, the ecosysytemic roots of such risk must be carefully traced back through its causal chains.

If forest management is to be more than a trial and error proposition, it must follow established ecological principles of 'forest protection'. These guidelines must be derived from a profound understanding of the origin of the risks potentially threatening the forests, and must be translated into practical methodology. A basic instrument for preparing protection-oriented decisions in forest management is 'Risk Assessment'. It should include all agents and influences which could potentially play a role as 'inciting factors', and should be based on the consideration of the respective 'predisposing' traits of the ecosystem.

'Risk Assessment' can serve different purposes, such as diagnosing the actual prevailing risk of a site or forest stand, or predicting forthcoming conditional risks based on circumstantial changes in the forest or on the realization of certain management concepts. Risk assessment has qualitative ('Risk Differentiation') and quantitative aspects ('Risk Rating').

'Diagnostic Risk Assessment' identifies the localization of risk and the nature of risk factors. This enables the forester to focus possible monitoring actions (1) *locally* on the critical sites and (2) *in content* on locally critical stress factors. Furthermore, it indicates where the management concept must be changed, in order to reduce the risk and to prevent damage. Another diagnostic aspect concerns the use of specific risk indicators for the causal interpretation of 'complex' forest diseases.

'Predictive Risk Assessment' must take into account the medium-term and long-term dynamics of the ecosystem under the influence of the environmental circumstances and of the projected management concept. 'Predictive Risk Assessment' must *not* be confused with the process of 'damage prognosis' (Schwerdtfeger 1981), which regards the short-term development of a pest population within a current outbreak. The long-term prediction of risks, which are implied in a certain management concept, is - in fact - an indispensable tool for sound management planning in forestry. It is a prerequisite of 'Preventive Forest Protection' and thus a basic contribution to 'Forest Health'. 'Predictive Risk Assessment' gains additional significance in view of changing environmental conditions.

The concepts of 'Forest Health' require practical and reliable procedures of 'Risk Assessment', that is, the 'Differentiation' and 'Rating' of risks, and the development of economically acceptable concepts of 'Preventive Forest Protection'. Since the methodology for these procedures and concepts is still very poor, considerable research effort must still be made to put them into use. Due to the ecosystemically rooted causality of forest diseases, progress depends on the degree of attention paid to these problems in Forest Ecosystem Research.

OUTLOOK

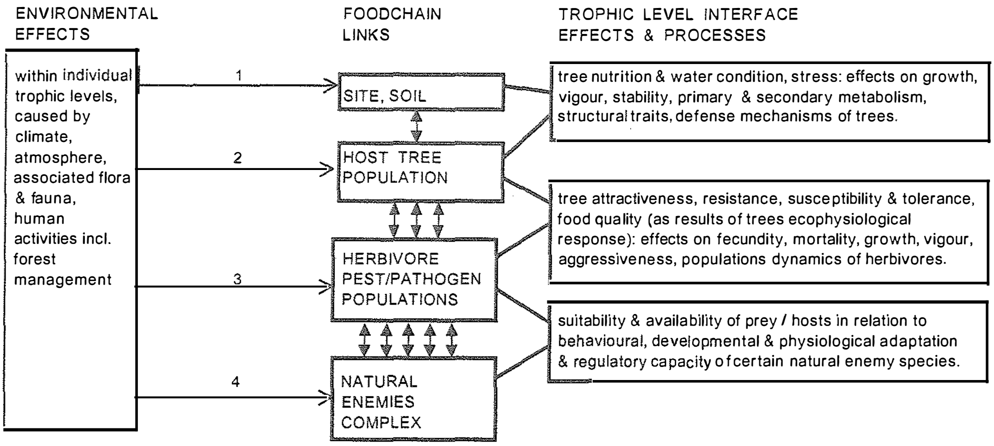
The analytical application of the principle of 'predisposition and incitement' appears appropriate to better understand the genesis of forest damage, resulting from environmental and biological influences. Considering environmentally caused damage, interactions between the physico-chemical site conditions and a tree's ecophysiological response are the primary subjects of interest. When pest organisms are the cause of forest diseases, the multitrophic nature of the involved system complicate the problem considerably. The epidemical behaviour of the pest / parasite population depends on several interactive processes in the ecosystem: (1) the influence of site conditions on the pest / pathogen itself, (2) the properties of the host plant population as the result of its interactions with site conditions, and (3) the regulatory potential of the natural enemy complex as the result of its interactions with site conditions as well as with the pest population itself. Although the basic principles operating on and between the involved trophic levels are theoretically understood, gaps in knowledge prevent the construction of consistent causal concepts to sufficiently explain the genesis in ecological terms of many important forest diseases. An explanation would be 'sufficient', if it allows the development of reliable methods for the assessment and mitigation of risks.

Gaps in knowledge may be primarily due to the complexity of the subject matter itself (host plant - herbivore - natural enemy - interactions) and, more directly, the increasing number of organisms that must be considered as one moves up the food chain. Regarding our knowledge of sequential stations in a consumer food chain, information about the nature and causality of ecological interactions declines

dramaticly the higher the trophic level. This is not due to the lack of epidemiological research of various pests and diseases, but such research is generally limited to phenomena located within a certain trophic level or to small sections of the entire interactive, causal context. Historically, research on forest pest population dynamics, for example, has passed through successive phases of causal interest: climatic factors, entomophagous organisms, and trophic factors. While there exist considerable amounts of isolated information, it is still too little and fragmented to be synthesized into clear principles applicable to individual cases or universal use.
A special problem arises in the difficulty to adequately bridge the interfaces between the different trophic levels (Fig. 3). This is especially the case with the host plant-herbivore/pathogen interface, where not only the manifestation of plant resistance is located, but also where the 'incitement potential' of the herbivore/pathogen may be strongly modified. In this field, entomologists and phytopathologists need methodological assistance from plant physiologists and chemists to find out which physiological and biochemical traits of the plant might be essential for epidemically relevant responses of the pest species. Thereafter, however, plant physiologists are challenged to find out the circumstances under which the host plant metabolism may, or may not, lead to conditions which meet the specific requirements of the herbivore. (This information is commonly not available because the interests of plant ecophysiologists usually are focused on other plant parameters.) In further consequence, at the plant-soil and the plant-atmosphere interfaces, the host tree-herbivore/pathogen 'pathosystem' must be linked to site conditions which potentially are operating as predisposing factors.

This illustrates the multidisciplinary nature of forest disease studies, when the causality of disease phenomena are to be analyzed, and particularly underlines the urgent need of an interdisciplinary approach. In view of the different theories offered to explain biological disease phenomena, and partially due to the biological differences between distinct types of pest organisms, divergent causal threads must be followed and thus involve several scientific domains in forest ecosystem research. Entomologists and phytopathologists should be encouraged to collaborate more in the forest ecosystem context (Führer 1995, 1996), and the traditional community of forest ecosystem researchers should be available as competent and interested counterparts.

There is still a lot of basic work to be done before the ecosystemic roots of the main pest/pathogen epidemics will be satisfactorily understood, but it need not start at point zero because literature provides a considerable pool of relevant knowledge. Basic and applied research should be devoted to the central objective of an ecosystem-based preventive pest management, i.e. to establish well-balanced food chains.



1 to physical, chemical, biological soil conditions
2 to ecophysiology of individual trees and to stand structure as related to density and age
3 to ecophysiology, propagative potential, interspecific competition of herbivores
4 to ecophysiology, propagative potential, interspecific competitiveness of natural enemies; supply of supplementary ecological requisites

Figure 3: Epidemically relevant processes and effects triggered off in the different trophic levels and in the between-level-interfaces of multitrophic consumer foodchains of forest ecosystems, induced by environmental factors

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PROBLEMS OF TRANSFER OF THEORETICAL KNOWLEDGE IN FOREST ECOLOGY INTO PRACTICAL APPLICABILITY.

ONLY A QUESTION OF SEMANTICS?

Simon HODGE
Forestry Commission Research Division, Northern Research Station
Roslin, Midlothian, UK

PERSONAL CONTEXT

- Forestry Commission Research aims 'to deliver high quality scientific research to inform the development of forestry policies and practices and promote high standards of sustainable forest management'.
- Woodland Ecology Branch aims 'to provide an ecological basis for the sustainable multi-objective management of biological resources in forests and woodlands; and to develop appropriate ecological resource management practices and encourage their adoption'.
- I am trained in environmental science and forestry; period in forestry; then into silvicultural research; then into woodland ecology research

THE REPORT OF THE FIRST MEETING OF EXPERTS OF RESOLUTION 6

The report of the Warsaw S6 meeting made it clear that the transfer and application of scientific knowledge on forest ecosystems is an important area of concern within EFERN:

- 'forest ecology is challenged to provide standards and guidelines upon which to base legislation';
- 'research into the forest ecosystem has, therefore, to find out how forest sustainability can be achieved';
- 'understanding (of forest ecosystems) should supply a tool by which to forecast future developments in forests reliably and to develop methodologies for sustainable forest management'.

PROPOSITIONS FOR DISCUSSION

The five propositions offered are not merely my intellectual response to a request to be the advocate for this proposition, but are the basis upon which I, and my organisation work. I have however, sought to be provocative and have been intentionally dogmatic as a result.

- Ecological knowledge is only valuable to the extent that it results in practical improvements in the sustainable management of forests.

- It is the responsibility of researchers to develop and promote the practical application of theoretical ecological knowledge.

- All major forest ecology research programmes should be demonstrably directed towards meeting the clearly defined information and decision support needs of end users.

- It is therefore vital that forest ecologists understand and relate to, and are seen as credible by, forest managers and forest policy makers.

- A major criteria of success of EFERN should be the extent it goes beyond drawing together knowledge and expertise, to promote the meaningful delivery of this wealth of knowledge to, and its adoption by, the end user.

PROBLEMS OF KNOWLEDGE TRANSFER

So, what are the problems of transfer of theoretical knowledge in forest ecology into practical applicability? Is it only a question of semantics?

If it was only a question of semantics, I believe we should have cause to consider what action can be taken to ameliorate the situation. However, I believe that the issue is more than just semantics.

- **Semantics.** Meanings are important and a common basis of understanding between scientists and information users is vital if meaningful communication and knowledge transfer is to take place. This issue is becoming even more pertinent as increasingly complex and subtle ecological information is required for the sustainable management of forests. If scientists believe that the adoption of their findings is important there needs to be consideration of how information can be 'translated' into language that the information user can understand.

- **Relationships.** Practitioners and policy makers can find scientists somewhat elitist and detached from the issues and information needs most important to them. The adoption of research findings is often as much to do with confidence in, and respect for, the scientist or institute undertaking the research as the importance or quality of the research itself. Effective networks are required that bring scientists and information users into contact, encouraging users to adopt research findings, and ensuring that scientists appreciate the circumstances and constraints experienced by practitioners and policy makers.

- **Relevance.** For good use to be made of research findings their relevance must be clearly defined to ensure that information users appreciate it's relevance. As well as indicating the scientific validity of research, it's practical importance should also be outlined (for example, a trend or relationship might be highly statistically significant, but of no practical significance).

- **Applicability.** How can relevant research findings best be delivered to help information users with practical and policy problems? Can we provide decision support tools that apply research findings to specific situations? Can our monitoring methodologies be reliably and consistently used by those charged with doing so? Can we offer quantitative thresholds and standards to guide decision making? Another aspect of this issue is the timelines of research information. The fact that the need for information tends to precede it's supply by several years is an inevitable feature of long-term research, but to what extent should scientists offer advice based on incomplete information and ecological intuition, even if it may not be the best, or even the right, solution in the long term?

These four parts to the issue can, I believe, be summarised in the question**: What is the responsibility of the scientific community in knowledge transfer and application?** The view of EFERN participants on this question should be carefully considered in the orientation of EFERN activities and design of the EFERN data base.

LINKAGE TO END USERS

Linkage of research with end use and the needs of the information user is not always possible, particularly with basic research. However, generally these linkages can be discerned and used to clarify research priorities and relevance, as well as to evaluate research findings.

- A key to establishing forest ecosystem research priorities is to work back from the needs of practitioners and policy makers.

- A key to judging the relevance of forest ecosystem research is the clarity of linkage with the needs of practitioners and policy makers.

- A key to evaluating the findings of forest ecosystem research is to ascertain the contribution it makes to providing, or enabling provision of, the practical research outcomes required by practitioners and policy makers.

END USER ORIENTED RESEARCH PLANNING: THE UK BIODIVERSITY RESEARCH PROGRAMME

The Biodiversity Research Programme (BRP) of the UK Forestry Commission Research Division was presented as an example of user-oriented research planning. The BRP was established by the Forestry Commission in 1994 to focus primarily on the 1570K ha of planted secondary forests in the UK. It aims to: develop monitoring protocols and collect base-line information on species, structural and habitat diversity in secondary forests; identify biodiversity criteria and indicators for secondary forests at the ecological unit () and landscape () scale; identify and recommend practical standards by which to appraise biodiversity in secondary forests; and identify and recommend silvicultural systems and management practices that maintain and enhance biodiversity in secondary forests.

The five constituent projects are being developed and integrated according to a multi-scale forest planning and management decision making process (figure 1) that we are promoting to the forest industry. It is intended that this conceptual framework for research will become the basis for integrated decision support outputs, possibly delivered as a computer based decision support system.

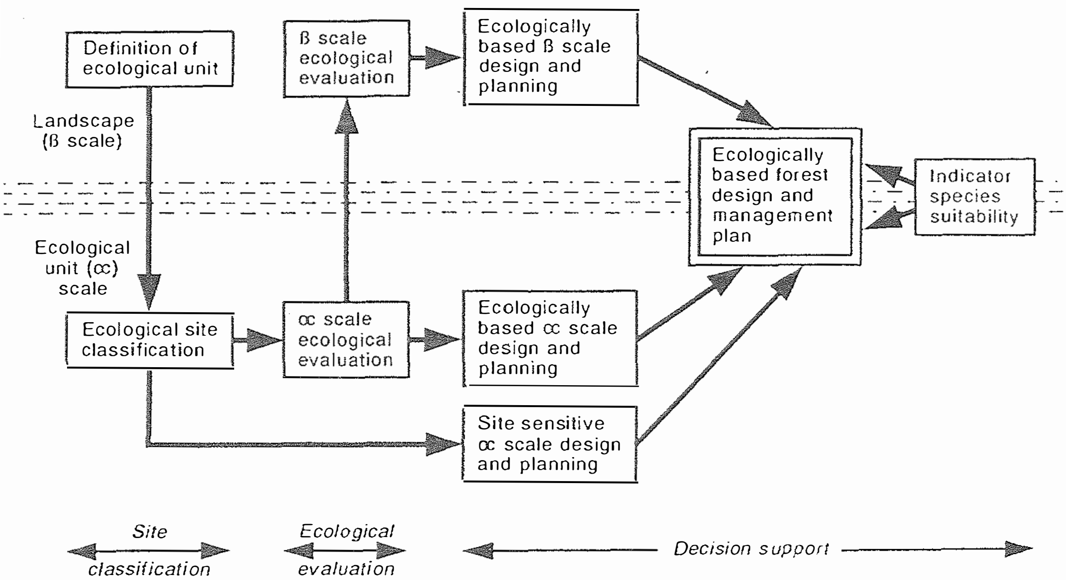


Figure 1: Decision process framework for the Biodiversity Research Programme

The first stage of the decision making process is the definition and classification of ecological units. The Ecological Site Classification project is developing a tool for sustainable forestry in Britain based on five factors: accumulated temperature, moisture deficit, windiness, soil nutrient regime and soil moisture. These factors are currently being used to predict tree species suitability and native woodland type, either for individual ecological units, or at the landscape and regional scale using GIS. A software version is being developed for use by forest managers, initially for choice of species and woodland type, but this will be extended by development of additional modules for site-sensitive forest operations and the semi-natural vegetation of open habitats.

Climatic and soil quality alone cannot provide the basis for guidance of the conservation of forest biodiversity. An ecological evaluation is also required to determine the current conservation importance of each ecological unit. The tools for undertaking such ecological evaluation are being developed in the Biodiversity Assessment Project which aims to determine the biodiversity status of plantation forests, develop practical assessment methodologies and identify potential biodiversity indicators.

Following evaluation of ecological units, an ecological evaluation must then be made at the landscape scale, as the juxtaposition of these units in the landscape will affect overall ecological values, increasing the value of favourably juxtaposed or particularly rare units. Development of the tools to undertake objective ecological evaluation and to provide ecologically based landscape scale forest design and management guidance is the role of the Landscape Ecology Project.

The final stage of the landscape scale decision process is to test the emerging design and management plan for its capacity to support key indicator species. The conservation management priorities in each forest area are often focused on scarce or keystone species, which themselves can be good indicators of forest suitability for a wider range of species. By developing population models for vertebrate indicator species we intend to define key habitat requirements as a set of parameters which can, through use of GIS, be used to test the capacity of a forested landscape to support each of these species, and the communities they represent.

END USER ORIENTED RESEARCH PLANNING: KRKONOSE NATIONAL PARK, CZECH REPUBLIC

Igino M. EMMER

The Netherlands Centre for Geo-Ecological Research (ICG), Department of Physical Geography and Soil Science, University of Amsterdam
Nieuwe Prinsengracht 130, 1018 VZ Amsterdam, The Netherlands

Current Address: KRNAP, 54311 Vrchlabí, Czech Republic

The Krkonose National Park is located in the area along the Czech-German-Polish border often called the 'Black Triangle'. This area is heavily affected by air pollution, causing severe damage to forests. In the Krkonose Mountains forest die-back has occurred since the 1970s. Foresters have taken measures to cope with the problem since the early 1980s, including liming and felling and replanting of Norway spruce. The extent of the forest damage has, however, gone beyond the control of the foresters. Large clear-cuts remain to be reforested, while die-back is spreading, although at a slower rate than a decade ago.

Areas with a high reforestation potential such as the Krkonose National Park have received particular attention by the Dutch Foundation, FACE (Forests Absorbing Carbon-dioxide Emission). This foundation aims at planting trees to sequester the CO_2 emitted by the Dutch electricity producers. It focuses on areas where their reforestation grant would be strictly additional to local programmes. In the Krkonose National Park 8000 out of 32000 ha of forest cover has disappeared. Forest restoration is only feasible at sites that have relatively favourable conditions, but on the other hand reforestation is a high priority on those areas that would be prone to severe erosion after clear-cutting. Particularly unfavourable conditions can be found at high elevation where peaty soils and peats have developed, where climate is harsh and pollution load is high. Therefore, in a parallel programme FACE funds research to sort out when and where reforestation should take place.

FOREST MANAGEMENT IN THE KRKONOSE NATIONAL PARK

During the last three decades foresters were preoccupied with salvage management of forest decline, involving the cutting and replanting of forest stands. A national institution provided management plans for 10 years, based on quite rigid schemes of cutting and planting of Norway spruce. In recent years restoration management has been instituted in recognition of the need for a more nature-based approach in place of inappropriate traditional silvicultural techniques based on the silviculture of mono-species Norway spruce stands throughout the middle and higher zones of the mountains. Unfortunately, because of their traditions, local forest managers lack sufficient experience to implement these new regimes. Particularly lacking is knowledge about the mechanisms of forest decline under pollution stress, ecosystem behaviour during the disturbance period and natural restoration under a scenario of decreasing industrial emissions.

Nonetheless, local managers now have greater opportunity since the centralisation characteristic of the pre-1986 era to make decisions based on science and local conditions rather than centralised control oriented towards maximum short-term profitability. Furthermore, the Park has built up a large database, held has layers on a GIS, including geo-referenced abiotic data such as geology, soils, site features and terrain. However, this resource is sadly under-utilised by forest managers, possibly due to lack of confidence and training in the use of this technology and the information it contains. The forest type map still officially serves as their basic source of information on growing conditions.

RESEARCH IN THE KRKONOSE NATIONAL PARK

In the 1970s and 1980s forestry research in the Park focused on understanding die-back patterns, the effects of liming and silvicultural techniques to improve tree growth and to increase the success of replanting. Little was learnt about the functioning of forest ecosystems under the local circumstances, although research has provided a good insight in the spatial variability of site factors. There still is a gap in knowledge on how forest vitality relates to abiotic factors and contemporaneous functioning of clear-cut ecosystems and affected forests. The research of our Department focuses on relevant management options in the Krkonose National Park, including:

- promotion of natural regeneration after clear-cutting;
- the effect of pioneer tree species on soil properties;
- the effect of deciduous long-lived tree species on soil properties;
- the distribution of sites suitable for reforestation or natural regeneration;
- the effect of the micro-site characteristics on the success of replanting.

This research is being carried out in close co-operation with Czech research institutes. Methods employed are botanical studies, soil chemistry research and modelling, and experimental research on soil nutrient dynamics. The work encompasses small scale site variations within a stand or a clear-cut, as well as the landscape scale, using available map based spatial information.

THE RESEARCH-MANAGEMENT INTERFACE

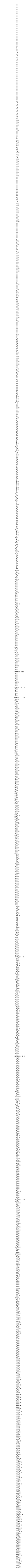
Applied research has no significance without application. Both researchers and managers have to find or develop ways to communicate relevant information and how to put recommendations into effect. General aspects of this process have been dealt with in the first part of this article by Simon Hodge. In the following a few examples are given regarding the role of applied research in forestry decision making in the Krkonose National Park.

The predicted degree of soil acidification and degradation is an important factor in determining the restoration potential of ecosystems in the area, and so the ameliorative effects of pioneer tree species are being investigated. It is well known from other studies that species such as birch and mountain ash can improve pH and levels of plant available nutrients. However, no quantitative information exists about the required density of pioneer stands and the duration of their presence before target species can be successfully regenerated. This is the information required by forest managers necessitating research on defining what constitutes an ecologically significant improvement under local site conditions.

A second example relates to scenario analyses based on soil acidification models. Such models are generally developed to predict pH and base saturation of the soil under certain dynamics of pollution inputs and vegetation cover. Again, the relevance of such an approach to forestry applications depends on what we define as being a ecologically significant amelioration of the soil. To support forestry planning in terms of when and where to plant trees facing such adverse effects in the Black Triangle, this definition must be established.

Apart from scientific or technical problems, a major pitfall to be encountered when operating at the research-management interface is the lack of motivation to implement new ecological knowledge. Foresters may be reluctant for various reasons, including silvicultural traditions and poor co-operation ,or even negative experiences, with scientists in the past. This can be observed in any country, but is particularly the case in the Czech Republic. It can be concluded that the application of research results in management requires extra steps. One of the main tasks in the FACE research project is therefore to persuade decision makers in forestry to make use of the information platform we provide. A good example of such a platform is GIS, a tool with obvious potential as an aid to site sensitive forest management. The two-step approach to meet our goals starts with a synthesis of existing geo-referenced information with particular focus on the relationship between forest vitality and abiotic factors which is important ecological information relevant to tree growth and the success rate of replanting. The second step will be the giving of guidance in the integration of GIS tools in forestry management.

A major challenge of this research project is how to change the way of thinking in forestry practice. In the Netherlands, for example, integration of information from science, politics and forestry practice is co-ordinated by an institution which is positioned between these three bodies. Although this institution lubricates the research-management interface, a strong bilateral interaction between scientists and foresters seems to be crucial in projects aiming at building management support systems. We hope that the FACE programme in the Krkonose Mountains will serve as a similar example for other forest areas in Central Europe.



RESTORATION OF DEGRADED FOREST ECOSYSTEMS IN THE MEDITERRANEAN REGION

Giuseppe SCARASCIA-MUGNOZZA
DISAFRI, University of Tuscia, I - 01100 Viterbo (Italy)

LAND-USE CHANGES IN THE MEDITERRANEAN REGION

The history of land use in Europe and, particularly, in the Mediterraean area is an history of forest fragmentation, degradation and, eventually, deforestation. The strong, continuous and long-lasting human pressure has even caused, according to di Castri (1981), coevolution of trees and other plant species with the Mediterranean man over more than 100,000 years. The spread of agricultural practices and animal grazing, the need of wood for shipbuilding, constructions and heating, the devastation of wars reduced the extension of the existing dense forests producing progressively open and degraded woods and, finally, bare lands with eroded slopes, especially in mountain areas (Thirgood 1981). Already in the ancient Greece, Plato recognized that as a consequence of deforestation "all the rich soil has melted away, leaving a country of skin and bone". The history of land-use changes has undergone periods of intense deforestation and, even, desertification coinciding with the rise of powerful civilizations, as in the Greek-Roman time, or the period of the Arab conquest or during the Renaissance that was characterized by an exceptional economic development, the spread of new agricultural techniques and the construction of large, military and commercial fleets, that imposed a big toll on Mediterranean forest resources. But, through times, periods of land abandonment also occurred as in the early Middle Age, that caused even a reversion of the deforestation trend and the increase of the forest surface and of the extensive use of the land.

In more recent times, the use of wood for energy was greatly increased when the industrial revolution spread also in Southern Europe, particularly in Italy, together with the large expansion of the railways network and the growth of human populations. From the political side, in the last centuries several decisions and actions greatly favored the destruction of many forests and the diffusion of agricultural activities on areas previously covered by natural vegetation; as an example, in Italy the following major legislative acts were adopted: the subversion of feudality (1806), the suppression of the properties of the Church (1866), and, lastly, the agrarian reform (1950) with the ensuing large-scale, land reclamation operations.

It is only at the end of the 19th century and at the dawn of this century that the Italian state and other Mediterranean countries such as France, Spain and others began to understand how dramatic were the consequences of deforestation, especially on hilly and mountain regions; accordingly, a new legislation was introduced to regulate the management of the remaining forests and to favour the diffusion of rehabilitation and reforestation activities. Initially, the objectives of forest restoration were both, wood production and environmental protection, especially soil conservation and flood prevention. More recently, the vast increase of scientific knowledge on forest ecosystems has clearly shown the importance of forests for the functioning of many different processes, at various scales; from the interactions with the climate and the atmosphere to the influences on the principal biogeochemical cycles, from the role in conserving biological diversity to landscape and recreational values. Consequently, ecosystem restoration has expanded its significance to include different aspects of strucural and functional improvement and reconstruction.

DEGRADATION OF FOREST ECOSYSTEMS

The significance of forest degradation spans from minor disturbances that can modify the composition and reduce the productivity of a forest ecosystem to the devastation and the complete destruction of a forest; disturbances can be caused by man, either directly or indirectly, or by natural factors; furthermore, types and intensity of disturbances change with geographic regions and environmental conditions. Forests can be damaged by natural disturbances such as lightning-caused fires, snow- and wind-storms, volcanoes and pests but they generally can recover to their original biomass, community structure and even a similar species composition through the process of secondary succession. Man-made disturbances occurring in the past were mainly caused by an excessive exploitation of forest resources for grazing, logging, fires, and expansion of agricultural land resulting, eventually, in the fragmentation and disappearance of forest cover, especially in those environments most unfavorable for the survival and growth of trees, as the semi-arid and warm Mediterranean region, particularly its steep and southern-oriented mountain slopes. More recently, other man-made disturbances have become frequent and particularly dangerous to forest ecosystems, also in other European regions as the Alps, and Central and Northern Europe: atmospheric pollution (ozone, nitrogen oxides, sulphur dioxide and "acid rain"), climate changes, excessive growth of wildlife populations, uncontrolled expansion of tourism, massive constructions (roads, industrial and urban areas), mines. This large increase of the potential of the human population to modify, damage and devastate the forest environment has also stimulated the definition of theories and the implementation of techniques to rehabilitate and restore disturbed ecosystems.

FOREST ECOSYSTEMS RESTORATION

The theory and practice of ecosystem restoration involves a wide array of interventions of increasing size and intensity. Ecological restoration can be defined as the process of intentionally altering a site to establish a defined, indigenous, historic ecosystem. The goal of this process is to emulate the structure, function, diversity and dynamics of the specified ecosystem (Society of Ecological Restoration 1991). Restoration ecology has its origin in older applied technologies utilised mainly for soil protection and water conservation as reforestation of bare lands, sand dunes fixation, mine site reclamation and tree planting along streams and water reservoirs. However, these technologies typically produce simplified communities, at least in the early stages of their development, or communities that cannot maintain themselves. With the emergence of the issue of biological diversity and the importance of its conservation, care is increasingly being paid, within projects of forest restoration, to species composition, niches for wildlife, forest structure, and reconstruction of forest functions.

According to Primack (1993), four main approaches are available in restoring degraded ecosystems:

- *no action* because restoration is too expensive, or because previous attempts at restoration have failed, or because experience has shown that ecosystem will recover on its own;
- *restoration* of the area to its original species composition and structure by an active program of reintroduction, in particular planting and seeding of the original species;
- *rehabilitation* of at least some of the ecosystem functions and some of the original species, such as replacing a degraded forest with a tree plantation;
- *replacement* of a degraded ecosystem with another productive ecosystem type, for example replacing a degraded forest area with a productive pasture.

The first step for the implementation of a restoration project is the definition of the objectives of ecosystem restoration. Many different kinds of action come under the general concept of restoration. If recovery of threatened species is a primary goal, this can vary from very minor manipulation to restoration of several biotic communities to provide habitat for target species. Restoration of communities themselves can range from repair work to complete restoration and reestablishment of many species. A further step is to create a new community for a specific conservation purpose.

It is then decisive to scientifically understand the process of recovering and of restoration. Scientific understanding of natural restorative processes is necessary if the identified goal is to be achieved. It is important to be aware of the kind of plant succession of a given site. An appreciation of nutritional needs will often be necessary to ensure that the restored community will be self perpetuating after human intervention is withdrawn. Restoration may have to be very site-specific within the target area; for instance, unstable fertile soils on steep slopes may require different combinations of species than would a stable infertile soil on a plateau. Trials should be used to identify the most ecologically effective and therefore cost-effective method of restoring a particular community. The restoration program should be replicated and documented so that errors in methods can be identified (Given 1994).

Where the scale of disturbance is small or its effects are relatively slight, natural regeneration may be sufficient so that minimum assistance is required. Help may only amount to periodic monitoring. Obviously, reestablishing plants with minimal interference can be very cost-effective, although natural processes are sometimes slow, particularly in more difficult and drier environments or in those sites where disturbances had not been eliminated.

Natural succession depends on several factors. One of the most important is availability of seed of the original vegetation components. How far away are the mature plants of the required species? Are they producing propagules? And are dispersal vectors available? Again, it may require several years before the regeneration process is triggered; it is, then, likely that soil may have become eroded, leached or significantly degraded. This is especially true in the Mediterranean region where reestablishment of forest frequently is hindered by the degraded condition of soils, as consequence of centuries of overexploitation. Nutrient and moisture status of the soil may have changed markedly; this also needs to be checked and remedied. Other severe constraints on natural regeneration can include grazing, factors causing accelerated erosion, frequent man-made fires, lack of mature individuals in the community and presence of weeds.

Restoration projects begin by eliminating or neutralising any factors that prevent the system from recovering. Then various methods are available to establish vegetation cover artificially. For instance, to establish a forest in open grassland, techniques ranging from aerial seeding to planting containerized seedlings, or even cuttings in favorable sites, can be applied. It is essential that trees and shrubs grow quickly to shade out and overcome competition with grass and low herbs that beside competing for nutrients and water are dangerously fire prone. Preferable colonizer species should be fast growing, fire- and grazing-resistant, with capacity to fix nitrogen (unless low fertility is desired). Species forming dense, monotypic stands should be used with caution, as this will prevent the succession of other species and eventually a climax forest. The food and shelter plants of birds, bats, insects, and other dispersal and pollinating agents must be considered as well. Immigration of these organisms from surrounding forests will itself introduce other fruits and seeds of other plants via defecation (Given 1994). However, it should also be plannned, in advance, the possibility of applying silvicultural operations during the life-cycle of these reforested stands in order to improve the community structure and to facilitate the succession to more diverse communities. In fact, in many cases coniferous afforestations open the way to regeneration of the Mediterranean sclerophyll species and, even, of mesic broadleaves. This aspect could be utilized with proper forest management practices to achieve a semi-natural, mixed and multi-layered, multiple purpose forest (Naveh 1987).

For more interventionist restoration, it is necessary to perform an analytic survey to identify former biological communities and assess the impacts that led to the loss of communities and modification of others. The end product of restoration must be clearly identified. Particularly pertinent aspects of overall survey and planning for major restoration projects include site analysis to obtain an understanding of the biotic and physical requirements of the desired natural community; site preparation to eliminate existing unwanted species or the formulation of a strategy to suppress them, and creation of an environment favorable to the desired species; species placement that takes into account distribution patterns and associations; and short- and long-term management and provisions for review and evaluation (Given 1994).

On extreme sites such as those left by open-cast mines, land-slides, areas affected by major public works and eroded slopes where the bedrock or unstable clay layers (“calanchi”) emerged at the soil surface, the complete reconstruction of vegetation may be the only option; otherwise, it may be feasible only to restore a habitat to near-natural conditions.

If the aim is to reestablish indigenous vegetation, exotic species should be used only as a temporary expedient when they are superior for soil rehabilitation, erosion control or as temporary nursery plants to shelter permanent plantings and when the intent is to eventually eliminate them. A valuable role for the mixed exotic and indigenous plantings can also be played in buffer zones between agricultural land and wild habitat. In nature reserves and other protected areas of high conservation value when natural vegetation is the desired end point it is usually undesirable to use introduced species for reseeding, especially as there may be uncertainty of how long they may persist (Given 1994). However, it should be stressed that there is much room for investigation of species and techniques that will eliminate the need for use of exotic nursery crops in rehabilitation projects.

ASPECTS OF FOREST RESTORATION IN THE MEDITERRANEAN

Precisely defining what forest degradation means is quite difficult, as already stressed, because a large gradient of vegetative conditions exist between completely degraded forests, or bare lands quite common in the Mediterranean environment, and natural, stable forests. In fact, in the Mediterranean forest conditions span from stable, mixed forests, especially of broadleaf trees; to natural high stands with decreased biodiversity, because of centuries of intensive and not always sound silvicultural practices; or from high stands of pioneer tree species (i.e. pines) originated either from reforestation (see Oswald, this volume) or from natural regeneration in a continuously disturbed landscape, to more disturbed forests as coppice stands, that represent generally a simplified forest ecosystem. Low stocked high stands or coppice stands represent another type of forest degradation, resulting from centuries of over-exploitation, forest fires and grazing. Macchia stands, consisting of dense thickets of Mediterranean trees and shrubs, not taller than 4 to 6 m, may represent a further step of the regressive dynamics of forest vegetation. The final stages of degradation all over the Mediterranean region are represented by the “garigue” and the Mediterranean “steppe” or pasture.

Completely degraded forest environments, where woody vegetation has been entirely eliminated, typically cover a large surface of the Mediterranean basin; in this case, quite often **rehabilitation** is applied, consisting of **reforestation** with indigenous, early successional tree species, as pines and cypress. The success of reforestation is assured if appropriate techniques and species are employed; then, the question is whether and how we should help or favour the later succession towards more stable and more diverse forest ecosystems.

Reforested coastal sand dunes may present interesting ecological and management aspects. In some areas along the Thyrrenian coast, reforestation was successfully accomplished about 200 years ago with *Pinus pinea* and *P. pinaster* mainly with the objective of soil protection from the marine winds transporting aerosols and sand, and also for the production of pine nuts. Actually, the system is not a stable one because maritime pine, usually planted closer to the sea because more resistant to aerosols, is much more "aggressive" than the stone pine and is invading with its seeds and seedlings the adjacent stand of *Pinus pinea*. The question is what should be done with these pioneer, early successional species: should we keep the Italian stone pine because of its landscape and cultural values (it is a typical tree of the italian landscape), it will also require highly intensive silvicultural operations to replant its seedlings, to thin and to prune its trees.

Another example of early successional forest ecosystems that sooner or later leave the ground to more stable, shade-tolerant forest stands are the beautiful pine stands of *Pinus laricio,* in the Calabria region. These forests originated either by natural regeneration after clearcuts or by reforestation. After the war, starting from 1950 large **reforestation programs** have been carried out utilising this pine, and to a lesser extent, chestnut, oaks and douglas fir; about 150,000 ha have been reforested in Calabria since then. These large land rehabilitation programs had profound and positive effects on soil protection, landscape value and wood production; hydrological studies show that soil erosion was greatly reduced as well as floods frequency. Now the question is again how to manage the resulting forest stands that are now adult or even mature. **To favour more stable ecosystems** would mean to manage these stands to facilitate the diffusion of *Fagus sylvatica* that, naturally, is already spreading in these forests. This is occurring, for instance, within the National Park of Calabria; until 30 years ago these stands were naturally regenerated by means of strip clearcuts. But then silvicultural operations have been abandoned and now beech trees are entering the Calabrian pine forests. In fact, under dense pine canopies no light penetrates and no pine regeneration occurs, therefore facilitating the arrival of beech. As soon as stand density is reduced, even with small clearcuts as gaps, the regeneration of Calabrian pine succeeds. In the Park and in natural reserves spontaneous, late-successional species should generally be favored by restoration practices but a diverse and more stable landscape should probably contain a mosaic of forest patches, including also Calabrian pine, pioneer forests.

Another aspect of forest degradation that requires a careful, scientifically sound process of restoration ecology is represented by an oak forest located south-west of Rome, one of the few remnants of a previous (1,000-2,000 years ago) widely distributed broadleaf forest belt, along the Thyrrenian coast and the banks of the river Tiber. This is an example of an overmature forest, with few, very large oak trees, approximately 150-200 years old, with a large crown. Density is very low and in between a coppice stand of many different species is found, mostly with *Carpinus* spp. or some evergreen species. The forest was used to produce firewood for the city of Rome, over many centuries. Presently, the problem is how to manage this forest, that is should we consider this forest a degraded one and how to restore it. This is a multifaceted problem; however, just a few aspects should be underlined:

- these oak trees are still vital, productive in terms of seeds but nevertheless wildlife control is crucial;
- parts of the forest are periodically flooded in winter, explaining the presence of mesic species as *Quercus robur, Q. frainetto* and *Q. cerris*;
- this forest is considered as a nice, natural forest but it contains quite a lot of roman ruins demonstrating that the forest is an example of a secondary succession that lasted almost 2,000 years.

The crucial point is, however, to implement an **effective wildlife control**. This forest is property of the President of the Republic, that was formerly a hunting reservation of the Italian kings. Recently, it became a natural reserve were hunting is strictly forbidden and for years and years there has not been any control of wildlife populations. This is obviously fundamental for restoring and keeping the forest ecosystem at a high stability level.

Coppice forest stands are widespread all over Italy, representing a good compromise (trade-off) between human needs and the conservation of a forest stand because it regenerates naturally from stumps. Sites may be quite fertile and stands may have good productivity; nevertheless they represent simplified forest communities of former much more diverse mixed deciduous stands. There is a need for more research to clarify the long-term effects of coppicing on ecosystem fertility. However, fertility can be better conserved if the land is flat or almost flat; but major consequences can arise on more or less steep slopes.

Conversion of coppice stands into high forests is an example of forest restoration improving forest structure, increasing biomass and carbon stocks and augmenting the biological diversity of the stands. Successful examples of coppice conversion can be found for many broadleaf species but, particularly, beech. It is also possible to operate with underplanting of native tree species such as maples, linden or ash.

Conversion of coppice into high stands: this is another way to improve biodiversity and, in general, stability of a forest but still a lot of research should be done to understand the relationships and differences between coppice and highstands.

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SPONTANEOUS AFFORESTATION OF FALLOW LAND

Pietro PIUSSI

Instituto di Selvicoltura, Universita di Firenze
Via San Bonaventura 13, I-50145 Firenze, Italy

1. Changes in land use, especially reduction of tilled and grazed land, since the early Fifities have been a widespread phenomen in Italy. Fallow land turnes into scrub or woodland; consequences on the landscape are sometimes impressive. This process is not limited to Italy but has been described in several other European countries and several research projects have been developed to analyse different facets of it: factors contributing to abandonment, landscape changes, management of new woody formations, impact on wildlife and water cycle, economic consequences.It seems therefore worthwile to describe the main features of this process in Italy and the problems rising as a consequence.

2. It is impossible to establish the area of fallow land. The Italian Forest Inventory includes in the same unit degraded forests and young woody formations since cursory field exams cannot always establish the difference between the two. During early abandonment stages it is not clear if fallow is permanent or only temporary. Abandoned tillable land has been frequently used as a hay meadow or as a pasture. Woody species invasion can therefore take place already during a different and less intensive form of land use. Secondary succession is not only a recent problem; a similar process has been taking place already in the first half of this century but its description by contemporaries has been done mainly from a social geographical point of view. Even more scanty is the information regarding the spontaneous afforestation of ancient periods, which sometimescan be discovered by archaeological findings.

3. Spontaneous afforestation in Italy has been described in every kind of natural environment: from the Pinus cembra and Larix decidua stands at the upper timber line (2300 m a.s.l.) until the arid fields and meadows along the coast. Obviously many different types of woodland or shrubland have been described: composition is clearly controlled by temperature, rainfall and soil conditions, but previous land use and presence of trees interspersed in the fields (traditional forms of agroforestry with fodder trees), meadows and pastures can influence the presence and abundance of some species. Terraces, heaps of stones and walls erected as borders have also a significant role as "safe sites" in the early stages of the colonisation.

   Structure and density can be quite various: where the succession takes place in few years tree species are dominant and stands are evenaged and rather dense since the early development stages.

   If dissemination is insufficient or site conditions are unfavourable for seedlings establishment some decades elapse before the ground is covered by trees or shrubs and the structure is irregularly unevenaged.

Secondary succession is not a phenomenon regarding only abandoned agricultural land: invasion of shrubs and trees takes place also in chestnut and olive groves so as in Pinus pinea and Quercus suber stands.

Besides native species some exotics spread easily in abandonend land. The most common is Robinia pseudoacacia, used frequently in afforestation of degraded sites but now invading fallow land, degraded chestnut groves and sometimes recently logged areas.

4. Consequences of spontaneous afforestation are rather complex and very little known. Early successional stages represent a dangerous mass of fuel and presumably are responsible, at least partially, for the increase of forest fires during the last decades. Scrubs are frequently situated at the border with forest stands so that fire can spread easily from the fallow land to the woodland. New stands are fire prone also because frequently pioneer species are conifers.

   Soil erosion is reduced even if grazing practised after cessation of tilling or mowing can damage existing stone terraces and cause locally the formation of gulleys. A satisfactory budget is still lacking.

   Important changes of fauna (especially ungulates) are taking place in abandoned farmland but the causal link between these phenomena is not clear.

   These landscape changes have a profound impact on its visual value and frequently are not appreciated by the society. In mountain territories these changes are considered negatively both by residents and by tourists. Shrubs and brambles represent a nuisance for hickers, and tree stands are an obstacle to the view. As a matter of fact these new woods occupy the space out of every kind of territorial planning.

   Where secondary succession develops rapidly as in the Central and Eastern Prealps 20 or 30 years are sufficient for the formation of fine mixed hardwood stands. Even if an intelligent management (thinnings, pruning) would permit the creation of fine stands and the production of quality timber, the fragmentation of land ownership and the absence of land owners, which frequently have migrated into towns or abroad, are serious obstacles so that the most common silvicultural choice is that of coppicing to produce fuelwood.

5. A better knowledge of spontaneous afforestation seems to be an important object of research. Consequences of this process are covering ecology, geography, land management (including silviculture, fire prevention, grazing, watershed management etc.), economy and sociology. Reseach should be developed both toward the origins of this new landscape and toward the future development. The ecological history of these stands, for which frequently we can reconstruct easily the development or even start a diachronic study, could explain some characteristics of many forest ecosystems that have been influenced in the past by human activity.

FLOODPLAIN FOREST ECOSYSTEMS IN EUROPE, THEIR CONDITION AND IMPORTANCE

Emil KLIMO

Institute of Forest Ecology, Faculty of Forestry and Wood Technology
Mendel University of Agriculture and Forestry, Brno, Czech Republic

Floodplain forests in Europe are a unique forest biome: Their main function consits in:

- high production level;
- high biodiversity based on high variety of forest sites;
- protection of watercourses against erosion and pollution;
- high number of nature reserves;
- recreational and aesthetic roles within the landscape.

On the one hand, their origin, development and existence are related to the development of watercourses and formation of alluvial areas during the Holocene and, on the other hand, their further development was markedly affected by man. Floodplain forests can be found in their initial stages under the influence of changing watercourses or in relatively steady natural conditions of floodplains characterized by regular floods or under conditions where floods have been quite eliminated and groundwater table markedly decresed. In these areas, the species composition of natural forests has been gradually changed either by spontaneous development or by the change of species composition due to the establishment of new forest plantations having often the character of a pure stand.

Historically, but also at present, floodplain forest ecosystems throughout Europe are under heavy anthropogenic impacts which can have various results under various conditions.

Main anthropogenic impacts are as follows:

- decrease of floodplain forest area in favour of agriculture, often to the level of riparian stands;
- watercourse regulation resulting in the termination of floods and groundwater table decrease;
- dam construction (hydroelectric power stations) or building water reservoirs resulting in the destruction of large floodplain forest areas (e.g. in the Dnepr river, the Ukraine or the Nové Mlýny reservoirs, S. Moravia);

- interactions between floodplain forests and housing estates (particularly increased recreational use of floodplain forests, road construction, sport areas etc., e.g. the Leipzig floodplain forest)
- interactions between floodplain forests and intensively managed agricultural land in their immediate vicinity (increased input of various substances particularly through wind erosion from fields to forests); exploitation of raw materials in alluvial plains and particularly in oxbow lakes after river regulation (sand and gravel exploitation);
- intensive game management (high game populations, establishing game preserves);
- fragmentation of floodplain forest ecosystems often below the limit of a minimum ecological range for a number of autochthonous plant communities and animal species and thus also the formation of ecotones or even barriers disturbing the integrity of ecosystems. The fragmentation of ecosystems and isolation of populations result in the fact that their subsistence requirements are not satisfied and this necessarily means increasing degeneration and population dieback. It is, therefore, very important to preserve as large as possible area of floodplain forests which are, as a matter of fact, of remnant character due to the anthropogenic activities mentioned above.

The effort aimed at the protection of floodplain forests in the alluvium of the Danube between Vienna and Hainburg resulting in the declaration of the area as the Donau Auen National Park can be evaluated as a very positive activity.

Floodplain forests in particular countries of Europe have their own history and their present condition is the result of the history. For example, the floodplain forest of Leipzig had the following species composition of stands in 1870: oak 60%, elm 20%, lime 0.6%, hornbeam 13%, alder 0.7%, maple 0.4%, ash 0.4%, and aspen 5.0% while in 1986, ash exhibited the highest proportion of 49.17% and oak decreased to 25%. In addition to ash, the proportion of maple increased to 13.7%.

One of the most important measures affecting the condition of the floodplain forests has been the period of the construction of hydroelectric power stations, water canals and river regulation. The process continued in the last fifty years when the area of alluvial forests decreased by 50% in the Rhine Alsatian forest (7500 ha as against 15 000 ha in 1930) and 25% in the case of Austria forest of the Danube (8000 ha as against 33 000 ha in 1930).

In the alluvium territory in the lower reach of the Morava river (Slovakia), the marked reduction of floodplain forest area occurred in favour of meadow ecosystems. Later on, the major part of the meadows was ploughed and used as arable land. The development of the proportion of floodplain forests, meadows and arable land in the territory is given in the following table:

Table 1: Development of the proportion of floodplain forests, meadows and arable land in the alluvium territory in the lower reach of the Moravia river (Slovakia).

year	arable land	meadows	forests	urban area	water surface
1782 - 1784	6,25	46,28	46,71	0,10	0,66
1882	27,26	47,90	21,84	0,10	2,90
1991	35,32	31,17	29,46	0,57	3,48

Also in Hungary, the area of the original 2.3 million km² of floodplain forests has been reduced to only 1.5 thousand km² due to river regulation.

As already given above, many floodplain forests disappeared by permanent flooding of alluvial land due to reservoir construction. For example, the Dnepr river (Ukraine) can well demonstrate the destruction of floodplain forests (see table 2):

Table 2: Area of flooded alluvial forests connected with the building of a water reservoir on the Dnepr river (thousand ha).

Water reservoir	forests	shrubs	total
Kievsky	10	5	15
Kanevsky	10	6	16
Kremunchugsky	30	10	40
Dnieprodzerzhinsky	12	2	14
Lenin Lake	2	-	2
Kahovsky	126	-	126
total	190	23	213

At present, only small areas of the Dnepr floodplain forests are fragmentarily protected in separate locations.

Based on the initiative of the European Forest Institute, Joensuu, information on the history, condition and possible development of selected areas of floodplain forests in Europe has been processed. I suppose that this biome, its condition, possible use and gene pool preservation provide great opportunity to establish an ecosystem study network within the EFERN project.

THEMATICAL FRAMEWORK FOR A CATALOGUE OF RESEARCH TOPICS (CATRES) WHICH ARE URGENTLY RECOMMENDED FOR FUTURE INVESTIGATION.

The thematical framework of the catalogue has been developed by the regional EFERN co-ordinators. The framework is adjusted to the problems of sustainable forest management in a changing environment and takes into account the diversity of problems caused by regional differences in European forestry.

The aim is to define important and hitherto neglected or poorly understood aspects of forest ecology and to find research subjects which are particularely important for the protection of forests.

I. DEVELOPING CONCEPTS FOR THE WISE USE OF EUROPEAN FORESTS

A) Principles:

- sustainability
- biodiversity
- resilience
- multifunctionality

B) Strategies:

- research
- searching bases for generalizing and scaling up
- prediction
- monitoring and risk assessment
- transfer (from research into management)
- planning in a landscape context in accordance with the principles (A)

C) Means and Tools:

- ecological forest management by implementing principles derived from the functioning of natural forest ecosystems considering variations in site, space and time:
  - new forests
  - restoration
  - conversion
  - reforestation/regeneration
- introducing alternative forestry concepts e.g.: bioenergy forests, periurban forests, afforestation of abandoned land, agroforestry
- adapting to diversity
  - regional aspects (boreal, temperate, mediterranean)
    - climate, edaphics and species
    - human influences (historic and present land use anagement)
- continuos monitoring of implementation for improved ecological forest management

II. SCIENTIFIC BASIS / KNOWLEDGE FOR SOLUTIONS RELATED TO PRINCIPLES (A)

Sustainability - Productivity

- biogeochemical principles
  - nutrient and carbon cycling; C and N sequestering
  - water cycling
- plant/soil interactions
- biomass production (all levels)
- food chain/web dynamics (herbivore and consumer food chains, plant-herbivore/pathogen interactions)

Biodiversity - Structure and Scale

- biotic and abiotic dynamics /succession
- forest ecosystem patterns/landscape

Resilience (Stability and Health)

Ecosystems have an ability to respond to disturbances caused by natural and manmade impacts by returning to original state or reach a new state of stability - resilience. Processes and mechanisms of these properties must be understood in order to derive variables as indicators of state and changes. Forest health aspects can also be related to stability processes of the ecosystem.

Multifunctionality

Today, forest management needs to consider both production values/functions as well as other values/functions of a forest. Therefore analyses are required to integrate monetary and non-monetary values, i.e. social, cultural and economic values.

III. GAPS IN KNOWLEDGE WITH PARTICULAR EMPHASIS ON REGIONAL ASPECTS

- basic research
- applied/adaptation research

IV. PRIORITY (SPECIFIC) RESEARCH NEEDS