Forest Ecosystems in a Changing Environment:

Identifying Future Monitoring and Research Needs

Report and Recommendations
COST Strategic Workshop
11 - 13 March 2008 Istanbul, Turkey

COST Strategic Workshop

Edited by Richard Fischer

Cover Photo: *Fagus orientalis* stand in "Belgrade Forest" near Istanbul

Photo references:
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Participants at the COST Strategic Workshop "Forest ecosystems in a changing environment" in Istanbul.
Integrated research, monitoring and modelling approaches require open communication platforms.

Introduction

The workshop

The COST Strategic Workshop "Forest ecosystems in a changing environment: identifying future monitoring and research needs" took place from 11-13 March 2008 in Istanbul and assembled 170 experts from nearly 30 countries. Plenary and parallel sessions focussed on:

- Climate change and forests
- Meteorology, phenology, water budget models
- Tree reactions
- Ozone
- Eutrophication, acidification and critical loads
- Element fluxes
- Biodiversity
- Quality assurance

Background

Unchanged high nitrogen deposition causing eutrophication and acidification, continuous exceedance of ozone critical levels, increasing CO_2 concentrations and global warming are aspects of a rapidly changing environment. At present, 45% of forests in Europe are exposed to nitrogen inputs that exceed the critical loads. In addition, the previous accumulation of acidifying inputs affects today's forest condition. As concerns gaseous pollutants, ground-level ozone is considered to be the most important toxic air pollutant for plants worldwide. It has been recognized as an important greenhouse gas and is a significant factor within "global change" comparable to carbon dioxide (CO_2). Depending on the model and scenarios used, temperature is expected to increase by 1.1 to 6.4°C by 2100 (IPCC Report 2007). It is expected that severity of extreme weather events, such as drought, heat waves and storms, will increase over most of Europe.

Forest ecosystems depend on the surrounding site conditions and climate and need long-term adaptation to environmental conditions. On the other hand, they have a major role in environmental protection, contain a large biological diversity, are significant carbon sinks and thus extremely relevant in the context of climate change mitigation. Forests also represent a controlling factor within the water cycle.

Objectives

The strategic workshop aimed at identifying monitoring related research needs in the field of climate change and air pollution effects on forest ecosystems.

Emphasis was put on (i) climate change effects on forests, (ii) ground level ozone and forest ecosystems, and (iii) critical loads and dynamic models for eutrophication and acidification. Biodiversity and quality assurance within related research and monitoring were tackled as well. Recommendations were developed for (i) future monitoring approaches, (ii) future cause-effect research, (iii) risk assessment based on critical loads and dynamic modelling, and (iv) data quality assurance procedures.

Summary of emerging monitoring and research needs

Richard Fischer [1]

The following summary is based on presentations and discussions at the COST Strategic Workshop "Forest ecosystems in a changing environment: identifying future monitoring and research needs". 170 experts from nearly 30 countries contributed to the outcome of the conference.

I. Climate change, pollutant deposition, ground-level ozone and biodiversity issues are closely linked and require more integrated research, monitoring and modelling approaches (Fig. 1).

The thematic fields tackled at the workshop are closely linked. Forests can mitigate climate change but on the other hand are threatened by changing environmental conditions. Many air pollutants have direct effects on forest ecosystems and act as greenhouse gases as well. They interact in the atmosphere and in their effects on forest ecosystems. In tackling such issues, researchers, monitoring experts and modellers need to collaborate more closely. Projects and programmes that provide an integrated and comprehensive approach need to be supported.

II. Biological reactions of forests to climate change need to be studied and monitored in detail.

Climate change reveals itself as temperature increase and change in precipitation regimes as well as in the frequency of extreme events, such as drought, heat waves and storms. It can both increase or decrease forest growth and carbon sequestration. It affects the health and diversity of forest ecosystems either directly or indirectly by changing the population dynamics of pathogens or insects, and by affecting ecosystem responses to pollutants.

The knowledge on vulnerability or resistance and adaptability of trees to environmental impacts needs to be further improved. Research towards additional, sensitive tree reaction parameters is necessary. These include carbon allocation in ecosystems, shoot growth, fine roots, ectomycorrhizae, fungi, leaf area index, competitiveness, stand structure, and regeneration. Cooperation and joint research of the EU/ICP Forests Level I and Level II monitoring network with more process-based networks should be intensified to improve the understanding of cause-effect relationships.

Time series of tree reactions are a valuable basis for the assessment of climate change effects. Important parameters to be assessed in the future include improved information on forest structure and density, tree species information, annual mortality and its causes, pathogen and insect occurrences, regeneration of tree species, and litterfall for estimation of leaf area index as well as for seed production. Defoliation and discolouration remain valuable indicators. Phenology is recommended as a very suitable direct indicator to assess the reaction of forest ecosystems to climate change. Phenology is strongly affected by temperature as well as by precipitation and can be used to determine the length of the growing season. Existing forest growth data from different sources need to be made available and need to be the basis for harmonized assessments of above ground

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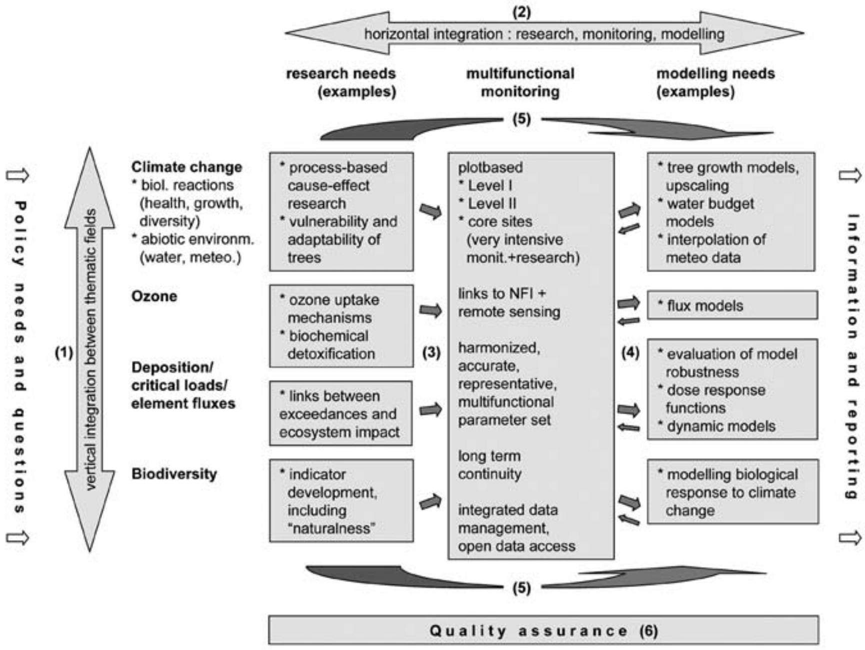

Figure 1: Future research, monitoring and modelling needs. More vertical integration between thematic fields (1) and more horizontal integration between research, monitoring and modelling (2) is needed. Basic research needs to support the identification and definition of monitoring parameters (3). An integrated monitoring system is necessary to provide data for different modelling activities and at the same time needs to take into account the data requirements for the models (4). Process understanding derived from research results is necessary for model construction (5). Quality assurance is a cross cutting issue (6).

biomass. Assessments of below ground biomass need further efforts. Methods for upscaling of carbon pool information and carbon sequestration information should be further developed.

III. Water supply and meteorological conditions are basic information but costly to measure.

To measure the actual changes in climate at the forest stand level, meteorological information is essential to improve the physical and physiological understanding of observed biological/ecological patterns. Methods to interpolate this information need to be further developed and harmonized in order to derive modelled meteorological data for a larger number of plots. Water supply in the soil is one of the key factors affecting tree vitality and forest condition. Based on a limited number of additional measurements and on data input from the above described models, water budget models including soil moisture retention curves and soil moisture contents need to be further developed and applied to existing monitoring sites.

IV. Improved ozone risk assessment: from the AOT40 to a flux approach.

Ozone is also a key player in climate change as it is a powerful greenhouse gas, interacting with other greenhouse gases. Ground level ozone both affects and is affected by the typical driving factors of climate change. Under changing environmental conditions such as climate warming, the currently used exposure index (AOT40) is an inadequate measure to protect European forest ecosystems from adverse ozone effects. Thus, there is a need for a biologically more relevant standard to protect forests from ground level ozone. A flux based approach is recommended.

Further research is needed in the field of ozone flux and uptake as well as defence mechanisms of forest plants. Based on this, models need to be further developed that help to quantify these processes on a larger number of sites in order to improve the assessment of ozone risk to forests.

Limited ozone experimental activities took place in Europe during recent years. The 6th Framework Programme of the European Commission did not fund any projects on ozone and vegetation. It is recommended to include this topic in the 7th Framework Programme.

V. Effects of critical load exceedances need to be substantiated. Dynamic modeling needs further implementation.

Critical loads for nitrogen are still exceeded in large parts of Europe but the extent and timing of impacts on forests needs to be further substantiated by monitoring and dynamic modelling. Dynamic modelling is the only way to assess combined effects of air pollution and climate change on soil and vegetation. Data from a representative set of intensively monitored plots covering the entire European forested area are vital to support these modelling efforts. This refers especially to carbon and nitrogen pools and their changes as well as complete element budgets. Knowledge on spatial variability of drivers and effects is important to quantify the robustness of models.

VI. Element fluxes are essential for understanding effects of disturbances on forests.

Element fluxes play a key role in understanding the effects of both natural and anthropogenic disturbances on the functioning of forest ecosystems and in devising strategies for counteracting the adverse effects of such disturbances. Specific items to be improved include (i) the role played by soil micro-organisms in carbon and nitrogen cycling, (ii) the production of greenhouse gases by forest canopy and soil, (iii) the evaluation of nutrient losses resulting from increased utilization of tree biomass compartments (bioenergy harvesting) and subsequent compensation requirements, and (iv) complete information on soil solution nutrient fluxes, including dissolved organic carbon and nitrogen (DOC and DON).

VII. An extended and integrated assessment of biodiversity indicators needs to build on existing facilities.

For a correct understanding of status and trend of forest biodiversity, an integrated assessment of qualitative biodiversity indicators is necessary, focusing on all levels and scales (genetic, species, community and landscape). Shifts in species composition and the adaptation of management systems need further consideration. Improved assessments of biological response indicators are needed. The concept of "environmental quality" or "naturalness" seems more useful in an operational context than the internationally agreed Convention on Biological Diversity (CBD) definition of biodiversity, which is very wide and general. A start has been made using the existing transnational forest monitoring network for the acquisition of standardized information. This approach needs to be followed in the future, but links to other existing networks and to the research community need to be further developed.

VIII. Consistent quality assurance programs help to guarantee the efficient use of financial resources.

Poor data quality results in an increase of costs and in a loss of confidence in results. Since there are different sources of error in designing and implementing research, monitoring and modelling activities, quality assurance (QA) procedures are necessary to minimize their impact on the results. QA programmes are therefore a vital need. Proper QA should ensure that all the steps of a given programme/investigation are considered, from research or monitoring design, to measurement/classification errors, errors caused by models and non-statistical errors.

IX. The further implementation of one coherent and integrated multifunctional forest monitoring system is strongly recommended.

The continuation, further development and funding of the existing European forest monitoring system of UNECE and EU is essential to understand the integrated effects of climate change and air pollution on forest ecosystems, to define the forest's potential to mitigate climate change, to promote forest adaptation to all these changes, and to provide policy-makers with scientifically-sound and up-to-date knowledge for the protection of forests in a changing environment. The existing facilities already provide data as a basis for evaluations in different thematic fields. National Forest Inventories, Level I and Level II plots of the European forest monitoring system and remote sensing information should be integrated into one coherent system. The selection and further instrumentation of a smaller number of adequately distributed core sites with even more intensive measurements is strongly recommended. These sites should be shared by research projects, monitoring, and modelling experts.

X. Data availability and evaluation should be considerably improved and extended.

Access to the existing forest monitoring data needs to be improved. Many researchers are not aware of the existence and availability of large transnational data sets. The data need to be advertised. An open online data base would support the wider use of the data. With increasing time series and new assessments added, the evaluation possibilities increase exponentially. The existing data sets are "underevaluated" and in general larger shares of the funds need to be spent on data evaluation.

XI. An expanded regional coverage of research activities and monitoring data is recommended.

Western, central and northern and parts of southern Europe are in general well equipped with research projects and monitoring sites. This holds as well true for Canada and the USA. Efforts to build up research and monitoring are seen today in a number of eastern and south eastern European countries. This needs to be further encouraged and supported. The Acid Deposition Monitoring Network in East Asia (EANET) is active in installing comparable monitoring sites in East Asia. Given the hemispheric transport of many pollutants, the support to countries on other continents to reduce emissions and to build up related research and monitoring seems very relevant also for an improvement of the European situation.

Storm damage in Slovakia in 2004. Under current climate change scenarios extreme events are predicted to increase. Biological reactions of forests and their possible adaptation need to be studied in detail and appropriate forest management systems are required.

Interactions between climate change and forest ecosystems

Matthias Dobbertin [1] and Wim de Vries [2]

Key messages

Forests in Europe serve as an important carbon sink, mitigating currently 10% of European induced CO_2 emissions (Fig. 2). Their future contribution as carbon sink depends on forest management, climate change and change in air quality (in particular nitrogen deposition and ozone).

Elevated CO_2 concentrations and nitrogen deposition increase forest growth and carbon sequestration, whereas elevated ozone concentrations reduce growth. Estimates for nitrogen vary from 10-200 kg additional carbon sequestration per kg nitrogen. Focused monitoring and related research is thus needed to reduce uncertainty in impact estimation.

Slowly changing environmental conditions, such as rising temperatures or changes of mean annual precipitation, will become increasingly important drivers of forest condition. They affect the potential ability of tree species to grow, to regenerate and to compete with each other and thus influence the carbon sequestration potential in the long run. Only in certain cases can this be linked to increased forest growth and carbon sequestration. On the other hand

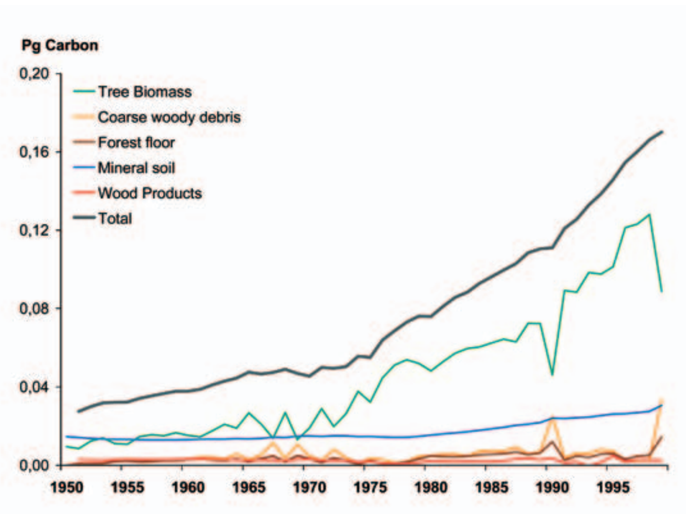

Figure 2: Total annual net carbon sequestration in various ecosystem compartments in Europe since 1950, indicating that approximately 10% of European CO_2 emissions are taken up by forests (after Nabuurs et al., 2003).

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[2] Alterra Green World Research, Wageningen University & Research Centre, Wageningen, The Netherlands

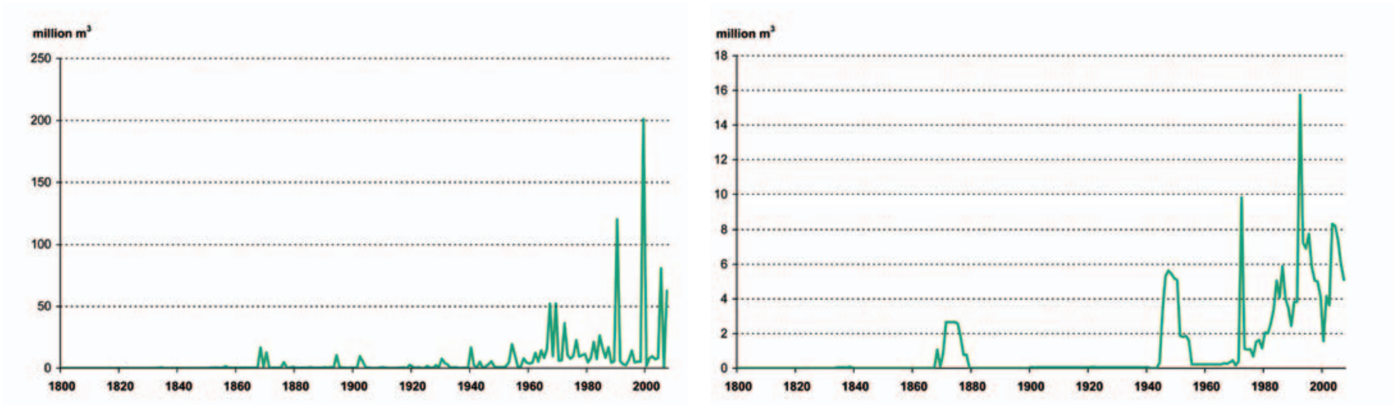

Figure 3: Timber volumes related to reported storm (left) and bark beetle damage (right) in European forests since 1850 (after Schelhaas et al., 2003, bark beetle updates 2004-07 still to be confirmed).

climate change can induce changes in the frequency of extreme events, such as drought, heat waves and storms, and thus decrease growth and carbon sequestration. Climate change further affects the health and diversity of forest ecosystems either directly or indirectly by changing the population dynamics of pathogens and insects. Monitoring data show an increase in storm damage and bark beetle damage since 1850 (Fig. 3) and future predictions estimate a further increase in response to climate change. Proper forest management aims to avoid unwanted effects and requires focused monitoring and related research.

Linkages between existing research and monitoring networks on the carbon and nitrogen cycles need to be established or strengthened. In addition to the essential national forest inventory plots, used for carbon storage calculations, monitoring networks like EU/ICP Forests Level I and Level II can provide additional data to improve these estimates, in particular concerning below-ground carbon storage and the effects of climate change and change in air quality on both, above and below-ground, carbon storage.

A better understanding of the processes of mortality and regeneration is needed for long-term prediction of the change in tree species ranges under climate change. This requires the monitoring of mortality and its causes, tree regeneration and, if possible, seed production and germination rates. Interaction of climate change, air quality (in particular nitrogen deposition, CO_2 and ozone levels) and forest management under different site conditions and for different tree species is not yet well enough understood and needs further research and better analysis of existing data. Neglecting, for example, nitrogen availability in models predicting impacts of elevated CO_2 concentrations leads to a large overestimation of the impact on carbon sequestration. Models for carbon storage and the reactions of forests to climatic change need to be better calibrated using existing monitoring data and need to be improved by integrating more interactive and dynamic processes.

Summary of presentations

Research and monitoring activities in the broad field of climate change and forests can be divided into the issues of: (i) mitigating effects of forests on green house gas emissions by acting as carbon sinks and (ii) the research on the effects of changing climate on forests. Of course, both are interlinked.

Mitigating effects of forests

In the plenary session several presentations were addressing the issue of the assessment of carbon storage of forests in Europe. In particular the use of monitoring data, mainly from national inventory networks, but also from EU/ICP Forests Level I and Level II plots was addressed as well as the need to link them with i) upscaling models to a European-wide scale, ii) future management, and (iii) climate change scenarios. By combining the above mentioned networks, it was shown that nitrogen deposition increases carbon sequestration in forest biomass and soils per kg nitrogen addition varying from 30 to 70 kg C/kg N. Considering an average human induced nitrogen input in Europe of 10 kg N/ha, this implies an average estimated growth increase varying from 10 to 25 %. Literature data (empirical data and model results) on carbon sequestration in biomass and soils per kg nitrogen addition vary, however, from 10 to 200 kg C/kg N. Focused continued monitoring and related research is needed to reduce this uncertainty in impact. Uncertainties in the estimation of the carbon storage of forests due to different biomass estimation methods and uncertainty in the measurements were addressed. In particular the assessment of carbon storage in forest soils is still a challenge and good estimation models are needed. Climate change can either directly affect the carbon storage of forests (for example during the 2003 heat wave in Europe, forest carbon sinks were reversed to sources because of reduced photosynthesis and increased respiration), or indirectly by an increase in forest fire frequency and severity, such as in 2003 in Portugal and 2007 in Greece.

Climate change effects on forests
During the workshop a model was presented using presently measured meteorological data and tree species information from monitoring sites in combination with climate change scenarios to predict potential future tree species distribution in Europe. Results show, for example, that the expected upward shift of the timber is slowed on one hand by the still fairly intensive grazing at the timber line and the sensitivity of seeds and young seedlings to germinate and survive in open field conditions.

The importance of indirect effects of climatic change was highlighted in a presentation on the current dramatic outbreak of the mountain pine bark beetle in North America. Populations of this bark beetle are limited by summer temperatures restricting the development of the larvae and by extreme winter cold causing beetle mortality. Winters without extreme frost and warm summers are currently allowing the beetle to extend its distribution range further north and to higher altitudes causing not only disastrous mortality to its usual host tree species but also to other pine species in the north and at high altitudes. Extreme mortality of dominant trees is leading to a drastic reduction in carbon stocks, complete alteration of forest ecosystems, and reduction of most forest functions.

The importance of linking monitoring results with more process-oriented field research was highlighted in a third presentation. More overlap of the process-based networks and their flux sites with intensive monitoring plots was recommended to enable a better understanding of the carbon fluxes and the hydrological cycle.

A fourth presentation showed the effect of summer drought and heat on the regeneration success of different species in Spain. Mortality of tree species with a more northern natural distribution was high following dry summers, while tree species with a more southern distribution range showed less effect.

Needs for future monitoring, cause-effect research and modelling

Monitoring
Future monitoring needs to include important forest ecosystem parameters such as forest structure and density, tree species information, tree growth (the latter preferably on an annual basis). Furthermore, on at least an annual basis, information is needed on mortality and its causes, on crown condition, pathogen and insect occurrences, regeneration of tree species, and litterfall for estimation of the leaf area index as well as for seed production. While many of the above parameters are being currently assessed by either national inventories or European monitoring networks, they are often not available on the same plots. For example, available data from national forest inventory networks or joint Level I/NFI plots could be used for forest growth, stand structure and regeneration assessment, while annual mortality rates and insect and pathogen occurrences are available from Level I plots. Currently, substantial effort is being undertaken to (i) harmonize national inventory results (Cost Action E43) and (ii) to establish joint NFI/Level I networks (so-called FutMon project proposal under LIFE+).

Cause-effect research at monitoring and process-based networks
In the workshop discussion a general agreement was found to improve and establish better links and cooperation between process-based field research and monitoring sites, ideally even linking them to field experiments. For example, cooperation and joint research between the EU/ICP Forests Level I and Level II monitoring network with the more process-based networks CarboEurope and NitroEurope should be increased to improve the understanding of cause-effect relationships. While Level II sites provide data on environmental stress factors, such as atmospheric deposition, air quality and soil chemistry, including carbon content, continuous CO_2 flux measurements are only available on CarboEurope sites while NitroEurope includes continuous CH_4 and N_2O flux measurements. While, ideally, the location of such 'super sites' should be well thought through, they will most likely develop out of merging existing sites and infrastructures.

Modelling data from monitoring and process-based networks
Existing forest models need to be adapted to interacting effects and need to be tested using data from monitoring and process-based networks. In particular, empirical growth models need to be adapted to climatic effects, while climate-driven growth models (for example gap models) need to be calibrated for interacting effects of nitrogen deposition and ozone concentrations. Different process-based models have already been used to quantify the effect of various environmental factors (mainly temperature change, nitrogen deposition and CO_2 change) under current conditions and future scenarios. While currently nitrogen deposition is an important driver of forest growth and carbon sequestration, in the future the effect of rising temperature and CO_2 will gain importance. However, the negative effect of rising ozone concentrations and changes in precipitation and water availability is often insufficiently represented. Regarding the climatic variables, this is partially due to a lack of prediction scenarios for precipitation and actual data to calibrate models. Currently a new Cost action (Action FP0603: Forest models for research and decision support in sustainable forest management) has been launched to promote the development of new methodologies to improve existing forest growth models for sustainable forest management. Testing of models in relation to carbon sequestration and greenhouse gas emissions can be carried out specifically at the process-based networks (e.g the CarboEurope and NitroEurope sites), while the monitoring networks (specifically the EU/ICP Forests Level I and Level II monitoring

network) are useful for applying the models in order to evaluate the impacts of climate change on forest ecosystems and to extrapolate results to the European scale. It was also discussed during the workshop that adaptation of tree species, for example within species by selection of more adapted genotypes, or by changes in species composition, either via competitive selection or by adaptive forest management is often insufficiently included in models of future species distributions. It was recommended to link the current monitoring activities to sites used in the current EU Project EVOLTREE, which intends to study the evolutionary history of forest trees to help predict how they may respond under changing climatic conditions.

Litterfall traps installed at a fir plot in Greece. Parameters for tree reactions to environmental changes like defoliation, discoloration, mortality, fructification, occurrence of pests and diseases, phenology, litterfall and forest growth are currently assessed on a European wide scale. Continuation of these assessments and their integrated evaluations need to be ensured in the future.

Tree reactions to environmental changes

Johannes Eichhorn [1] and András Szepesi [2]

Key messages

Forests have always been subject to different natural impacts resulting in changes of ecosystems and adaptation to new conditions. Tree reactions to different environmental impacts are a normal phenomenon in forest ecosystems. However, these reactions can also indicate disturbances and can be used as key indicators of forest ecosystem health and vitality. It is necessary to improve our knowledge on tree reactions especially to identify and quantify disturbances more accurately and separate them from "normal" reactions.

Human activities, like deforestation, forest management, air pollution, and climate change dramatically increase the pressure on forest ecosystems. Therefore observation, measurement, analysis and interpretation of tree reactions to these impacts can actively contribute to the protection of forest ecosystems. Better integration of the existing European forest monitoring systems, especially EU/ICP Forests Level I, Level II and National Forest Inventories should be achieved. Monitoring of climate change effects and changes in biodiversity in forests should be integrated into the existing systems.

As a result of more than 20 years of forest condition monitoring (ICP Forests), continuous forest inventories and forest ecosystem research, a tremendous amount of data on tree reactions to ecosystem changes is already available. Analysis and more effective utilization of these databases should be promoted and also used for future development of the monitoring systems in Europe.

Several parameters for tree reactions have already been identified and applied successfully in research and monitoring activities, and their assessment has to be continued. Research towards additional, sensitive tree reaction parameters is necessary.

Summary of presentations

The effect of climate change on the health status and the distribution of beech in Hungary was demonstrated. A xeric limit and tolerance index for beech was developed. Re-

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sults show that distribution of beech is determined by short term dry periods rather than climatic means. Expected future distribution of beech was calculated for the middle and the end of the present century. A dramatic reduction of beech distribution is predicted for the future. Level I data were also used for this study.

Growth patterns of forest stands are the biological system response to pollutants and climatic impact. This was demonstrated based on German Level II plots. Comprehensive analysis of tree and stand growth patterns proved to be appropriate tools to provide findings on the impact, especially of climate change and air pollution patterns. Time series of retrospective tree ring growth were successfully related to climatic impacts. Models can be used to forecast future tree and stand vitality.

Tree responses (birch, alder, beech) to elevated atmospheric carbon dioxide in a free air enrichment experiment (FACE) were investigated in Wales. After 3 years of CO_2 enrichment, a clear increase of both, above and below ground biomass, was observed. A mixture of tree species resulted in higher growth rates as compared to those predicted from single species measurements. Increased litterfall and longer leaf retention of birch were observed in the elevated CO_2 treatment.

Recommendations

- The general knowledge on vulnerability or resistance and adaptability of trees to environmental impacts needs to be further improved.
- To achieve this goal, the time series of continuous and periodic monitoring of tree reactions are essential.
- Existing European forest monitoring systems, especially EU/ICP Forests Level I, Level II and NFIs should consider and properly address new monitoring issues, like climate change or biodiversity, therefore the development of a more comprehensive European monitoring system is required. This new or adjusted system should provide reliable and representative time series of tested and verified parameters, especially on tree – forest ecosystem – reactions to environmental impacts.
- Valuable and available data already collected in forest condition monitoring (ICP Forests), in continuous forest inventories and in forest ecosystem research have to be used more effectively to clarify effect-response relationships.
- Integrative parameters for tree reactions to environmental changes, like defoliation, discoloration, mortality, fructification, pests and diseases, injuries, phenology, litterfall or growth remain valuable in the future. Several examples proved the relevance of these parameters. Correlations to environmental impacts were verified.
- Non specific response parameters should be better related to specific impacts. Therefore accurate and reliable data on impact parameters, as well as on stand and site history are essential.
- Research towards additional, sensitive tree reaction parameters and their application in monitoring systems is necessary. They include carbon allocation in trees and ecosystems, shoot growth, dendroecology, fine roots, ectomycorrhizae, fungi, leaf area index, competitiveness, stand structure, and regeneration.
- Remote sensing and additional area related information have to be considered and applied to complete plot based monitoring data in large scale analysis of forest ecosystem responses to environmental impacts.

Norway spruce at different phenological stages (before flushing, flushing, after flushing). Phenology is recommended as a very suitable direct indicator to assess the reaction of forest ecosystems to climate change. It is strongly affected by temperature, as well as by precipitation and can be used to determine the length of the growing season.

Meteorological conditions and water supply are drivers for biotic reactions

Stephan Raspe [1] and Egbert Beuker [2]

Key messages

Climate is one of the most important impact factors for the health and vitality of forest ecosystems. Besides changes in temperature, also changes in precipitation are projected and in addition there will be large regional differences. This will influence both, water budgets and phenology. Phenology is probably the clearest biological indicator for the reaction of forest ecosystems to climate change. The water budget reacts strongly to both, changes in precipitation as well as temperature (through changes in transpiration and evaporation). Phenology and water budget also affect each other, on one side by the length of the vegetation period and on the other by the water availability.

To understand the physiological processes and their changes within a forest stand or ecosystem, carefully collected on-site climate data is required. Interpolated data from nearby weather stations is most often not accurate enough .
The assessment of the end of the growing season is still the most challenging task within phenological assessments. The use of remote sensing seems promising, but the techniques have still to be developed further.

Water supply in the soil is one of the key factors affecting tree vitality and forest condition, but a limited number of additional measurements (soil physical and hydraulic properties, soil moisture contents, rooting depths) and meteorological data, are needed to apply water budget models to existing monitoring sites in order to follow the reaction of forest ecosystems to better explain changes in forest ecosystem vitality and behaviour.

Summary of presentations

Meteorology

To understand the physiological processes and their changes within a forest stand or ecosystem, accurate on-site climate data are required. Often, however, interpolated data from nearby meteorological stations are used. For gapless long-term time series of meteorological data also modelled meteorological data is used.

Studies have shown that temperature is easier to interpolate than precipitation values, and that maximum temperatures are less prone to interpolation errors than minimum temperatures. Also, the accuracy decreases with increasing distance to the closest climate station, especially in mountainous areas. Short-term values show large errors, whereas long-term means can be interpolated with reasonable accuracy. This indicates that it is important to use on-site measured data if accurate information at high temporal resolution is required in order to develop the physical and physiological understanding of observed biological and ecological changes.

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[2] Finnish Forest Research Institute, Punkaharju, Finland

Rainfall needs on-site measurements. Extrapolations will smoothen extreme weather events. Extrapolation is mainly useful for filling gaps, but even then the distance between the plot and the station should not be too far. Weekly or biweekly precipitation sums may be used. Radiation is difficult to assess because of the technical requirements of the stations. Methods for wind speed should be developed and included in the meteorological models.

The use of different techniques affects the comparability of the data. Reliable equipment and regular calibration is needed, otherwise the actual measured values may become worse than interpolated values. Checking the obtained data from the on-site stations is necessary, but difficult and time consuming. Meta data on the measurements have to be completed and added to the existing database. This will substantially increase the value of existing data.

Phenology

Phenology is a sensitive and relatively easy to assess indicator for the reaction of ecosystems to climate change. However, long-term and comparable assessments are required. Phenology is strongly affected by temperature and precipitation. Change in the length of the growing season results in changes in forest production. This has not only economic, but also ecological consequences as it is related to carbon uptake, species competition, as well as pests and diseases.

The upscaling of phenological assessments to larger forest areas is difficult. One solution may be satellite-based mapping for certain areas. This method has been tested for birch in Fennoscandia. It was found that the method is suitable for assessing spring phenology, but is at present still less reliable during autumn. However, assessing the end of the growing season is also still a problem for ground assessments. Using remote sensing, regional trends could be observed that would not have been detected using ground observations. Remote sensing may use other indexes, such as photosynthesis. Until now, the method can only be applied to large homogeneous areas, as the satellite data are only available in 250 x 250m grids. Data in higher spatial resolution (e.g. Landsat) are only available in too low temporal resolution.

Water budgets

The water supply in the soil is one of the key factors affecting tree vitality and forest condition. Moreover, determination of the water budget has been shown to be of central importance in understanding a number of physiological processes like nutrient uptake, growth and response to biotic stress factors. However, the measurement of water availability is very laborious and expensive and can therefore only be carried out at a limited number of sites.

Water budget equations are alternative tools for the quantification of the water cycle. For the further development of the equations and the calibration of the models more sites with soil moisture monitoring, meteorological assessments (precipitation, temperature, wind speed and radiation) and various stand, site and soil parameters (soil texture, situation of the sites and slope) are needed.

Based on measurements, water budget models can be further developed and validated at the plot level and applied to Level II and Level I plots. Modelling and measuring of the water budget would increase the understanding of water-use and evapotranspiration by forests, and enable explanation of changes in forest ecosystem vitality and behaviour (e.g. defoliation, litterfall, phenology, growth, and rooting) related to climate change.

Future monitoring, research and modelling needs

There was general agreement within the group that a number of "super" plots should be established, equally distributed over the geological and ecological regions in Europe. These plots should also include below ground assessments, high tech meteorology stations (incl. soil moisture) as well as phenology assessments.

Ozone fumigation system (left), eddy-flux measurement system (middle), and radiation sensor (right) at the free-air ozone fumigation facility at Kranzberg Forest, Germany. For accurate ozone risk assessment modeling more information on real-time ozone concentrations and gas exchange is needed. Such data can be provided by free air fumigation, sap-flow and eddy-flux measurements that are combined with meteorological and soil monitoring.

Ground level ozone effects on European forest ecosystems

Marcus Schaub [1], *Elena Paoletti* [2], *Andrzej Bytnerowicz* [3]

Key messages

Ozone affects humans, plants, animals and materials. Even though ozone impacts on health are of main priority for both the UNECE Convention on Long-range Transboundary Air Pollution and the EU, there is a risk that in the process of the revision of the UNECE Gothenburg Protocol ozone impacts on vegetation will not be considered. Therefore it is essential to understand that vegetation is very sensitive to ozone and can be endangered by ozone exposure before humans are.

Ozone is also a key player in climate change as it is a powerful greenhouse gas, interacting with other greenhouse gases. Ground level ozone both affects and is affected by the driving factors of climate change. Fore example, increasing temperature may lead to increased ozone concentrations while increasing ozone can affect the lifetime of other greenhouse gases such as methane.

Under changing environmental conditions such as climate warming, the currently used exposure index (AOT40) is regarded as an inadequate measure to protect European forest ecosystems from adverse ozone effects. Thus, there is a need for a more biologically relevant standard to protect forests from ground level ozone. A flux-based approach, similar to the phytomedical one applied to protect human health, has been recommended (Fig. 4).

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[3] USDA Forest Service, Pacific Southwest Research Station, Riverside CA, USA

Summary of sessions

Ground level ozone poses a serious threat to forest ecosystems across Europe. In contrast to elevated nitrogen deposition and CO_2, ground level ozone can reduce biomass production and carbon sequestration. Further adverse ozone effects can be expected on species diversity or on below ground processes that can predispose forests to other stressors like drought, pests, pathogens, forest fires, windthrows, or frost.

The application and use of response parameters such as biodiversity, above and below ground carbon allocation, premature senescence and ozone induced visible injury can be used to assess and communicate the actual ozone risk. In addition, the combined use of the response parameters needs further investigations.

The currently available data sets from forest monitoring networks like the EU/ICP Forests Level I and Level II in combination with the findings from intensive research activities have so far allowed identifying areas of risk. Geographical and temporal distribution patterns of ozone exposures measured by passive sampling and ozone induced visible injury across Europe have been described. However, there are limited data for most parts of Europe such as eastern Europe, Russia, the Balkans and parts of the Mediterranean. Furthermore, poor correlations between ozone exposures and occurrence of symptoms have been found due to the influence of environmental factors such as soil moisture, air temperature, relative humidity, etc. This underlines the need for the development of a more meaningful biological approach (Fig. 5).

Future monitoring, research and modeling needs

In order to make use of the extensive monitoring data combined with the present mechanistic understanding of ozone plant effects, and to develop accurate ozone risk assessment and a biologically meaningful ozone standard for Europe, long-term and adequate EU funding is needed.

For an accurate risk assessment modeling, more information on real-time ozone concentrations and gas exchange of key forest tree species growing in various areas of Europe is needed. A combination of sap-flow measurements with eddy flux measurements has been suggested as a very promising and cost effective research and monitoring method for both calculation and validation of the ozone flux estimates to forests. Adverse ozone effects not only depend on stomatal uptake/closure but also on the capacity to defend and repair intracellular ozone damage. Therefore such information is crucial to understand the biochemical potential of trees for ozone detoxification under ambient field conditions. In all these aspects of monitoring and research, long-term programs are needed considering dynamic, and often unpredictable, climatic and socio-economic drivers of change. Different methodological issues need to be developed and validated by experimental approaches.

In order to strengthen the current efforts towards a biologically more meaningful ozone standard and to make better use of the existing synergy between research, monitoring, and modeling, the establishment of "Supersites", if possible along natural gradients (e.g. altitude, latitude, pollution), is recommended. At such sites continuous monitoring of ozone should be performed at the canopy top (+ profiles) combined with the monitoring of the respective meteorological and soil input parameters required for the ozone flux modeling. In this respect, main European climate types can serve as test areas for evaluation of ambient ozone effects on forests.

For model validation, ozone flux measurements by eddy covariance combined with sap-flow measurements are needed. For logistic and financial reasons, existing networks such as CarboEurope and NitroEurope should be considered.

Results from experimental approaches such as the application of ethylenediurea (EDU) and free air fumigation, conducted under realistic conditions are necessary to validate monitoring results from field observations. Controlled or semi-controlled chamber experiments are useful for the mechanistic understanding of ozone impact on trees.

The further installation of passive sampler networks is necessary, specifically in areas under-represented in existing networks. Results from such networks will allow finding "hot spots" where subsequently more intensive monitoring and research would be performed.

There is a need for effective interactions and exchange within Europe and beyond, including Asia and North America in the area of long term monitoring and research on ozone effects on forest ecosystems. A close collaboration between involved organizations such as IUFRO and ICP Forests is also recommended.

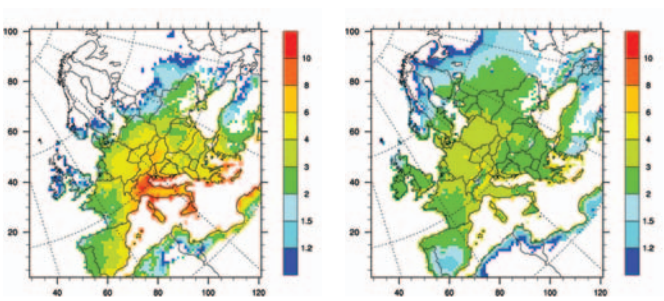

Figure 4: Distribution of the relative exceedance of the critical level (1 = 100% exceedance) for forests in the year 2000 for the concentration-based AOT40 index (left) and the flux-based AFst1.6 index (right). (Simpson et al., 2007).

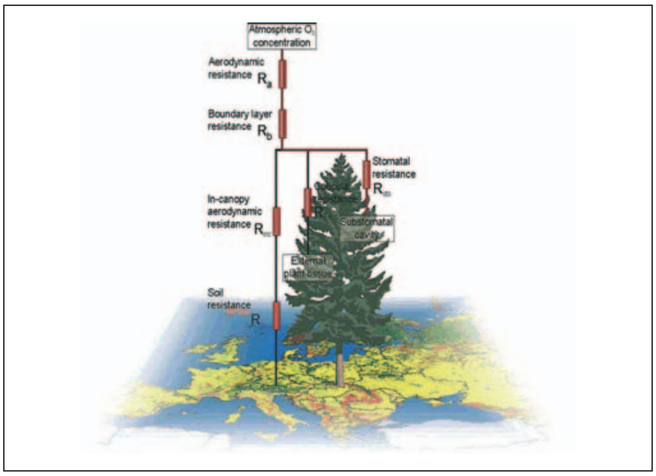

Figure 5: Ozone flux model (Emberson et al., 2000). Ozone uptake by plants is modelled as ozone flux. This is more relevant for the assessment of ozone risk than the mere ozone concentrations in the ambient air.

Deposition measurement equipment (left), tree stems (middle), and soil profile (right). Key processes included in dynamic soil chemistry are element fluxes in deposition, nutrient uptake by trees, and nutrient cycling in the soil.

Further development of deposition monitoring, critical loads calculations, and dynamic modelling

Jean-Paul Hettelingh [1], Max Posch [2], Gert Jan Reinds [3]

Objectives of the sessions

The sessions focussed on possible contributions of the forest monitoring community to improve the knowledge on:

- Dose-response functions for forest ecosystems
- Links between critical loads exceedances and impacts like e.g. biodiversity loss
- Robustness of model results (exceedance, violation of criteria, delay times)

Current status

- Critical loads have been successfully used – and will be used – in designing European air pollution reduction policies under the Convention on Long-range Transboundary Air Pollution and the European Commission.

- Empirical critical loads are based on field evidence of the relationship between nitrogen inputs and reported adverse effects.

- Modelled critical loads are computed by simple biogeochemical models relating inputs (sulphur and nitrogen deposition) to chemical variables (soil solution concentration, availability) which are linked to effects on plant species composition or forest health.

- Dynamic models are needed to assess temporal aspects of changes of depositions relative to critical loads to quantify damage and recovery delay times with respect to geochemical indicators and biological endpoints (Fig. 6).

Presentation conclusions

- Model parameters should be based on monitored data that are sufficiently representative for broad regional applications in Europe; a sufficient regional coverage over Europe of plots with a dataset on complete budgets of all individual ions, using harmonized methods is recommended.

- The coverage and density of the plots should be sufficient for modelling of impacts in all regions that are homogenous with respect to forest ecosystem characteristics.

- Information on the links between geochemistry and biological impacts should be routinely reappraised.

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This means that geochemical and biological indicators should be measured concurrently.

- Monitoring at Level II plots should encompass the data needs for the application of integrated soil-vegetation models on a European scale; monitoring could give guidance to extend the models with relevant processes. It needs to be investigated how to upscale such models, also in light of data requirements related to the high species number in southern Europe.

- Future monitoring should include data on the influence of climate change on biogeochemical cycles.

- For forests exceedances of critical loads for nutrient nitrogen (CL(N)) lead to changes in species composition in the ground vegetation; CL(N) are still exceeded at many Intensive Monitoring Plots

- Monitoring should be intensified on plots where critical loads are exceeded to corroborate hypotheses on the linkage between these exceedances and biological impacts.

- Manganese in biomass can be used as an indicator for acidification.

- A definition of "naturalness" or "good ecological state" is needed to help focus the modelling on desired recovery; this requires a holistic approach. It is unrealistic to assume that the target situation can be identical to the situation in pre-industrial times.

- Knowledge on spatial variability of inputs and outputs within the plot is required to quantify the robustness of models.

- Even though exceedances of critical loads of acidity are predicted to diminish in the future, soil recovery may take long under the current emission reduction legislation.

- Dynamic modelling of future effects of changes in nitrogen deposition and climate may be uncertain but it is necessary to evaluate future scenarios. Current nitrogen storage fluxes in soils are not likely to continue in the future. Monitoring of (changes in) soil carbon and nitrogen is vital. Climate change affects many relevant processes but the effects can vary strongly both in spatial pattern as well as in magnitude.

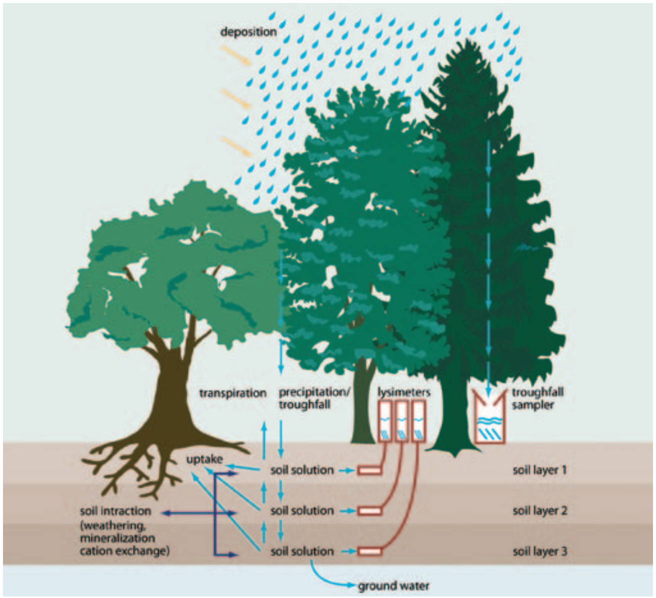

Figure 6: Measurements and processes which are the basis for dynamic soil chemistry models (Fischer et al. 2005). Dynamic modelling is an important method to assess combined effects of air pollution changes and climate change on soil and vegetation.

Intensive Monitoring site in Germany. The quantification of element fluxes in forest ecosystems requires the continuous assessment and measurement of a wide range of ecosystem parameters.

Element fluxes as indicators for ecosystem disturbances

Nicholas Clarke [1] and John Derome [2]

Key messages

- The session clearly emphasized the importance of monitoring element fluxes on the EU/ICP Forests Level II plots. Integrated Level II monitoring provides a valuable tool in understanding and modelling the effects of climate change, air pollution, and changing forestry practices including bioenergy utilization, on forest ecosystems.

- The quantification of element fluxes (plant nutrients and carbon) in forest ecosystems requires the continuous assessment and measurement of a wide range of ecosystem components including element inputs (bulk deposition), outputs (CO_2 evolution from the soil, percolation water), the movement of elements within the ecosystem (stand throughfall, stemflow, above- and belowground litterfall, soil solution), element stocks (tree components, ground vegetation, soil), and environmental regulating factors (temperature, moisture etc.). These attributes and parameters should be measured in an integrated fashion on the same plots using harmonised methodology.

- Element fluxes are sensitive indicators for both, short-term (e.g. insect attack) and long-term (air pollution, climate change, intensive biomass utilization, groundwater pollution) disturbances.

- Monitoring changes in element fluxes plays a key role in devising strategies for counteracting the adverse effects of disturbances on ecosystem functioning, e.g. through forestry management practices.

- The monitoring of element fluxes plays a key role in evaluating the effects of e.g. political decision-making (reductions in sulphur and nitrogen emissions, Fig. 7), and provides important information about the degree and rate of recovery of ecosystem functioning.

- Monitoring the level of nitrogen in deposition and its effects on nitrogen in soil solution and the soil have enabled estimates to be made of the degree of nitrogen saturation of forest ecosystems, and the subsequent risk of nitrate leaching into the groundwater.

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[2] Finnish Forest Research Institute, Rovaniemi, Finland

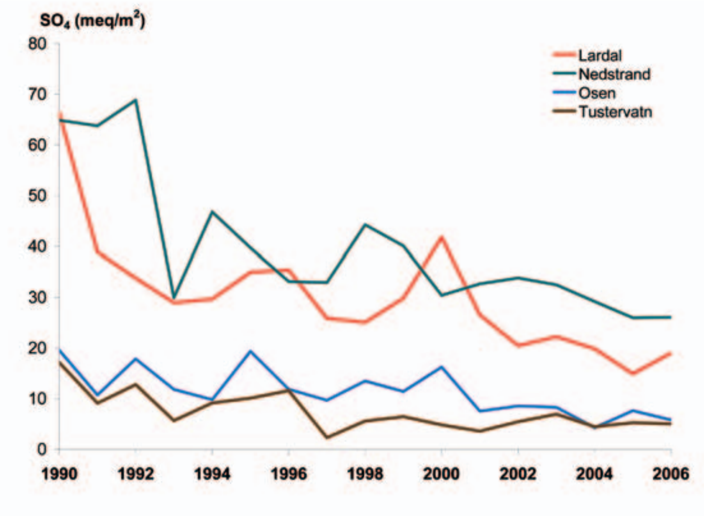

Figure 7: Reduction in deposition of non-marine sulphate at Norwegian Level II plots as a result of clean air policies. The reduction is greatest on the southern plots (Lardal and Nedstrand).

Summary of presentations

The four presentations in the session concentrated on evaluating the role of element flux monitoring in addressing the current and future threats to forest ecosystem functioning.

Climate change will have a clear effect on element fluxes because precipitation is the main driver of these. In northern Europe, for instance, the decrease in the proportion of precipitation falling as snow will have a major effect on e.g. element leaching into both surface waters and ground water. Higher temperatures, combined with higher moisture conditions, will most probably result in increased accumulation of organic matter (increased carbon stocks) during the dormant season. Increased aridity and temperatures during the growing season, on the other hand, will increase decomposition, resulting in increased nitrate production in nitrogen-saturated ecosystems and the loss of carbon.

In Switzerland, the monitoring of nitrogen in deposition, soil solution and soil has enabled estimates to be made of the degree of nitrogen saturation, and subsequent risk of nitrate leaching into the groundwater. The C/N ratio of the organic layer has been found to be a relatively reliable indicator of the degree of nitrogen saturation of forest ecosystems, and can be used for identifying sites where nitrate leaching is likely to be a problem in the future, especially if elevated nitrogen deposition is combined with the higher temperatures and changes in precipitation patterns foreseen under climate change scenarios.

The monitoring of long-term trends in wet and dry deposition has confirmed the successful implementation of sulphur and nitrogen emission reduction policies. The monitoring of throughfall and soil solution has identified possible signs of ecosystem recovery from sulphur deposition, primarily related to changes in dissolved organic carbon (DOC) and dissolved organic nitrogen (DON), as well as the effects of changes in temperature and moisture regimes (climate change). Throughfall monitoring has also highlighted the possible role played by attacks of phytophagous insects in carbon and nitrogen fluxes between the tree cover and the soil.

The monitoring of element fluxes in German forests has provided information about means of maintaining sustainable forest management in areas subjected to high deposition loads. The tree species composition and soil types in some forest areas in Germany considerably increase the risk of soil acidification resulting from elevated acidifying deposition loads. Changing the tree species composition and management regimes can considerably alleviate these problems.

Recommendations for future monitoring and research

Monitoring

- A fully integrated ("core") Level II plot network using harmonised methodology should be developed. The monitoring of deposition, litterfall, soil solution, and meteorology should be concentrated on the same core plots. Currently only ca. 200 of the almost 800 European Level II plots correspond to such core plots. The core plots should be representative of climatic and geographic zones, forest types etc., and less emphasis should be put on national needs.
- The development of regional core plot networks that take into account the conditions and problems in larger regions (e.g. Nordic and Baltic countries, Mediterranean region) should be intensified.
- Additional information is needed on deposition and soil solution nutrient concentrations, including DOC and DON. Not all countries are measuring DOC, for instance.

Research

- Studies on the role played by soil micro-organisms in carbon and nitrogen cycling, and the production of greenhouse gases by the canopy and soil are needed.
- Studies on the role of forestry practices in combating the threat of nutrient loss related disturbances are needed as well.
- Evaluations of nutrient losses resulting from increased utilization of tree biomass compartments (bioenergy harvesting) and countermeasures need to be carried out.
- Integrated studies on nitrogen saturation and the risk of nitrate contamination of groundwater reserves should be intensified.
- Regional co-operation on element flux monitoring and modelling is strongly recommended.

Deadwood in a managed lowland beech stand. Deadwood is an important indicator for biodiversity. Related information is available from different sources such as National Forest Inventories and a number of EU pilot projects. Biodiversity assessments need to be harmonized in order to derive comparable information.

Towards the implementation of an integrated forest biodiversity assessment

Bruno Petriccione [1] and Tor-Björn Larsson [2]

Key messages

Available long-term forest monitoring facilities can contribute to the reporting obligations of European countries and the EC related to the status of biological diversity. Qualitative information and the main scientific findings obtained in the frame of future European forest biodiversity projects will be able to feed a number of international conventions and processes such as the Convention on Biological Diversity (CBD), the Ministerial Conference for the Protection of Forests in Europe (MCPFE) and the Convention on Long-range Transboundary Air Pollution (CLTRAP) and to give urgent answers to the high-level policy questions in the context of halting (or significantly reducing) the loss of biodiversity by 2010.

For a correct understanding of status and trends of forest biodiversity, an integrated assessment of qualitative indicators is necessary, focusing on all levels and scales (genetic, species, community and landscape). Also, quantitative information about changes of land cover, land use and landscape pattern, based on remote sensing data, can enable the identification of the main pressures on biodiversity on landscape level.

Report from the session

Biodiversity change is driven by many kinds of changes in stand structure, forestry and land use, lack of natural forest fires or abundance of human-induced forest fires, grazing, nitrogen deposition and climate change. It is also likely that there are multiple causes instead of a single one and in some cases the cause-effect relationships need to be further investigated.

Change of forest biodiversity is related to forest health and vitality. This can be demonstrated through the measurement of a range of biodiversity quality indices. The concept of biodiversity quality seems more useful in an operational

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[2] European Environmental Agency, Copenhagen, Denmark

context than the internationally agreed CBD definition of biodiversity, which is very wide and general.

In the frame of the European Environment Agency (EEA) programme SEBI2010 (Streamlining European Biodiversity Indicators by 2010), a specific forest qualitative indicator, taking into account status and trends of key characteristics of forest ecosystems, has been developed by the Italian Forest Service (Forest Status Indicator, FSI). FSI is based on sub-indicators identified and implemented at pan-European and national level, such as tree condition, forest structure, deadwood, plant species composition and naturalness. Input data are mostly available at European level and collected according to harmonised methods in EU pilot projects like ForestBIOTA and BioSoil, under the EU Forest Focus, the UNECE ICP Forests and ICP Integrated Monitoring programme, and in National Forest Inventories. Changes in the time and "distance" from a defined target or other reference values can be easily recognized by the change in shape of the applied "radar" diagrams.

Recommendations

Future forest biodiversity monitoring should also be able to address upcoming issues like climate change and increased harvest of wood for energy. Generally, future forest management is expected to give increased consideration to the multifunctional importance of the forest ecosystems. This may require new types of assessments, such as the planned EEA ecosystem assessment for Europe, and new participatory processes, and may also require the involvement of new bodies. It may need new sources of funding and include new or changed reporting obligations. However, also if new aspects of forest biodiversity and ecosystems will be monitored, it is important to capitalise on the experience gained by existing monitoring networks in order to implement the expanded monitoring quickly and without unnecessary costs. A specific trans-national project (FutDiv) has been submitted under the EC Regulation LIFE+, aiming at an extension of the existing forest monitoring at pan-European level, in order to include a harmonised system for long-term biodiversity monitoring, and to provide prompt responses to the requirements of the UN Convention on Biological Diversity.

Analysis of soil solution in the laboratory. Quality assurance procedures for laboratory work have been successfully implemented in recent years within the EU/ICP Forests monitoring programme. In the coming years, the development of a more comprehensive quality programme including in addition field assessments, data management and evaluations needs to be supported.

Overall quality assurance programs are needed to ensure the efficient use of resources

Marco Ferretti [1] and Nils König [2]

Key messages

Monitoring needs to provide reliable answers on reactions of forests to environmental stressors. This is essential to evaluate the results of environmental policy and for setting realistic targets for the management and conservation of environmental resources.

Effective monitoring has to rely on defensible and documented data: poor data quality leads to an increase of monitoring costs and to a loss of confidence in monitoring results. Since there are different sources of errors in designing and implementing a forest monitoring programme, Quality Assurance (QA) procedures are necessary to minimize their impact on the results.

A QA programme is therefore a vital need for any future monitoring programme. Proper QA should be applied to all the steps of a given programme or investigation, from monitoring design, to measurement and classification errors, errors caused by models and nonstatistical errors.

Summary of presentations

Although there was a general agreement that monitoring design is the area where most improvements are needed, the importance of measurement and classification errors should not be neglected. These errors may occur in the field (e.g. crown condition) as well as in laboratories (e.g. chemical analyses). Measurement errors in the laboratories were considered from two different perspectives: how to reduce errors and how to assess the impacts of possible errors on the results.

Results of intercomparisons between laboratories in Germany and the resulting quality control programme for the second German soil survey were described. They showed the benefits arising from a formal Quality Control Plan:

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[2] Northwest German Forest Research Station, Göttingen, Germany

the variability between labs was strongly reduced as soon as clear procedures, guidelines and standardized good laboratory practices were adopted. The collected data were also useful to document the progress in data reliability.

The impact of laboratory data quality on the monitoring results can be substantial. Poor quality of the instrumental analysis blurs the data to the extent that environmental monitoring or long-term ecological research programs can lose the ability to detect trends. This is a considerable problem for a monitoring programme that – by definition – aims to track the status of an environmental entity through time. If the quality of measurements is not satisfactory, the time needed to detect a given trend may increase considerably, and this has an impact on the monitoring costs.

For these reasons, a broad QA/QC concept is necessary. For example, the EANET (Acid Deposition Monitoring Network in East Asia) QA/QC programme covers all the activities, from site selection to data reporting. EANET recommends to develop a set of procedures and to have a national QA/QC manager, designated in each country to assist the network manager in implementing the monitoring activities. In addition, a number of steps are undertaken to cover specific monitoring needs, from plot-scale soil and vegetation monitoring to catchment-scale ecological investigations.

Recommendations

The various contributions emphasised the importance of documented, high data quality at all steps. In the past, a number of activities have been carried out in Europe to document and possibly improve the quality of forest monitoring data: crown condition training and intercomparison courses and ring-tests for laboratories are examples of this. These activities should be maintained and possibly extended to all the investigations carried out in the various forest monitoring programmes (including NFIs). A more comprehensive QA concept appears necessary to further develop and improve the forest monitoring in Europe. This new concept should be a reference framework for a consistent development of monitoring design and implementation. The new concept should be seen as a set of instruments and actions designed to ensure that methods are unambiguous, clearly presented, accepted and applied consistently across the monitoring domain.

Ideally, the concept should consider the various error sources and all the steps necessary to document and improve data quality:

- formal definition of the monitoring objectives
- clear definitions of attributes and reference standards
- sampling errors and non measurement errors
- analysis to identify necessary statistical power
- explicit, unambiguous indicators of data quality
- a set of procedures to be considered when data are of poor quality
- data storage
- data processing

Without being able to steer, control and document the quality of monitoring data, evaluations will be hampered, monitoring will fail to meet its objectives and will most likely result in a waste of time (and money).

Annex: List of oral presentations

Augustin, S.:	Linking critical thresholds for acidity to forest damage by using element contents in tree rings
Basaran, S. et al.:	Ambient Ozone Levels in the Eastern Mediterranean Region and Assessment of its Effect on the Forest Areas of Southwest Turkey
Beck, W.:	Growth patterns of forest stands –the biological system response to pollutants and climatic impact
Belyazid, S. et al.:	Modeling the combined effects of Nitrogen input and climate change on forest ecosystems: Implications for the critical loads of nitrogen
Bernhofer, C. et al.:	Impacts of climatic extremes on carbon fluxes: results from long-term monitoring
Bobbink, R.:	Plant species diversity in forests and the exceedance of N critical loads: results and future data requirements
Bytnerowicz, A. et al.:	Ozone effects on forest ecosystems in North America - a summary of research and monitoring activities, results and prospects
Castro, J. et al.:	Climate change alter recruitment success of woody species in a Mediterranean mountain (Sierra Nevada, SE Spain)
De Vries, W. et al.:	Effects of climate change, CO_2 fertilization and nitrogen deposition on growth and carbon sequestration of forest ecosystems in Europe
Dobbertin, M.:	Main achievements of forest monitoring and related research in Europe
Feest, A, et al.:	The measurement of biodiversity quality change and its application in the detection of environmental effects
Godbold, D. et al.:	Tree responses to elevated atmospheric carbon dioxide
Granke, O. et al.:	Biodiversity Assessment in Forests in the Focus of Climate Change – from Genetic Diversity to Landscape Diversity
Grebenc, T. et al.:	Ozone stress and ectomycorrhizal root-shoot signaling in beech
Johannessen, T. et al.:	Twenty-Five Years of Effects Research for the Convention on Long- Range Transboundary Air Pollution
Karlsen, S.R. et al.:	Satellite-based mapping of changes in the growing season in Fennoscandia
Karlsson, P.E.:	Ozone impacts on trees
König, N.:	The Achievements of the QA-QC working group of the German Forest Research Laboratories during the last 20 Years
Kuylenstierna, J.:	Climate change, pollutant deposition and the ozone situation worldwide. Implications for, and the role of European forests
Logan, J.A. et al.:	Assessment and Monitoring of Catastrophic Whitebark Pine Loss in the Greater Yellowstone Ecosystem
Larsson, T.-B.:	Forest biodiversity monitoring in Europe, status and future needs
Lorenz, M. et al.:	Deposition measurements and critical loads calculations: Monitoring data, results and perspectives
Lundin, L.:	Element budgets, acidification, nutrient N in a climate change perspective for the northern forest region
Manning, W.:	Defining Research Needs for Ozone and Forests: Cause and Effects Research
Matteucci, G. et al.:	Response and functioning of forest ecosystems to climate change: the need of better process understanding and integration of research and monitoring at different scales and levels
Matyas, C. et al.:	The effect of climate change on the health status and the distribution of beech in Hungary
Matyssek, R. et al.:	The Challenge of Making Ozone Risk Assessment more Mechanistic for Forest Trees
Moldan, F.:	Dynamic modeling of air pollution effects on forested watersheds in Sweden: current status, gaps and possibilities for further development
Nabuurs, G.J.:	European scale forest resource modelling at high resolution based on inventory data
Olschofsky, K. et al.:	Trans disciplinary Research on forest ecosystems under climate change: state of the Art and Future Needs
Pitman, R.:	What has monitoring shown and how can it be adapted to future drivers?
Posch, M. et al.:	Critical Loads and Dynamic Modelling of Nitrogen: Data Requirements for Forest Ecosystems
Reinds G.J. et al.:	Critical loads of sulphur and nitrogen for terrestrial ecosystems in Europe and Northern Asia; using Forest Intensive Monitoring data to assess uncertainties
Sase, H. et al.:	QA/QC activities and ecological monitoring in the Acid Deposition Monitoring Network in East Asia (EANET)
Schaub, M. et al.:	Ozone effects on forest ecosystems in Europe
Senyaz A. et al.:	Climate Change and Emerging Forest Research Needs in Turkey
Starr, M.:	Water and forest ecosystems - budgets, integration and linkages
Sulkava M. et al.:	Quality of monitoring programmes is determined by the quality of the collected data
Tonteri, T.:	Challenges of vegetation monitoring in analysing causes for ecosystem change: vegetation-based site classification in Finland as an example
Tuovinen, J.-P.:	Ozone flux modelling for risk assessment: status and future needs
Von Wilpert, K. et al.:	Forestry Management Options to maintain Sustainability – Element budgets at Level II Sites in South-West Germany
Waldner, P. et al.:	Assessing the risk of future changes of the nitrogen cycle of forest plots
Zimmermann, N.:	Measured versus interpolated climate data – what errors do we expect
Zimmermann, N.:	Potential future range shifts of European tree species – projections, discussion and possible implications for monitoring

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