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NATIONAL AND REGIONAL CLIMATE CHANGE IMPACT ASSESSEMENTS IN THE FORESTRY SECTOR - WORKSHOP SUMMARY AND ABSTRACTS OF ORAL AND POSTER PRESENTATIONS

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Abstract

Climate change is likely to affect forests and the forest industry during the 21st century. Different processes in forest ecosystems and the forest sector are sensitive to climate and many different projects have been conducted, in which the scale of study varied from the individual leaf to the whole globe. Several attempts have been made to link impact models (e.g., ecological and socio-economic models), and to integrate them in national or regional climate impact assessment studies. However, integration of climate impact assessments for the forestry sector is still a relatively new issue on the research agenda. From November 10 to 13, 1999 the Potsdam Institute for Climate Impact Research and the European Forest Institute organised a workshop in Wenddoche near Belzig (Germany) to bring together individuals and research groups from the currently developing research community, to provide a forum for the exchange of experience, and to stimulate further research collaboration.

The workshop attracted 31 scientists from 12 countries, representing a wide range of disciplines covering ecophysiology, soils, forest ecology, growth and yield, silviculture, remote sensing, forest policy, and forest economics. Several presentations investigated possible impacts of climate change on forest growth and development. A second major topic was the carbon budget and the possible contribution of forestry to carbon dioxide mitigation. The third important focus was the application of economic models to estimate socio-economic consequences of changes in forest productivity and the linkage of ecological and economic models. Non-timber forest benefits were addressed in one regional impact assessment and in two national integrated assessments from the U.S. and Germany. The latter also included social components with the involvement of stakeholders and the decision making of forest owners under global change.

An important objective of the NIMA workshop was to review the state-of-the-art of integrated climate impact assessments in the forest sector. Three working groups were tasked with discussing the state of knowledge, the currently available methodology, and the remaining uncertainties regarding (i) scaling up impact assessments from stand to regional and national scale, (ii) integrating cross-disciplinary impact assessments, and (iii) climate impact assessments and policy making. Among the issues discussed were scaling up methodologies (e.g. simplification of information, application of models in scaling up, error analysis), different ways of integrating cross-disciplinary impact assessments (linking, coupling, and roofing of simulation models), how to deal with uncertainties, and what information climate impact assessments can provide to policy making.

The participants felt that there is a need for improved cross-disciplinary research collaboration. After a successful and stimulating workshop it was agreed to organise another meeting to continue with the exchange of ideas and experiences, possibly in the U.S.

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Preface

This report is based on an international workshop which was jointly organized by the Potsdam Institute for Climate Impact Research (PIK) and the European Forest Institute (EFI) to review the state of knowledge regarding the integration of climate change impact assessments for the forestry sector. The workshop brought together 31 scientists from 12 countries, representing a wide range of disciplines covering ecophysiology, soils, forest ecology, growth and yield, silviculture, remote sensing, forest policy, and forest economics.

The workshop was supported by the Deutsche Forschungsgemeinschaft (DFG) and was held from 10 to 13 November 1999 at the Hotel Wenddoche near Belzig, Germany. I would like to thank Gabriele Dress of PIK for her great efforts in the organization of the meeting and the editing of documents for the workshop homepage and this report and Renate Kahle who took care of all financial issues connected to the workshop. Furthermore I would like to appreciate the support from Brita Pajari and Timo Karjalainen of EFI in the planning process of the meeting. Finally I would like to acknowledge the German Federal Ministery of Research and Technology for funding of the project GERMAN FOREST SECTOR UNDER GLOBAL CHANGE (DLR 01LK9528), which enabled significant research progress in the development of an integrated impact assessment for the forestry sector in Germany. his was a major motivation to organize this meeting.

This report compiles abstracts of all workshop presentations and summarizes the most important results and conclusions. Selected papers will be published in a special issue of Forest Ecology and Management. All documents of this report are also available online at the Workshop homepage at http://www.pik-potsdam.de/cp/chief/nima.html.

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Workshop Summary

National and Regional Climate Change Impact Assessments in the Forestry Sector (NIMA)

Compiled by Marcus Lindner with contributions from Frank Berninger, Wolfgang Cramer, Rüdiger Grote, Linda Joyce, Timo Karjalainen, Piers Maclaren, John Perez-Garcia, Manfred Lexer, David Price, Santi Sabaté, Brent Sohngen, Peter van der Meer, and other participants of the NIMA workshop

Climatic change is likely to affect forests and the forest industry during the 21st century. For the last 10 years, the possible impacts of a changing climate have been a major focus of national and international research. Different processes in forest ecosystems and the forest sector are sensitive to climate at greatly varying scales; therefore many different projects have been initiated, in which the scale of study varied from the individual leaf to the whole globe, covering many forestry-related disciplines including: ecophysiology, genetics, forest ecology, forest growth and yield, silviculture, resource planning, forest economy, and social sciences.

Several attempts have been made to link impact models (e.g., ecological and socio-economic models), and to integrate them in national or regional climate impact assessment studies. One such effort is the „German Forest Sector under Global Change“ project, in which both ecological and socio-economic impacts of climatic change on forests and the forest industry in Germany are being investigated, using a suite of different simulation models (a forest dynamics “gap type“ model, a single tree based forest growth simulator, a forest enterprise model and a timber market model, see also Biber, Döbbeler and Schlott in this volume). Another example is the currently ongoing first U.S. national assessment of climate variability and change, which is examining impacts on forest productivity, species distributions and shifts in community types, as well as economic aspects (Joyce, this volume). Other similar studies include linkage of the vegetation dynamics output from a gap model to a carbon budget model of the forest sector (Karjalainen *et al.* 1995; Karjalainen 1996); linkage of a large scale vegetation model with a timber market model (Sohngen & Mendelsohn 1998; Sohngen *et al.* 1998); use of impact assessments from vegetation and pest dynamics models for forest management planning (Lexer 1997; Lexer & Hönninger 1998); and the analysis of possible consequences of changes in forest productivity on the national forest sector (Nabuurs & Moiseyev 1999).

Integration of climate impact assessments for the forestry sector is still a relatively new issue on the research agenda. The motivation behind the workshop was to bring together individuals and research groups from the currently developing research community, to provide a forum for the exchange of experience, and to stimulate further research collaboration.

The workshop attracted 31 scientists from 12 countries, representing a wide range of disciplines covering ecophysiology, soils, forest ecology, growth and yield, silviculture, remote sensing, forest policy, and forest economics. Several presentations investigated possible impacts of climate change on forest growth and development. A second major topic was the carbon budget and the possible contribution of forestry to carbon dioxide mitigation. The third important focus was the application of economic models to estimate socio-economic consequences of changes in forest productivity and the linkage of ecological and economic models. Non-timber forest benefits were addressed in one regional impact assessment and in the two national integrated assessments from the U.S. and Germany. The latter also included social components with the involvement of stakeholders and the decision making of forest owners under global change. The general emphasis of the presentations indicated that there is a relatively strong research community investigating ecological impacts of global change, and increasing interest in economic impacts and policy recommendations (especially in the context of carbon mitigation and the post Kyoto process). To date, however, there seems to be relatively little involvement from the social sciences in forest sector impact research.

Regional impact assessments

Four regional studies were presented from Austria (Lexer), Brandenburg/Germany (Lasch), Catalonia/Spain (Sabaté), and the Netherlands (van der Meer).

1. Manfred Lexer introduced a climate change impact assessment study for Austrian forests which utilised spatially explicit soil, climate and vegetation data, and dynamic modelling techniques. The 3D-patch model PICUS (Lexer & Hönninger 1998; Lexer & Hönninger 2000) was applied to project forest development starting from current stand structure and composition of 3300 Austrian forest inventory plots. Included in PICUS is a bark beetle risk model to account for catastrophic bark beetle induced mortality of Norway spruce. In order to estimate adaptation potentials a hierarchy of indicators, both for the short to mid-term and the long-term adaptation potential, were applied.

2. Water stress and forest fires are key processes in Mediterranean forest ecosystems: the study presented by Santi Sabaté underlined the concern that climate change may impose additional stresses in these systems. The model GOTILWA and results of model runs from the EU-funded LTEEF-II project were presented. Without drought stress there was a clear effect of increasing atmospheric CO_2 concentration on forest growth, whereas in the case of reduced water availability, increased CO_2 did not affect growth. Simulation results and empirical evidence from a strong drought period in 1994 indicate that adaptive management can reduce the susceptibility of forest stands to drought stress, because thinned stands are less affected by extreme drought.

3. The third regional impact assessment study, of climate change impacts on forests in the state of Brandenburg (Germany), was presented by Petra Lasch. The analysis included both managed and unmanaged forests and investigated the effect of different management strategies on forest structure and function. Although forest productivity responded strongly to climate change, the composition of 480 investigated forest stands was determined mainly by management strategy. The climate scenario investigated in this study had a negative effect on carbon storage, ground water recharge and the majority of biodiversity indicators.

4. Peter van der Meer reported a Dutch case study on the effects of climate change and ungulate grazing on succession in a pine forest, in which information from a complex process- based forest model was transferred to a simpler gap model based on light-use efficiency. Simulated light use efficiency was changed with increasing carbon dioxide concentrations and changing temperatures using relationships derived from the process-based model. The results showed that climate change and grazing may accelerate the succession but not the general trend and the final outcome of succession. Elevated carbon dioxide concentrations increased production while grazing and higher temperatures decreased production.

Although in some cases a need for a more sophisticated representation of soil processes and of below-ground allocation was detected, the major uncertainties in the regional studies were not assumed to be in the level of detail of the processes implemented in the models. Instead, the importance of using realistic patterns of inter-annual, intra-annual, and perhaps also daily, climate variability was stressed because this variability is the key factor in the occurrence of extreme events. Such events include both direct effects of climate (e.g. drought) or indirect effects (e.g. increased probabilities of fire or insect damage). The second important issue needing further work is the representation of extreme events themselves.

Forest management was discussed as another important influence that can positively or negatively affect the response of forests to changing environmental conditions. Drought periods in Spain, for example, were shown to have much severer effects on the trees if they occurred in dense stands with high potential evapotranspiration. Management scenarios should be further elaborated in regional impact studies. In particular, the sensitivity of forest responses to management alternatives, and thus the possibilities for mitigating negative impacts on growth, deserve further investigation.

Economic impacts of climate change induced vegetation changes

Two global analyses presented by John Perez-Garcia and Brent Sohngen aimed to connect simulated effects of climate change on forest production to economic impacts, while recognizing the sensitivity of these effects to the choice of the climate change scenario. It was agreed that future effects on global economy cannot be predicted with confidence because of major uncertainties in (i) the climate change scenarios, (ii) the simulation of biological responses, and (iii) the effects of political decisions, the latter probably being the most important. Consequently, efforts should be directed towards the reduction of uncertainties rather than towards the analysis of specific scenarios. One approach should be to determine more appropriate linkages between models, for example to use carbon or stem volume instead of NPP as a measure of timber supply for economic evaluations, because these represent a level of aggregation, where responses can actually be observed in the "real world".

If no major changes in the political boundary conditions are assumed, both economic impact assessments predict a general decline of wood prices due to increasing wood supply. Because it is expected that the major part of this surplus in supply will be gained from low latitude plantations, suppliers in many developed countries might be subjected to higher competition. This may also lead to increasing wood stocks and thus carbon storage in the less accessible regions of the world. It should be noted, however, that on a short-term perspective stock decreases are likely to occur in many regions, where declining forests cannot be replaced by more suitable species at the same rate.

National impact assessments

National case studies were presented for the U.S., Germany, Canada, and Russia. For the U.S., Linda Joyce presented the national assessment of the potential consequences of climatic variability and change. She stressed an integrative approach where investigators with a wide range of different skills and backgrounds participated. The national assessment process considered not only forestry but also water availability, human health, agriculture, forests, coastal zones and marine resources, native people and reservation areas. Very important in this assessment were the interaction with stakeholders and strong regional participation. Two climate scenarios, from the Hadley Centre and the Canadian Climate Center, were investigated, resulting in different pictures in the impact assessments

Peter Biber from Germany presented the SILVA model, a single tree-based, distance-dependent forest growth simulator, which uses a three dimensional approach with statistically-fitted model equations. The model employs a potential height growth approach, based on a parameterization for a broad range of site conditions. Designed for forest management purposes primarily, the model has also been applied in regional and national scale impact analyses where it can be linked with socio-economic models. A more detailed model, based on a layered representation of stand balances of carbon, nitrogen and water, was presented by Rüdiger Grote. The latter model produces a balance between environmental impacts and feedback responses, both at tree level (growth) and stand level (competition).

The SILVA model has been used in the "German Forest Sector under Global Change" project to simulate the growth of representative forest stands of a virtual forest enterprise which was introduced in a separate presentation by Walter Schlott. Whereas much research has focussed on the impacts of climate change on forest ecosystems and on quantitative economic effects of changes in forest productivity, few investigations have considered forest owners' strategies and changes in the legal framework. Schlott described a strategy for dealing with these problems. Based on German forest inventory data, a virtual forest enterprise was defined, which was managed according to four different forest management strategies: “silvicultural optimum“, “social benefits“, “timber production“, and “do nothing“. Future changes in the legal framework were anticipated through expert interviews. Discussion following the talk focussed around the question of how different management strategies can be evaluated.

David Price and Grant Hauer presented an outline of a linkage between the Integrated Biosphere Simulator (IBIS model of Foley et al. 1996) and an economic partial equilibrium model for use in national scale assessment of climate change impacts on the Canadian forest sector. Proper consideration of regional and national forest age-class dynamics is key to this assessment, because they determine annual harvestable timber volumes, while being very sensitive to changes in the natural disturbance regime, which is important for the future carbon storage role of Canada’s forests. IBIS estimates forest biomass (which can be treated as an index of timber volume and related to economic value), NPP (an indicator of timber production) and all ecosystem carbon pools. At the same time IBIS can simulate large-scale changes in dominant cover types. Problems identified were model validation at the large scale, the simulation of disturbance effects on forest age structure, and the linkage to economic assessment models. Some modifications are being introduced to simulate forest age structure within single IBIS grid cells. On a 0.5 degree resolution, predictions of biomass for the west coast were poor, probably because of problems in climate data interpolation in the mountainous terrain characteristic of this region. Ongoing research aims at using IBIS estimates of changes in biomass and NPP to drive regional economic assessments based on inferred changes in land values.

Vladimir Stolbovoi stressed the need for data base development to link climate, vegetation, terrain, topography, soils, land categories and agricultural data, together with statistical inferences at the continental scale. He pointed out the need for an integrated database that allows analysis from a systems viewpoint. Dramatic changes may happen at the current limits of forest ecosystems, for example at the southern border of the boreal forest in Russia. He stressed the importance of carrying out “full carbon accounting“ when constructing a global C budget, to avoid missing some sinks; some current IPCC practices produce only a partial carbon budget.

Pierre Bernier presented the Canadian ECOLEAP project that focuses on scaling up process-based forest productivity models from the tree to the landscape, but with a spatial resolution that remains pertinent to forest management. The project addresses questions related to the impact of climatic change on forest productivity, but still wants to maintain strong links to the forestry-level applications. In order to maintain these links, Bernier emphasized the need to integrate databases and concepts familiar to the forest management community into the research effort to facilitate the acceptance of new models and methods. Also discussed was the need to produce different tools for different objectives as a single model could clearly not satisfy all objectives of the project.

Carbon storage and mitigation potentials

The last group of papers focussed on the carbon balance and how countries could assess carbon stocks within their forests.

Rod Keenan presented the use of the process-based model 3PG to estimate the carbon balance of a state forest in Australia. He discussed problems with initialisation of the model from standard inventory data, particularly how to determine site classes from independent variables. He also addressed the potential drawbacks of initialising the model from plot data. Keenan claimed that errors of the model at a single location may be large while results at larger spatial scales were more realistic. Spatial averaging of model inputs did not cause particularly large errors in his case.

Jari Liski presented methods for using forest inventory data to assess carbon in forest soils and commented on the utility of these approaches for estimating total ecosystem carbon. The approach used forest inventory data from 1950 to 1990 to estimate historical soil carbon, and then projected soil carbon into the future using forest inventory projections for each Western European country to 2040. The analysis suggested that forest soil carbon is increasing in Western Europe although there are a number of factors which introduced considerable uncertainty into these results. These factors include: estimation of litter production from living trees; an assumption that wood biomass density (kg m^{-3}) remained constant over the tree life history; the assumption that forest soil carbon was in equilibrium in 1950; and the assumption that climate has been constant and would remain constant. Liski concluded that the greatest improvement in estimating soil carbon would result from closer examination of litter production estimates.

Timo Karjalainen presented research related to the LTEEF-II project to estimate climate change impacts on forest carbon across Western Europe. Jari Liski's study was one part of this much larger study. The LTEEF-II study links process-based models, forest inventory, and large scale scenario modelling in order to account for forest carbon budgets at the country level in Western Europe. Process-based models and detailed information within each country provided the ecological information on forests, while the scenario-based model operated at the country level. The analysis for Finland was presented as a case example. Future carbon budgets for the forest sector were projected without climate change and with climate change. Based on these analyses, Karjalainen concluded that research can provide information to decision makers about the functioning of the forest system, the potentials and uncertainties of the system, and the sensitivities of the system to changes in management and climate.

Piers MacLaren presented a comparison of the carbon accounting methodologies currently under discussion to estimate national forest carbon budgets. He contrasted the real-time tonne-years approach with his proposed method of a one-off stock change. He criticised the potentially large costs of computing carbon based on the real-time accounting approach. In addition, afforestation in the tonne-years approach was not seen as symmetrical to deforestation. The one-off stock change approach generated much discussion in the group as the methodological aspects were scrutinized and the incentive implications to forest managers were explored. MacLaren maintained that this approach would facilitate a movement to increased tree planting and stimulate the formation of a sustainable biomass resource.

Working group discussions

An important objective of the NIMA workshop was to review the state-of-the-art of integrated climate impact assessments in the forest sector. Three working groups were tasked with discussing the state of knowledge, the currently available methodology, and the remaining uncertainties regarding

- Scaling up impact assessments from stand to regional and national scale. The group considered both temporal and spatial scaling. Scaling up may be a simple transfer of information, but it may also be a more complex process including some extraction/ simplification/ reparameterisation of data, models and/or model results.
- Integrating cross-disciplinary impact assessments. The group defined integration as linking between at least two different disciplines, whereas the coupling of different layers of information within one discipline was referred to as increasing complexity.
- Climate impact assessments and policy making. The group tried to define which kind of information policymakers do ask for and what needs for further research in ecology, economics and social sciences are resulting.

Scaling up impact assessments from stand to regional and national scale

It appears that relatively little formal knowledge on scaling up methodologies exists. Notable examples include problems addressed in landscape ecology (O'Neill *et al.* 1986; O'Neill 1988; King *et al.* 1990), and in particular aspects of micrometeorology (e.g., Jarvis & McNaughton 1986). In general, researchers attempt to judge what is appropriate in the specific context of the problem which they are addressing. They should attempt to acknowledge the feedforward/ feedback processes across temporal/ spatial scales by strictly applying appropriate scaling rules. This approach leads to the following issues:

- In models which aggregate from fine scale data to coarser scales ("upscaling"), many variables will become constants due to a lack of information on them. Data quality/resolution is invariably worse at the landscape level compared to plot/stand level. Thus, simplification (at the coarser scale) is an appropriate approach. In contrast, if important processes/features are lost by such an approach (i.e., those factors which are sensitive to environmental change), then direct transfer of information from plot/point level to landscape level might be necessary, even when the resultant errors may be large and unquantifiable.
- In general, scaling implies the application of some form of model. In some cases, such as stock-based estimation of woody biomass or total carbon, the model may be very simple and requires sample data obtained according to an acceptable sampling strategy (i.e., error statistics are determined directly from measurements). In other cases, it may be a complex process model requiring lots of spatially and/or temporally detailed data that are largely unobtainable; in such cases, uncertainties are present at many points in the scaling methodology: in the assumptions used to construct the model; in the values of parameters, and in the input data which often require some form of interpolation or other large-scale manipulation.

Other questions addressed by the group included:

- Can extreme events be scaled in time? For example, can the effects of frost events be adequately represented when rolling up daily minima to obtain monthly extreme minima? Proper simulation of unusual frost events (the timing of which can also be expected to change with a warming climate) derived from monthly data would require that assumptions concerning the sequence of frost occurrences be made. Are such assumptions important? It will be crucial to ask similar questions for all climate variables of importance.
- How can error analyses be performed satisfactorily when scaling data from point to region? Error limits should be assessed and reported in a meaningful way so that stakeholders do not place undue confidence in the scaled results.
- How do we deal with effects of larger scale processes (e.g., disturbances) which may not be considered in fine scale measurements, but could dominate them at large spatial scales over longer periods?

In a short discussion of "emerging technologies", there was general agreement that remote sensing offers several possibilities for providing data useful for validating models at larger scales. There are also specific instances of using satellite data as input, e.g., NDVI to estimate leaf area index, but such approaches still require considerable investment in ground truthing if uncertainties are to be reduced to acceptable levels. Another method of interest is isotope ratio discrimination applied to soil parameters such as decomposition and nitrification. Isotopes of interest include: ^{18}O, ^{15}N, ^{13}C.

Integrating cross-disciplinary impact assessment

The simplest, and to date the most common, method for linking cross-disciplinary impact assessments is a "one-way" approach where information from one disciplinary model/assessment is fed into another model/assessment. This approach lacks true integration and often is imbalanced because the different components are treated with greatly varying detail and accuracy.

The currently limited ability of modelling systems to handle data or computations may impose limits on true integration because it forces simplification and reduction of complexity. The evolution of models has mostly been within disciplines and interdisciplinary work on a common integrated approach is still exceptional, at least for forest sector impact assessments. Ideally, interdisciplinary groups should work together to decide how much detail to keep/carry in the different components of the integrated assessment. Consequently, the collaboration between disciplines should begin at an early stage of an integrated assessment project, rather than being delayed until close to project completion.

Social sciences sometimes depend on qualitative methods (e.g., in assessments of biodiversity and recreation), which may be difficult to link with the more quantitative methods generally used in natural sciences or economics.

Three ways of integrating cross-disciplinary impact assessments were discussed and compared: *linking*, *coupling* and *roofing*. Linking was characterised above as a one-way approach without any feedbacks between models/assessments. With coupling of separate models, there is usually more exchange of information between models/assessments (e.g., every time step) and feedbacks could also be included. Roofing was considered to be the third step, where different sub-models are imbedded into a common model framework.

In coupling (or roofing) models often become (over-) simplified, which often causes criticism of disciplinary scientists. There is no fully integrated (roofing) model in the forestry sector that achieves balance in the representation of disciplinary processes, and sub-models are not always compatible with one other (e.g., in time step, spatial scale, aggregation, computation platform, ...)

How big are the remaining uncertainties, how do we deal with them?

Perhaps the most important point is that there exists the perception of uncertainties in modelling results. From the notion of uncertainty we conclude that it is important to identify the reasons of uncertainty. Uncertainties in the results of impacts studies may originate from a variety of causes: (i) in data needed to drive models (e.g., climate change scenarios, spatially extrapolated climate and/or soil data), (ii) in implicit/explicit model assumptions (e.g., light response curves at the leaf level applied at the stand level; adopting the species as the basis of parameter estimation (thus neglecting genotypic variability)), (iii) key processes which are known to be extremely variable (in time and/or space), for which scaling algorithms or models cannot provide estimates of acceptable accuracy (e.g., soil respiration).

To know how large these uncertainties are, there is just one solution: Quantify them! Quantification might be achieved by appropriate sampling procedures from the population of possible parameter/data values (e.g. Latin hypercube sampling). Scenario analysis techniques where the range of possible parameter/data values is tested for its effects on model output offer another way of evaluating uncertainties. Furthermore, the explicit definition of assumptions made in scaling would help in the identification of uncertainties. It was agreed that it should be obligatory to include some uncertainty measures in research reports/scientific papers to improve the applicability of results.

What happens to uncertainty when models are integrated? It could propagate largely unchanged, multiply or cancel out, but there is also the possibility of additional new uncertainties. There is a need to track uncertainties from input (measurements) through the different stages of model calculations all the way to final output. Confidence intervals would be useful in this respect. Combination of many scenarios (in general there is uncertainty in each disciplinary component) will always increase complexity: therefore it is essential to limit the number of scenarios.

There are several ways of dealing with uncertainty in integrated assessments:

- Focus on the extremes as well as the central tendency (i.e., be careful with "best guesses", even though these are sometimes necessary). Build a framework of possible pathways.
- Use scenario analysis and sensitivity analysis to characterise uncertainty
- Ensure logical consistency within methods of integration: this should allow modellers to limit the effects of passing uncertainty from one model to the next. The number of scenarios can be limited by identifying extreme cases at the outset.

Given the large number of sources of uncertainties it may be important to consider whether models provide correct *trends* even if though they may be highly inaccurate in absolute terms.

Climate impact assessments and policy making

Are climate impact assessments of interest to policy making? Policy-makers are very sensitive to news media headlines. Because research results from climate impact assessments are normally not spectacular enough to raise interest in the media, there are only specific impacts of climate change which are an issue for policy makers. Most people do not seem concerned about what will happen in 100 years' time - this is too far in the future and people have more immediate concerns. Sudden events such as disturbances (drought, fire, pests) with catastrophic and spectacular impacts appear in the news and dominate the public perception of climate change impacts. In contrast, gradual changes in species composition, which could have more drastic economic consequences, are hardly newsworthy. (In Germany, however, the situation seems to be slightly different, because German culture and history was strongly shaped by woodlands and certain tree species.)

If climate impact research is to have an effect on policy making it must "measure" the effects policies intend to change, because policy makers use measures to gauge effectiveness of programs. For example, the impacts of a 2 degree warming on physiological changes at the forest level will have little implications for policy making until the right "measure" is defined, which in this case could be the area of forest die-back.

In this context the most important questions regarding the impacts of climate change on ecology are from a policy point of view (in approximate order of priority):

1. What are the impacts of disturbance regimes on forest growth and carbon storage?
    a) Catastrophic disturbances, e.g., droughts resulting in forest death, extreme fire events, extreme pest epidemics, collapse of the North Atlantic circulation leading to general cooling of Europe.
    b) Increased incidence of normal disturbances, e.g. fire, snow, wind, insects/pests, and erosion.
2. What is the impact on global and regional freshwater supply, especially as influenced by the change in forest cover?
3. What is the impact on biodiversity? How quickly can natural ecosystems migrate or adapt?
4. What is the impact on carbon sequestration and emissions? (This is largely known, except for the wood products and soil carbon pools).

Perspectives for improved research collaboration

There is a need for cross-disciplinary collaboration, including greater interaction between foresters and ecologists. Other essential disciplines include climatology, policy analysis, economics and other social sciences. There is also a need to involve scientists from countries who tend to be poorly represented at climate conferences, especially Japan, China, Russia and the Group of 77. Better communication among disciplines and between countries is as important as collaboration, but this is often inhibited by lack of fluency in a common language.

Possibilities to improve successful collaboration:

- increased sharing of data and models ("model shootouts"). This is perhaps most productive on a one-to-one basis rather than through big organised intercomparisons (although the latter certainly have their place). Model comparisons are useful as a practical means of allowing researchers to identify and concentrate on the limitations of their models. Publications reporting the results of such comparisons are an additional benefit.
- inter-disciplinary studies. Many researchers tend to make gross assumptions about the factors for which they are less knowledgeable. By involving more people from different disciplines, many of these gross assumptions can be challenged and/or tested before too much effort is invested in them. At the same time, some intra-disciplinary approaches also need to be sacrificed (or at least modified) to enable integration.
- test agreement between estimates obtained from models operating at different spatial resolutions -"hierarchical approach to scaling".

For a balanced integrated approach, collaboration is needed. Researchers should work together from the beginning, preferably before any models are developed and certainly before linkages are attempted (an ad hoc basis not always good enough). Successful collaboration also requires a co-ordinator/facilitator/moderator to organise (and respond to the concerns of) the different disciplinary groups.

The success of the NIMA workshop showed that meetings of inter-disciplinary research groups and the exchange of experiences and ideas can be an important basis for research collaboration. There is currently no institutional framework to organise meetings of this relatively new and diverse research community. Among the possibilities discussed was an initiative to develop a proposal to set up a IUFRO working group on integrated forest impact assessments. The reorganization of GCTE and other IGBP programmes may also offer improved institutional support in the future.

Funding for joint projects that bring together groups from different continents is difficult to obtain. A useful first step may be to link projects within individual regions, using existing national funds. A similar problem is caused by the narrow disciplinary structure of many funding agencies, which often have difficulties dealing with inter-disciplinary projects (although everybody calls for inter-disciplinary collaboration!).

It was agreed to investigate the possibility of organising the next meeting on integrated forest sector impact assessments as a NCEAS workshop in Santa Barbara (California, U.S.).

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The Potential Impacts of Climate Change in the Eastern Alps. A Risk Assessment Based on Large-scale Forest Inventory Data

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Austrian forests comprise a wide range of ecological site conditions from high altitude coniferous mountain forests to low elevation forests dominated by broadleaved species. These forests in general have to serve a multitude of functions and in particular play an irresistible role in maintaining alpine landscapes. Discussions on a likely global climate change give rise to questions on possible impacts on forest ecosystems. To integrate available knowledge vegetation models which are responsive to environmental changes are employed. So far model applications to assess the potential impacts of climate change on forests share one or more of the following features: (i) simulation studies for individual more or less synthetic site conditions conducted with forest succession models of the gap-model type miss the spatial dimension and coverage, (ii) risk asessment studies with static vegetation-site equilibrium models miss the individualistic nature in the formation of vegetation composition, (iii) the non-consideration of todays forest composition and structure in simulation experiments. In an attempt to circumvent these limitations the objectives of the described risk assessment were:

- representative for Austria´s forests
- the utilization of spatially explicit soil, climate and vegetation data
- the application dynamic modelling techniques
- the consideration of composition and structure of current forests

Approximately 3300 sample plots of the Austrian Forest Inventory (AFI) which represent the various vegetation/site-combinations of Austrian forests were selected. To initialize a dynamic vegetation model quantitative soil information is required. Unfortunately large scale forest inventories such as the AFI do not provide such information. Therefore the site water holding capacity (WHC), the pH-Value (PH) as well as the C/N-ratio (CN) of the uppermost 30 cm of mineral soil were estimated by means of probabilistic relationships which had been parameterized from a subsample of the AFI with detailed soil data (Lexer and Hönninger, 1998a, Lexer et al., 1999a). To initialize model runs with current species composition and stand structure species specific diameter distributions for trees with dbh > 5 cm were calculated from the vegetation data of the AFI (Anonymous, 1995). Existing regeneration might be of particular importance for the response of forests to a changing environment. Therefroe from the data of the AFI a seedling pool for each site was calculated which considered the five most abundant species in the regeneration layer in six height categories.

The newly developed 3D-patch model PICUS v1.2 (Lexer and Hönninger, 1999) is applied to project forest development starting from current stand structure and composition. PICUS v1.2 operates on a 10 x 10 m^2 - basis where the vertical dimension is depicted by canopy layers of 5 m width. PICUS includes a radiation submodel for direct and diffuse radiation above and within the canopy. Compared to earlier patch models substantial modifications were made with regard to the temperature response functions. These modifications were based on an analysis of stand growth data from the combined network of forest inventory, soil and meteorological data (Lexer and Hönninger, 1998b). In contrast to other "classical" patch models in PICUS v1.2 tree growth is not restricted at superoptimal temperatures. A fuzzy logic controll approach is used to calculate a knowledge-based estimate of tree response to site nutrient status from WHC, PH and CN (compare Lexer et al., 1999b). Included in PICUS is a bark beetle risk model to account for catastrophic bark beetle induced mortality of Norway spruce (Lexer and Hönninger, 1998c). PICUS requires monthly temperature and precipitation data which are provided by a weather generator. Monthly mean temperatures are stochastically drawn from a normal distribution, precipitation from a 2-parameter gamma distribution.

For the risk assessment we required current climate and climate change scenarios. Current climate for all AFI-plots was extrapolated from the network of more than 600 Austrian weather stations by inverse distance weighing techniques (IDW). It is planned to derive transient climate change scenarios by means of statistical downscaling techniques. This task imposes particular difficulties due to the heterogenous alpine landscapes. This part of the study is not yet finished. To demonstrate the risk assessment methodology we used average anomalies for temperature and precipitation of GCM gridpoints over Central Europe. According to this procedure it is assumed that summer temperatures increase linearly by 2.5 °C until the year 2050; winter temperatures by 2.0 °C. Accordingly precipitation is assumed to decrease by 15 % in summer. From the year 2050 on it is assumed that climate has stabilized again just varying around the longterm means.

To identify climate change impacts on vegetation development the vegetation anomalies between a control run under current climate and a run under the climate change scenario are quantified by means of a similarity measure (Bugmann, 1994). To represent short- to midterm climate change impacts this similarity criterion is calculated for the years 2010, 2020, 2030, 2040 and 2050 respectively. The comparison of the potential natural vegetation (PNV) under current and future conditions is used to characterize a shift in the ecological site potential. Finally the current species composition is compared with the set of species present in the PNV under altered climate. An additive utility function from multiple-attribute-utility-theory (MAUT) (compare Keeney and Raiffa, 1993) is utilized to synthesize these assessment criteria to indicators for the short- to midterm adaptation potential (SMAP) and to the longterm adaptation potential (LAP) respectively (*Figure 1*).

The parameters in the additive utility model are estimated by the eigenvalue method as presented by Saaty (1996). This method utilizes pairwise comparisons on a ratio scale to derive preference values for the elements under evaluation.

The described methodology is demonstrated for a subset of AFI-plots in the ecoregion 4.2 ("Northern front range of the Alps"; Kilian et al., 1994). Figure 2 presents the distribution of indices for SMAP stratified into todays submontane (450 – 700 m a.s.l.) and montane (750 – 1400 m a.s.l.) vegetation zone. It can be seen that forest diebacks are only indicated for a minority of plots in the submontane zone. This feature is due to secondary Norway spruce forests which had been planted at todays moderately dry silicatic beech sites. Figure 3 presents the indices for LAP accordingly. It is obvious that the forest model simulates substantial shifts in PNV-species composition, both in the submontane and montane vegetation zone. From this follows that todays forest composition largely differs from the simulated future steady state species composition, thus indicating a rather poor longterm adaptation potential to the ecological site conditions.

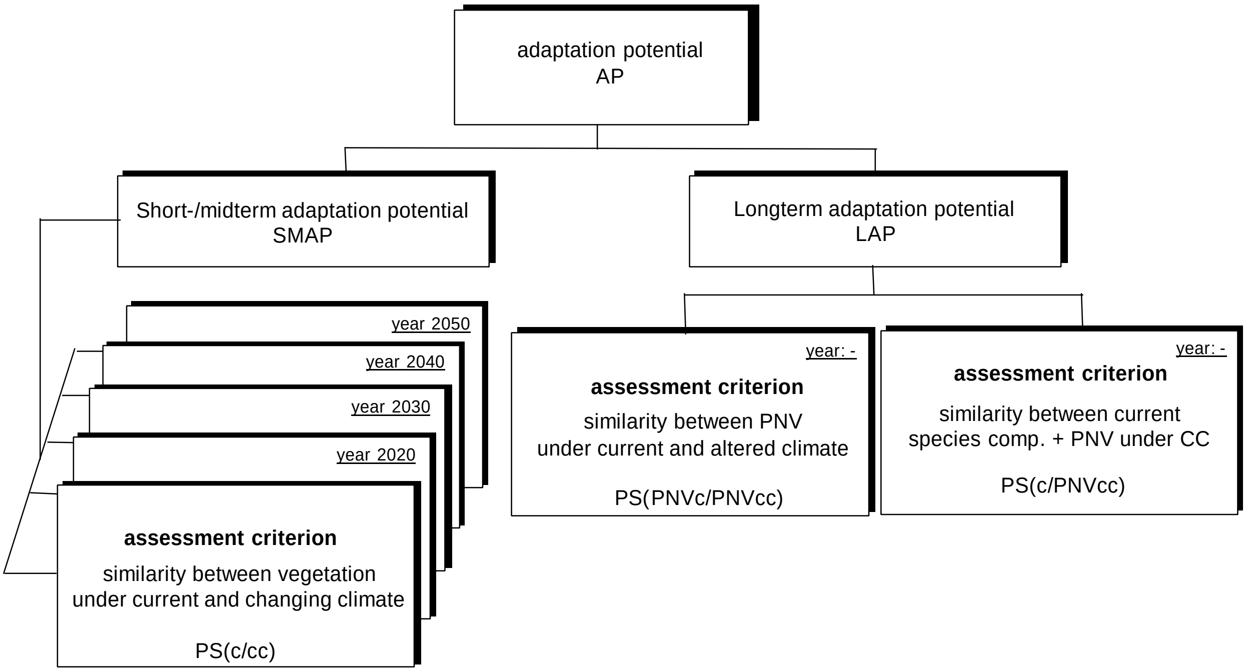

Figure 1: Hierarchical structure for the aggregation of assessment criteria to indices for the adaptation potential of current forests.

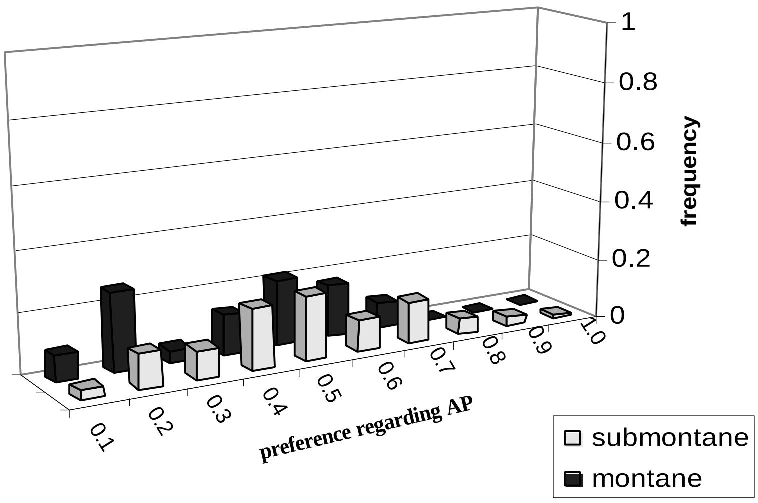

Figure 2: Distribution of indicator values for the longerm adaptation potential (LAP) of current forests in the submontane and montane vegetation zone of ecoregion 4.2 (Kilian et al., 1994). – Low values of LAP denote low adaptation potential.

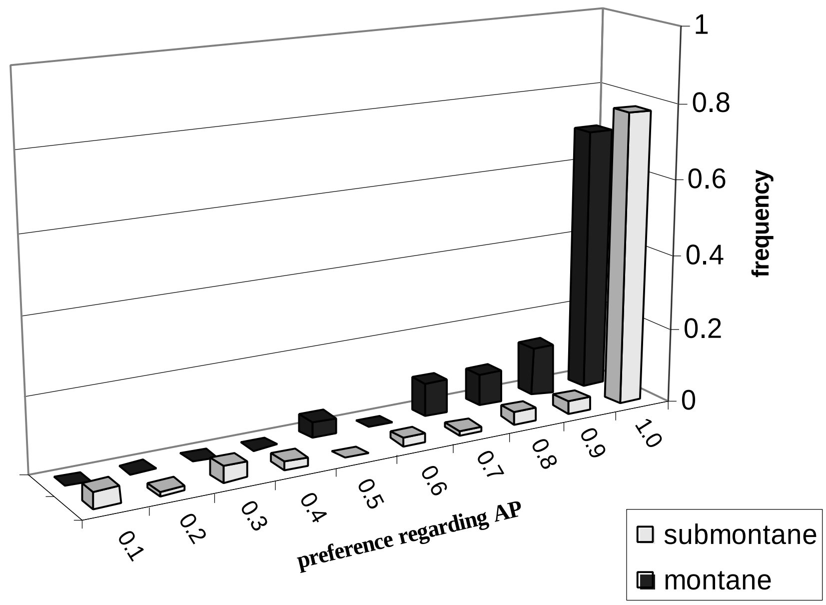

Figure 3: Distribution of indicator values for the short-/midterm adaptation potential (SMAP) of current forests in the submontane and montane vegetation zone of ecoregion 4.2 (Kilian et al., 1994). - Low values of SMAP denote low adaptation potential.

From the results it is concluded that the presented methodology is well suited to identify potential problem areas where the functioning of forests might not be granted under the assumed climatic changes. However, to derive forest management measures to mitigate the impacts of a potential climate change and to secure the sustainable functioning of alpine forest ecosystems forest management has to be considered explicitely. What is important to note, that optimized silvicultural response strategies within the frame of a multiple objective forestry have to be planned at larger spatial scales than at the stand level.

Acknowledgements:

This work was conducted within the research study "The Adaptation Potential of Austrian Forests under Scenarios of Climatic Change" jointly funded by the Federal Ministry of Agriculture and Forestry, the Federal Ministry of Environment, Youth and Family Affairs and the Federal Environment Agency. We are grateful to Karl Schieler, Klemens Schadauer, Franz Starlinger and Michael Englisch for making the data of the Austrian Forest Inventory and the Austrian Forest Soil Survey available as well as for valuable comments.

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Regional Impact Assessment on Forest Structure and Functions - The Brandenburg Case Study

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A forest simulation model has been applied in a regional impact assessment to investigate impacts of a changing climate on forest structure and function in the Federal state of Brandenburg, Germany. The forest model FORSKA-M (Lasch et al. in press; Lindner in press) was linked to a GIS that included soil and groundwater table maps, as well as to climate data. Two climate scenarios were used to assess the sensitivity of species composition to climate change. The current and climate change scenario (1.5 K temperature increase which is combined with a precipitation decrease varying from 40 to 140 mm) were produced by a statistical method (Werner & Gerstengarbe 1997) for 40 meteorological stations in and around Brandenburg. Furthermore, the implications of vegetation changes for other forest functions were analysed by means of several indicators. To evaluate the impacts of climate change on biodiversity measures of species diversity (Shannon and Simpson- index) and habitat and structural diversity (Seibert-index, Seibert 1980) were applied. The evaluation of impacts on ground water recharge of natural and managed forests was carried out using empirical functions developed for forests in the state of Brandenburg (Simon 1984) and the soil water balance model of FORSKA-M.

At first, model simulations of the potential natural vegetation on the whole area of Brandenburg with different climate scenarios were analysed. The results indicated that climatic warming would lead to a shift in the natural species composition in the state of Brandenburg towards more drought tolerant species. The simulated diversity of the forests would be reduced, and ground water recharge would be decreased.

The majority of forests in the state of Brandenburg have been managed intensively in the past. At present, large areas of Brandenburg's forests are dominated by pure stands of Scots pine, but current forest management practice aims at increasing the share of deciduous and mixed forests. In order to analyse the possible consequences of climate change on forest management, forest inventory data were used to initialize FORSKA-M with representative forest stands. Simulation experiments were run with three different adaptive management strategies (Lindner, M. in press): (i) MS1 - traditional management, favouring economically important species, (ii) MS2 - adaptive forest management, favouring the climatically best adapted species, and (iii) MS3 -maximising species diversity.

The simulation experiments with managed forest stands showed that the short to mid term effects of climatic change in terms of species composition were not as severe as expected. Figure 1 demonstrates the similarity of simulated forest types under both climate scenarios. However, the comparison of different diversity measures (figure 2) indicates a decrease of the species diversity in contrast to an increase of habitat diversity under climate warming. Furthermore, a decrease in productivity and carbon storage was simulated under the climate change scenario.

The regional impact assessment corroborated the high sensitivity of natural forests in the region to the projected climatic change and it underlined the importance of adaptive management strategies to help forestry to cope with climatic change.

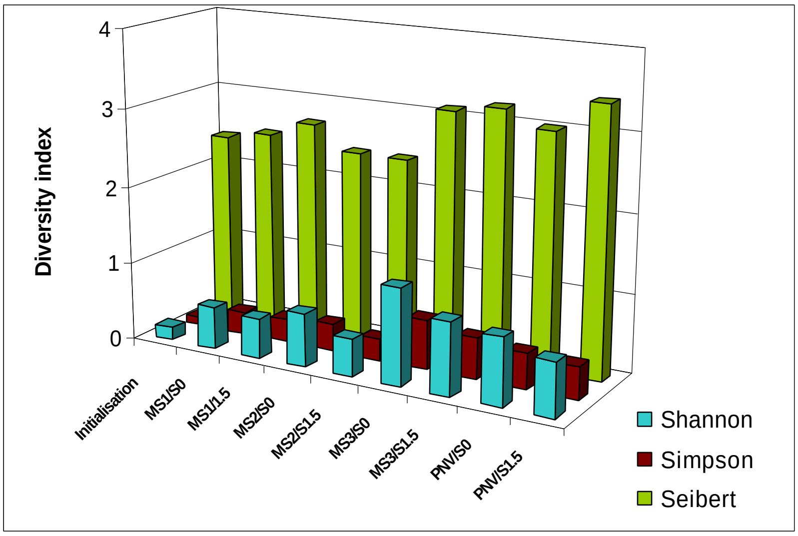
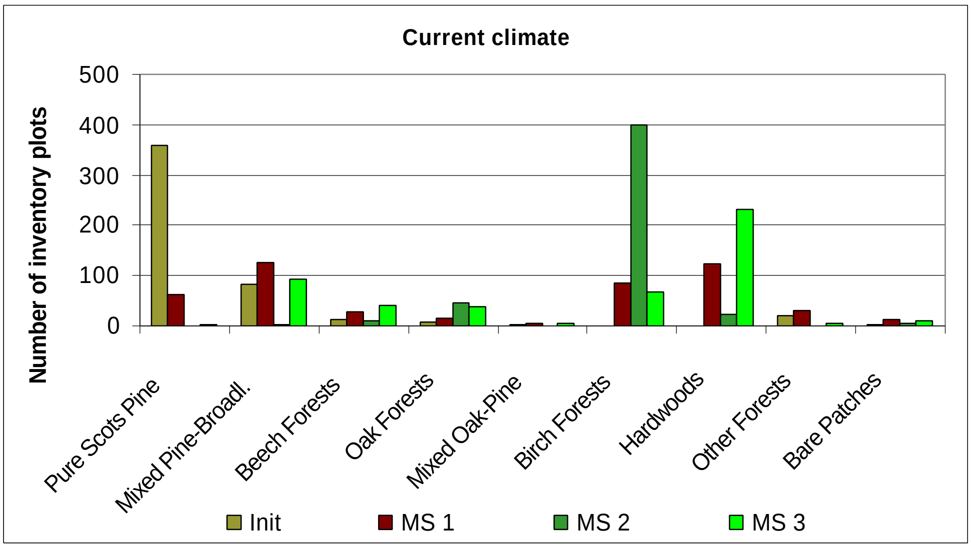


Figure 2: Comparison of diversity indices under 2 climate scenarios (S0 - current climate, S1.5 - climate change) and three management scenarios



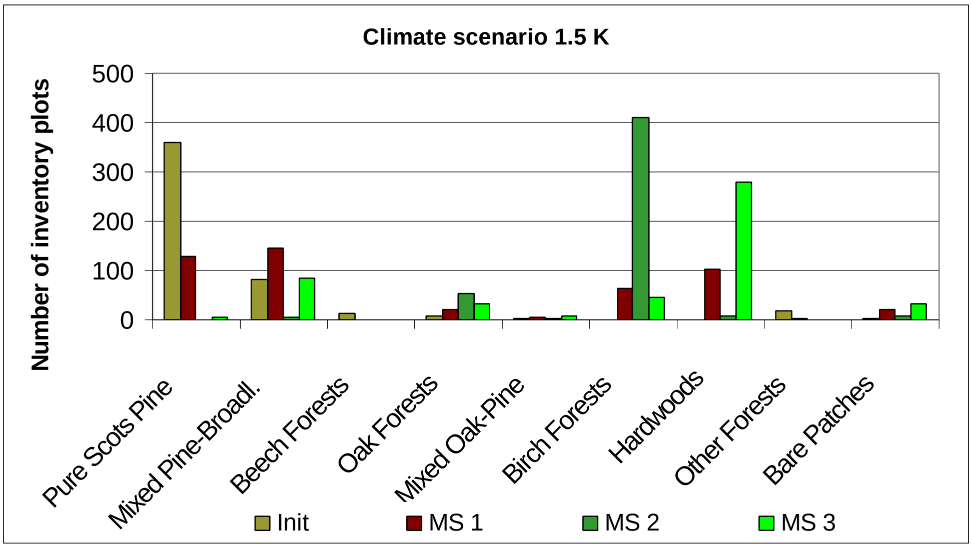


Figure 1: Frequencies of occurrence of simulated forest types at the inventory plots after 110 years under current climate and climate change

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Climate Change Impact Assessment in the Mediterranean Region: Analysis of Particular Needs and Tools

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In the Mediterranean area, the concerns about the impact of climate change on forest ecosystems are mainly focused on two questions: Are Mediterranean forest ecosystems going to experience an increased physiological stress such as that produced by the current summer drought in the area? Are these forests going to experience an increased frequency of forest fire occurrences?

What is known at present is that production of Mediterranean forest ecosystems is highly constrained by water, and to a lesser extent by nutrients (N in siliceous soils and P in calcareous soils). Growth is not limited by a lack of radiation. However, excessive summer radiation combined with drought increases water stress and forest fire occurrences. This is clear when we look at the average pattern of monthly rainfall and potential evapotranspiration (PET) over the year. The minimum rainfall coincides with the maximum PET and the average annual value of PET is double the amount of rainfall (*Fig. 1.1,* 1980-94 period at Poblet meteorological station). This is a characteristic trait of the Mediterranean climate in addition to the high variability between years. The drought of 1994 in the western Mediterranean was extremely severe (see *Fig.1.2* from Poblet meteorological station) and plants experienced extreme physiological stress (Gracia et al 1999). On the other hand, forest fires that year were also very important (Pons et al. 1997).

Focusing on Climate Change Impact Assessment, it is important to have accurate predictions on whether episodes like those of 1994 described above will occur more often in the future. It is also necessary to analyse whether the Forest Ecosystems may overcome such conditions combined with other factors such as increased temperatures. In other words, the positive, null or negative effect of Climate Change on forest ecosystems depends on how new climatic conditions would take place in relation to the present ones, and mainly in relation to water availability for plants and the increase in temperature. Despite an increased CO_2 concentration, plants may not respond with an increased growth rate when they experience increased water stress (*Fig. 2*, from Sabaté et al. 1997).

In the framework of the LTEEF project, the GOTILWA process based model has been applied in the Mediterranean area taking into consideration climatic scenarios provided by PIK (Potsdam Institute for Climate Impact Research) and two Mediterranean species, *Quercus ilex* and *Pinus halepensis.* In this paper, the results on growth of *Q. ilex* and *P. halepensis* given by the GOTILWA model in the locations of Prades (Spain) and Ginosa (Italy) respectively, are discussed and compared with how they both grow in a drier (currently) area representative of the southern Spain climatic zone (named S14 within the LTEEF-framework).

The general tendency of the projected climates in Prades, Ginosa and S14 over time is similar rainfall or just a slight increase. Ginosa appears to be the wettest location and S14 the driest despite its convergence with Prades over time (*Fig. 3*). The tendency of temperature is to rise over time. Ginosa is the hottest location and shows a more dramatic increase over the projected period. Prades is the least warm location but tends to overlap with S14 during some periods (*Fig. 4*).

The results show that the above-ground biomass and growth of *P. halepensis* is greater in Ginosa than in S14, at the beginning of the period. The reason for this is the projected drought in S14 from the middle of the seventies until the middle of the eighties, in particular the extreme drought of the last part of this section. However, later on the growth of *P. halepensis* is greater in S14 and this is due to the very high temperatures at Ginosa over the two last thirds over the simulated period. The high temperatures decrease mean leaf life-span, and increase leaf and fine root turnover (see *Fig. 5, 7*). Aboveground biomass and growth of *Q. ilex* is greater in Prades than in S14. Again, the effect of drought in S14 described above is shown. Later, the growth of *Q. ilex* converges at both sites due to the convergence of rainfall (*Fig. 6, 8*).

Management is important to sustain the forest ecosystems especially to overcome severe periods of drought and high temperatures. When unmanaged forests are simulated, both *Q. ilex* and *P. halepensis* cannot survive the S14 drought described above. In addition, *P. halepensis* hardly survives the hottest part of the period in Ginosa (*Fig 9 and 10*).

To connect Forest Inventory Data with reliable meteorological information on the territory and process-based models would be an important tool for the analysis of impact assessment in the forest ecosystems at a more detailed landscape level. Nevertheless, the lack of detailed information on climate and soil processes makes this difficult at the moment. Further efforts to get this type of information are necessary to make the present assumptions more accurate. On the other hand, Forest Inventory data has been proved useful to analyse the probability of forest fires and provide suggestions for solutions at the landscape level (Pons et al. 1997). The tendency of increased temperature with climate change reduces the relative humidity and this combined with the summer drought may lead to forest fires. The application to define fire-cut corridors on the territory is an example in this type of application in Catalonia.

In conclusion, a decrease in rainfall would produce a decrease in standing biomass and production, despite the positive effects of increased CO_2. If rainfall increases, a positive effect on growth is very likely. But, if temperature rises, in the long-term its negative effects may not be compensated by increased rainfall and CO_2. Management is therefore very important to sustain Mediterranean forest ecosystems under climate change.

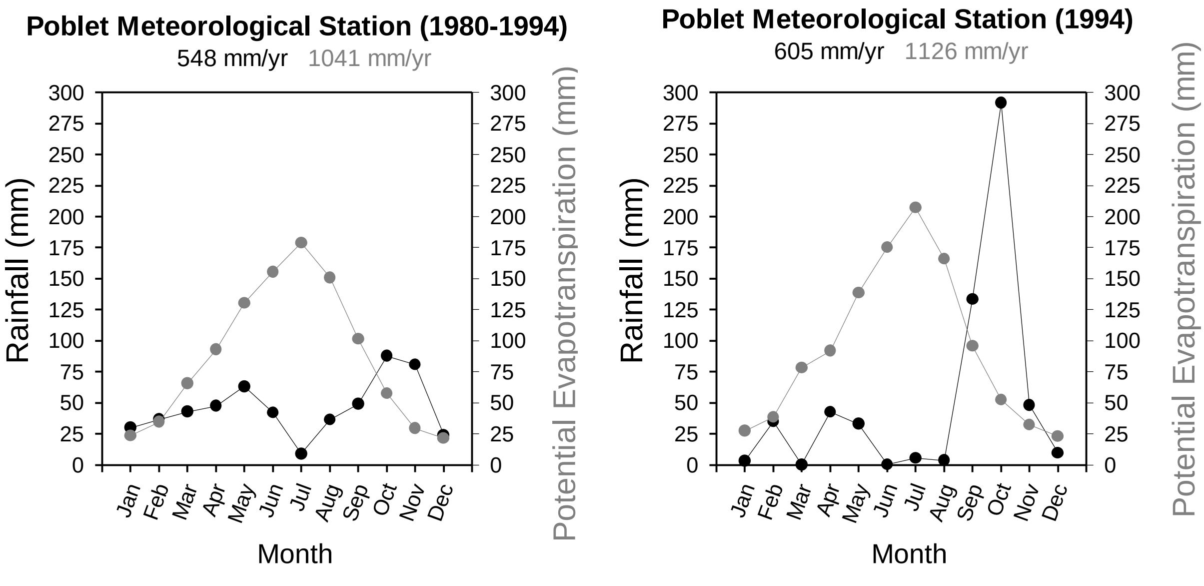

Figure 1: Rainfall and Potential Evapotranspiration in Poblet Meteorological Station (1980-1994 monthly average values) left (*Fig. 1.1*) and 1994 monthly right (*Fig. 1.2*).

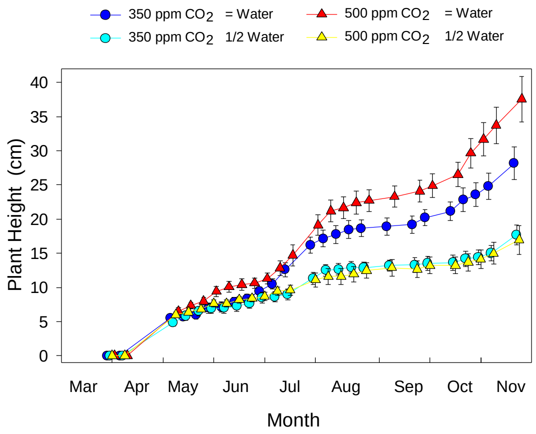

Figure 2: Evolution of plant height (cm) of *Quercus ilex* seedlings during the sampling period in controlled environment chambers. Values are mean ± std. err. See legend above for treatments. (From López et al. 1997). Water means the Mediterranean pattern according to Poblet meteorological station (see *Fig. 1.1*)

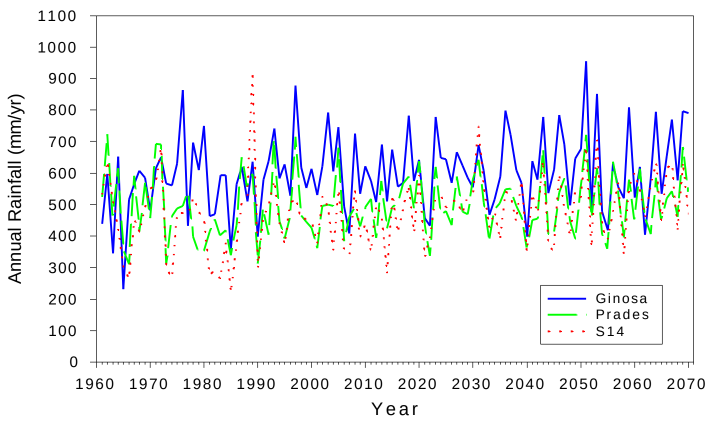

Figure 3: Annual Rainfall Ginosa (Italy), Prades (NE Spain), and S14 (South Spain) projected by PIK in the frame work of LTEEF-II.

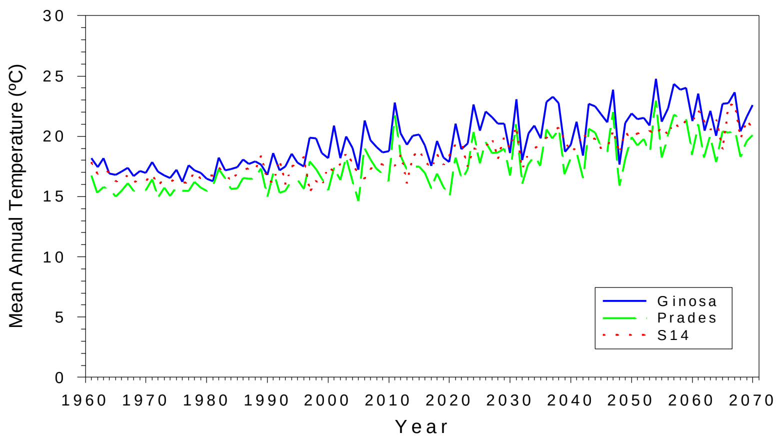

Figure 4: Mean annual Temperature in Ginosa (Italy), Prades (NE Spain), and S14 (South Spain) projected by PIK in the frame work of LTEEF-II.

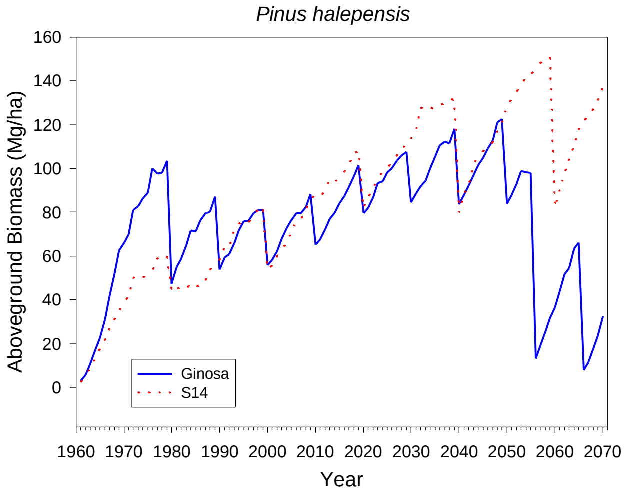

Figure 5: Aboveground Biomass of Pinus halepensis, growing in Ginosa and S14 climatic conditions.

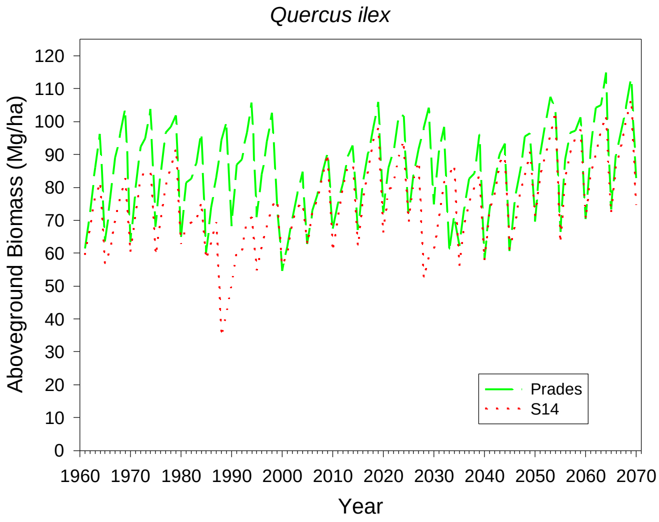

Figure 6: Aboveground Biomass of *Quercus ilex*, growing in Prades and S14 climatic conditions.

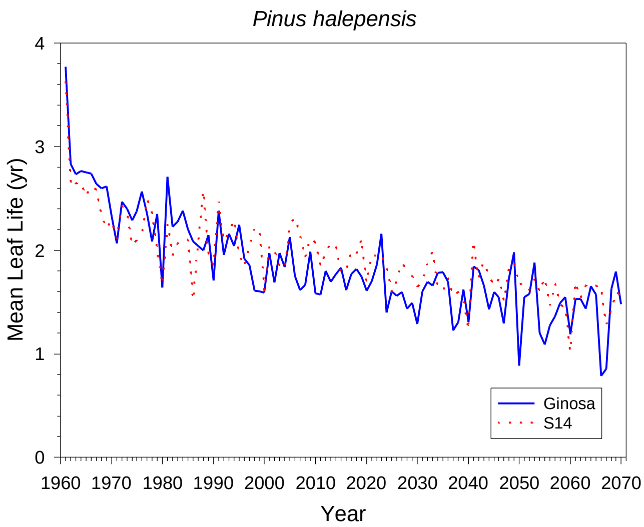

Figure 7: Mean leaf life of Pinus halepensis, growing in Ginosa and S14 climatic conditions.

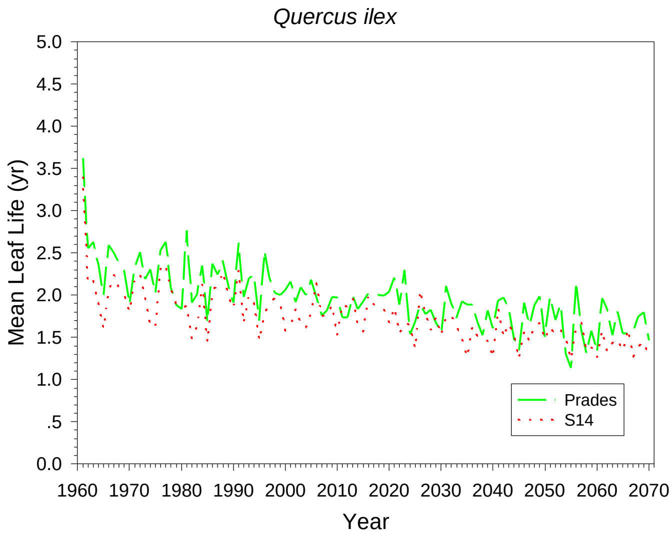

Figure 8: Mean leaf life of *Quercus ilex*, growing in Prades and S14 climatic conditions.

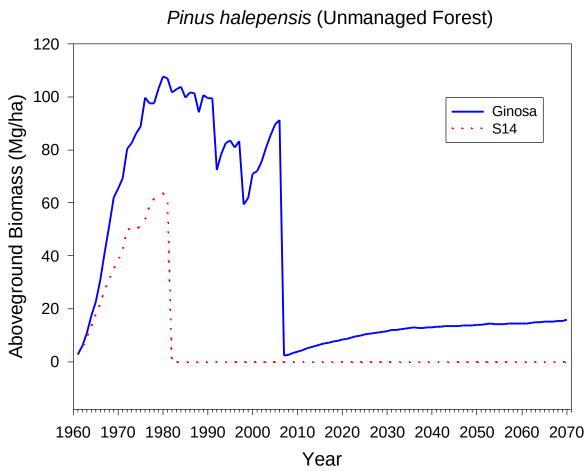

Figure 9: Aboveground Biomass of Pinus halepensis, growing in Ginosa and S14 climatic conditions without management.

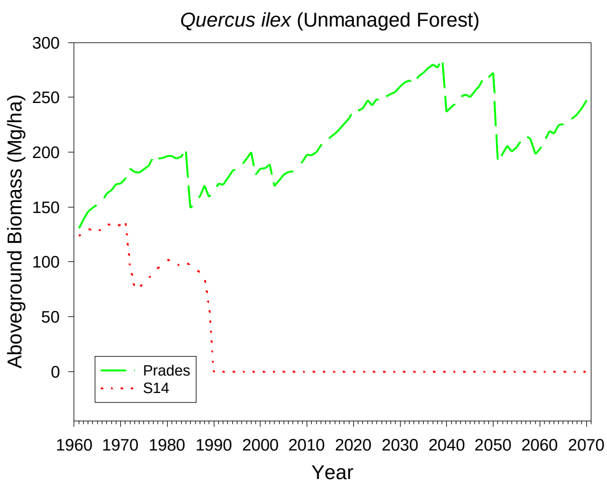

Figure 10: Aboveground Biomass of *Quercus ilex*, growing in Prades and S14 climatic conditions without management.

Ecological Change and Regional Estimates of Climate Change Impacts on Timber Markets

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Ecological models predict that climate change will have widespread impacts on the distribution and growth of forests around the globe. In recent years, a number of economists have estimated the effect of climate change on timber markets (Binkley, 1988; Joyce et al., 1995; Perez-Garcia et al., 1998; Sohngen and Mendelsohn, 1998). This earlier research has made a number of contributions to economic analysis of climate change. First, the researchers have shown how large-scale models that predict ecological changes can be linked to economic models. While the linkages have provided interesting implications for markets, the linkages are typically one way in that information has flowed from the ecological models to the economic models, but not vice-versa. A useful research endeavor would be to link the economic models to ecological models in order to capture the effects of land-use on the ecological response to climate change. Sohngen et al. (1998) for example, suggest economic adjustments to climate change in forest markets could mitigate or reverse the flux of carbon from forests to the atmosphere. To the extent that this can alter the climate response, the models should be fully integrated.

Second, the researchers have captured a fairly wide range of ecological effects, including changes in forest productivity and changes in forest structure (i.e. biome shifts from one region to another or expansions and contractions of forested biomes; See VEMAP Participants, 1995 for a description of the types of ecological changes used in many economic analyses). Biome shifts have been coupled with predictions of wide-spread forest dieback during climate change (see for example, King and Neilson, 1992) to produce transient scenarios of ecological change. These transient models of ecological change have been linked to economic models to predict the path of ecological effects, ranging from changes in productivity to changes in the area and extent of different forest types (Sohngen and Mendelsohn, 1998). Unfortunately, many of the ecological effects used in economic models reviewed in this paper have not been derived from transient ecological models, but rather economic modelers have worked with ecological modelers to develop potential pathways outside of the ecological modeling system. Thus linking economic to ecological models will become more important as ecological models continue to advance with transient predictions.

Third, many analyses that link ecological to economic models predict that forest inventories will increase during climate change (see Joyce et al., 1995; Perez-Garcia et al., 1997; and Sohngen and Mendelsohn, 1998). While some of this expansion is caused mainly by gains in ecological productivity, Sohngen and Mendelsohn (1998) suggest that some of the expansion results from optimal management of timber stocks during climate change. As a result, the studies uniformly predict that supply will increase and that prices will fall. Sohngen and Mendelsohn (1998) provided welfare estimates of the consequences to markets in the US, while Perez-Garcia et al. (1998) provided estimates for the globe and for separate regions within the globe. Joyce et al. (1995) did not estimate welfare effects, but the lower prices predicted by that analysis suggests higher welfare for consumers.

These studies have informed our general understanding of the potential response of markets to ecological impacts of climate change. However, one of the interesting implications of the earlier research is that forest product prices could change dramatically during climate change. Furthermore, the ecological models have provided results that suggest that ecological changes could vary substantially over the globe (see for example Haxeltine and Prentice, 1996). Some regions could see increases in productivity while others see decreases, or short-term dieback effects could be substantial in some regions and minimal in others. This suggests that it is important to capture ecological impacts in a consistent global modeling system because global timber prices will adjust to short-term (i.e. dieback) and long-term (i.e. productivity and forest area changes) ecological effects not only in the home region, but also to effects elsewhere. In the studies mentioned earlier, only Perez-Garcia (1997) examined the global implications of climate change on timber markets, but that study considered only productivity effects, and not potential dieback effects and changes in forest area.

The importance of capturing global impacts can be seen by example. Haxeltine and Prentice (1996) predict large increases in the area and productivity of northern boreal forests and decreases in the productivity of forests in Australia and New Zealand. Because Australia and New Zealand contribute to global timber markets through fast-growing plantations, and reductions in forest growth rates or area there could alter future supply and global prices. On the other hand, increases in boreal forest area and productivity could make those regions more attractive for timber market investments. Optimal economic analysis can help assess how markets are likely to substitute supply from regions that are contracting to regions that are expanding. The extent of expansion of timber harvests in boreal regions for example, is tied to the economic trade-off between the price of timber on global markets and the cost of extraction.

This presentation reports on research that links regional predictions of global changes in net primary productivity and biome distribution from the BIOME3 model (Haxeltine and Prentice, 1996) with an optimal control model of global timber markets (Sohngen et al., 1999). This economic model incorporates 46 different ecosystem and management types throughout the globe, ranging from heavily managed subtropical plantations, to unmanaged inaccessible forests in tropical and boreal zones. The model endogenously predicts optimal forest harvests and investments in all modeled regions. Dynamic global analysis such as this is useful because it captures the complex dynamic economic adjustments that are an integral part of this problem. The economic adjustments and the economic welfare associated with transient ecological effects depend heavily on the optimal adjustments made along the path of ecological change.

By capturing both dieback and productivity effects, we capture a wide range of potential responses. Although estimating economic impacts over additional climate and ecological scenarios would be a useful exercise, we are limited to linking results from two climate scenarios and the BIOME3 ecological model. Sensitivity analysis over alternative economic assumptions, however, is performed to assess how the results vary under alternative economic futures. One reason why this is useful is that the baseline economic model (without any climate change effects) predicts heavy expansion of subtropical plantation region supply and declining boreal forest supply. The ecological model also predicts that the best places to establish forests under climate change are subtropical regions. It is therefore helpful to assess how the results differ if extraction costs in boreal regions are lower and plantation establishment costs in subtropical regions are higher.

The results suggest that climate change will expand long-term global timber supply, reduce timber prices, and increase global timber market welfare between 2% and 8%. Climate change is also expected to increase inaccessible forest area leading to a gain in the area of unmanaged forest ecosystems, both in boreal and in tropical regions. In addition to considering the effects of global climate change on global timber markets, the results are dis-aggregated into regional predictions of economic impacts. The regional effects, however, are not all positive, with some regions experiencing losses. While consumers in all regions benefit from the lower prices, suppliers in developing countries benefit, but suppliers in developed countries probably will be hurt. Economic welfare of suppliers in developed countries declines as those regions experience heavier dieback effects at a time when prices are lower because developing regions, particularly the subtropical emerging plantation regions, are experiencing gains in timber productivity and supply is expanding.

The sensitivity analysis over alternative economic scenarios suggests that the results are fairly robust to alternative economic futures imposed by economic growth rates, interest rates, or boreal forest extraction costs and plantation establishment costs. These results contrast some earlier estimates of impacts in developed countries by Joyce et al., (1995) and Sohngen and Mendelsohn (1998). One reason for the difference is that the model includes the effects of climate change in other regions. Although inventories in the US are expected to increase over the long term in our model, changes are more positive in other regions in the short-term, and this causes short-term losses in that region.

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An Approach to Study the Effect of Climate Change on Forest Succession: A Dutch Example

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Introduction

Antropogenic climate change is likely to alter growth patterns of plant species which will result in changed patterns of forest succession. One way to study the relation between climate change and forest succession are forest succession models (so called gap models) (e.g. Shugart & Smith, 1996). Gap models are relatively simple and do not need a lot of physiological data which is an advantage as those data are often hard to obtain. The effect of climate change on forest succession can be studied with gap models by adjusting model parameters according to the variation in climatic conditions.

An important model parameter in at least one gap model is the radiation use efficiency (RUE or ε), which is a species-specific linear relationship between absorbed photo-synthetically active radiation absorbed (APAR) and the net primary dry mass production (NPP). Climate change, like CO_2 and temperature increase, will affect several physiological processes in plants (e.g. Jarvis 1998), and RUE values will change accordingly. By using a detailed physiological model the change in RUE caused by climate change can be calculated, and by applying this in a gap model the effect of climate change on patterns of forest succession can be estimated.

Here we want to illustrate how such a combination of a detailed physiological growth model and a (less complex) gap model was used to study the effect of increased levels of CO_2 and temperature on forest development in the Netherlands.

Methods

The physiological stand growth model FORGRO (Mohren & Vandeveen 1995) was used to calculate how RUE values would change under different climate change scenario's. To calculate the change in RUE of Scots Pine, FORGRO runs over 90 years were done using a Scots Pine forest (site Loobos). Daily climate data (1901-1990) from De Bilt were used, and runs were done for a stable climate, a CO_2-increase (150 ppm over 90 years), a temperature rise (3^o C over 90 years), and a combined CO_2 and temperature scenario. In calculating annual average RUE values for Scots Pine, only the most productive days were considered (Julian days 90-150). Linear regressions were calculated between RUE and time, and the proportional change in RUE was calculated.

No data were available to calculate RUE values for the other two broad-leaved species (Birch and Oak). On the basis of some trial runs with another broad-leaved species (Beech, *Fagus sylvatica*) it was decided that changes in RUE-values for these species would be double that of the change in RUE values of Scots Pine.

The gap model FORGRA was developed to investigate the effect of ungulate grazing on forest development in several forest types in the Netherlands (Jorritsma et al. 1999). FORGRA runs were done using a 77 year old Scots Pine (*Pinus sylvestris*) forest stand with some sparse Birch (*Betula pendula*) and Oak (*Quercus robur*) on poor sandy soils in the Netherlands (Forest Reserve Zeesserveld) as a starting point.

Nine runs of 100 years were done, using three climate scenario's (no change, CO_2 change, and temperature change), and three intensities of grazing (no grazing, light roe deer (*Capreolus capreolus*) grazing (2 roe deer 100 ha^{-1}), and heavy roe deer grazing (15 roe deer 100 ha^{-1}). For the climate change scenarios, RUE values of the species changed linearly according to their calculated (for Scots Pine) or inferred (for the broad-leaved species) rate of RUE change.

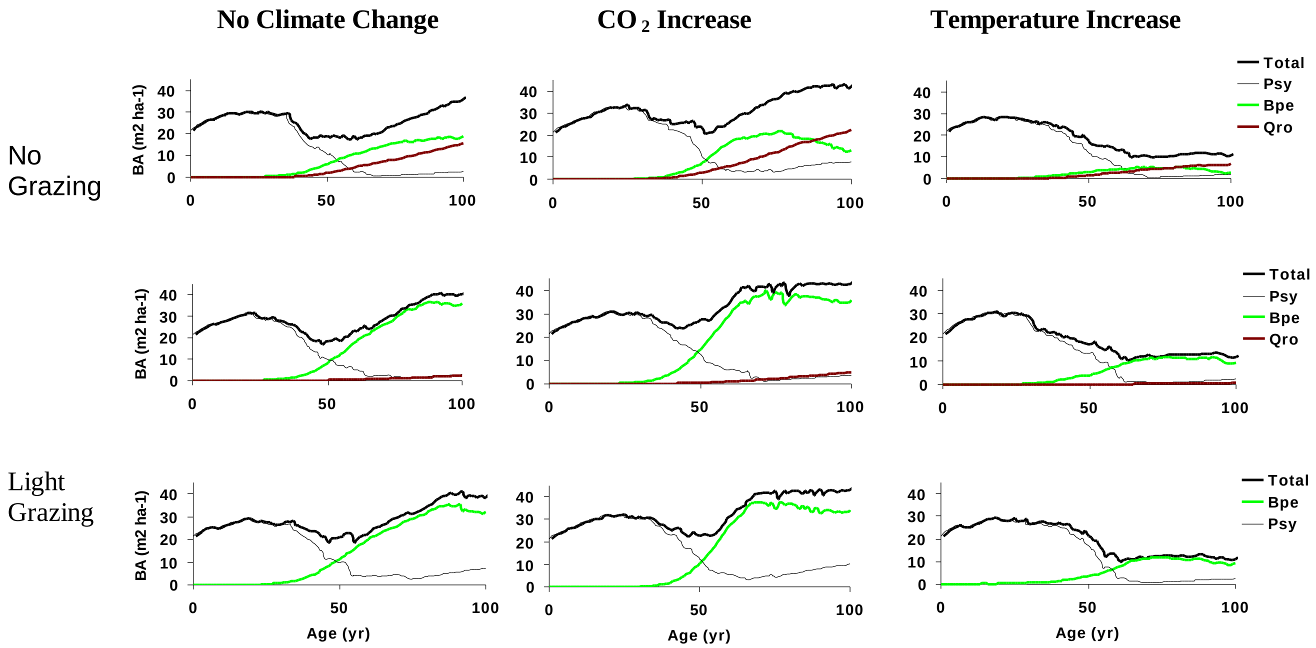

Figure 1: Development of basal area of Scots Pine (Psy), Birch (Bpe), and Oak (Qro) in a Dutch forest over 100 years under different climate change scenarios (no change, CO_2 increase (150 ppm 90yr^{-1}), temperature increase (3^{o}C 90yr^{-1})), and different grazing pressures (no grazing, light grazing (2 roe deer 100ha^{-1}), heavy grazing (15 roe deer 100ha^{-1})).

Results

FORGRO

For Scots Pine, RUE values under the CO_2 scenario showed a 17 % increase over 90 years (df = 88, F = 7.964, p = 0.006), whereas under temperature increase the RUE values decreased by some 15 % over 90 years (df = 88, F = 7.576, p = 0.007). Under a stable climate, the average annual RUE value showed a slight but not significant increase, and the combined effect of CO_2 and temperature did show a slight but not significant decrease in RUE values.

FORGRA

Without grazing and no climate change, the forest slowly develops into a mixed Birch-Oak forest, with some second generation of Scots Pine (Figure 1). Under the CO_2 scenario, succession seems to have sped up and total production is higher then under no climate change: the forest develops into a mixed Oak-Birch-Pine forest, with an increasing domination by Oak. With the temperature scenario, growth of trees is reduced and succession has slowed down. At year hundred a mixed Oak-Birch-Pine is present with a drastically reduced total basal area.

Light grazing mainly affects Oak, and in all three climate scenario's a Birch forest has developed at year hundred. However, Oak is still present in all three scenarios, and in the long term Oak is likely to dominate again, with the possible exception of the temperature scenario where Oak growth is very slow. The speed of succession and total biomass production show the same trend as in the non-grazing scenario runs.

Under heavy grazing Oak is totally excluded, and Birch will eventually dominate.

Discussion & Conclusion

Linking a physiological model with a gap model seems to be a robust way to incorporate the effects of CO_2 and temperature change on the growth function in a gap model. RUE values are significantly affected by a change in climate, which has clear consequences for the gap model outcomes: an increased CO_2-level increases production, speeds up succession, and changes the relative abundance of species. A rise in temperature decreases production, slows down succession, and changes the relative abundance of species.

Ungulate grazing is an integral part of forest development in the Netherlands. This study indicates that the effects of climate change on species composition are most profound when grazing is light or absent. Under heavy grazing pressure climate change does not affect species composition. Trends for forest growth (biomass production) and the speed of succession however do not differ between different grazing intensities and climate scenarios.

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Theme II - National case studies

America's Forests and Climate Change

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The United States has embarked on the first national assessment of climate variability and change - a public-private effort to analyze and evaluate the potential consequences of climate variability and change in the context of other pressures on the public, the environment, and the resources of the U.S. This effort has included over twenty regional teams, five national sector teams, working groups within the federal government, a national synthesis team, and a national coordinating office. Stakeholders from a variety of perspectives have influenced the direction of the assessment effort. Quantitative analyses of ecological and economic systems played an important part of this assessment. As part of the national effort, 100 years of observed climate data for the United States were summarized and made available to the regional and sectoral teams. In addition, transient climate scenarios from the Hadley Centre and the Canadian Climate Centre were made available to the regional and the sector teams. Socio-economic projections, including population and gross domestic production, were also available. It is within this large national effort, that I discuss the assessment of the impact of climate change on America's forests.

One of the 5 national sectors was forest ecosystems and the forest sector. This sector activity was coordinated by Dr. John Aber, University of New Hampshire, and Dr. Steve McNulty, USDA Forest Service. Four teams of scientists concentrated on the potential changes that could occur with climate change, specifically the productivity of forests and carbon storage, species diversity, forest disturbances, and socio-economic changes in the forest sector.

The models used in this analysis of forests were many and varied. Forest productivity and biome shifts were examined at the national scale with several biogeochemistry and biogeographical models. These models were used as part of the VEMAP effort. Changes in forest productivity were simulated using the Terrestrial Ecosystem Model, the CENTURY model, the BIOME-BGC model, and the dynamic vegetation model, MC1. Biome shifts were examined using the MAPSS model. The statistical model, DISTRIB, was used to project the distribution of 80 tree species and in aggregation, community types in the eastern United States. The patterns in species richness for trees and terrestrial vertebrates were examined using multiple regression models. The socio-economic impacts of climate change on recreation were reviewed. In addition, the economic impacts of climate change on forests were looked at using a dynamic programming model of the forest sector, FASOM, the two climate scenarios and changes in productivity from the TEM and the CENTURY models. The results of the forest sector analyses will be presented in 4 papers now in review.

A Growth Simulator and Management Tool Applicable for Climate Impact Assessment on German Forests

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Forest Growth Simulator SILVA

General Description

The forest growth simulator SILVA, developed since 1989 at the chair of forest yield science by Prof. Dr. Pretzsch and his research group is a modern software tool for forest management, research and education. The simulator regards a forest stand as a three-dimensional system, consisting of interacting single trees. This conception overcomes the limitations of the classical yield tables, which are limited to even-aged pure stands and a small number of thinning concepts.

The equations which form the underlying growth model are fitted statistically using a great amount of research plot data to achieve a sufficient model precision for management purposes. On the other hand it is important, that the equations are not simply linear ones but are reasonable from the biological point of view. The recent version of the model is calibrated for norway spruce, scots pine, silver fir, beech, oak and alder under a broad range of site conditions. As input data for SILVA may be used data sources in a range from intensively measured research plots to data from inventory samples. Different data interfaces are used to set up a reasonable start situation for growth simulation even if information (e.g. on spatial tree distribution) is missing or given only in qualitative terms. The growth prognosis is performed in five-year-steps. The output of the simulator gives information on expected development of classical forestry parameters for stands and single trees. In addition, detailed monetary and also structure and diversity related analyses can be performed.

Sensitivity on Climatic Parameters

The climate-sensitivity of SILVA is based upon the site dependent potential growth submodel realised by Kahn (1994). This system calculates for any interesting tree a site dependent maximum growth under optimal competition conditions. Competition among trees will reduce this potential more or less to the expected extent of growth. The growth potential is derived from a Chapman-Richards growth curve. The three parameters of this curve are kept site dependent. The five site-parameters expressing climate properties are

- the number of days per year warmer then 10°C,
- the mean temperature of the months May-September,
- the absolute difference between warmest and coldest monthly average temperature,
- the sum of precipitation in the months May-September,
- the aridity index by DeMartonne for the months May-September.

In addition, four site parameters are used to express soil moisture and different aspects of nutrient supply.

For each site parameter a tree-species specific so-called effect function exists, which transforms the site parameters in values between 0 (worst condition) and 1 (optimum). These effect values are aggregated in a way that compensations are possible. The aggregated values are used to calculate the parameters of the Chapman-Richards potential growth curve for the site conditions of interest. The functions for aggregation of the effect values and calculation of the potential growth curve are fitted statistically using data from long-term-research plots from Northern Germany to the Swiss Alps.

Application of SILVA for Climate Impact Research

The following chapters give a short view on projects at the chair of forest yield science which already used or use SILVA as a tool for climate impact research.

Project: Growth Trends of Spruce in Bavaria (Pretzsch, Utschig)

Project objective was to identify growth trends of spruce in Bavaria based on forest inventory and data from research plots. One sub-task was to find out which of the ecoregions (Wuchsbezirke) in Bavaria, will or will not be suitable for spruce silviculture in future assuming climate to be warmer and dryer than today. Using the data mentioned before, typical pure and mixed spruce stands for each ecoregion were formed virtually as start situations for simulations with SILVA. Growth prognoses using the assumed future climate scenarios allowed to determine ecoregions, where spruce silviculture may be problematic in future.

Project: Mixed Mountain Forests in the Alps under changing climatic Conditions (Biber, Rappold, Pretzsch)

The project was embedded in the large interdisciplinary Bavarian research activity BayFORKLIM: "Climate changes in Bavaria and their effects on microorganisms, plants, animals, and man." Some sub-projects were concerned with forest ecosystems. The project conducted at the chair of forest yield science was named „Growth dynamics of mixed mountain forests in the Alps under changing climatic conditions“.

For recent climatic conditions in the Werdenfels Mountains and assumed future conditions of climate being warmer but also more humid, growth simulations on mixed mountain forests (norway spruce, silver fir, beech) were performed and compared. The simulation results indicate, that the assumed climatic changes will result in higher vitality of beech in the mixed mountain forests. As vitality of spruce and fir under these conditions is not reduced considerably there is a slight increase of productivity to be expected in the research region.

Project: German Forest Sector under Global Change (Dursky, Pommerening, Pott, Fabrika)

The project „German Forest Sector under Global Change“ is an interdisciplinary research project to identify consequences of possible climatic changes on the forest ecosystem and forestry in Germany. Institutions involved: Potsdam Institute for Climate Impact Research (Co-ordination), TU Munich: Chair of Forest Growth and Yield Science, Chair of Forest Policy and Forest History, Chair of Forest Economy, Forest Research Station of Lower Saxony, Federal Research Centre for Forestry and Forest Products, Eberswalde and Großhansdorf.

SILVA is used in two different ways in the project:

1. Use of SILVA for middle-term (30-50 years) prognoses on forest district extent. SILVA is used by the research groups at TU-Munich, Chair of Forest Policy and Forest History, Chair of Forest Economy, supported by the chair for forest yield science. Objectives are to determine the effects of changing climate, silviculture and legal constraints on different typical forest enterprises and the timber market in Germany.

2. Long-term prognoses are performed at the chair of forest yield science directly. Data of the Federal Forest Inventory from 1989 and Datenspeicher Waldfonds are used as start situations. The prognoses are performed on the typical forests in the 18 aggregated ecoregions („Wuchsregionen“), Germany can be divided in, under different climatic scenarios and silvicultural treatments. The following problems have to be solved:

- Development of methods for strata reproduction from inventory plot data and implementation of these methods for practical use in the SILVA-software (Pommerening),
- Validation of the SILVA-growth model equations with Federal Forest Inventory data and Datenspeicher Waldfonds to achieve a higher precision in growth prognosis for th project purposes (Dursky),
- Connection of GIS and databases with SILVA to achieve practical tools for viewing and interpreting simulation results as well as for managing the input data (Pott, Fabrika).
- Preparation of the SILVA-Software for automatic prognosis in addition to the standard interactive version.

Enlarging the Growth Simulator for Application in an Interdisciplinary Project Concerning Resource Distribution and Competition

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Within the framework of a multi-disciplinary project, concerned about tree growth and competition of tree species under different environmental conditions, a new simulation tool is developed. This model is especially suitable to be applied at experimental forest sites. It includes the representation of carbon, nitrogen and water cycle as well as basic physiological processes on the level of the individual tree. It thus serves on the one hand for integration of measurement results up to stand level and on the other hand can be used for scenario assessments with varied environmental conditions or different management options.

The basic new features of the model are:

- Combination of crown-competition indices with physiological processes
- Development of crown- and root system extensions from the effectiviness of the utilization of resources at specific crown/root locations
- Simulation of resource exploitation and distribution, considering crown- and root system dimensions as well as the specific location of the individual tree within the stand

The presentation intents to give a brief overview of the model, examples of possible applications and linkages to the SILVA growth simulator, intended for simulations on larger scales.

Fully Integrated Assessment of Climate Change Effects on Forest Systems With Non-linear Response Paths: A Canadian Study

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Northern forests are closely linked to the social, cultural and economic infrastructure of communities in North America, Europe and northern Asia. There is a need, therefore, to predict the potential consequences of anticipated environmental change on the stream of renewable goods and services derived from natural and managed ecosystems (including agricultural crops, timber and non-timber benefits) in northern countries. Changes in land rents and/or property values generally lead to changes in land management. It is also to be expected therefore, that landowners will adapt to climate change by trading land, or by changing land-use and/or current management practices. Hence, the future effects of climate change will be a function of both the ecological responses to climate change and human adaptation. Not accounting for human adaptive responses may lead to incorrect estimates of the impacts of climate change on ecosystems, while ignoring ecological effects on land productivity will result in misleading forecasts of the socioeconomic impacts. Developing credible estimates of the consequences of climate change requires a comprehensive modelling approach that integrates both economic and ecological systems.

Major ecological concerns include changes in the distribution and geographic range of productive forests, changes in species composition affecting non-timber values, and increased areas lost due to natural disturbances. Economic concerns include regional and national timber supplies and accessibility for harvesting and tourism. Social consequences include the fate of rural communities that rely on local forests as economic drivers (via forest operations, saw- and pulp-milling, tourism, hunting). Both rates of change and the duration of periods of adjustment may be critical.

To date, a limitation of integrated assessment modelling efforts has been the assumption that ecosystems change linearly from their existing state toward some future stable condition. Realistic assessments of the ecological effects of environmental change, however, require process-based models that include physically and physiologically correct representations of climate-vegetation interactions over time. Given the time-frame during which these effects are expected to occur (next 50-100 years), these transient responses may be much more important than end-point equilibria. The recent development of large-scale dynamic vegetation models (DVMs) is seen as an important step in providing such information. Successful integration of the economic consequences of transient changes, however, requires more than a simple linkage of ecosystem model output to economic model input. It also needs well-defined representation of continuous feedbacks between the ecological and economic components, and also among different sectors of the economy (e.g., changes in land-use between agriculture and forestry).

A major complication results from the *interactions* between forest ecosystems as suppliers of goods and services, and the adaptive management strategies which can be imposed on them as conditions change. For example, Mendelsohn and Neumann (1999) carried out a series of studies to assess the impacts of a range of climate change scenarios on vegetation zones within the U.S., and hence on various sectors of the U.S. economy. Following their example, in this project we are trying to create a spatial, dynamic, integrated assessment model for predicting changes in rural land use in response to plausible scenarios of climate change, mediated by natural ecosystem responses and adaptations in management. A dynamic linkage will be built between the IBIS DVM of Foley et al. (1996, 1997) and an econometric model of property values for land (including marginal agricultural land and private forest land where possible). Using the DVM's annual estimates of changes in net primary productivity and biomass as indicators of forest production and future timber availability, changes in product supply and demand, price equilibrium and land distribution can be modelled. Management feedbacks must then be related to economic impacts, and forecasts of ecosystem responses (using the DVM's predictions as "decision support") for different scenarios of change.

This paper will firstly describe how IBIS is being used to investigate climate change effects on Canada's forests and the outputs available for economic assessment. We will then outline our current thinking and initial steps in developing a fully-integrated assessment model. Potential problems will be identified and our strategy for dealing with them discussed.

Integrated Land Information System of Russia and Forestry in 21[st] Century

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Background

Forestry as any other semi-natural (FAO, 1996) land use synthesizes traditional natural sciences with demographic, economic, technological, social and political socio-economic dimensions. Operating as a system of interrelated subsystems it interfaces with other land uses as well as natural ecosystems, i.e. meadows and swamps and forming a mosaic picture of present-day earth cover where changes in one of elements may cause a diversity of responses in another having different trajectories in space and time. The implications of global change for sustaining human society and its well-being have created a sense of urgency in understanding these trajectories and their consequences.

Among major problems to model the earth system in an integrated holistic fashion, i.e. IMAGE at the global scale or LUCC for the Northern Eurasia continent, the lack of adequate information has always been posed as a critical one. It will be true to say that projects are based upon data availability rather than scientific ambition or practical demand. Clearly, this practice leads to ignoring data quality and consistency that makes the results uncertain and impractical. In fact, the importance of verification and validation becomes a very crucial issue. It will be experts who have to massage the results leaving modeling behind.

Tasks

The paper has twofold goals: 1) to introduce a new integrated land information system of Russia (ILISR); 2) to give examples on the implications of the database to forestry studies, namely: 1) integrated characterization, 2) a new classification related to climate warming, 3) full carbon budget account.

Materials and methods

A big effort has been undertaken by IIASA, FAO, Russian institutions to build up the (ILISR) to meet requirements of modern integrated modeling tools related to the analysis of natural and environmental resources. The database (DB) resolves to the geographical scale of 1:2.5 and 1:5 million and allows operating with 1 km x1 km grid. The DB core builds upon the FAO concept (FAO, 1976) which is discribed land as the Earth system comprising major biophysical and socio-econonomic elements. The ILISR has been derived from the newest sources including numerous maps, scientific literature, statistic, the state land and forest accounts and is handled by GIS Arc/Info. The DB has the following criteria:

- completeness to meet a variety of the calculation tasks;
- complexity to describe a diversity of the task aspects;
- consistency: to provide results compatibility; to be at the compatible scale and, to characterize compatible time horizon;
- uniformity, to be standardized and formatted allowing the modern calculation routine to perform.

It is assumed that any task could be matched with the ILISR body and find a certain solution. However, an appropriate concrete answer might need some specific data that could be easily incorporated into DB.

Results and conclusions

The ILISR is planed to be placed on a CD ROM. Meanwhile, the DB elements could be found in a set of the IIASA interim reports (Stolbovoi et al, 1998) and to be appeared as a FAO (1999) CD ROM on Soil and Terrain database on the Northern Eurasia.

Based on the ILISR a modern characterization of Russia forest has been distinguished. It discovers forest in an ecosystem fashion (Stolbovoi, et al, 1999a), in a relation to the naturalness (Stolbovoi, et al, 1999b) and take into account human induced land degradation (Stolbovoi, 1997; Stolbovoi, et al, 1999c). The inventory is aimed at the formulation of a new ecologically-oriented policy for forestry and development of relevant regional strategies.

Applying the DB, we have found that traditional forest-climate associations (zones, provinces, etc.) are inappropriate for the understanding of forcasted climate warming effects on forests (Stolbovoi, 1999; Stolbovoi and Nilsson, 1999). The dependence of forests appearance on temperature provides more sophisticated information allowing grouping forest according to the thermal behavior and temperature response groups. The finding supports to develop adaptive forest management strategies.

A new horizon for forestry is posed by the Kyoto Protocol (UNFCCC, 1998) calling for serious concerns regarding carbon management. A full carbon budget account believes to meet the Kyoto commitments (Steffan et al, 1998; Jonas, et al, 1999). However, such an account should be heavily rooted on numerous variables operating in the terrestrial carbon cycle. The ILISR is an essential tool to make such a computation (Nilsson et al, 1999).

The general conclusion has been drawn that the ILISR is a fundamental tool for scientific and practical implications and, perhaps, has no alternative to discover forestry in 21st century.

Environmental Control of Net Primary Productivity in the Eastern Boreal Forest of Canada: A Project Overview

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The boreal forest of Northern Canada is one of the largest expanse of contiguous forests in the world. Yet, this immense assembly of forest stands grows under harsh conditions characterised by short growing seasons, low soil temperatures and generally nutrient-poor soils of granitic origin. Because of these constraints on growth, boreal forest ecosystems should be very responsive to alterations in their natural growing environments. Of particular concern are the potential impacts of large scale disturbances linked with predicted climate change scenarios in northern latitudes. The five-year ECOLEAP (Extended Collaboration for Linking Ecophysiology And forest Productivity) project now underway has therefore as its primary goal to quantify the relationship, at the tree, stand and landscape levels, between net primary productivity (NPP) and site-level environmental variables in specific forest ecosystems of the eastern boreal forests of Canada. The objective is to develop a predictive tool that could be used to assess the impact of changes in forest-related properties (e.g. changes in forest composition, insect defoliation) or climate-related variables on the NPP of these ecosystems.

The project is composed of three main activities: Data acquisition, modelling and scaling procedures from the plot to the stand and to the landscape. Data acquisition takes place on seven sites positioned within three dominant forest types of Eastern Canada. The two or three sites within each of these forest types have been selected along a gradient of productivity, mostly through differences in climatic conditions. The most northerly sites is in black spruce (*Picea mariana* [Mill] B.S.P.) dominated forests. The mid-latitude sites are in the more productive balsam fir (*Abies balsamea* [L] Mill.) forest ecosystem. Finally, the three most southern sites, located in sugar maple (*Acer saccharum* Marsh) dominated sites provide data from the most productive forests of Eastern Canada.

On each site, major components of the water, carbon and nutrient cycles are measured on different time scales. Key environmental variables such as air and soil temperatures, net solar radiation and precipitation are monitored year-round. Major nutrient pools and nutrient turnover rates are quantified throughout the growing season, as well as carbon allocation to above-ground and below-ground forest components. Tree transpiration is measured *in situ* on selected trees. Some of the more challenging aspects of this effort are the characterization of canopy-level properties, the quantification of fine roots dynamics, a major component of both carbon and nutrient cycles, and the scaling up of NPP processes from the leaf to the tree and to the stand. Destructive measurements at satellite sites have been used to develop allometric relationships needed for NPP and LAI monitoring.

The data gathered on the ECOLEAP sites through constant monitoring and intensive field campaigns are being used to calibrate or adapt a physiologically-based computer model of NPP. The current iteration of the modelling component uses 3PG (Landsberg and Waring, For. Ecol Manag.1995: 3, 209 - 228). Modifications are underway in the representation of phenology, and in the allocation of carbon between the different tree components.

Finally, extrapolation to larger areas is being carried out using a combined GIS - remote sensing approach to drive the site-calibrated model. Remote sensing is used to obtain stand-level information on vegetation type and characteristics needed to select within the model the proper values of specific parameters. Remote sensing also provides estimates of the fraction of absorbed photosynthetically active radiation. Climatic inputs are obtained by spatial interpolation from the existing network of meteorological stations. Digital elevation maps are used to correct for the elevational differences between meteorological stations and stand location. A GIS-driven data base manages the input-output flow of the model, providing spatially-explicit estimates of NPP over the pilot areas. Major challenges in that portion of the work lie in improvement of extraction of biophysical information from spectral reflectance data, as well as the linkage between input variables acting over different temporal and spatial scales and the process model.

Estimation of Landscape Level Forest Biomass Accumulation Using a Physiological Growth Model

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Introduction

Quantifying landscape level forest biomass change is a major task for greenhouse gas inventory, for assessing the interaction between vegetation and the atmosphere, and for predicting potential forest production. However, there is considerable difficulty in applying empirical approaches to modelling forest growth in landscapes where there has been limited silvicultural management or plot measurement. Historically, the Australian forest industry was based on native forest harvesting. About 1 million ha of (mostly exotic softwood) plantations have been established since the 1940's and these now provide about 45 percent of the harvested timber volume. The area of plantations is increasing at a rate of about 60,000 ha/year. These are largely eucalypts for pulp and solid wood on previously-cleared, marginal agricultural land.

Methods used to predict plantation growth in these landscapes include:

1. *Phytocentric indices.* For example, site index (mean stand height at a given age), indices based on successive permanent plot measurements, predictive systems based on a single stand assessment, 'natural' basal area or maximum stand height.
2. *Site or geocentric indices*. For example, climatic indices (generally utilitised at broad regional or national scales), topographic indices, or soil or geological indices, although with the exception of some broad geological classes these have generally been unsuccessful.
3. Vegetation based or community composition indices

With the emergence of some simple, general physiological principles and improved capacity to generate topographic models and climatic and edaphic surfaces alternative approaches to these traditional methods are now possible.

Methods

This study used the model 3P-G (Physiological Principles for Predicting Growth, Landsberg and Waring 1997) in a GIS to model potential forest growth. 3P-G is an even-aged forest growth simulator. It calculates GPP as a function of utilisable absorbed PAR and canopy quantum efficiency and modifiers reflecting effects of VPD, water availability and sub-zero temperatures. NPP is a fixed proportion of GPP (0.45) and allometric functions distribute this NPP to foliage and stems. Allocation below-ground varies with soil fertility. A sub-model based on -3/2 power law simulates self-thinning. Stand growth declines with age according to established principles and the model runs on a monthly time step. For spatial application, the model was converted to Arc Macro Language, and is menu-driven allowing easy selection of parameters, input surfaces, pre-processing and selection of outputs.

As a demonstration the model was applied in the Bago-Maragle State Forest, a 50,000 ha area of natural eucalypt forest located about 35°S in latitude. The forest covers a high plateau

1000-1200 m.a.s.l., mean annual rainfall ranges from 1500 to 2000 mm. The area is underlain by weathered sedimentary and igneous substrates with sporadic capping of basalt. The vegetation is dominated by 3 eucalypt species: *E. delegatensis, E. dalrympleana,* and *E. radiata.* The forest has a long history of selection harvesting, and is now predominantly mixed age. Long-term measurement data for 14 permanent sample plots located across the area was used to calibrate the model. Spatial inputs included:

- topography from a 25 m DEM,
- radiation from the SRAD model and,
- climate data interpolated from weather station data using the ESOCLIM
- soil water holding capacity and fertility (available P) surfaces derived from regression analysis and radiometric data.

Model runs were conceptual in the sense that an even-aged stand was assumed across the landscape. Runs compared standing biomass after 30 years and growth from 15-20 years using long-term average versus actual rainfall over the 30 year period, a mean soil fertility value versus the variable soil surface.

Results and Discussion

For the 50,000 ha area, there was little difference in biomass accumulation estimates between runs using the long-term average rainfall and actual rainfall surfaces, or between the varying soil fertility surface and a mean surface (Table 1). However, there were considerable variations at the local scale between runs using the varying fertility surface and those using the mean surface.

Run	Mean standing biomass (t/ha)	Biomass increment Age 15 –20 (t/ha/yr)
80 year	512.4	na
30 year:		
Long-term rain/ soil surface	355.5	10.58
Actual rain/ Mean soil	340.4	10
Actual rain/ Soil surface	339.6	9.84

Table 1: Total standing biomass and biomass increment for four runs of 3PG-Spatial

These results suggest that a relatively simple physiological model can be used in a spatial application to extrapolate from plot data to the landscape scale. The model is dependent on quality input surfaces for topography, radiation, temperature, precipitation and soils, quality calibration data across the target environment and an understanding of species' responses to climate and soil variables. Desirable improvements to the model include the ability to disaggregate and run the model for different management units and age classes across the landscape and the ability to incorporate disturbance, particularly harvesting and fire.

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Integrated Ecological/Economic Assessments at the Global Scale: Lessons Learned and Uncertainties

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Over the past several years, research using the CINTRAFOR Global Trade Model (CGTM) and the Terrestrial Ecosystem Model (TEM) has helped us to understand how climate change may potentially effect the global forest sector. The process of linking these two models - many model runs with alternative economic, ecological and climate scenarios - provides useful information on

- the behavior of the economic model under alternative assumptions,
- integrated economic/ecological results and
- their implication for decision makers.

As with any research employing simulation models, the key to comprehending research outcomes lies in understanding modeling sensitivities to alternative assumptions. Our work indicates that assumptions on economic actions, ecology behavior and data linkages are all important. Alternative economic assumptions lead to large uncertainties in climatic change impacts on the forest sector. Alternative ecological assumptions have a significant effect on economic behavior and lead to additional uncertainty. Linking models through alternative data transformation also adds uncertainty. Gauging these uncertainties is an important procedure to accurately infer the climate change effect on the global and regional forest sectors. The paper outlines lessons learned placed within the context of uncertainty and discusses the implication from our work with an integrated economic/ecological global model for decision-making.

Simulating a Virtual German Forest Enterprise Through the Application of Basic Forest Management Strategies

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The presented paper is part of the study "German Forest Sector under Global Change" with the objective to analyze the socio-economic effects of climate change to forestry in Germany.

Forest structures in Germany are heavily influenced by management activities, which are differentiated by form and intensity through different management objectives.

To include the panacea of these objectives basic forest management objectives have been formulated. They build the cornerstones of possible management options and therewith a framework for all real existing objectives.

To fulfill a certain management objective, the design of corresponding guidelines is necessary.

The chosen basic management objectives are "timber production", "silvicultural optimum", "social benefits" and "do nothing", with the corresponding guidelines "capitalization method", "silvicultural guidelines", "legal constraints & scientific demands" and "do nothing".

On this base, concrete management strategies have been worked out.

For the simulation of these strategies the forest management model „ActioSilva“ has been developed. It is based upon the data of the German National Forest Inventory 1987 to 1989. "ActioSilva" uses the forest growth simulator SILVA for simulating forest stand developments. In addition SILVA allows to include data on modified site conditions through climate change.

Inputs for "ActioSilva" are the defined management strategies which have been converted to automated instructions. It is planned to simulate the different basic management strategies for a period of 30 years (see figure 1).

Finally the simulation results for every management option will be evaluated through its corresponding evaluation criteria and methods. To enable a comparison of the different results a cross-check of evaluation methods and results has to be carried out.

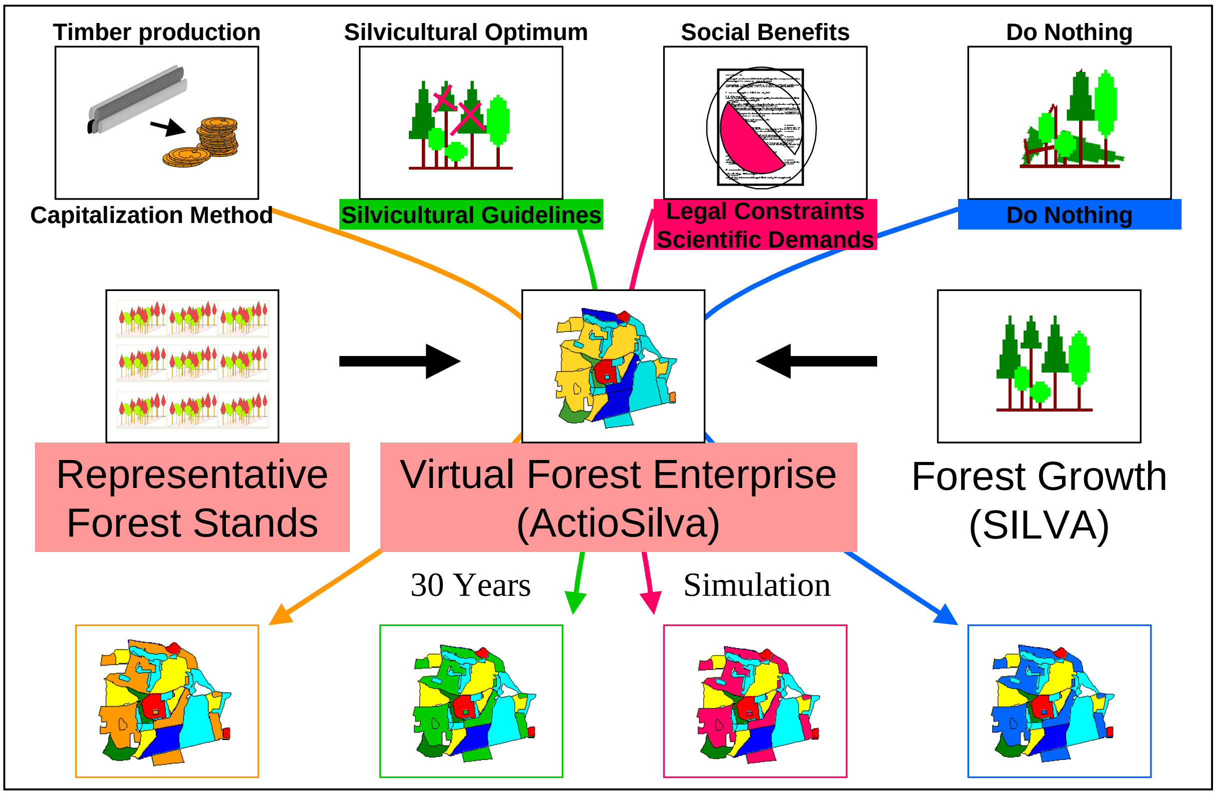

Figure 1: Modeling a Virtual Forest Enterprise

Carbon Sink in the Forest Soils of Western Europe Induced by Increased Tree Growth

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Tree biomass has been increasing in western Europe already for a few decades as tree growth has exceeded harvesting (Figure 1). At present, the carbon pool of the trees has been estimated to increase about 70 Tg/year. It is about 7% compared with annual anthropogenic CO_2 emissions in western Europe. The increasing trend in tree biomass is expected to continue in the future.

The increasing tree biomass can also increase the carbon pool of soil. This increase has not been quantified yet although it may be large. Soil contains more carbon than trees do in many forests.

The objective of this study was to estimate changes in the carbon pool of forest soils in western Europe between 1950 and 2040. Carbon input to the soils was calculated from forest inventory data and a scenario of future forest resources. Carbon output from the soils was calculated using a dynamic soil carbon model. The changes in the carbon pool of the soils were compared with those in the trees.

The soil carbon pool in 1950 was estimated at 4500 Tg (Figure 2). It increased to 5000 Tg until 1990 and to nearly 7000 Tg until 2040 due to increased litter production of increasing tree biomass. The soil carbon sink in 1990 was 26 Tg/year and in 2040 62 Tg/year. The sink per unit area in 1990 was largest, more than 10 g/m^2/year, in the countries of central and northwestern Europe and Italy. The tree carbon pool in 1950 was 1300 Tg smaller than the soil carbon pool but it increased faster. In 1990 it was already as large as the soil carbon pool and in 2040 nearly 1000 Tg larger. The soil carbon sink was 20 to 50% compared with the tree carbon sink between 1960 and 1990 and about 70% after this. According to an uncertainty analysis, the soil carbon pool in any year may be 34% smaller or 60% larger than estimated above and the soil carbon sink in 1990 may range from 17 to 38 Tg/year.

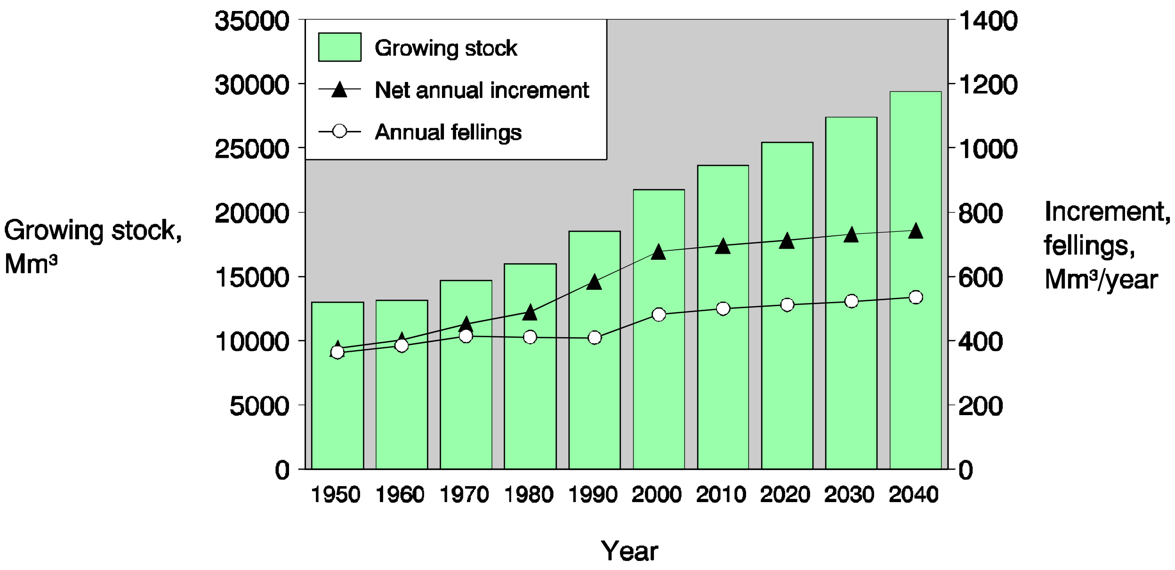

Figure 1: Growing stock, net annual increment and annual fellings of forests in Europe between 1950 and 2040 (Kuusela, K. 1994. Forest resources in Europe 1950-1990. EFI Research Report 1., Pajuoja, H. 1995. The outlook for the European forest resources and roundwood supply. ETTS V Working Paper. UN-ECE/FAO Geneva).

a) b)

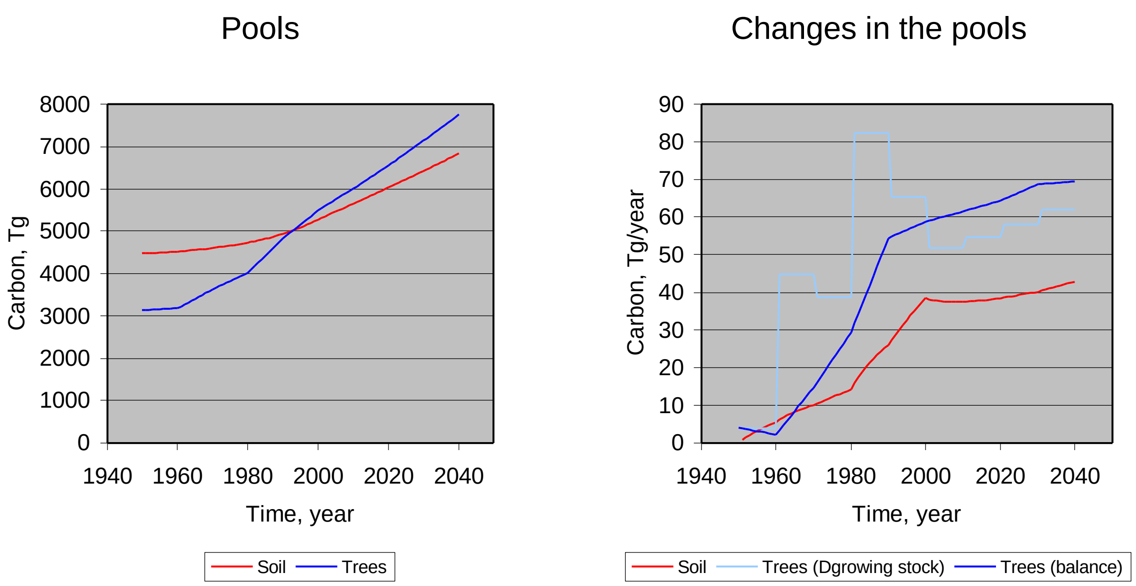

Figure 2: The carbon pools of soil and trees (a) and changes in the pools (b) in western Europe between 1950 and 2040. "Trees (Dgrowing stock)" shows the change in the carbon pool of trees calculated based on growing stock measurements. "Trees (balance)" shows it as calculated based on the difference between net annual increment and fellings.

How to Estimate Impact of Forest Management and Climate Change on European Forest Sector Carbon Budget?

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European Union funded LTEEF-II project "Long-term regional effects of climate change on European forests: impact assessment and consequences for carbon budgets" (duration 1998-2000) investigates the impacts of climate change on long-term growth and development of European forests. The main focus in this project is on carbon fluxes between the forests and the atmosphere, and on long term carbon budget of the forest sector (for further details see http://www.ibn.dlo.nl/lteef-II).

In the LTEEF-II project, regional level impacts of climate change on forest growth are assessed with process-based models and these responses are then scaled up to country and European level with national forest inventory data in a large-scale scenario model EFISCEN (European Forest Information Scenario Model). Another upscaling approach is through remote sensing data and models capable to simulate gross primary production, net primary production and net ecosystem exchange on given grid resolution. This paper concentrates on upscaling based on responses from process-based models, forest inventory data and large scale scenario modelling.

Applied large-scale scenario model was originally developed at the Swedish University of Agricultural Sciences (Sallnäs 1990) and was used to project development of forest resources in Europe (Nilsson *et al.* 1992). This model has been further improved and used for new analyses at the European Forest Institute Europe (for e.g Nabuurs *et al.* 1996, 1998, Päivinen *et al.* 1999). National forest inventory data is used as input data, containing area, volume and net annual increment by age classes for more than 2500 forest types. Forest types are defined by country, region, owner, site class, and species (*Figure 1*). Currently EFISCEN can simulate development of whole tree biomass, soil organic matter (according to Liski *et al.* 1998) and wood products (according to Karjalainen *et al.* 1994) under different forest management regimes (for further details of the model development and application, see http://www.efi.fi/projects/forsce). The current net annual increment curves, biomass allocation and litter production are adjusted for changing climatic conditions based on simulations with process-based models on representative sites across Europe (Karjalainen *et al.* 1997).

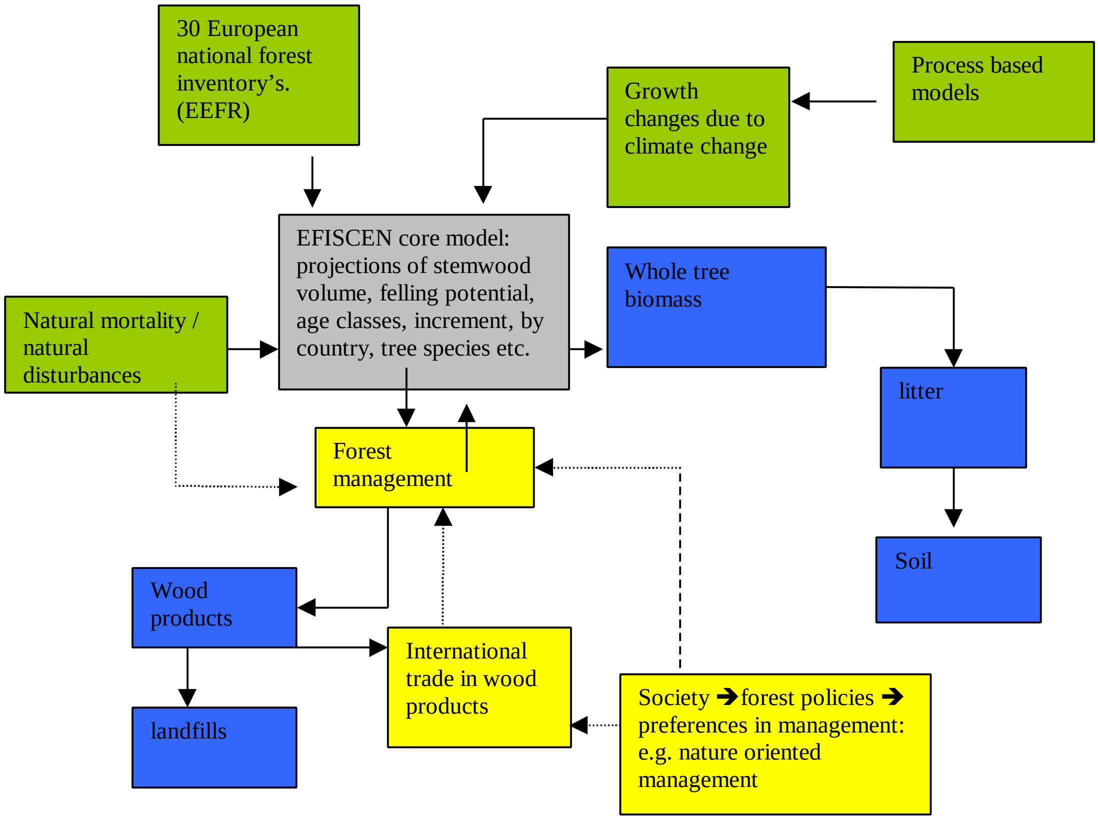

Figure 1: Outline of the EFISCEN model

Main results from a case study presented in *Table 1*. Conditions for the simulations for a case study were following:

- forest inventory data for Finland, covering years 1986 - 1992 and 19.6 Mha
- harvesting level was "business as usual scenario" with continuation of the 1990 harvesting levels for 100 years, assuming 54 million m^3/yr of which 30% from thinning
- biomass distribution parameters from literature
- current and changing climatic conditions: climate change: impact of 4 ^{o}C temperature increase during the 100 year period and rise on increments were simulated according to Kellomäki & Kolström 1994; no data of the effects on biomass distribution or litterfall were given
- carbon stock in the soil includes only carbon from wood biomass and therefore is lower than in studies including also carbon brom ground vegetation (Liski & Westman 1997)
- manufacturing of wood products, and parameters based on statistics and inventories (Pingoud *et al.* 1996)

Table 1: Simulated carbon stocks for both scenarios

		1990		2040	
		no climate change	Climate change	No climate change	Climate change
Growing stock	Million m^3	1819	1819	2640	2956
Carbon in biomass	Tg C	562	562	813	909
Carbon in soil	Tg C	792	792	849	837
Carbon in products	Tg C	129	129	296	296
Total carbon	Tg C	1483	1483	1958	2043
Standing volume	m^3/ha	93	93	135	151
Carbon in biomass/ha	Mg C/ha	28.6	28.6	41.4	46.3
Carbon in soil/ha	Mg C/ha	40.4	40.4	43.3	42.7
Carbon in products/ha	Mg C/ha	6.6	6.6	15.1	15.1
Total carbon/ha	Mg C/ha	75.7	75.7	99.9	104.2

In LTEEF-II project, selected forest management scenarios will be applied for current and changing climatic conditions for 30 European countries.

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Carbon Accounting Methodologies - A Comparison of Real-time, Tonne-years, and One-off Stock Change Approaches

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Trading in carbon credits from afforestation and reforestation is foreshadowed by the Kyoto Protocol. Human-induced sinks can compensate for human-induced emissions, but given ongoing combustion of fossil fuels, there needs to be an ongoing contribution of sinks. Because forests are sinks only when they are expanding in area or growing stock, afforestation must be continuous. Obviously, this cannot continue in perpetuity as the global plantable area is limited. Even if 500 million hectares of land were afforested worldwide, and resulted in a one-off increase in carbon-density of 100 tonnes/ha, this amounts to only 50 Gt C removed from the atmosphere. The IPCC Second Assessment Report examined scenarios of carbon accumulation from 1991-2100 of 630-1410 Gt C, so it can be seen that the potential contribution of afforestation is very small. Forest sinks are a popular topic in the current decade because they are seen as being a relatively low-cost first step to reduction of net greenhouse gas emissions.

Before trading in carbon sinks can eventuate, however, numerous technical difficulties have to be resolved including the acceptance of a standard method of carbon accounting. The concept of “tonne-years”, whereby the quantity of carbon sequestered is multiplied by the time it is out of atmospheric circulation, appears to be gaining credence in international fora. This concept is flawed and threatens to undermine the “stocks” based accounting approach that is built into the Kyoto Protocol. A preferable approach is to accept that afforestation is merely the reverse of deforestation, and is a one-off movement of carbon from the atmosphere to the earth’s surface. Carbon credits could be a one-off payment made to a land owner who undertakes to change the long-term carbon density of a piece of land and, possibly, to retain that increased carbon density in perpetuity.

Active trading in carbon credits would lead to an increase in the forested area of the world. While this might saturate the world with wood, and thereby reduce timber prices, it may also presage the way to an global economy based, in part, on bioenergy. Bio-fuels from sustainably harvested forests trap and store the current energy income of the planet (ie sunlight), just as fossil fuels represent the captured energy of previous millennia. It is unsustainable to live off one’s capital, rather than one’s income.

The long-term benefit of trading in carbon sinks, therefore, may be to stimulate planting and thereby permit the formation of a sustainable biomass resource. The current rationale for such trading - sequestration of carbon - is likely to prove ephemeral.

Posters

CARBO-AGE - A Project Under the European Union's 5th Framework Programme

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The Kyoto Protocol requires European countries to produce carbon budgets for their forests by 2008. Forests may act as sinks or as sources of carbon to the atmosphere depending on many factors. Carbon fixation by the vegetation and carbon release by the soil vary dramatically throughout the life cycle of a forest ecosystem (i.e., from initial planting to final logging). Understanding the age-related dynamics of net ecosystem exchange is the most important step to take to integrate forest carbon budgets across space and time. This is an essential element to reduce the uncertainties and to inform policy-makers and others who seek to apply carbon budgets.

The objectives (from general to specific) of this proposal are:

1. To provide decision-makers with reliable estimates of long-term carbon accumulation in recently afforested sites, as required by the Kyoto protocol. To include forestry logging operations in carbon budgets of forest ecosystems.
2. To extend present estimates of carbon sink strength of European forests (for instance, those obtained within Framework IV) to include all stages of the life cycle of forest ecosystems, from initial planting to final logging.
3. To anticipate whether increases or decreases in rotation length have significant consequences on carbon accumulation of European forests.
4. To interface existing information on age class distribution of European forests with estimates of carbon sequestration during each stage of forest development.
5. To determine the relative magnitudes of gross carbon sequestration by the vegetation and carbon respiration by the soil during stages of forest development.

Present estimates of carbon sequestration by European forests are either incomplete or biased, by not accounting for carbon fluxes to the atmosphere during all stages of stand development, especially the initial and final periods when disturbance takes place (i.e., site preparation for planting and logging). This problem is at the heart of some of the most important controversies surrounding the budget of carbon sequestration of the so-called ‘Kyoto forests’, i.e., those forests that will be considered under Art.3.3 and 3.4 of the Kyoto Protocol, signed by the EU.

This project will use five sequences of stands of different age in five countries spread throughout Europe. We will select representative forests at different stages of stand development, from initial planting to final logging, to calculate carbon budgets for the whole life cycle of these ecosystems.

In each chronosequence, at least four sites (plus the fifth EUROFLUX site) will be selected for analysis, and carbon stocks and fluxes will be measured. Net ecosystem exchange will be determined by eddy covariance. The sensors will be mounted on a mobile tower, which will be periodically moved from one site to the other throughout the year. We will separately measure carbon stocks in the vegetation and the soil. Rates of photosynthesis and carbon losses by respiration from the soil will also be measured.

An Adaptive Management of Forests Under a Global Change – The Polish Case Study

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In Poland, as in other European countries, the primary goal of forest management has been traditionally the maximization of sustainable timber production. However, today's society, with growing concern for a loss of biodiversity and a destruction of nature, is shifting this aim to the procurement of optimal combination of various forest benefits and services, including amenity, soil and water conservation, and the conservation of unique forest ecosystems and their biodiversity.

A present situation of forests and forestry is further complicated by present and projected environmental changes (climate change, CO_2 increase, NO_x fertilization etc). Both long-term studies on natural stand dynamics, as well as many simulation experiments suggest significant changes in a competitive ability of particular tree species and shifts in their respective geographical ranges.

Under conditions of Polish lowlands, Scots Pine belongs to most threatened tree species. For a long time Scots Pine was preferably planted as an important commercial tree species. However, considering the fact that ecological and economical risk of mantaining dominant position of Scots Pine is systematically increasing, there is an urgent need to replace Scots Pine with other tree species which are preassumably better adopted to future conditions, first of all broadleved species, such as for example Pedunculate Oak.

From silvicultural point of view, a major problem today is to develop (or to adopt) such silvicultural methods and systems, which would mimic natural processes as far as possible, would enable successful regeneration of desired tree species, and would allow for establishing of mixed stands distinguished by a high structural diversity. In this respect, among silvicultural systems currently in use in Polish forests, so called „group selection system (GSS)" deserves for a special attention.

A classical form of the GSS („Femelschlagbetrieb") was developed under Swiss conditions (H. Leibundgut) and applied for stands composed mainly by shade tolerant tree species: Silver Fir, Common Beech and Norway Spruce. „Silvicultural Principles", applied in Polish forestry, also advice application of GSS in similar categories of stands. However, many authors point out that the GSS is very flexible and can be used under different site conditions and applied for different tree species.

In an ongoing project, a possibility of using the GSS in stands composed mainly by intolerant tree species, such as Scots Pine and Pedunculate Oak, is tested. Among other aspects, a possibility of increasing a share of Oak in a future stand composition is studied.

Major features of the GSS include:

1. trend towards mixed stand composition;
2. use of natural regeneration whenever possible;
3. tending of growing stock (permanent improvement of stand technical quality).

The above principles were largely elaborated under conditions of Swiss forests which in many respects (climate and site conditions, forestry history, ownership structure) differ from Polish conditions. It seems, however, that the same general principles, after appriopriate modification and detailization, can also guide the management of Polish forest stands.

Together, they constitute the adaptive strategy for forests and forestry under altered environmental conditions and changing social preferences. The ongoing research should help to introduce those principles to wide forestry practice, among others, by creating demonstration objects and elaborating detailed management schemes and solutions.

Methodological Approach to Characterize Silvicultural Concepts Taking the Yield Level into Account

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Objectives

This research is part of the project „German Forest Sector under Climate Change". The goal is to explore silvicultural strategies under current climatic conditions and to adjust these strategies to changing climatic conditions using the growth simulator SILVA (KAHN & PRETZSCH1997). Finally, reducing the risk factors can be achieved concluding from the results of the simulation scenarios.

Previous work

4. Comparing the silvicultural concepts of selected German states regarding regeneration, stand treatment and harvesting
5. Literature study: state of the art considering climatic effects on natural processes (regeneration, growth and mortality), stand structures (horizontal/vertical) and forest productivity, wood quality, recreational values, nature conservation, and risk factors

The analysis focussed on investigating the effects of disturbances in forest ecosystems emphasizing the climatic influences.

Methods

To characterize different concepts of stand treatment quantitatively the method of SPELLMANN et al. (1999) was applied. For each major tree species three treatment phases are defined by top height ranges. In each top height range the potential stocking density is reduced to a predefined basal area density (tab. 1).

Treatment phase / Tree species	Phase 1		phase 2		phase 3	
	BA_{max}	h_{dom}	BA_{max}	h_{dom}	BA_{max}	h_{dom}
Norway spruce	0,70	14 – 20 m	0,75	20 – 26 m	0,80	> 26 m
Beech	0,70	16 – 22 m	0,65	22 – 28 m	0,75	> 28 m

Tab. 1: Management strategies for Norway spruce and beech in Lower Saxony

The maximum basal area necessary as a reference is calculated using the method of STERBA (1975, 1981 u. 1987). Utilizing experimental plot data the specific relationship between the diameter of the mean basal area tree (dg), top height (h_{dom}) and stem number per hectare (N) is derived:

$$dg = 1 / (a_0 * h_{dom}^{a1} * N + b_0 * h_{dom}^{b1})$$

The coefficients are estimated using nonlinear regression techniques. Applying these coefficients, the maximum basal area (BA_{max}) is determined with top height as the independent variable:

$$BA_{max} = \pi / (16 * a_0 * b_0 * h_{dom}^{(a1 + b1)})$$

Taking the yield level into account, the calculations are based on four rsp. five larger regions of Germany (*fig. 3*), which are a result of site mapping (WOLFF et al. 1999) and the theoretical knowledge and experience of the yield level (among others ASSMANN 1974).

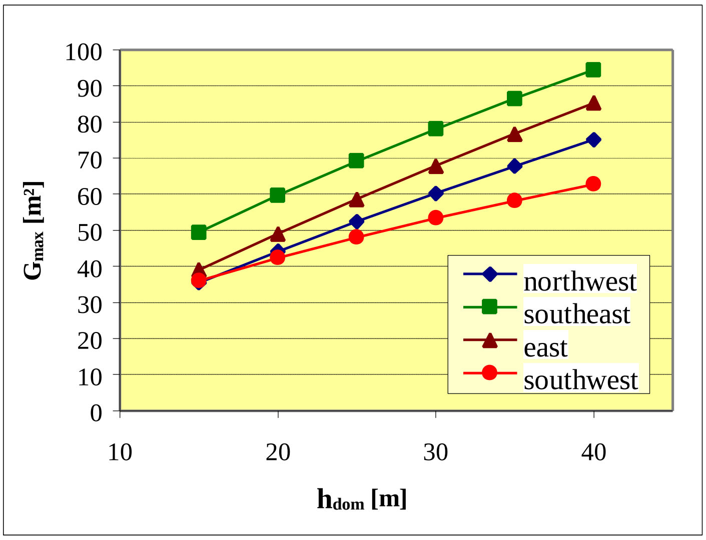

Fig. 2: Maximum basal area of Norway Spruce

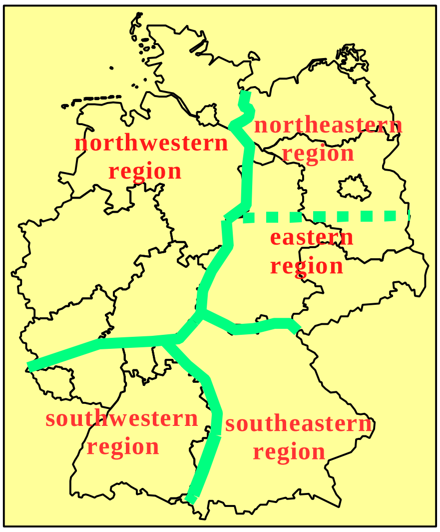

Fig. 3: The different regions of Germany

Scenario analyses using SILVA

Representative stand types on representative sites are selected on the basis of the National Forest Inventory and the „Datenspeicher Waldfonds“ (forest management database). The following scenarios are simulated for each stand type:

1. without thinning
2. with thinning } under current climatic conditions
3. without thinning
4. with thinning } under a changing climate scenario

Furthermore, growth reactions should be investigated for extreme sites, assuming that these sites emphasize the sensitive influence of changing climatic conditions on growth. The results will be evaluated using a catalogue of criteria which is subdivided into the four groups growth and yield, net revenue, stand stability, and stand structure.

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Integrated Assessment of Global Change Impacts on Forests and the Forest Sector in Germany

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Project Goals

The aim of this national case study is to assess the nature and extent of possible impacts of global climate change on forests and the forest industry in Germany. Several simulation models will be applied to national forest inventory data to simulate and assess possible consequences of different climate scenarios on forest development and wood production in German forests. Additionally, the genetic adaptability of major forest tree species will be analysed, decision making in forest enterprises will be investigated, and socio-economic consequences of these scenarios for the forest industry will be estimated.

A systems analysis of the German forest sector

The focus of this study lies on the application of existing models of forest development and stand growth using available data resources from the first national forest inventory. For the socio-economic assessment new models had to be developed since no suitable methodology was available for German conditions.

The following simulation models will be applied in the systems analysis:

- the FORSKA forest gap model to analyse possible changes in competitive relationships between species
- the SILVA forest simulator to project changes in growth and yield of the most important forest types
- the process-based gap model 4C to analyse the sensitivity of the main forest species towards changes in CO_2, climate and N deposition
- the EcoGene model to analyse the genetic adaptability of major forest tree species
- a forest enterprise model to analyse the consequences of alternative forest management strategies in economic terms
- a timber market model to investigate implications of the alternative climate and management scenarios on the supply and demand for timber

Data from European provenance trials will be used to study the genetic adaptability to probable changes in climate.

Application of simulation models

Several lines of model simulations are planned:

6. The models FORSKA and SILVA will be run for all grid points of the national forest inventory to project the development of the forest resources under different climate scenarios, indicating the magnitude of possible changes and possible regional differences in the vulnerability of the existing forests against the projected changes in climate.
7. The full set of simulation models will be run for virtual forest enterprises, which consist of representative forest types, (i) for the whole country, and (ii) for selected forest regions. The SILVA forest simulator will be initialized with data from the national forest inventory. If stand regeneration occurs in the projection period, information about suitable species will be taken from the FORSKA model output. SILVA produces projections of growth and yield which will then be used to analyse the impacts of climatic change on
8. economics and decision making in the forest enterprise, and the
9. demand and supply on the timber market.
10. The forest enterprise model simulates three extreme management scenarios reflecting different objectives of forest owners: (i) maximized economic return, (ii) optimized silviculture, and (iii) priority for social forest functions. As a baseline one simulation run without management is also included.
11. Sensitivity analysis will be conducted with the models 4C and SILVA to investigate the relative sensitivity of selected forest stands to changes in climate, CO_2-concentration of the atmosphere, and N deposition. More-over, the potential role of genetic adaptation will be investigated.

Outlook

This study is the first attempt to make an integrated assessment of climate change impacts on the forest sector at the national scale. It will synthesize our current understanding of climate change impacts and associated risks for German forests and forestry. First simulation experiments are scheduled for autumn 1999. The project terminates at the end of June 2000.

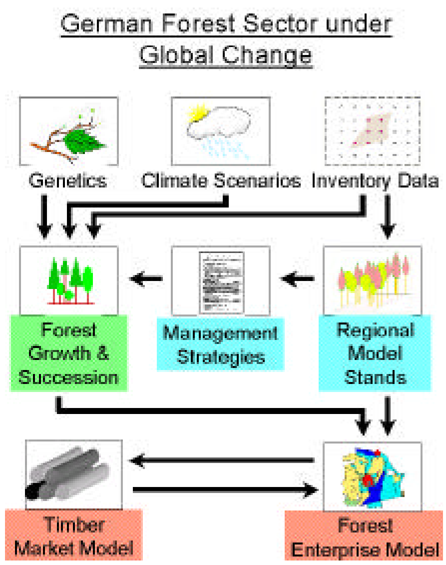

Fig.1: Project overview

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