Towards the Sustainable Use of Europe's Forests – Forest Ecosystem and Landscape Research: Scientific Challenges and Opportunities

Folke Andersson, Yves Birot and Risto Päivinen (eds.)

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Torikatu 34
FIN-80100 Joensuu, Finland
Phone: +358 13 252 020
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A Moving Target: Forest Growth in a Changing Environment – the Role of Long-Term Dynamics

Hans-Peter Kahle, Jörg Hansen and Heinrich Spiecker

Institute for Forest Growth, University Freiburg
Freiburg, Germany

Abstract

European forests have changed because management induced drastic shifts in tree species and tree age composition, as well as due to changes in site conditions and areal extent of forests. Management affects site productivity by altering nutrient cycling and by changing competition for light, nutrients and water. The observed increase in wood production and growing stock at many forest sites has been accompanied by a loss of biodiversity, a shift to non-site-adapted tree species, and an increase in biotic and abiotic risks. Changing forest conditions and changing needs of society require a widened scope for forest management.

Knowledge on the effects of management options on functions and processes in forest ecosystems and their environmental services is rather limited. Processes in forest ecosystems are operating on multiple spatial and temporal scales. Response time of forest ecosystems to disturbances ranges from the short-term up to decades and even centuries, depending on the condition of the system and the type, intensity and duration of the external stimuli. The actual state of forest ecosystems largely depends on processes of the past. As an object of research, forest ecosystems are not easy to approach.

For the control and management of sustainability in the development of the forest resources, specific scientific knowledge needs to be considerably deepened and enlarged: the relevance of tree species composition, mixture and canopy structure for the impact of environmental changes, their dependency on site conditions and their modification through management need to be analyzed on a broad scale. Sensitive parameters for assessing the state of the forest ecosystems with respect to their resilience towards environmental threats need to be identified. Retrospective observational studies provide a means for describing short- as well as long-term forest dynamics and the complex structure of multi-scale relationships. Results of the studies on long-term dynamics and the associated key processes will be of significant value for improving our understanding and hence for improving the predictive power of process-based modelling approaches.

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1. Forests in the face of change

Forest ecosystems in Europe experienced drastic changes due to centuries of large-scale human activities associated with the use and sometimes overuse of natural resources. Intensive land-use changes have largely modified the face of European landscapes and forests (Williams 1990; Bork et al. 1998; Kirby and Watkins 1998; Küster 1998; Glatzel 1999; Hunter and Schuck 2002). The management of forests affects tree species composition, stand structure and hence site productivity by altering nutrient cycling and by modifying competition for light, nutrients and water. Forest ecosystem processes are furthermore altered through human induced changes in disturbance regimes (e.g. pest control, fire control) which together with the long-lasting preference of certain tree species have led to new types of forest ecosystems(e.g. Jahn et al. 1990). The increase in wood production and average growing stock which is observed at many forest sites in Europe (Kauppi et al. 1992; Kuusela 1994; Spiecker et al. 1996) has been accompanied on a large scale by a loss of biodiversity and a shift to non-site-adapted tree species both resulting in a decrease in stability against biotic and abiotic disturbances (Spiecker 2003).

Forests provide well-recognized goods, including timber, fuel-wood, and raw materials for industrial products. Beside their productive function forest ecosystems also provide services such as maintaining biodiversity, water and soil protection, mitigation of floods, cleansing of the atmosphere, sequestration of carbon, aesthetics and recreation (Arbeitskreis Zustandserfassung und Planung 1974), services which have only recently received increased recognition (Linckh et al. 1997; Weidenbach 2001; Gadow et al. 2002; Johnson et al. 2002).

The management and use of forest resources can directly alter the functioning of forest ecosystems and the services they provide. However, human activities also indirectly affect goods and services provided by forests through changes in the environmental systems that interactively control forest ecosystem functioning. Observed and anticipated directional changes in the atmospheric, climate, soil, and hydrologic systems due to e.g. air pollution, atmospheric matter deposition and CO_2 enrichment are creating novel conditions that affect the functioning of forest ecosystems and their stability (Kellomäki et al. 2000; Kirschbaum 2000; Watson et al. 2000; Dale et al. 2001; Karnosky et al. 2001; Hunter and Schuck 2002).

For managing and sustaining forest ecosystems under changing environmental conditions and in changing socio-economic contexts – with altered needs of society, increasing public awareness and number of stakeholders – new management approaches and a widened scope of forest management is needed. The challenge for sustainable forestry today is to identify and define the attributes of forest ecosystems that are ecologically and societally important and to optimize and sustain ecosystem goods and services in the face of change (Chapin et al. 2002; Mårell et al. 2003). To achieve these goals, a more comprehensive understanding is needed of:

- the role of forest properties for ecosystem functioning,
- the relation between ecosystem functioning and goods and services provided by forests,
- the interactions and trade-offs between goods and services provided by forests,
- the interrelationships between land-use history, management practices and ecosystem functioning.

Improved scientifically based knowledge is necessary in order to implement ecological principles into forest management planning, management strategies and operations (Chapin et al. 2002). This paper is focused on research questions arising from the need for new management strategies and practices. The authors emphasize the need for studies on forest growth as a key process in forest ecosystem functioning. The role of dynamics in forest growth on various time scales is highlighted with special consideration on long-term processes.

The aim is to formulate relevant research topics which should be addressed in order to provide the detailed knowledge needed for the development of appropriate management approaches. By nature these topics require integrated multidisciplinary and multi-scale approaches. Generalizations of research findings from studies on processes and the functioning of forest ecosystems will provide the most valuable knowledge basis for decision making processes on the strategic and operational management level. The suggested research topics address questions which are of relevance for the advancement of forest management all over Europe. However, due to significant differences in environmental conditions and landscape histories over Europe, regional specific issues have to be taken into account. The suggested research approaches reflect the contributions which forest growth research can add to the challenging tasks in forest sciences.

2. Managing and sustaining goods and services provided by forests

Management options today are most commonly targeted towards the end products respectively yield outcomes, e.g. maximizing the volume of high valuable timber or current net present value of forests. Sustaining environmental services provided by forests is explicitly part of the management objectives in multipurpose forestry (Weidenbach 2001; Pukkala 2003) and landscape management (Heilig 2003). However, in the past it has most often been assumed that provision of environmental services is achieved as a “by-product” of forest production without much extra effort or significant production restrictions (Rupf 1960). Hence, sustaining environmental services has rarely been regarded as a stand-alone objective of forest management. Attempts have been made to describe relations between stand characteristics and the environmental services provided by forests (Arbeitskreis Zustandserfassung und Planung 1974; Mitscherlich 1975, 1978, 1981; Spiecker 2003), but knowledge on the effects of management options on patterns and processes in forest ecosystems which are causative for specific environmental services is still rather limited, and the trade-offs between the provision of goods and services are not well understood (Johnson et al. 2002; Mårell et al. 2003).

The relevance of tree species composition, mixture and canopy structure for the effects of environmental changes on forest ecosystems and the goods and services provided by forests, their dependency on site conditions and their modification through management need to be analyzed on a broad scale. For the control and management of sustainability of forest resources under change specific scientific knowledge needs to be considerably deepened. To be of use for the formulation of new management approaches research findings need to be generalized in a comprehensive way whereas scaling issues in the temporal and spatial domain have to be considered adequately. Sensitive parameters for assessing the state of the forest ecosystems with respect to their resilience towards environmental threats need to be identified to be of use as decisive criteria for decision support in forest management.

Management of forest ecosystems has to ensure the sustained and continuous delivery of multiple interrelated and sometimes conflicting goods and services. Key hypotheses concerning principles for sustainable management of forests under change were recently summarized by Sverdrup and Stjernquist (2002). One of the basic prerequisites of an ideal forest structure in the temperate zone and beyond is that of mixed stands: it is hypothesized that increasing the proportion of mixed stands will increase sustainability by achieving greater soil fertility and biodiversity.

The severe damages in western and central European forests caused by theextreme storm events of the early and late 1990s have been recognized as indicators of major threats to sustainability and have led to an increased awareness of the susceptibility of the forest resources to disturbances (Kronauer 2000; Teuffel 2001; Weidenbach 2001). As a consequence, the importance of risks and the role of ecosystem stability have been re-evaluated. Threats also arise from anticipated environmental changes which will most probably put European forests under more severe stress (Kellomäki et al. 2000; Aber et al. 2001; Lindner and Cramer 2002).

An important impact of these discussions is that research into the issues of mixed versus pure stands and into the question of conversion from pure to mixed stands has been largely intensified in recent years (Spiecker 1999b; Hasenauer 2000; Spiecker 2000a, 2000b; Matthes and Ammer 2001; Gadow et al. 2002; Schütz 2002; Spiecker 2003; Hansen et al. 2004; Spiecker et al. 2004). However, the mechanistic test of key hypotheses is still incomplete. Our understanding of the functioning of pure and mixed forest stands and of forest stands during conversion phases with respect to the goods and services provided is not yet sufficient for decision support (Hasenauer 2000; Makkonen-Spiecker 2001; Hansen and Spiecker 2004; Spiecker et al. 2004).

3. Research approaches for the study of long-term dynamics of forest ecosystems

The emerging challenge for forest ecosystem management today is to improve our understanding of the properties and processes that allow forest ecosystems to persist in the face of environmental changes. Since temporal dynamics of forest ecosystems operate on multiple time scales, long observation periods are necessary in order to identify the key processes that govern the system's behavior at a considered time scale (Likens 1989, 1998). Responses of forest ecosystems to perturbations occur on time scales ranging from less than a year to the order of decades or even centuries, depending on the state and condition of the system and the nature, intensity and duration of the perturbation (Spiecker 1995, 1999a; Hansen and Spiecker 2004). Therefore it is important to consider that today's conditions of forest ecosystems depend on both the current environment and past events. The persistent effects of past events are maintained as legacies that can only be resolved and understood by studies which cover the characteristic time scale where these effects are expressed (Kahle and Spiecker 1996; Chapin et al. 2002).

Classes of ecological phenomena for which long-term studies are recognized as essential include:

- **slow processes**: e.g. stand dynamics, long-lasting effects of disturbances, soil development, land-use history
- **rare events or episodic phenomena**: e.g. disturbances like droughts, floods, frost, outbreaks of pests and pathogens, windstorms, reproductive patterns of trees
- **processes with high variability**: subtle processes and complex phenomena require long-term studies in order to separate pattern from noise. Subtle processes are characterized by a high-frequency variance which is large compared to the magnitude of the medium- to long-term trend (Franklin 1989). Complex ecological phenomena involve many factors interacting on different scales. Long-term studies are important in such cases to identify the relative contribution of multiple factors by obtaining an increased sample depth in time

- **multiple equilibrium states**: transient dynamics of forest ecosystems as a whole or their components between multiple equilibrium states can only be resolved by examining long-term studies.

Considering long observation periods is a key issue for generalization and up-scaling in forest ecosystem research (Bierkens et al. 2000). The straightforward approach to analyze system behavior in the long-term is the continuous observation through measurement and monitoring over extended time periods. Observational studies might be extended by implementing experimental manipulations which allow the rigorous analysis of treatment effects when based on a proper research design. However, maintaining long-term research plots and conducting continuous or repeated assessments is time consuming, costly and results will only be available after the time of observation.

Retrospective observational studies, like forest growth studies based on the stem analysis technique (Nagel and Athari 1982; Abetz 1985; Kahle et al. 2004), are valuable in providing a means for analyzing short- as well as long-term forest dynamics and for assessing the complex structure of the multi-scale relationships in forest ecosystems (Kahle and Spiecker 1996; Spiecker et al. 1996; Dhôte and Hervé 2001). By providing baseline data retrospective studies extend the time frame of long-term studies and give an opportunity for calibration (Davis 1989). They are particularly well-suited to the study of slow processes because they can include a long time span – decades to centuries – and therefore they also have great potential usefulness for recording rare events (Spiecker 1991; Olsen 1992).

Retrospective studies can provide insight into the key processes that determine the current state and long-term behavior of forest ecosystems, knowledge which is needed to examine the role of feedback mechanisms in ecosystem dynamics. Predicting long-term forest ecosystem behavior is still a challenge for process-based scenario modeling (Van Oijen et al. 2004). This is particularly true when increasingly complex models with numerous functional relations and parameters are employed (Dale 2003; Monserud 2003). The main reason for this weakness in model performance is the lack of more detailed knowledge about the role and nature of feedback mechanisms and scale dependent interactions in forest ecosystems (Pretzsch 1997; Van Oijen, in these proceedings). The longer the prediction period the more the system behavior is determined by system dynamics (Haken et al. 1995). In providing information about key-processes that govern long-term dynamics of forest ecosystems retrospective studies constitute essential components in integrated studies aiming to deepen system understanding, for the scaling-up from forest stands to landscapes (Lertzman and Fall 1998) and finally to improve the predictive power of models (Van Oijen, in these proceedings).

Due to their usually holistic perspective retrospective studies are also appropriate to contribute significantly to the implementation of ecological knowledge in forest management decision making processes (Dewar 2001; Dale 2003).

A major weakness of retrospective growth studies lies in their limited potential to infer causality. The restricted ability to assign causal relationships between the treatments and the responses is due to the fact that the approach is inherently *a posteriori*, typically implying that

- **the study units** (e.g. trees, stands, sites) might not be optimally homogeneous in their potentially relevant attributes. Additionally information on such attributes might not be available or incomplete. As the relevant time for recording such data has often passed, it is very difficult if not impossible to obtain them;
- **the treatments** might not be orthogonal to each other, producing confounding in the results. Hence, factor specific causal effects are not identifiable from the data with certainty. This drawback can be reduced by setting up the retrospective study to mimic experimental conditions (e.g. transect study, gradient study) but strict orthogonality will hardly be accomplished; and that

- the treatments are not randomly **assigned** to the study units, instead the study objects simply exist in their particular circumstances.

Consequently, empirical results from comparative observational studies need to be interpreted with adequate care. Formally taken, the most significant benefit of observational studies is that they contribute to the generation of improved research hypotheses. However, under the given research questions and circumstances, there are often no real alternatives to this approach. Before the results are generalized the hypotheses generated from observational studies need to be tested in designed experiments wherever possible.

4. Challenging research topics

4.1 Research into forest ecosystem processes and functioning

The research topics described in this subsection address the research area 'forest ecosystem processes and functioning'. Research in these topics is relevant for establishing the knowledge base needed for an environmentally and socio-economically acceptable and improved forest management that is based on ecological principles.

Long-term changes in growth and mortality in forests
In order to improve our understanding of functions and processes in forest ecosystems, changes in forest growth and tree mortality and their relations to changes in environmental conditions need to be analyzed on multiple temporal and spatial scales. Dynamics and the underlying key processes e.g. changes in site productivity, stand dynamics, effects of disturbances require special emphasis. The aim is to improve understanding, model and predict growth of trees, and stand development, and to assess ecological risks for important tree species on different sites and under different environmental and management scenarios (e.g. Lasch et al. 2002; Lindner and Cramer 2002).

Retrospective growth data originating from stem analyses conducted in important forest ecosystems in the major European regions should constitute the core of the growth data base needed for this type of analysis. The intensive stem analysis data could be complemented by data from long-term forest research plots as well as by inventory data on tree and stand growth, on the amount of wood due to mortality and/or damaged wood due to biotic or abiotic disturbances. Information on site factors has to be compiled from other assessments e.g. site classification maps. Environmental data collected in monitoring networks e.g. meteorological data, deposition data, or aggregated/modeled data like critical loads have to be compiled and standardized for uniform analysis where needed.

The European research project RECOGNITION (Relationships between recent changes in growth and nutrition of Norway spruce, Scots pine and European beech forests in Europe) (Schuck et al. 2000; Karjalainen andSchuck 2004) is an interesting example how data from different sources can be successfully analyzed in an integrated multidisciplinary and multi-scale approach to investigate key processes in forest ecosystems. Another challenging feature of this research study is the close link between an empirical correlative approach and a process-based modeling approach.

Effects of increasing stand age on growth, vitality and mortality in forests
Growth, growth responses and mortality in forest stands at different advanced developmental stages need to be analyzed with special regard to the role of tree age for ecosystem stability

and risks of abiotic and biotic disturbances. Over Europe mean age of forest stands has considerably increased during recent decades (Spiecker 1999a, 2001). The increase in stand age is often accompanied by an increase in growing stock. The aim is to assess the ecological risks which are involved in these processes. Questions which need to be addressed are: How is tree age and tree vitality linked? What is the role of tree vitality for forest ecosystem resilience? How is the adaptive potential of forests under climate change affected by tree respectively stand age?

4.2 Research into forest management and practices

The research topics described in this subsection address the research area 'forest management and practices'. Research in these topics is needed for the successful implementation of ecological principles in strategic and operational forest management and to achieve optimized provision of forest goods and services.

Forest resource management tools to improve the ecological, economical, and societal benefits from forests
New scientifically based forest resource management tools need to be developed based on a better understanding of the key patterns and processes governing the stand dynamics in pure and mixed stands. The aim is to provide management options and tools which help to optimize multi-functionality and sustainable delivery of forest products and services which are demanded by society (Carnus et al. 2001; Mårell et al. 2003; Hansen and Spiecker 2004). A special focus should be laid on the consideration of "low input forest management": effects of reduced management intensity and their ecological, economic, and societal impacts need to be analyzed at high priority.

Strategies for the conversion of forests on sites where current tree species are not adapted
Strategies for the conversion of pure even-aged forest stands of non-site adapted species into more natural forests need to be developed. At present, the conversion of mono-species mostly coniferous forests into broadleaf dominated forests is the most challenging silvicultural task in major areas in Europe (Hasenauer 2000; Klimo et al. 2000; Gardiner and Breland 2002; Hansen et al. 2004). The aim is to develop integrated management options which minimize economic and ecological risks inherent in the conversion process and to provide the techniques necessary for their implementation (Hansen and Spiecker 2002; Spiecker et al. 2004).

Management of valuable broadleaf forests
New management options, practices and techniques for improving the ecological, economic, and societal benefits of broadleaf forests will be developed. Forests with tree species such as *Acer spec., Fraxinus excelsior, Prunus avium, Alnus spec., Ulmus spec., Sorbus spec.* bear a high potential for improving economic and ecological value by application of optimized management options.

5. A network of excellence for implementation of the emerging research tasks

The suggested research topics described in the preceding chapter are of relevance all over Europe. The concept of linking research units from different disciplines of natural and social sciences that are working on relevant topics in a European wide network bears maximum potential to achieve these research challenges in a highly efficient way. Existing research activities in Europe have to be restructured and integrated in a common framework. The instruments 'Integrated Project' and 'Network of Excellence' of the 6th Framework Programme for European research offer excellent possibilities to implement these ideas.

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