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Introduction

Trends in modeling to address forest management and environmental challenges in Europe

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Forests cover almost one third of Europe's land area (193 million hectares, excluding the Russian Federation), representing 4% of the world's forests (FAO, 2007), and they provide a range of important goods and services (de Groot *et al.,* 2002). In spite of their relatively small area, European forests account for 23% of global round wood removals; European removals have increased from 400 million m^3 in 1990 to nearly 500 million m^3 of timber in 2005 (FAO, 2007). The European forest sector accounts for about one quarter of the world's industrial output of forest products (Mery *et al.,* 1999). Removals from non-wood products are estimated to be more than half a million tones per year (FAO, 2007), with Europe being the main global producer for some of them, such as cork, pine kernels and chestnuts. In certain areas such as the Mediterranean region, the profitability of non-wood products is considerably higher than that of wood products (Palahí *et al.,* 2009). In addition to merchantable goods, European forests provide a multitude of non-market services, including carbon storage, soil protection, climate regulation, water purification, biodiversity and recreational possibilities; in addition, in mountain terrain they have a very important function for preventing natural hazards such as floods, avalanches and rockfall, with significant downstream benefits.

Despite their relatively intensive use, forest resources in Europe are growing; the average growing stock increased from 124 m^3 ha^{-1} in 1990 to 141 m^3 ha^{-1} in 2005, and forest area is increasing by about 0.4% per year (FAO, 2007). However, European forests are increasingly exposed to environmental change including natural disturbances, which can cause major losses in terms of living biomass and the provision of goods and services (MEA, 2005; IPCC, 2007). Climate change in Europe is manifest by an increase in temperature and by regional changes in precipitation regimes, which may be causing more frequent extreme events such as drought (Ciais *et al.,* 2005; Allen *et al.,* 2010), heat waves and storms which, in turn, tend to increase the frequency and intensity of pathogen outbreaks and forest fires (Lindner *et al.,* 2009). For example, forest fires burn an average of 500,000 ha per year in Europe, which is about 1% of Mediterranean forests (Birot, 2009), while large storm damages have amounted to $^1/_3$ or even $^1/_2$ of the planned European fellings in some years (Schelhaas *et al.*, 2003). For example, in 1999 the storm Lothar caused the highest damage ever reported in Europe, amounting to 175 Mio m^3 of merchantable timber, which is equivalent to nearly half the annual European wood production. Therefore, climate change and exceptional natural disturbances are highly likely to drastically affect forest dynamics as well as the provision and quality of a wide array of forest goods and services.

In central Europe, the concept of multi-functional forestry was developed to reconcile the multiple and sometimes conflicting demands for forest goods and services at small spatial scales. However, with increasing and quickly changing societal demands in addition to strong and unprecedented environmental changes,

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this concept may find its limits (cf. Puettmann *et al.,* 2009). For example, profitable, mechanized wood production is often in conflict with the demands from an increasingly urbanized population that forests should serve a recreation purpose where nature can be experienced (rather than forest operations). Similarly, carbon sequestration may be in conflict with the protective function of forest stands against natural hazards, etc. Thus, novel tools are required that support decision making, aiming at reconciling the provision of forest goods and services at landscape to regional scales with the demands from widely different user groups.

The need to consider ecosystem goods and services at larger spatial scales than in traditional sylviculture in combination with impending or ongoing environmental changes requires a paradigm shift to *ecosystem* management (cf. Christensen *et al.*, 1996) as well as *adaptive* approaches to management (*e.g.* Gray 2000). While sylviculture has always been adaptive in the sense that management interventions were based on past experience and the current state of forest stands, modern land management schemes need to take into account the anticipated *future* development of forests under environmental changes, including the associated uncertainties.

Due to the complexity of these tasks, and taking into account the dynamic nature of forest ecosystems, the multiple goods and services they provide, the diversity of forest ecosystems as well as the high number of management alternatives and the large spatial and temporal scales involved in ecosystem management, the anticipation of the consequences of management decisions in the context of potential environmental changes and their associated impacts is a key task in modern forestry decision making (cf. Pretzsch, 1992). Within the past two decades, much effort has been devoted to the development of modeling concepts and simulation models that address the need for understanding and predicting the consequences of forest management under changing environmental conditions, so as to guarantee the sustainability of the provision of forest ecosystems goods and services.

Any model is a deliberate simplification of reality, and thus the question arises what the key elements are that need to be included in a model *vs.* what can be treated only coarsely or may be ignored entirely. According to Levins (1966), models in the environmental sciences face a fundamental trade-off between realism (simulating system behavior based on a qualitatively realistic model structure), accuracy (simulating system behavior in a quantitatively accurate manner), and generality (representing a broad range of systems behaviors with the same model; cf. Odenbaugh, 2006).

On the one hand, keeping models simple by using relatively aggregated formulations of processes (often called «empirical modeling») has the advantage of keeping model complexity low, thus making it easier to track model behavior to specific formulations; also it is often possible to estimate parameters based on widely available growth data as provided by forest inventories and increasingly available spatial environmental data, using statistical techniques. However, this comes at the cost of sometimes having to use the model in extrapolation mode, *i.e.* beyond those conditions for which the functions were calibrated, particularly when studying the impacts of environmental change on forest development, thus casting doubt on the robustness of the results. In addition, the temporal scales usually represented in simple models (typically, annual to monthly at best) hinder the accurate simulation of short-term events such as disturbances.

On the other hand, increasing model realism usually implies including more detailed structure and process representations and their dependences to environment, or enhancing the temporal or spatial resolution of the model, thus leading to what often has been termed as «mechanistic» or «process-based» modeling. According to Landsberg (2003), process-based modeling implies that a model of a given system is, at whatever level of complexity, based on the description of the constituent processes whose interactions determine the behavior of the system; this is in essence the idea of ecosystems as hierarchical systems (cf. O'Neill *et al.,* 1986). A classical example for this is the explicit modeling of (1) photosynthesis at the leaf level and (2) respiration at the whole-plant level as a function of ambient CO_2 concentration, temperature, radiation and air humidity, thus giving rise to a «mechanistic» estimation of net plant production.

Such «mechanistic» approaches necessarily come at the cost of increased model complexity, which among others entails a higher number of parameters, a substantial need of calibration data, and increased simulation time. However, a more detailed representation of processes to better mimic their occurrence in the real system should bring about an enhanced robustness of the model projections, particularly under changing environmental conditions. Yet, process-based models have shortcomings regarding their applicability in forest management and in providing outputs of interest for forest management decision-making (see Landsberg *et al.*, 2003; Bugmann and Martin, 1995). In this context, the trend is towards hybrid modeling by combining physiologically-based growth models with forest management-oriented, empirical models. It is the exact research or management question and thus the objectives of a study that determine the kind of model that is most useful and the degree of temporal and spatial resolution that is most appropriate, following Box's (1978) famous quote: «All models are wrong, but some model are useful».

In addition, it is important to keep in mind that all models that are geared towards practical applications (*i.e.,* unlike those *e.g.* in theoretical ecology) rely on data for parameter estimation, for calibration if data for individual parameters are not available, for the initialization of simulations, and for the evaluation of their performance (Vanclay, 2003). At least two issues require a re-appraisal of the data on which forest models are based. On the one hand, forest management is becoming more diverse: in some situations, it is becoming more intensive with precision silviculture (*i.e.,* for industrial sawlog production); elsewhere it is increasingly relying on non-timber forest products; in some remote localities, it is involving natural or artificial regeneration with trees that may never be harvested (*e.g.,* afforestation for soil protection or avalanche control). This diversity poses interesting challenges for modellers as traditional growth and yield databases may not provide the required information for these management challenges. On the other hand, new and highly useful databases are increasingly becoming available from environmental surveys and monitoring programmes (*e.g.* the ICP Forests Network), the expanding flux tower network (*e.g.* EUROFLUX, AmeriFlux), and other sources. This type of information is crucial especially for models that are concerned with the impacts of environmental change on forest productivity. In the face of changing environmental drivers, Beetson *et al*. (1992) and Vanclay *et al*. (1995) suggested innovative ways in which results from such databases could be compared with model-based production estimates to examine the extent to which the predictions are extrapolations rather than interpolations within the sampled data space.

Ultimately, models to be applied in forest management need to be integrated and used within computer-based decision support systems (DSSs; cf. Reynolds *et al.*, 2007), including multi-criteria decision methods, optimization techniques, advanced visualization techniques and participatory decision making tools. DSSs are crucial in supporting adaptive forest management as they provide (1) insights for the structuring and effective analysis of management options by explicitly taking into account «uncontrollable factors» such as disturbances, future prices of forest products, etc., and (2) guidelines how to react to such changes.

Given the degrees of freedom that a modeler has when designing, developing and implementing a model, it is important to have a good overview of the available tools and their advantages and limitations, and to identify the most promising perspectives for building models applicable in forest ecosystem management. Therefore, the aim of this Special Issue entitled ***Trends in modeling to address forest management and environmental challenges in Europe*** is to review the forest models and related simulation tools that are available in Europe to address a number of emerging challenges in forest management. The Special Issue is structured around five review articles focused on five questions that were chosen based on of their intrinsic scientific importance as well as their significance for decision-making in forest management: (i) Models for supporting forest management in a changing environment (Fontes *et al.,* 2010); (ii) Recent approaches to model the risk of storm and fire to European forests and their integration into simulation and decision support tools (Hanewinkel *et al.,* 2010); (iii) Simulating wood quality in forest management models (Mäkelä *et al.,* 2010); (iv) Modelling non-wood forest products in Europe: a review (Calama *et al.,* 2010); and lastly, (v) Simulation tools for decision support to adaptive forest management in Europe (Muys *et al.,* 2010). In addition, the special issue is complemented with two original papers dealing with forest genetics modeling (Kramer and Van der Werf, 2010) and an example of modeling forest birds using neural networks (Gil-Tena *et al.,* 2010).

This Special Issue is a result of the work conducted by Working Group 1 of the COST Action **FP0603 «Forest models for research and decision support in sustainable forest management»**. The Action is structured in four Working Groups:

— Working Group 1: Inventory and review of existing models (WG1).

— Working Group 2: Underlying concepts and theories, model extensions (WG2) .

— Working Group 3: Data-model interactions (WG3).

— Working Group 4: Applying models at different temporal and spatial scales (WG4).

More information on this COST Action can be found on the internet under http://www.isa.utl.pt/def/fp0603forestmodels/.

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