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Potentials and limitations of using large-scale forest inventory data for evaluating forest succession models

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ABSTRACT

Forest gap models have been applied widely to examine forest development under natural conditions and to investigate the effect of climate change on forest succession. Due to the complexity and parameter requirements of such models a rigorous evaluation is required to build confidence in the simulation results. However, appropriate data for model assessment are scarce at the large spatial and temporal scales of successional dynamics. In this study, we explore a data source for the evaluation of forest gap models that has been used only little in the past, i.e., large-scale National Forest Inventory data. The key objectives of this study were (a) to examine the potentials and limitations of using large-scale forest inventory data for evaluating the performance of forest gap models and (b) to test two particular models as case studies to derive recommendations for their future improvement.

We used data from the first Swiss National Forest Inventory to examine the species basal area and tree numbers in different diameter classes simulated by the gap models ForClim (version 2.9.3) and PICUS (version 1.4) for forest types that are typical of mountain forests in Switzerland. The results showed the potential of data from large-scale forest inventories for evaluating model performance. Since this type of data is typically based on a large number of samples across environmental gradients, they are particularly suited for investigations at the general level of the dominant species based on stand basal area. However, the surprisingly small variability of juvenile trees (trees <12 cm diameter at breast height; dbh) indicated limitations of the data used. Insufficient representativeness due to small sample plot size and uncertainty regarding past management limit an evaluation of structural forest aspects such as species diversity, and number of small trees (dbh < 12 cm).

The examined models reproduced the observed species composition satisfactorily. However, there were clear model deficiencies in the simulation of successional patterns and of juvenile tree numbers. We identified priorities for future model development.

We conclude that large-scale forest inventory data can be valuable for model evaluation, particularly when they cover large environmental gradients and do not come from intensively managed forests. Due to their limitations, they must, however, be complemented by other data such as from a full cruise.

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1. Introduction

Forest succession models from the family of gap models (Botkin et al., 1972; Shugart, 1984) have been used widely in applied research to examine, for example, the effects of climate change on forest development (e.g., Shugart, 1998; Bugmann et al., 2001; Lasch et al., 2002). Due to the complexity and parameter requirements of these models, a rigorous evaluation is needed to build confidence in the simulation results prior to such applications (Bugmann, 2003). However, the large spatial and temporal extent of forest succession and the lack of appropriate empirical data render the evaluation of gap model simulations a non-trivial task.

A common approach to evaluate forest gap models has been to compare simulated species composition at equilibrium with estimates of potential natural vegetation (PNV; e.g., Lasch et al., 1999; Bugmann and Solomon, 2000; Lindner et al., 2000; Bugmann et al., 2001; Lexer, 2001; Shao et al., 2001). Major problems with this method are: (a) PNV itself is a model construct that is not based on "hard" data (cf. Ellenberg, 1996); (b) since PNV represents the "climax" state of a forest, only the simulated equilibrium species composition can be tested, but not the simulated dynamics; and (c) no quantitative assessment is possible (Badeck et al., 2001).

In other studies simulated data were compared with pollen records from paleoecological studies (e.g., Solomon and Webb, 1985; Lotter and Kienast, 1992; Heiri et al., 2006). Key problems with this approach are: (a) to obtain climatic data series to drive the model that are independent of the pollen data and (b) the low temporal and sometimes also low taxonomic resolution of the pollen data.

More recently, simulated forest dynamics were compared quantitatively against local time series of stand development (e.g., Lasch et al., 2005; Risch et al., 2005; Seidl et al., 2005; Wehrli et al., 2005). Model evaluation based on this approach is also prone to limitations because: (a) the legacies of the past such as natural and anthropogenic disturbances that have shaped observed forest stands are uncertain, (b) the assumption that the measured data are representative of regional forest dynamics as simulated by succession models may not be correct (cf. Bugmann, 2001b), and (c) the measured time series usually span a few decades only, which is exceedingly short compared to the century-long forest dynamics simulated by the models.

In this paper, we explore another data source for the evaluation of forest gap models that has been used only limited in the past (e.g., Rickebusch et al., 2007), i.e., large-scale National Forest Inventory data. These data do not represent "natural" forests but they often span large environmental gradients along which forest properties such as diameter distribution and species composition should be reflected adequately by forest gap models. Particularly in central European mountain regions (e.g., Switzerland or Austria) where "near-natural" forest management has been prevailing since decades (Gamborg and Larsen, 2003), we can profit from large environmental gradients over short horizontal distances along which the human fingerprint on forest attributes is less pronounced than in more intensively managed low-elevation regions (e.g., Grabherr et al., 1998).

The key objectives of this study are: (a) to examine the potentials and limitations of using large-scale forest inventory data for evaluating the performance of forest gap models and (b) to test two particular models as case studies and to derive recommendations for their future improvement.

2. Methods

We adopt a novel approach to achieve our objectives. We used data from several thousand forest plots sampled in the first Swiss National Forest Inventory 1982–1986 (EAFV and BFL, 1988) to derive "average" forest conditions for 15 regional mountain forest types that can be compared with simulated forest data from two current gap models, ForClim v2.9.3 (Risch et al., 2005) and PICUS v1.4 (Seidl et al., 2005).

Most previous model evaluations focused on stand properties such as species-specific biomass or basal area. In our analysis, however, we are seeking to complement the evaluation of stand properties by structural features such as tree numbers, particularly of juvenile trees <12 cm diameter. The numbers of juvenile trees are of particular importance, e.g., when succession models are used to assess the impacts of ungulate herbivory (e.g., Jorritsma et al., 1999; Kienast et al., 1999; Seagle and Liang, 2001), but the accuracy of the models in reproducing the numbers of small trees has rarely been scrutinized rigorously.

2.1. *Gap models*

Gap models are individual tree-based models that simulate forest development based on the patch dynamics theory (Watt, 1947; Picket and White, 1985). Establishment, growth and mortality of individual trees on independent, small patches of land (size 0.01–0.1 ha) are simulated as a function of biotic (competition) and abiotic factors (climate). Succession is driven by the mortality of large, dominating trees that produce gaps in the forest, leading to increased tree recruitment rates and a growth release of suppressed trees. Tree growth and properties such as height and leaf area are calculated using species-specific allometric functions based on tree diameter at breast height.

We selected the gap models ForClim v2.9.3 (Risch et al., 2005) and PICUS v1.4 (Seidl et al., 2005) for our analysis because these two models represent strongly different lines of development of this large class of models (Bugmann, 2001b) with ForClim being closer to a "traditional" gap model (sensu Botkin et al., 1972; Shugart, 1984) and PICUS being a "hybrid" model that incorporates elements of physiology-based forest growth models.

2.1.1. ForClim

ForClim has maintained the "traditional" approach of forest gap models, with multiple new formulations to better reflect climatic influences on tree population dynamics. Rather than tracking each individual tree, the fate of cohorts of trees of the same age is modeled (Bugmann, 1996; Bugmann and Solomon, 2000). Tree growth is specified as a species-