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Forest Ecology and Management 205 (2005) 149–167
Forest Ecology and Management
www.elsevier.com/locate/foreco

Using a forest patch model to predict the dynamics of stand structure in Swiss mountain forests

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Received 5 November 2003; received in revised form 3 September 2004; accepted 12 October 2004

Abstract

Forest patch models have been applied to simulate forest development and long-term forest succession in many studies. The main focus of these simulations has been on species composition and biomass in natural forests, but these models could also become useful for the prediction of other structural forest patterns such as size distributions. Up to now, most of these models have been validated by approaches such as comparison of simulation results with potential natural vegetation (PNV), or national forest inventory data. While these approaches may be appropriate to validate the simulated species composition, they are not sufficient in testing the prediction of other structural patterns. Thus, little is known about the accuracy of forest patch models in simulating structural forest patterns such as size distribution of different forest types. For this reason, we tested the forest patch model ForClim against empirical data from three Swiss mountain forests. The objectives of this study were: (i) to investigate the performance of ForClim in simulating structural forest patterns and (ii) to assess the influence of the regeneration, growth and mortality submodels of ForClim on the simulation results.

Several shortcomings of the model were identified and quantified. In particular, the stress-induced mortality implemented in ForClim was found to overestimate the actual mortality rates. The excessive mortality was most likely caused by an inaccurate growth function or an overestimation of light competition. Once the stress-induced mortality was reduced, ForClim was able to reproduce structural forest patterns in an accurate manner. Based on these encouraging results, we suggest that ForClim as well as other forest patch models could become important tools for further applications in forest research.

Keywords: Forest patch model; ForClim; Model test; Mountain forest; Diameter distributions; Forest structure

1. Introduction

Forest patch models (or 'gap' models, cf. Shugart, 1984) have been widely used in ecological applications for more than three decades (Shugart, 1998; Hasenauer et al., 2000). Since the creation of the first

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doi:10.1016/j.foreco.2004.10.043

forest patch model JABOWA (Botkin et al., 1972), many similar models have been developed for a broad range of forest types and other ecosystems, such as grasslands and savannas (cf. Shugart, 1998). A recent review of forest patch models has been published by Bugmann (2001b).

The main focus of these models has been on the simulation of forest development and long-term succession (species composition and biomass) in natural forest stands under different climatic conditions and in different climatic regions (e.g., Botkin et al., 1972; Bugmann, 1994; Desanker, 1996; Lexer and Hönniger, 2001; Shao et al., 2001; Talkkari and Hypen, 1996). Therefore, most of the models do not include forest management submodels (Hasenauer et al., 2000). Nevertheless, patch models have not only been used to predict vegetation patterns under different conditions, but they have also been relatively successful in reproducing average compositional and structural forest patterns such as tree size distributions in Africa, America, Asia and Australia (cf. Shugart, 1998; Huth and Ditzer, 2000). Therefore, they have the potential to become an important tool for further applications in forest research in these regions.

In Europe, however, the application as well as the validation of patch models has been constrained by the fact that the majority of the European forests are either still managed strongly, or they have at least been modified by humans (e.g., forest pasture, timber harvesting; cf. Badeck et al., 2001). Due to the lack of data on unmanaged forests, only very few models have been validated by comparing model results with empirical forest stand data. For example, Lindner et al. (1997) presented a test with data from a managed beech stand in Germany. Instead, different approaches have been used to test patch models. These approaches include: (i) comparisons with the potential natural vegetation (PNV sensu Tüxen, 1956; e.g., Lexer, 2000), (ii) comparisons with national forest inventory data (e.g., Löffler and Lischke, 2001) and (iii) the use of pollen records to evaluate predictions of long-term vegetation dynamics (e.g., Lischke et al., 1998). While these approaches may be appropriate to validate the simulation of tree species composition and biomass, they are not sufficient for testing the prediction of more detailed structural forest patterns. Thus, little is known about the accuracy of patch models in simulating structural forest patterns such as size distribution of different European forest types. Therefore, their application to other research questions in Europe has been limited to date.

Forest patch models simulate the establishment, diameter growth and mortality of each tree in a given area (a *patch*). Individual tree growth is thereby calculated using a maximum growth potential derived from empirical data, which is reduced by environmental constraints, i.e., light, temperature, soil moisture and nutrients (Bugmann, 2001b). Among these constraints, light competition is commonly a major factor. Therefore, the accuracy of the growth function strongly depends on the capability of the model to accurately predict stem numbers. Since stem numbers and species composition also depend on the performance of the regeneration and mortality algorithms included in a model (Lindner et al., 1997), these two processes have to be considered as well. The integration of these processes in current patch models has recently been reviewed critically by Keane et al. (2001) and Price et al. (2001). They stated that tree regeneration and tree mortality caused by natural or anthropogenic disturbances (i.e., silvicultural operations) are not satisfactorily integrated in patch models yet. However, the influence of these shortcomings on the accuracy of model predictions is not clear.

The objective of this study was: (i) to test the capability of the forest patch model ForClim (Bugmann, 1994, 1996) to predict structural forest patterns in different European mountain forests and (ii) to assess the performance of the regeneration, mortality and growth submodels included in ForClim. For this reason, we compared simulation results to empirical data from permanent plots in Swiss mountain forests. Since no time series on unmanaged forests were available, the test was performed with data from managed stands.

2. Methods

2.1. The patch model ForClim

ForClim is based on the FORECE model (Kienast, 1987) and was originally developed to assess the impacts of climatic changes on tree species composition and biomass of forests in the Swiss Alps