Forest Landscape Development: Linking Forest Structure to Landscape Function

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Abstract: Forests provide a wide range of ecosystem services, including timber production, carbon sequestration, water regulation, protection from natural hazards, preservation of biodiversity, and recreation. Many of these functions depend on forest structure, which is characterized by species composition and tree size distributions at different spatial scales. Environmental change is expected to affect forest structure and landscape function. In order to understand the medium- and long-term consequences of environmental change and alternative management options for landscape function, process-based simulation models of landscape dynamics provide a valuable tool. The aim of this research project is to link an established forest landscape model, LandClim, to existing process-based models of specific landscape functions, in particular (a) sediment flux and water regulation, and (b) landslides for the Soyang watershed in South Korea. These coupled models will provide an explicit description of how forest structure translates into landscape functioning, and will allow the analysis of trade-offs between management options for different ecosystem services and biodiversity conservation.

Keywords: *forest structure, landscape function, process-based simulation model, LandClim, sediment flux, water regulation, landslides*

1. Introduction

1.1 Background

The multitude of ecosystem services provided by forests, and the long timescales involved in forest development require integrated assessments of management options for which simulation models are important tools (Pretzsch et al. 2008). For example, in a study of the Willamette Basin, Oregon (United States) for the time period 1990 to 2050, Nelson et al. (2009) analysed alternative management scenarios with respect to a suite of ecosystem services and biodiversity conservation. They found little evidence of trade-offs between ecosystem services and biodiversity conservation, but trade-offs between commodity production values on the one hand and ecosystem services and biodiversity conservation on the other hand. However, it is currently an open question whether these results also hold for other ecosystems and when climate change is considered in addition to land use changes.

1.2 Aims and Research Questions

The main aim of the study is to improve our understanding of how forest landscape structure translates into landscape function, to what extent trade-offs exist in the provisioning of ecosystem services and biodiversity conservation in forest landscapes, and how climate change might affect these relationships. In particular, the research is structured by the following research questions:

- What role does spatial forest structure (where structure is characterized by species composition and age distribution) play for
  - biodiversity conservation (assessed via empirical relationships of forest structure, including dead wood distribution, with bird diversity)?
  - ecosystem services related to hydrology, in particular sediment transport and coarse woody debris, and prevention of landslides?

- What are likely effects of climate change on forest structure and thus on biodiversity conservation and ecosystem services?
- How do alternative management scenarios modulate these effects?

2. Material and Methods

2.1 Study Area

The main site for the studies is the Soyang Lake watershed in South Korea. See Tenhunen et al. TERRECO Geographical Setting in the proceedings for further details.

2.2 LandClim

The following description of LandClim is modified from Pretzsch et al. (2008). LandClim was developed to study the effects of topography, climate and land use on forest structure and dynamics. LandClim is a spatially explicit, stochastic landscape model, based on the well-established LANDIS model (He et al., 1999). A particular focus is on large-scale natural disturbances such as fire (Schumacher et al., 2004, 2006) and the consequences of climate change for forest landscape structure (Schumacher and Bugmann, 2006). Processes at the stand scale, i.e. growth and mortality, operate on annual time steps, whereas landscape-scale processes, i.e. fire, wind, harvesting and seed dispersal, are simulated in decadal time steps (Figure 1). The state of the forest at each grid cell (stand scale, 25 x 25 m) is represented by the number and biomass of trees in cohorts (individuals of the same age and species). LandClim allows simulating forest development over short (decades) as well as long time scales (hundreds to thousands of years) and large spatial extents (> 100 ha) at a relatively fine spatial grain. For example, LandClim has recently been used to study forest development in alpine sites over the Holocene (Henne et al. 2011). Current developments of LandClim include modules for the simulation of insect disturbances and for the description of intraspecific variation in traits such as drought tolerance.

LandClim has been designed to have comparatively modest input requirements. It needs a digital elevation model at approx. 25 m resolution and a map of soil depths. The essential climate inputs are mean monthly precipitation sums and temperature means at a reference elevation, together with altitudinal lapse rates. Wind disturbance is characterized by mean disturbance size and return interval. Harvest rates can be differentiated with respect to size class, species and spatial position (Gustafson et al., 2000; Schumacher et al., 2004). Simulations can be started from bare ground or from an initial spatial distribution of tree cohorts.

LandClim provides aggregated output on biomass and stem numbers per species along elevation bands, or complete information on the state of individual cells. In addition, information on the harvest and disturbance regimes is reported, e.g. records of fire dates and sizes as well as maps of fire events. Figure 2 provides example output from LandClim, contrasting the distribution of dominant tree species in a Swiss alpine valley for two climate scenarios.

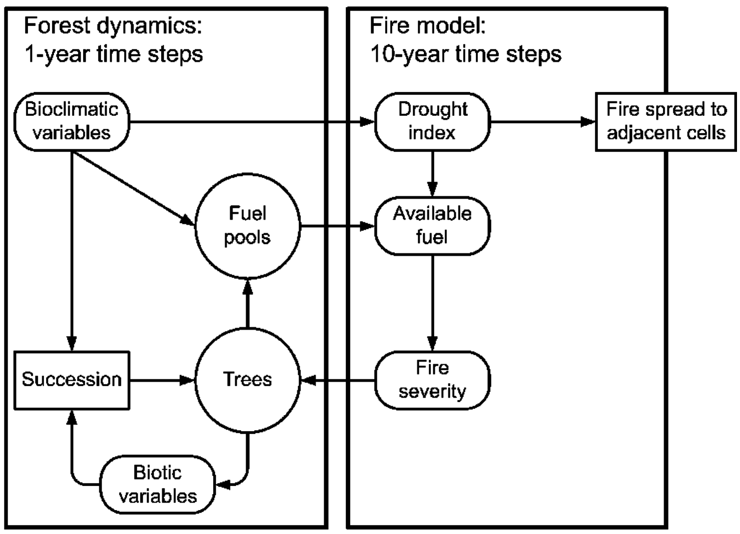

Figure 1. Structure of the forest landscape model LandClim, reproduced from Schumacher et al. (2006)

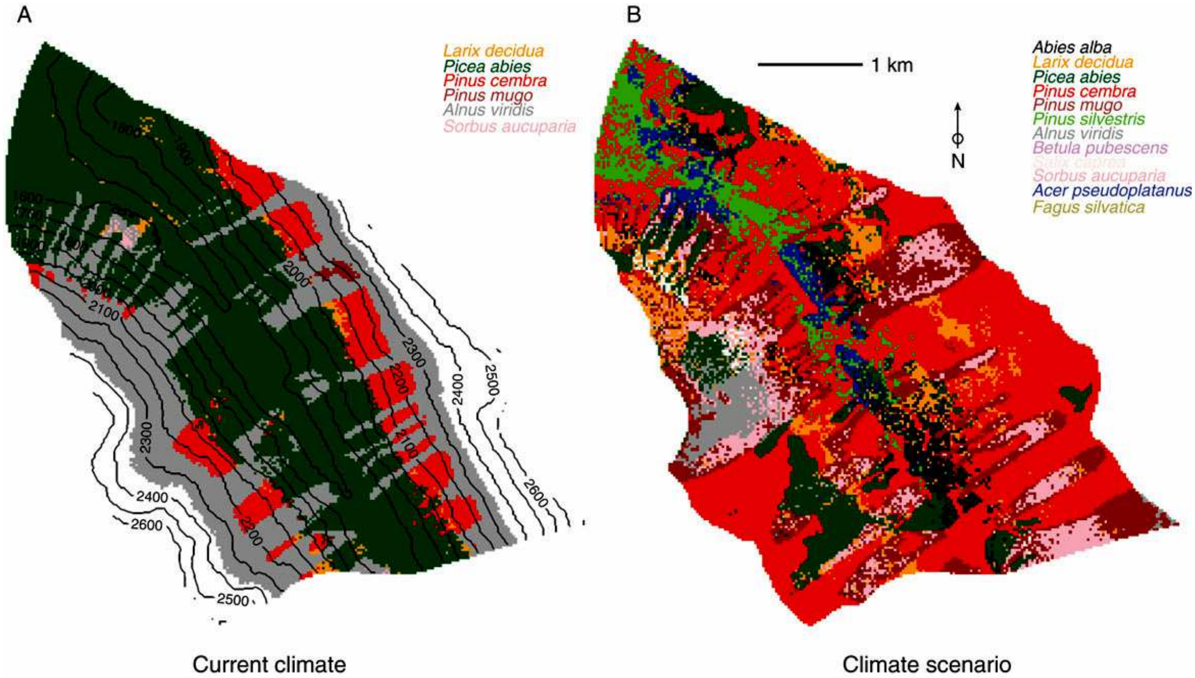

Figure 2. Distributions of dominant tree species in the Dischma valley (Switzerland) simulated with LandClim for (A) current climate conditions (3.2 °C mean annual temperature, 900 mm mean annual precipitation) and (B) a climate warming scenario (6.2 °C mean annual temperature, 700 mm mean annual precipitation). Reproduced from Pretzsch et al. (2008)

2.3 Process Models of Landscape Function

In order to address how forest landscape structure translates into landscape function, LandClim will be coupled to established process-based models of specific landscape functions.

With respect to ecosystem services related to hydrology, in particular sediment transport and coarse woody debris, we intend to use SWAT (e.g. Gassmann et al. 2007).

With respect to landslides, we intend to use process-based models of slope failure that include the physical processes governing slope stability on the basis of geomorphic, hydrological, geological, and vegetation data (e.g. Montgomery and Dietrich 1994, Wu and Sidle 1995).

2.4 Working Plan

This study is organized into a suite of interrelated work packages. The study will

- Parameterize LandClim for forests of the Soyang lake area, and provide an assessment of valuable future data for the reduction of parameter uncertainty, using modern techniques of confronting stochastic simulation models with data (Hartig et al. 2011).
- Simulate likely future forest landscape development under climate change scenarios
- Couple LandClim to suitable process-based models of important ecosystem services in the Soyang lake area, e.g. sediment retention, water storage, and prevention of landslides.
- Investigate the relative roles of landscape level forest heterogeneity for the provisioning of the selected ecosystem services. In particular, we will compare the role of heterogeneity in tree age classes vs. heterogeneity resulting from species composition and related trait diversity for the means and variabilities of these services
- Investigate trade-offs between the selected ecosystem services
- Assess alternative forest management strategies (de-/reforestation; tree species selection and harvesting regimes) and investigate trade-offs between selected ecosystem services.

3. Outlook

In order to evaluate alternative management options for forest landscapes, an improved understanding of the relationships between forest structure and landscape functions is relevant. Such an understanding will aid in assessing the relative importance of stand structure vs. species composition, and in identifying potential tradeoffs between different ecosystem services and biodiversity conservation. Process-based simulation models provide a powerful tool for this research challenge.

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