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Forest Ecology and Management 254 (2008) 371–374
Forest Ecology and Management
www.elsevier.com/locate/foreco

Editorial

Forest landscape models, a tool for understanding the effect of the large-scale and long-term landscape processes

Forest landscape models have become important tools for understanding large-scale and long-term landscape (spatial) processes such as climate change, fire, windthrow, seed dispersal, insect outbreak, disease propagation, forest harvest, and fuel treatment, because controlled field experiments designed to study the effects of these processes are often not possible (Shifley et al., 2006). In the past decade and a half, significant advances in theory and technology have been incorporated into the development of forest landscape models (Mladenoff and Baker, 1999; Gardner and Urban, 2003; Keane et al., 2004; Brown et al., 2006). From a theoretical perspective, forest landscape models continue to build upon the rich ecological theories of disturbance, succession, and equilibrium and non-equilibrium dynamics of ecosystems processes (Mladenoff, 2004). It is now widely acknowledged that the future status of forest ecosystems is constrained by both local-scale (ecosystem) and large-scale (landscape) processes (Turner et al., 1993; Wu et al., 2006). From a technological perspective, forest landscape models have benefited greatly from the rapid development of computing capacity, GIS, and software engineering. Determining which ecological processes to incorporate into a forest landscape model, how to represent those processes, and how to simulate the interactions among such processes can be facilitated by improved software products with features such as fully modularized model design and interchangeable module components (Fall and Fall, 2001; He et al., 2002).

To facilitate the exchange of the progress made in theory and application of forest landscape models, the China Natural Science Foundation and the International Association of Landscape Ecology sponsored an international workshop of forest landscape modeling in June 2006. The workshop was organized by the Institute of Applied Ecology, Chinese Academy of Sciences. The purpose of the workshop was to study and discuss the strengths and weaknesses as well as opportunities and limitations of the modeling approach and applications embodied in forest landscape modeling. Over 50 papers were presented at the workshop, of which 12 were selected in this special issue, and one paper (Zollner et al., 2008) was invited. We have organized the papers into three sections that describe current activities in forest landscape modeling: (1) effects of climate change on forest vegetation, (2) forest landscape model applications, and (3) model research and development.

1. Effects of climate change on forest vegetation

The first section contains papers of applying landscape models to studying potential distribution of tree species, historical range of variability of landscape composition and structure, and forest harvesting and afforestation strategies under climate warming. Forest landscape models are shown as an important tool in studying the effects of climate change, which involve large spatial extents and long time spans.

Keane et al. (2008) present a simulation study that generates reference landscape composition for all combinations of three climate scenarios (warm–wet, hot–dry, and current) and three fire regime scenarios (half-historical, historical, and double historical fire frequencies) to determine if future climate change has an effect on landscape dynamics. Forest landscape dynamics were simulated using the LANDSUM model (Keane et al., 2002). They found that simulated time series using future predicted climate scenarios are significantly different from the simulated historical time series and any changes in the fire regime tend to create more dissimilar and more variable simulated time series. Their results suggest that historical time series should be used in conjunction with simulated future time series as references for managing landscapes.

The Iverson et al. (2008) paper presents a culmination of years of research on the current and future ranges of tree species in the eastern United States. Using advanced statistical techniques such as Random Forests, this team was able to map the potential habitat for 134 tree species under six future climate scenarios, including three general circulation models and low and high emission scenarios. Their results indicate that any reduction in human-related carbon emissions will decrease migration pressure towards more hospitable environments. In general, they found that oaks and pines may increase in area under most future climates while spruce and fir will tend to decrease. Of the 134 species, around half showed potential increases of at least 10% under most climate scenarios. These models are important to land management because they can

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doi:10.1016/j.foreco.2007.09.069

help guide future efforts of reforestation, restoration, and harvesting.

Effects of climate warming on tree species cover in northeastern China were investigated by Bu et al. (2008) using landscape forest modeling with the LANDIS model. They found that both Korean pine (*Pinus koraiensis*) and ribbed birch (*Betula costata*) will increase in cover while larch (*Larix gmelinii*), fir (*Abies nephrolepis*), and spruce (*Picea koraiensis* and *P. jezoensis*) will decrease under a warmer climate. This has great implications for the timber industry in that they found that over 20% of the harvested areas will require additional planting treatments and there will be an increase of 11–42% in the area of potential timber harvest. This application of forest landscape modeling was used to guide forest harvesting and planting under the predicted warming climate scenarios.

Another example of modeling the effects of climate warming on trees in northeastern China was provided by Leng et al. (2008). They worked with three species of larch (Dahurian larch (*Larix gmelinni*), Korean larch (*Larix olgensis var. changpaiensis*), and Prince Rupprecht larch (*Larix principis-rupprechtii*)). They used the Random Forest modeling technique (Prasad et al., 2006) to investigate the relationship of the species' current distribution to 18 environmental variables from that region. They found that the suitable habitat for each of the three species would be reduced substantially within northeastern China, including a likely total loss of habitat for the Prince Rupprecht larch.

2. Forest landscape model applications

The second section describes specific applications of forest landscape models to address research and management questions including alternative forest planning, historical and current fire regimes, and oak decline risk assessment.

Forest planning is an increasingly important activity in which forest landscape models can provide valuable assistance and Zollner et al. (2008) provides a very nice contribution that demonstrates a way to evaluate alternative management plans and assess if they are likely to meet their stated, multiple objectives. They used LANDIS to predict forest composition and landscape pattern under seven alternative forest management plans drafted for the Chequamegon-Nicolet National Forest in Wisconsin, USA. In most cases, the model showed that multiple objectives were obtainable without conflict, but in 20% of the cases, land managers would need to prioritize among eight timber and wildlife management objectives. Some desired outcomes were obtainable only by mutually exclusive management activities.

In northeastern China, fire suppression has been implemented for over a half century and it has profoundly changed the fire regime in that region. Chang et al. (2008) used a forest landscape model to investigate the effects of historical and current fire regime in northeastern China. They found that the current fire regime can lead to more intense and catastrophic fires than the historical fire regime. Prescribed burning and coarse woody debris reduction is recommended as a means to reduce potential fire risk. Such a recommendation is significant because even though fuel treatments have been widely used in many parts of the world, they have not yet been introduced into forest management plans in China.

Spetich and He (2008) parameterized LANDIS to delineate the extent and dispersion of oak decline in the Boston Mountains, Arkansas, USA. This model was used to better understand how species composition, age structure, and ecological land types interact with simulated fires to affect the dynamics of oak decline. Two fire regimes representing fire return intervals of 50 (historical regime) and 300 (current regime) years were used over 150 years of simulation. They found that after 150 years, 30% of the sites were classified as potential oak decline sites under the current regime, while 20% of the sites were decline sites under the historical regime. This tool thus allows a determination of potential oak decline sites and a risk rating over the entire area.

A robust spatial metric called the topographic roughness index (TRI) was presented as a possible variable to determine wildland fire activity across large landscapes by Stambaugh and Guyette (2008). This index is computed by estimating the planimetric surface area of the landscape and adjusting it for the topographic slope. The TRI can then be statistically correlated to fire frequency field data to create models that predict fire regimes across large regions. A mean fire return interval model was developed for a large landscape in Missouri, USA and, while the model only explained 46% of the variance, it appeared to identify topography as the most important variable controlling fire dynamics during 1620–1780 AD. This index may have use as a predictor variable for many other landscape modeling efforts.

Shifley et al. (2008) discussed issues, limitations, and opportunities of applying forest landscape models, based on their more than a decade experience of model applications. They found that applications of forest landscape models are hampered by the difficulty of deriving the initial landscape layers needed for model simulation and by the complexity of calibrating forest landscape models for new geographic regions. They also pointed out that landscape model applications are complicated by issues of scale related to the size of the landscape, the resolution at which the landscape model is modeled and analyzed, and the cost or complexity of applying a landscape model. They pointed out that future development and application of forest landscape models can be facilitated by (1) cooperative efforts to create layers of initial conditions for more and larger landscapes, (2) creating partnerships of practitioners and scientists, (3) developing permanent mechanisms for user support, (4) add new model capabilities based on their experiences of coupling habitat suitability index (HSI) model with a forest landscape model, (5) increasing efforts to evaluate model performance, and (6) developing methods to choose among complex and multi-resource alternatives.

3. Model research and development

Section 3 contains papers that explore the theoretical and technical development of forest landscape models. Characterizing and classifying forest landscape models provide guidelines in model selection and interpreting differences for both modelers and users. Several studies have been conducted to classify forest landscape models (Baker, 1989; Gardner et al., 1999; Keane et al., 2004; Perry and Enright, 2006; Scheller and Mladenoff, 2007). Building on previous studies, He (2008) provided definitions of key terminologies commonly used in forest landscape modeling to characterize and classify forest landscape models. A general definition of a forest landscape model is a model that predicts changes in spatial characteristics (distribution, shape, abundance, etc.) of the target being modeled such as gradient-based, mathematic models that predict distributions of tree species are forest landscape models (e.g., Iverson et al., 2008; Leng et al., 2008). A specific definition of a forest landscape model is one that *simulates* spatiotemporal characteristics of at least one recurrent spatial or landscape process in a spatially interactive manner. He (2008) presented a set of qualitative criteria for model classification. These criteria represent model definitions and key model implementation decisions, including the temporal resolution, number of spatial processes simulated, and approaches to simulate site-level succession. Compared to previous model classification efforts (e.g., Baker, 1989; Gardner et al., 1999; Keane et al., 2004; Perry and Enright, 2006; Scheller and Mladenoff, 2007), this classification can be more efficient for comparing approaches and techniques that are specifically associated with forest landscape modeling.

Fire is one of the most important processes simulated in forest landscape models. Various approaches for simulating fire spread may yield different results in the simulated fire regimes and vegetation dynamics (c.f. Keane et al., 2004). Li et al. (2008) provided an overview of fire regime modeling. They used the Ecological Disturbance Model (EDM), a simulation shell, to compare behaviors of three commonly used fire spread algorithms: DISPATCH, percolation, and cellular automata. They found that these fire spread algorithms do not result in significant differences between user-defined and simulated fire frequencies, but result in significant differences in simulated forest dynamics. They further found that cellular automata appeared to be better approximating fire spread processes than other the two approaches, whereas the differences between using four or eight directions in the fire spread is not large in simulated fire regimes and forest dynamics.

The simulation of fire dynamics (spread and subsequent fire effects) within forest landscape models is very important to model results, so Wimberly and Kennedy (2008) investigated the sensitivity of important model parameters (fire rotation, successional pathway time spans, fire spread rates, and fire size distributions) to simulated landscape composition to understand how landscapes respond to changes in fire regimes. They found closed canopy forests tended to decrease with increasing fire frequency and longer successional pathway transition times. This indicates that an accurate representation of the fire regime is critical as inputs to forest landscape models and improperly parameterized models could produce results that may not accurately portray landscape response to changing fire regimes.

Seed dispersal is another important process simulated in many forest landscape models. For forest landscape models that simulate seed dispersal, distance-dependent probability functions are often used (e.g., He and Mladenoff, 1999). Qiu et al. (2008) pointed out that zoochory (animal), anemochory (wind), hydrochory (water), and brochory (gravity) are four agents that play a much more significant role than the distance to seed sources in seed dispersal. They developed a GIS-based, spatially explicit model of dispersal agent behavior (SEMODAR) to simulate the behavior characteristics of all four dispersal agents. They did an experimental simulation study using three hypothetical species with different competitive and migration abilities. Their study revealed the important role of agent behavior in seed dispersal process and the biased impact of landscape fragmentation on superior competitors that are not superior dispersers (Qiu et al., 2008).

The papers represented in the special issue of forest landscape modeling highlight the advances and applications of forest landscape models. They show that forest landscape models are irreplaceable tools to conduct landscape-scale experiments while physical, financial, and human constraints make real-world experiments impossible. Most of the results presented in this issue would not have been possible without the use of forest landscape models. Forest landscape modeling is a rapidly developing field. Its development and application will continually be driven by the actual problems in forest management planning and landscape-scale research. We hope that the papers contained in this special issue will serve both researchers and managers who are struggling to incorporate large-scale and long-term landscape processes into their management planning or research.

Acknowledgements

We would like to thank Robert H. Gardner, Eric J. Gustafson, David J. Mladenoff, and Mike B. Flagnigan for their suggestions for the international workshop of forest landscape modeling. We thank all speakers of this workshop. We also thank Bojie Fu, Xingyuan He, Shirong Liu, Liding Chen, Keming Ma, Hui Zeng, Zhiyun Ouyang for their logistic help and scientific input for the workshop. Funding supports for the workshop were from China Natural Science Foundation, USDA Forest Service, Chinese Academy of Sciences, and University of Missouri.

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11 September 2007