LANDSCAPE MODELING FOR FOREST RESTORATION: CONCEPTS AND APPLICATIONS

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Abstract-Restoration planning, evaluation, and implementation are of paramount importance in many areas where the magnitude of the abiotic and biotic disturbance agents has altered the resources and conditions of forest landscapes. However, the effect of restoration practices is difficult to measure, and in many areas the restoration goals are yet less clear. Landscape modeling provides useful tool for effectively evaluating the outcomes of various management practices and restoration strategies. Here we provide a framework of using landscape models for forest restoration; in particular we present a case application of using a landscape model, LANDIS, to simulate the effects of forest management strategies of the Southern Pine Beetle damaged forests in southern Appalachians. Our research suggests that landscape models can be an effective management tool, and in conjunction with other assessment techniques, could be a valuable aid in forest restoration decision-making process.

Restoration planning, evaluation, and implementation are of paramount importance in forested areas of the United States and in many other regions of the world. In the United States, forest restoration has become an urgent task for forest health and sustainable development (The United States Congress 2003, Stanturf 2005). Using landscape models to investigate forest restoration provides a promising opportunity for planning and evaluating restoration strategies in forest areas damaged by insects and diseases, fire, hurricanes, invasive species, and other forest environmental threats. In this paper, we provide a framework for using landscape simulation model to restore forests; present a case study using this approach to explore the effects of forest restoration strategies of the Southern Pine Beetle (SPB; *Dendroctonus frontalis* Zimmermann) damaged forests in the southern Appalachians, USA; and use SPB as an example to illustrate, in a broader context, how landscape models can be used to support restoration planning and evaluation.

A Framework of Landscape Modeling For Forest Restoration

Landscape models simulate change throughout time using spatially referenced data across a broad spatial scale (ca. 1~1,000s km^2). They have been used to explore the reciprocal interactions between forest structure and a variety of natural disturbance agents including wildland fires (He and Mladenoff 1999, Shang and others 2004, Scheller and others 2005), pests and disease (Sturtevant and others 2004) characteristic to a geographical area. These models have also been used to simulate the effects of a variety of human-made disturbances such as harvesting, thinning, and planting (Gustafson and others 2000, Shifley and others 2000).

A general framework of landscape modeling for forest restoration is to integrate natural disturbance agents and restoration strategies into a landscape model capable of simulating vegetation dynamics through space and time. Using auxiliary models, these forest patterns and restoration strategies, described as simulation scenarios, can be evaluated according to various criteria including the cost of the management strategy versus the utility of the simulated landscape.

The desired goal of a restoration strategy may be known and well defined a priori. In these cases, a modeling approach can be used to determine the management strategy that leads to the landscape structure that best fits this ideal. However, determining restoration goals a priori is difficult owing to limitations of historical data; the long term horizons of forest dynamics; unprecedented human impacts on forest landscapes and the fact that effective management involves the optimal allocation of limited economic resources.

Where restoration goals cannot be defined a priori, an iterative modeling approach can be used to explore various management strategies and their consequences for landscape structure. This process leads to the identification of appropriate and practical restoration goals. Clearly, the success of this iterative approach depends upon having a model that is flexible enough to represent a variety of disturbance agents and management practices.

A Case Study Using LANDIS to Model Restoration of Appalachian Pine Forests Damaged by SPB

SPB is the most destructive native insect affecting

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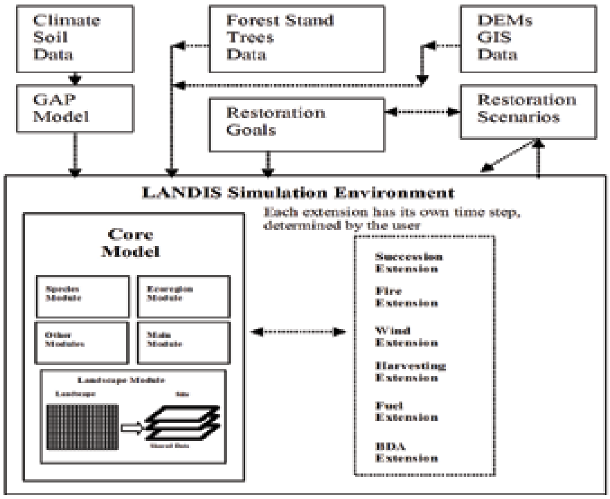

Figure 1. The working flow using LANDIS model for SPB restoration planning and evaluation. BDA in this figure refers to Biological Disturbance Agent

the southern US forests. In the southern US, there is currently a substantial program, administered through the USDA Forest Service, entirely dedicated to restoring public and private forests damaged by SPB (USDA Forest Health Protection 2005). In the years of 2000-2003, SPB caused catastrophic damage in the southern Appalachian Mountains. Restoring yellow pine forests is an important and challenging task for forest owners and managers in this region.

We used landscape modeling to evaluate and plan management strategies for forests damaged by SPB in the southern Appalachians (Coulson and others 2004, Waldron and others 2005, 2007, Lafon and others 2007 in press). Our goal was to develop a procedure to facilitate restoration planning and evaluation for SPB-damaged pine forests in the southern Appalachians. Our specific objectives were to: 1) Facilitate the use of landscape models in forest pest and pathogen damage restoration planning and evaluation, and, 2) Develop model-informed restoration plans that can be implemented in a sustainable forest management context.

We chose LANDIS (LANdscape DIsturbance and Succession, both LANDIS 4.0 and LANDIS-II) as our primary modeling tool for forest restoration because it provides a framework for determining the effects of disturbances such as fire regimes, insect outbreaks, harvesting and planting on changes in forest structure (Mladenoff 2004, Waldron and others 2005). LANDIS is a spatially explicit landscape-scale simulation model that incorporates natural processes, ecological succession, seed dispersal, and forest management practices. We parameterized LANDIS for the southern Appalachian forests. Existing forest stand conditions and land types were used as the starting point for landscape simulation (Figure 1). Site specific Forest Management Plans based on Forest Service practices were then used to determine the desired future forest conditions and the specific restoration goals (Table 1).

Our modeling projections suggest that a combination of fire and SPB disturbance creates sustainable yellow pine forests, and the regime of multiple interacting disturbances have important implications for succession in yellow pine forests of the southern Appalachians (Waldron and others 2005, 2007). Our results also suggest that Table Mountain pine could be a species of particular interest for restoration efforts on low- to mid-elevation ridges and southeast-west facing open slopes in the southern Appalachians. Table Mountain pine, a southern Appalachian endemic, contributes to the high biodiversity of the region. In addition, the model projections imply that reintroducing fire would help maintain open pine stands in southern Appalachians similar to those thought to have occupied dry sites on Appalachian landscapes in the past (Lafon and others 2007 in press). Our findings are currently in review by the USDA Forest Service.

Overall, our research suggests that LANDIS is a useful management tool and a valuable aid in the forest restoration decision-making process. The LANDIS model we used incorporates ecological succession, natural disturbance (e.g., wildfire, windstorms, and insect outbreaks), seed dispersal, and forest management practices. It has the

1. Control (No action alternative)	
	No harvest/fire exclusion
	Fire exclusion plus current management levels of harvest
	Current SPB outbreak rate and intensity
2. The minor action alternative	
	Natural Regeneration with burning (prescribed fires)
	Use of wildfire plus thinning, common size harvestings
	Current SPB outbreak rate and intensity
3. High action alternative	
	Use of fires to restore Table Mountain pitch pine forests
	Combinations of larger harvest/thinning, planting & fires
	Current or higher SPB outbreak rate and intensity

Table 1--Using LANDIS model under different forest management and restoration scenarios

appropriate spatial scales and details needed to represent forest change over time, and therefore can be used for forest restoration efforts.

Broader Applications of Landscape Modeling for Forest Restoration

LANDIS provides a proven framework for investigating the interaction between abiotic and biotic disturbances, forest management practices, and forest structure and composition over broad landscapes (He and others 1999, Mladenoff and others 2004). Many of the forest landscape restoration and management problems are represented by the spatial and temporal scales of the LANDIS approach (ca. 1 to 1,000 km^2). As a result, the methods outlined here are best described as a multi-tiered approach where the LANDIS model integrates detailed knowledge of vegetation dynamics and provides a quantitative output amenable to the evaluation of restoration goals. In the context of forest restoration, such an approach is important because, while vegetation dynamics may operate over relatively long time scales, the costs of restoration practices are high, and the demands for effective research are often immediate.

While we can justify the large spatial and temporal scales of the LANDIS approach, it is also important to note that our approach does not preclude the use of modeling at a finer scale. In fact, the success of the LANDIS approach requires a proper understanding of the dynamics of vegetation at much smaller spatial scales for it is an overview of these relationships that are used to parameterize the broader scale model. Some of the critical parameters can be calculated by using certain finer-scale forest gap models (e.g., Linkages). Additionally, the outputs from LANDIS may require knowledge-based interpretation to make assessments of the utility of a particular management strategy.

In all cases, we find that a modeling approach provides a valuable tool for decision makers for a number of reasons: (1) The relationships between landscape function, human-made impacts and desired forest conditions are too complex to formulate and explore without quantitative modeling tools, (2) Quantitative outputs are a common requirement for decisions that involve federal agencies and multiple stakeholders, (3) Forest landscapes operate on spatial and temporal scales that prohibit in situ experiments, and (4) Modeling encourages the collection and organization of data and knowledge and the formulation of well defined restoration goals.

Moreover, our use of LANDIS suggests that these functions can be performed efficiently and procedurally. LANDIS can be parameterized effectively for many forest landscape restoration problems and in doing so researchers and forest managers gain the benefit of using a model that has been well studied, has a significant user base, and produces comparable quantitative outputs. This is especially true in the United States, where publicly available data allows models to be run on 'real' landscapes (i.e., landscapes that incorporate details of the current distribution and composition of forests), and where there is considerable data detailing the life-history of relevant species, allowing effective parameterization of broader scale interactions.

In summary, there are many advantages of the landscape modeling approach for forest restoration. Forest landscape models simulate change through time due to the interactions between succession and external drivers (e.g., disturbances or climate change) across a spatially extensive forest landscape. The models provide projections of long-term and broad-scale forest change and allow experimentation and comparisons between scenarios. They are useful tools for synthesizing data and models of smaller-scale processes. They also can be used in conjunction with restoration scenarios to examine management consequences over time.

Conclusion and Future Directions

The work presented here is part of a larger effort to investigate the utility of landscape models as a decision-making tool for pre-damage impact analysis and post-damage restoration of forest landscapes threatened by a variety of invasive pest species. Our research suggests that landscape models are a useful management tool and a valuable aid in the forest restoration decision-making process. This landscape modeling approach allows forest managers to determine the effects of changes in forest structure and tree composition on biodiversity and habitats. The result is the identification of the best strategies for restoring key forest landscapes that may be significantly impacted by multiple threat interactions.

Our goals for future research are to: (1) Test the capability of the LANDIS approach to evaluate changes in composition and structure of eastern US forests undergoing multiple interacting environmental threats and global warming in forest management decision-making, (2) Develop methods that make the parameterization of the model and the interpretation of its results more efficient and available to a wider scientific audience, and (3) Test the results of LANDIS by implementing recommendations based on the modeling scenarios in test locations and then monitoring those areas to determine the effectiveness of using the model as a management tool.

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