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Simulated effects of forest management alternatives on landscape structure and habitat suitability in the Midwestern United States

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Abstract

Understanding the cumulative effects and resource trade-offs associated with forest management requires the ability to predict, analyze, and communicate information about how forest landscapes (1000s to >100,000 ha in extent) respond to silviculture and other disturbances. We applied a spatially explicit landscape simulation model, LANDIS, and compared the outcomes of seven forest management alternatives including intensive and extensive even-aged and uneven-aged management, singly and in combination, as well as no harvest. We also simulated concomitant effects of wildfire and windthrow. We compared outcomes in terms of spatial patterns of forest vegetation by age/size class, edge density, core area, volume of coarse wood debris, timber harvest, standing crop, and tree species composition over a 200-year simulation horizon. We also used habitat suitability models to assess habitat quality for four species with diverse habitat requirements: ovenbird (*Seiurus aurocapilla*), prairie warbler (*Dendroica discolor*), hooded warbler (*Wilsonia citrina*), and gray squirrel (*Sciurus carolinensis*). Management alternatives with similar levels of disturbance had similar landscape composition but different landscape patterns. The no-harvest scenario resulted in a tree size class distribution that was similar to scenarios that harvested 5% of the landscape per decade; this suggests that gap phase replacement of senescent trees in combination with wind and fire disturbance may produce a disturbance regime similar to that associated with a 200-year timber rotation. Greater harvest levels (10% per decade) resulted in more uniform structure of small or large patches, for uneven- or even-aged management, respectively, than lesser levels of harvest (5% or no harvest); apparently reducing the effects of natural disturbances. Consequently, the even-aged management at the 10% level had the greatest core area and least amount of edge. Habitat suitability was greater, on average, for species dependent on characteristics of mature forests (ovenbird, gray squirrel) than those dependent on disturbance (prairie warbler, hooded warbler) and habitat suitability for disturbance dependent species was more sensitive to the management alternatives. The approach was data-rich and provided opportunities to contrast the large-scale, long-term consequences for management practices from many different perspectives.

Keywords: LANDIS; Simulation; Ozark highlands; Oak–hickory; Disturbance; Fire; Wind; Timber harvest; Coarse woody debris; Wildlife; Habitat suitability index

1. Introduction

Management of forest landscapes can benefit from the ability to predict and assess the long-term, large-scale consequences of natural and anthropogenic disturbances (or their absence) on forest structure, species composition and the related spatial patterns of forest vegetation. Such information is key to understanding how management alternatives are likely to affect wildlife habitat, timber, recreation opportunities, species diversity, landscape diversity, and a host of other products, amenities, and ecological services that forests provide. All these factors are affected by the current and future condition of forest vegetation at site, stand, and landscape scales. On public lands there is an additional need to effectively communicate the expected outcome of various management alternatives.

Simultaneous consideration of all these factors mandates working at the landscape scale — typically thousands to tens of thousands of hectares in spatial extent. In most situations, landscape-scale field experiments are impractical, but spatially

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explicit computer simulation models can effectively provide such a landscape perspective (Mladenoff and Baker, 1999). Parameterization of such models for specific ecological conditions can be difficult, and data requirements for model implementation are often demanding. Landscape simulation models, however, are often the best tools available to predict future forest conditions and provide perspective on long-term, large-scale outcomes of management decisions. Maps of projected forest conditions can illustrate general landscape patterns through time and provide data needed to assess future impacts on wildlife habitat, aesthetics, large-scale biodiversity, and a host of other factors that depend on the spatial arrangement of landscape features. Maps of projected conditions are also useful for illustrating and discussing management alternatives (e.g., Gustafson et al., 2000; Zollner et al., 2005).

Selection of forest management methods and the level of harvest or rotation period are major factors affecting forest landscapes. For example, the application of even-aged versus uneven-aged management has implications for tree species composition, stand structure, landscape structure and wildlife populations in Midwestern, oak-dominated forests (Thompson et al., 1995; Johnson et al., 2002; Dey, 2002). Forest management planning on public lands in the United States often is contentious because of the important consequences of management decisions on forest landscapes and implications for the array of benefits that society expects from public forests. Although harvest (or its absence) is the greatest contemporary disturbance process affecting U.S. forests, other ever-present factors can also greatly affect landscape change and wildlife (e.g., weather, fire, invasive insects, disease, etc.) (Brawn et al., 2001).

In this paper we use a spatially explicit landscape simulation model, LANDIS (Mladenoff et al., 1996; He et al., 1999, 2005; Mladenoff and He, 1999), to simulate seven forest management alternatives for a 71,142-ha forested landscape in the Missouri Ozarks. We apply landscape-scale habitat suitability models (Larson et al., 2003, 2004) to assess the effects of these landscape changes on wildlife habitat. This region is one of few locations in the Midwest where detailed information on ecological land types, forest type and size class, and wind and fire disturbance patterns exist for a large landscape. Our objectives are to (1) demonstrate the utility of this approach to forest planning and management, (2) to draw general conclusions about long-term and large-scale effects of forest management alternatives in oak-dominated forests, and (3) quantify the impact of alternative forest management practices on wildlife habitat quality. The spatially explicit nature of the model allowed us to contrast management alternatives over time in terms of forest size structure, patch size, length of edge habitat, spatial juxtaposition, timber harvest, residual timber, down wood, wildlife habitat suitability, and other metrics.

2. Methods

2.1. Study site

The study area is a 71,142 ha portion of the Mark Twain National Forest in the Missouri Ozarks (Fig. 1). We chose this region because it provided an extensive mapped landscape including hypsography, ecological land types (Miller, 1981), stand boundaries (i.e., contiguous operational management units 1–20 ha in size), management area boundaries (i.e., thematic management zones thousands of hectares in size and often spatially discontinuous), and an inventory of initial vegetation conditions (age and forest cover type) (Table 1, Fig. 1). The area also has a well-documented fire history (Westin, 1992; Guyette, 1995; Guyette et al., 2002) and local information on wind disturbance (Rebertus and Meier, 2001).

Table 1
Initial area by management area, ecological land type, and tree size class in the landscape used to simulate forest management scenarios and natural disturbance in southern Missouri, U.S.A.

Category	Amount
Management area	
Managed (ha)	59298
Reserved (ha)	11844
Ecological land type	
N and E slopes (ha)	18177
S and W slopes (ha)	21054
Ridgetops (ha)	26141
Upland drainages (ha)	3484
Mesic sites (ha)	1189
Limestone substrate (ha)	842
Glade/savanna (ha)	255
Dominant size class	
Seedling: 0–10 years (ha)	1016
Sapling: 11–30 years (ha)	12947
Pole: 31–50 years (ha)	21723
Sawlog: >50 years) (ha)	35456
Number of stands (n)	9576
Initial timber volume	
Total (m^3)	4449000
Per ha (m^3)	63
Initial down wood volume	
Total (m^3)	2201000
Per ha (m^3)	31

2.2. Simulating vegetation change

We applied the LANDIS software (version 3.6) (Mladenoff et al., 1996; He et al., 1999, 2001, 2005; Mladenoff and He, 1999) to simulate forest vegetation response to disturbance by timber harvest, wind, and fire. In LANDIS, a landscape is organized as a mapped grid of cells (or sites), with vegetation information stored as attributes for each cell. Within each cell LANDIS represents the forest vegetation as a matrix with the presence or absence of tree species (or species groups) recorded by 10-year age classes. LANDIS simulates four spatial processes (fire, windthrow, harvesting, and seed dispersal) that affect the projected species composition and age structure of individual cells and, in aggregate, of the landscape as a whole. LANDIS and its various modules are described elsewhere in greater detail (Mladenoff and He, 1999; He and Mladenoff, 1999; He et al., 1999; Gustafson et al., 2000).