



Simulating restoration strategies for a southern boreal forest landscape with complex land ownership patterns

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ABSTRACT

Restoring altered forest landscapes toward their ranges of natural variability (RNV) may enhance ecosystem sustainability and resiliency, but such efforts can be hampered by complex land ownership and management patterns. We evaluated restoration potential for southern-boreal forests in the ~2.1 million ha Border Lakes Region of northern Minnesota (U.S.A.) and Ontario (Canada), where spatially distinct timber harvest and fire suppression histories have differentially altered forest conditions (composition, age-class distribution, and landscape structure) among major management areas, effectively resulting in forest landscape “bifurcation.” We used a forest landscape simulation model to evaluate potential for four hypothetical management and two natural disturbance scenarios to restore forest conditions and reduce bifurcation, including: (1) a current management scenario that simulated timber harvest and fire suppression practices among major landowners; (2) three restoration scenarios that simulated combinations of wildland fire use and cross-boundary timber harvest designed to emulate natural disturbance patterns; (3) a historical natural disturbance scenario that simulated pre-EuroAmerican settlement fire regimes and windthrow; and (4) a contemporary fire regime that simulated fire suppression, but no timber harvest. Forest composition and landscape structure for a 200-year model period were compared among scenarios, among major land management regions within scenarios, and to six RNV benchmarks. The current management scenario met only one RNV benchmark and did not move forest composition, age-class distribution, or landscape structures toward the RNV, and it increased forest landscape bifurcation between primarily timber-managed and wilderness areas. The historical natural disturbance scenario met five RNV benchmarks and the restoration scenarios as many as five, by generally restoring forest composition, age-class distributions, and landscape structures, and reducing bifurcation of forest conditions. The contemporary natural disturbance scenario met only one benchmark and generally created a forest landscape dominated by large patches of late-successional, fire-prone forests. Some forest types (e.g., white and red pine) declined in all scenarios, despite simulated restoration strategies. It may not be possible to achieve all objectives under a single management scenario, and complications, such as fire-risk, may limit strategies. However, our model suggests that timber harvest and fire regimes that emulate natural disturbance patterns can move forest landscapes toward the RNV.

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1. Introduction

As human activities move ecosystems beyond their ranges of natural variability (RNV), natural resources, ecological services (e.g., water supply, pest suppression), and native species diversity may be threatened (Christensen et al., 1996; Poiani et al., 2000), while the frequency of uncharacteristically severe disturbances

may increase (Swetnam et al., 1999). Thus, managing ecosystems within their RNV has been proposed as a key strategy for promoting long-term resource use and ecological sustainability (Aplet and Keeton, 1999; Landres et al., 1999). However, defining and achieving RNV benchmarks may be problematic for several reasons, including uncertainty about historical conditions, effects of climate change, and potential conflicts with resource use and suppression of natural disturbance events (Hobbs and Norton, 1996; Landres et al., 1999; Nonaka and Spies, 2005). Moreover, effective restoration of ecosystem components, structures, and processes that define RNV typically requires a multi-scale approach operating within a landscape or regional context (Poiani et al., 2000; Lindenmayer and Franklin, 2002; Lindenmayer et al.,

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Table 1

Target RNV benchmarks; estimated from previous research.

Attribute	Source
Forest cover type composition (based on %cover of three major forest types: aspen–birch, jack pine, and red/white pine)	Estimated from: Heinselman (1973, 1980, 1996), Swain (1980), Friedman and Reich (2005)
Age–class distribution for southern boreal forest (negative exponential distribution for all forest types combined)	Van Wagner (1978), Bergeron et al. (2002)
Proportion of total forest area in largest patch size by forest type (calculated for two major forest types: red/white pine and jack pine)	Estimated from: Heinselman (1973, 1980, 1996)

2006). For example, restoring or emulating the effects of natural disturbance regimes for forest restoration purposes requires meeting both landscape-level (e.g., distribution of disturbance patches) and within-stand (e.g., live-tree retention) objectives (Bergeron et al., 2002; Mitchell et al., 2002).

Restoration at landscape and regional scales is often further hampered by spatially complex land ownership and management patterns that can create unintended forest patch mosaics and disturbance dynamics (Mladenoff et al., 1993; Nonaka and Spies, 2005) and can constrain potentially useful management options (e.g., fire use) across boundaries (Ward et al., 2005). For instance, landscapes composed of both conservation reserves and timber-managed lands can develop spatially bifurcated forest compositional and structural conditions (e.g., Tinker et al., 2003). Sharply contrasting patterns of forest conditions over a given landscape can result in divergent trends in ecological processes over time and space (Turner et al., 2001), including wildlife population dynamics, disturbance regimes (Franklin and Forman, 1987), and biogeochemical cycles (Valett et al., 2002), and may impede cooperative, multi-ownership management (Sample, 1994; Lytle et al., 2006). Thus, a strategic hurdle for restoration of large forested landscapes is to develop approaches that account for patterns of ownership and management (Lindenmayer and Franklin, 2002; Thompson et al., 2006). For instance, wildland fire may achieve restoration objectives in large conservation reserves with fire-dependent ecosystems (Baker, 1989, 1994; Kneeshaw and Gauthier, 2003), but silvicultural or prescribed fire strategies may be required in human-dominated landscapes (Lindenmayer et al., 2006).

Understanding spatial and temporal interactions among disturbances and disparate management activities may be critical to effectively meet ecological restoration and other management objectives, including sustainable forestry, biodiversity conservation, and wildfire control (Gustafson et al., 2004; Thompson et al., 2006; Syphard et al., 2007). Spatially explicit, dynamic forest landscape simulation models (FLSMs) can elucidate potential effects of alternative management strategies and disturbance interactions on forest composition and landscape structure over large landscapes and long time periods (Mladenoff, 2005). Model outcomes can be examined in relation to desired ecological restoration objectives (Scheller et al., 2005; Shifley et al., 2006; Xi et al., 2008). However, due to challenging parameterization and data requirements (Shifley et al., 2006), only a few forest modeling studies have simulated forest management practices stratified across complex ownership and management patterns at regional scales (Mehta et al., 2004; Nonaka and Spies, 2005; Thompson et al., 2006; Gustafson et al., 2007). Moreover, quantitative comparisons between modeled management scenarios and RNV benchmarks for restoration are problematic, as RNV conditions are often only qualitatively defined or even lacking for many ecoregions (but see Wimberly, 2002; Tinker et al., 2003). In the one published modeling study we are aware of that quantitatively assessed multi-owner land management policies in relation to RNV, Nonaka and Spies (2005) determined that current forest policies in the Oregon Coast Range would not restore forest landscape structure over time, due in part to management constraints

among owners, and that several centuries would be required to achieve RNV benchmarks using a wildfire-only policy.

In the present study, we used a spatially explicit, dynamic FLSM to explore restoration options in the southern boreal and northern-mixed forests of the Border Lakes Region (BLR), a multi-ownership landscape in northern Minnesota and northwestern Ontario. Despite complex ownership and management patterns, ranging from large, protected wilderness to intensively managed timberlands, there is a common desire among major landowners to move forest ecosystems toward their RNV in order to meet ecological sustainability objectives (Ontario Ministry of Natural Resources, 2001; Minnesota Forest Resources Council, 2003; USDI National Park Service, 2002; USDA Forest Service, 2004). However, meeting these objectives requires developing appropriate, regional-scale targets for restoration and assessing the feasibility of achieving these targets across complex ownership patterns.

To assess the potential to move the BLR forest landscape toward its RNV, we simulated forest dynamics over a 200-year period under six different scenarios that reflected unique fire and timber harvest regimes. We hypothesized that a restoration management scenario simulating wildland fire within large conservation reserves, and two scenarios that simulated cross-boundary timber harvest emulating natural disturbance patterns, would most effectively move the landscape toward the RNV compared to a current management scenario reflecting fire suppression and no cross-boundary harvest. To distinguish the effects of fire versus timber harvest on forest landscapes, we also modeled a pre-EuroAmerican fire regime scenario with short-rotation fire cycles and a contemporary fire regime scenario reflecting fire suppression and no timber harvest. We speculated that the pre-EuroAmerican fire regime and contemporary fire regime scenarios would move the landscape toward and away from the RNV, respectively. RNV measures included six estimated benchmarks for forest composition, age–class distribution, and patch size that potentially capture key characteristics of the pre-EuroAmerican forest landscape (Table 1). We also determined the effect of each scenario on the spatial bifurcation of forest conditions between wilderness versus timber-managed areas, by comparing forest type composition, age–class distribution, and landscape structure among major land management areas.

2. Study area

The Border Lakes Region (BLR) covers ~2.1 million ha in northern Minnesota and northwestern Ontario (Fig. 1) and represents an integration of U.S. and Canadian ecological land classifications (Superior Mixed Forest Ecoregional Planning Team, 2002). The region has a cool-continental climate, with warm, short summers and long, cold winters (Heinselman, 1996). Elevations range from 335 to 701 m above sea level, and landforms are characterized by glacially scoured bedrock uplands and rock outcrops of Precambrian origin. Soils are generally thin loamy sands to sandy loams, with scattered deposits of lacustrine and organic soils (Anderson and Grigal, 1984; Ecological Stratification Working Group, 1995). Freshwater lakes occupy nearly 20% of the region (see Appendix A). Forest communities are transitional

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