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# An indicator system to assess ecological integrity of managed forests

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ABSTRACT

Ecological integrity of managed forests includes the ability of an ecosystem to support a community of organisms with a similar species composition and functional organization as found in nearby natural systems. We developed an indicator system for ecological integrity based on simulated natural disturbance and indicator species to test if forest condition and habitat in managed forests are similar to that found or expected in natural systems. We then applied the method in an area of the boreal forest (Ontario, Canada) where the objective of Ontario's strategic forest management planning approach is, in part, to conserve ecological integrity through the emulation of the natural disturbance process. Forest condition controls the supply of habitat to support the diversity of native organisms, and historically in boreal forests the natural disturbance process drove forest condition. We selected indicators of forest condition (landscape pattern and compositional mosaic) and habitat function (occupancy rates for a broad range of forest birds), and applied our assessment system to test whether indicators of forest condition and habitat function reflect outcomes expected if natural disturbance processes were successfully emulated. We collected occupancy data in natural and managed forest disturbance types using autonomous acoustic recorders, applied occupancy/detection modeling to estimate corrected occupancy rates ($\psi$), and then tested for differences in $\psi$ between disturbance types. Some indicators of forest condition were within the range expected under natural disturbance, but we found relatively less old conifer, more young deciduous and greater edge density in managed forests relative to forests of natural disturbance origin. Most species (11 of 14) occurred with equal $\psi$ in habitat originating from the two disturbance types. Brown creeper (*Certhia americana*), bay-breasted warbler (*Mniotilta varia*) and red-eyed vireo (*Vireo olivaceus)* differed between disturbance types. Brown creeper uses older conifer and occurred at lower rates in managed forest, while red-eyed vireo uses a range of deciduous forest ages, and occurred at higher rates in managed forest. Differences in quantity and/or quality of specific habitat types likely explain the responses. The results suggest what directional changes in the forest pattern and compositional mosaic would improve ecological similarity with natural systems, but also indicate what further research is required. We believe this approach to assessing ecological integrity can be adapted to study the effectiveness of conservation management strategies in other systems, and will contribute to adaptive management approaches and evidence-based policy development.



## 1. Introduction

In many European and North American jurisdictions boreal forest management and conservation planning have evolved from a focus on the production of a range of socio-economic products (including habitat for wildlife of significant socio-economic value) to a broader focus on ecological integrity, where the goal is sustainable provision of a range of ecosystem goods and services while conserving biodiversity and ecological processes (Hunter, 1999). Ecological integrity includes the ability of an ecosystem to support a community of organisms with a similar species composition and functional organization as found in nearby natural systems (Parrish

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et al., 2003), and contributes to ecosystem resilience, the capacity of ecosystems to absorb disturbances without undergoing fundamental change (Drever et al., 2006). For ecological systems where integrity has been conserved, the critical structural, functional, and process components of the system (e.g., forest condition, diversity and quality of habitat, and disturbance process) occur within the natural range of variation.

Forest management strategies for conserving ecological integrity remain largely untested (Drever et al., 2006; Klenk et al., 2009; Perera et al., 2007; Simberloff, 2001). An evaluation mechanism is required to objectively assess whether selected management approaches are indeed conserving ecological integrity, and to provide critical evaluation and feed-back for adjustment or abandonment of the approach. Without a mechanism to assess success, the management strategy becomes untestable and largely unscientific (Carignan and Villard, 2002), depending upon anecdotal ad hoc assessment of how well natural forest conditions have been conserved. Rather, it is useful to view the policy or management strategy as a hypothesis with an appropriate reference condition or null model (Thompson, 2006; Thompson and Harestad, 2004), and design a monitoring system that provides information to ultimately improve or reject the management strategy.

In practice, ecosystem processes are too complex and the number of species is too large to assess ecological integrity directly (Wiens et al., 2008). Simplified systems using indicators have been used to plan for and assess elements of integrity (Angelstam, 1998; Angelstam et al., 2003; Lambeck, 1997; Parrish et al., 2003; Villard et al., 2007; Wiens et al., 2008). From an adaptive management context the model system is most useful if the indicators relate directly to the management system, as this provides a feedback mechanism to adjust management based on monitoring outcomes.

In this study, we develop an assessment system for ecological integrity using forest bird species as indicators for forest condition and habitat function, and explore the application of this system in a managed boreal forest region of northwestern Ontario, Canada. We illustrate how a properly defined system can be linked to conservation and management policy objectives, and provide critical feedback for review and adjustment. We focus on emulation of natural disturbance because this is the strategic management approach adopted in the case study, but the approach could be applied to other conservation and management approaches.

## 2. Assessment system for ecological integrity

Our assessment system is designed to address the question, “has forest management emulated the conditions found in a natural forest, resulting in the diversity and quality of habitat necessary to support native biodiversity?” This question is fundamentally related to ecological integrity, which reflects both process and pattern. An assessment system of ecological integrity should relate key ecological processes (e.g., forest disturbance) to measurable patterns of ecosystem structure (e.g., forest condition) and function (e.g., diversity and quality of habitat) (Fig. 1). Forest condition drives the creation and supply of habitat, and some forest certification systems rely on forest condition as their indicator of how well biodiversity has been conserved. Although evaluation of forest condition is a necessary component of assessment, it is insufficient for evaluating ecological integrity because it does not directly evaluate the diversity and quality of habitat created. If habitat functions similarly between forest disturbance types, then the response of a broad range of representative wildlife should also be similar between forest disturbance types, reflecting similarity in diversity and quality of habitat.

### 2.1. Disturbance dynamics and forest condition indicators

Fire is a significant driver of natural disturbance in much of the boreal forest (Angelstam, 1998; Hunter, 1993; Rowe and Scotter, 1973), and affects three principal measurable characteristics of forest condition: pattern, composition, and structure (Fig. 1a,b). Forest pattern, including the interspersion of young and older forest, the size class distribution of young forest patches, and the contiguous nature of the mature forest matrix are all shaped by disturbance processes (Angelstam, 1998; Bergeron and Harvey, 1997; Hunter, 1993; Johnson, 1996; Perera and Buse, 2014; Rowe and Scotter, 1973). The forest composition (mosaic of deciduous and conifer species) is influenced by the interaction of soil moisture, nutrient availability and disturbance dynamics, while stand structure is largely driven by stand age. Stand age affects tree height and volume, accumulation of carbon stores and vertical and horizontal complexity.

Disturbance processes are largely stochastic, affecting the extent, intensity, and timing of disturbance events, successional pathways and post disturbance transitions. Consequently the expected natural forest condition cannot be measured directly, and the pre-industrial forest condition is only a single instance of how these factors combined for a particular outcome. Instead, we simulated natural disturbance on the landscape to estimate the natural forest condition and associated range of natural variation. We used a process-based landscape-level simulation model that integrates the Canadian Forest Fire Behavior Prediction System and Fire Weather Index system (Wotton et al., 2009) with locally calibrated, empirical forest succession rules driven by a time-dependent Markov model (Perera et al., 2008).

### 2.2. Forest condition and habitat indicators

Forest condition (e.g., landscape interspersion pattern, tree composition and stand structure) contributes to the diversity and quality of habitat that supports native biodiversity (Fig. 1c). If habitat functions equivalently between naturally disturbed areas and those created through forest harvesting, then there should be no difference in the diversity and quality of habitat between disturbance types. Diversity of habitat can be revealed by those species with the most extreme environmental requirements, as they are representative of the range of variability in habitat function (Carignan and Villard, 2002; Lambeck, 1997). Habitat quality refers to all aspects of habitat related to individual fitness, including forest conditions necessary for attracting mates, breeding, rearing, food sources, predator avoidance, etc., and consequently is difficult or impossible to measure directly. Instead we use the response (occupancy rate) of representative wildlife as a surrogate for habitat quality, where occupancy rate is expected to be similar if habitat function (diversity and quality) is similar between forests of natural and managed disturbance origin.

We used forest birds as indicators because they occupy a broad range of forest habitat types and food sources, are responsive to the types of changes in forest condition caused by forest management, are an unexploited species, can be cost-effectively and unobtrusively monitored, vocally defend breeding territories, and are a high conservation priority and responsibility for resource managers in the boreal forest. Collectively the food resources required by forest birds are diverse, with birds feeding on a host of insects, ground invertebrates and seeds (Canterbury et al., 2000). Conceptually, species are selected from the corners of the habitat niche-space box, where collectively these species occupy a broad range in habitat conditions representative of the natural range of variation (Fig. 1c) in critical landscape condition variables. If the box “shrinks” or “shifts” because forest management is not sufficiently emulating the suite of natural forest conditions