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Two scales are better than one: Monitoring multiple-use northern temperate forests

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ABSTRACT

Managing forests for multiple, often conflicting values, coupled with the uncertainty of global environmental change, requires a more flexible approach to maintaining functioning ecosystems into the future. Adaptive management offers such flexibility, but is often hampered by a lack of targeted monitoring data collected in a consistent manner—the evidence base. Moreover, effective management of expansive forest ecosystems requires data on both landscape scale processes, as well as finer-scale data on vegetation structure and composition. To address the challenges of adaptive management in forest ecosystems, we tested the ability of a small set of multi-scale indicators to inform management of Minnesota's Northern Great Lakes forest. Using remotely sensed and field data, we monitored changes in forest condition over a 20-year period in the 42,000 ha Manitou forest landscape in northeastern Minnesota. We used multi-temporal remote sensing data to assess landscape-scale changes in disturbance rates, patch size and age structure. With field data, we used a chronosequence method to assess management effects over time on finer scale characteristics such as canopy composition, tree regeneration, vertical structure and coarse woody debris. Combining remotely sensed and field data provided a more robust evidence base for decision-making than either approach could have provided alone. For example, examining remote-sensing data alone indicates that the rate of severe disturbance (timber harvest) peaked during the 20-year analysis period, and has declined in recent years. As disturbance rates declined, patch size and the proportion of forest in later successional stages all increased from year 2000 levels. These indicators of landscape structure showed positive shifts towards conservation objectives, but only tell part of the whole story. Field data elucidate a number of negative trends, including poor regeneration of key species (*Picea glauca*, *Pinus strobus*, *Thuja occidentalis*, *Betula alleghaniensis*), and simplified structure in young and mature growth stages. In addition, much of the mature forest transitioning into later-successional growth stages lacks the long-lived species and structural characteristics needed to develop late-successional conditions. An evidence base compiled from data gathered at both the stand and landscape scale provides the flexibility on which sound adaptive management depends.

1. Introduction

The use of ecologically based management has increased significantly over the last 2 decades in response to a century of forest homogenization and habitat degradation. This approach shows promise for restoring and maintaining compositional and structural diversity and increasing forest resilience and adaptive capacity (D'Amato et al., 2011; Gustafsson et al., 2012). However, the lack of consistent and targeted monitoring limits our knowledge and understanding of the effectiveness of these strategies and our ability to adapt management approaches (Deluca et al., 2010; Lindenmayer et al., 2011; Corona, 2016).

Forest ecosystems in the northern Great Lakes region have been significantly altered over the last 150 years due to Euro-American settlement era land use changes making them more vulnerable to a variety of stressors including climate change (Handler et al., 2014). Forest composition and structure (Schulte et al., 2007) as well as spatial patterns (White and Host, 2008) have become dramatically more homogenous. The legacy of extensive logging and intense slash-fueled fires in the late 19th and early 20th centuries was a shift from later successional forests dominated by conifers such as white spruce (*Picea glauca* [Moench] Voss), white pine (*Pinus strobus* L.) and white cedar (*Thuja occidentalis* L.) to an early successional forest landscape dominated by sprouting, shade

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intolerant deciduous species, primarily quaking aspen (*Populus tremuloides* Michx.) and paper birch (*Betula papyrifera* Marsh) (Schulte et al., 2007).

Stress on forests in this region will likely increase with acceleration of climate change, and increased pressure from invasive plant species, deer herbivory, insects and diseases, development, and demands for wood products (Frelich and Reich, 2010; Handler et al., 2014). In response to past changes and current threats, land management agencies and conservation organizations have developed landscape scale strategies to restore compositional and structural diversity in order to sustain key forest ecosystem services such as biological diversity, carbon storage, wood products, wildlife habitat, water quality, and recreation (MFRC, 2003).

Viewing forests as complex adaptive systems can provide a useful structure for adaptive management in an era of rapid environmental change and high uncertainty as to management outcomes (Puettmann, 2011). This approach uses a multi-scale perspective that integrates stand, and landscape scale processes and their interactions (Puettmann, 2011; Cornett and White, 2013). Species and structural diversity, and landscape-scale spatial patterns are elements of complexity that are both strongly influenced by management and are necessary for fostering self-organization and adaptability and thus are essential for maintaining functioning forests in this era of rapid global change (Messier et al., 2013).

Effective management that promotes complexity calls for a monitoring program that works at complementary spatial scales and captures the key elements of complexity that are influenced by management (Cornett and White, 2013). Adaptive management is a key component of these forest strategies as management can be shifted in response to changing conditions and management outcomes. Adaptive management requires knowledge and understanding of forest change and responses to management and stressors (Deluca et al., 2010; Corona, 2016).

Since 2001, The Nature Conservancy has collaborated on forest management with public and private owners in the 42,000 ha Manitou forest landscape in northeastern Minnesota. The group established general goals to restore forest composition and age structure (MFRC, 2003), but lacked a monitoring system to guide management actions. Requirements for a monitoring system to inform adaptive management included a limited number of indicators that are repeatable, sensitive to change, and affordable. In this study we used satellite imagery to capture landscape scale indicators such as disturbance rate, and patch size combined with a chronosequence sampling approach to collect field data on current composition and structure at the stand scale. We used the results from both data sets to assess the effects of past management, develop directional objectives for key indicators, and make management recommendations based on these results

To our knowledge, this is the only long-term monitoring plan designed for the adaptive management of temperate forests from stand- to landscape-level. The flexibility afforded by this approach can be adapted to a variety of temperate forest settings.

1.1. Study area

The Manitou forest landscape study area covers 42,000 ha located primarily in the North Shore Highlands ecological subsection (McNab and Avers, 1994; MN DNR, 1999), (Fig. 1). The climate is characterized by long, cold winters and short, mild summers. Annual precipitation ranges from approximately 530–780 mm. Proximity to Lake Superior influences local climate conditions, creating cool, moist conditions in spring and summer and warmer conditions in fall and winter relative to inland areas (Baker and Keuhnast, 1978; Baker et al., 1985).

Located within the north-temperate-southern boreal forest transition zone and the North Shore Highlands subsection (MN DNR, 1999), the study area consists of a complex mosaic of forest and wetland communities. The matrix upland forest is composed of a historically fire-dependent system, hereafter referred to as fire-dependent forest. Current composition includes mixtures of quaking aspen, paper birch, balsam fir (*Abies balsamea* [L.] Mill), white spruce, white pine, and red maple (*Acer rubrum* L.). White cedar is also an important component on mesic sites in this region (MN DNR, 2003). Jack pine (*Pinus banksiana* Lamb.) and red pine (*Pinus resinosa* Aiton) also occur in the fire-dependent forest but are uncommon in the Manitou landscape. This community type occurs on well-drained sandy-loams and loamy sands on till plains and stagnation moraines. Prior to European settlement high severity fires occurred at a rotation of approximately 220 years (MN DNR, 2003).

Mesic hardwood forests are currently dominated by sugar maple (*Acer saccharum Marsh.)* with lesser amounts of yellow birch (*Betula alleghaniensis* Britt.), red maple, white cedar, and white spruce. This system typically occurs on loamy soils on ridgetops. Paper birch, and quaking aspen may be abundant on younger stands (<75 years). This community has a fine-scale disturbance pattern characterized by small tree-fall gaps from mortality and windthrow. High severity fire was extremely rare in this community (MN DNR, 2003). Catastrophic windthrow also occurred infrequently in the North Shore Highlands, with a rotation period in the range of 3000 years (White and Host, 2008).

The Manitou forest landscape (Fig. 1) has been identified by The Nature Conservancy and the Minnesota Biological Survey (MN DNR, 2014) as an area of high biodiversity significance (Fig. 1). The Manitou is a multi-ownership landscape with significant holdings by state, federal, county, private industrial, and private non-industrial owners. While there are significant protected areas within the Manitou landscape, this is a working landscape where timber harvest is an important objective for public and private land owners.

2. Methods

A wide variety of ecological indicators for monitoring conditions in forested landscapes have been proposed (Noss, 1999; Lindenmayer et al., 2000; Tierney et al., 2009). We selected a subset of metrics that capture key elements of forest complexity from stand to landscape scales that are tied to conservation objectives and are useful in landscapes where management is a strong driver of forest condition (Table 1).

2.1. Landscape scale indicators

Landsat Thematic Mapper (TM) imagery (28.5 m pixels) was used to derive high severity disturbance rate, area in large patches (>100 ha), and landscape age structure. We updated a classification of Landsat TM imagery classification from 1990 (Wolter et al., 1995) at 5–6 year intervals (1995, 2000, 2005, and 2011) using methods described in Wolter and White (2002). To detect changes from 1990 to 1995 we identified pixels from 1995 growing season imagery that showed a positive or negative difference in reflectance from 1990 to 1995. We used a normalized version of the short wave infrared/near infrared ratio (SWIR/NIR) using TM band 5 (1.55–1.75 μm) and TM band 4 (0.76–0.90 μm). The SWIR/NIR ratio – or normalizations of this basic ratio – is far more sensitive to forest canopy disturbance than the commonly used NDVI (Vogelmann and Rock, 1988; Jin and Sader, 2005). Interpreted color infrared aerial images were used to determine threshold values for forest change. The 1990–1995 change pixels were used to select pixels from the 1990 classification. The clipped 1990 classification was then used as a template to classify raw 1995 TM data. This