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Dynamics of a temperate deciduous forest under landscape-scale management: Implications for adaptability to climate change

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ABSTRACT

Landscape forest management is an approach to meeting diverse objectives that collectively span multiple spatial scales. It is critical that we understand the long-term effects of landscape management on the structure and composition of forest tree communities to ensure that these practices are sustainable. Furthermore, it is increasingly important to also consider effects of our management within the context of anticipated environmental changes, especially future climate. This study investigated two decades of tree community dynamics within a long-term, landscape-scale management experiment located in a temperate deciduous forest in southeastern Missouri, USA. This experiment tests three alternative landscape management systems: even-aged management (EAM), uneven-aged management (UAM), and no-harvest management (NHM). Specifically, we evaluated effects of landscape management alternatives on: (1) structural and compositional dynamics of the tree communities and (2) adaptability of the tree communities to projected climate change. Changes in the abundance of dominant species under these landscape management systems suggested a prevailing successional trend on these relatively xeric, oak-dominated landscapes. In the overstory layer, there was a decrease in the abundance of red oak species (Section *Lobatae*), mainly black oak (*Quercus velutina* Lam.) and scarlet oak (*Quercus coccinea* Muenchh.), and an increase in white oak (*Quercus alba* L.) suggesting a shift to white oak dominance is underway. In the midstory and understory layers, flowering dogwood (*Cornus florida* L.) abundance declined substantially, while maples (*Acer* spp. L.) and several minor species increased. Declines in shortleaf pine populations indicated that regeneration harvesting is not regenerating this species. Experiment-wide changes in tree community composition suggest that adaptability to projected future climate may have increased over the first two decades of the MOFEP experiment under all management systems and that diverse management objectives can be realized through active management, including adaptation to climate change. However, future research is needed to test this working hypothesis and to more fully evaluate the impacts of silviculture treatments within the context of projected climate.

1. Introduction

Forests are increasingly managed to meet multiple objectives designed to address a diverse set of ecological, social, and commodity goals (Gustafsson et al., 2012). These objectives can include conservation of biodiversity, natural community restoration, sustaining timber production, aesthetics, improving forest health, and climate change adaptation. In some cases, the objectives for a given land holding may require an approach capable of addressing desired conditions at sub-stand to landscape scales. Landscape management (i.e., management of an area composed of many stands) is one approach to integrating objectives across a wider range of scales (Hunter, 1999; Crow, 2008). For example, landscape management using even-aged and uneven-aged systems is being applied on public land in the Missouri Ozarks for conserving biodiversity, improving wildlife habitat, enhancing forest health, and sustaining timber production (Olson et al., 2015). Although these forms of even-aged and uneven-aged management can theoretically sustain a particular landscape structure, less is known about how they affect tree community composition and the adaptability of forests to future environmental conditions at the landscape scale.

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Climate change is regarded as one of the most challenging issues confronting forest management (Crow, 2008; D'Amato et al., 2011). Although there are many uncertainties regarding future climate change and its impact on forests, the consensus is that many forests will likely experience pronounced changes in climate over the next century (Park et al., 2014). Collaborative, multi-agency initiatives have started to promote an understanding of potential climate change impacts on forests and how to address climate change proactively through management (e.g., Climate Change Response Framework Projects in the United States). Efforts such as these depend on the knowledge gained from scientific investigations to help inform decisions on the adoption of management strategies for adapting to climate change.

There is considerable interest in management approaches that enhance the ability of forests to recover rapidly after disruptions induced by climate change (i.e., resilience) and to adapt to future climatic conditions and other perturbations (i.e., adaptive capacity) (Keenan, 2012; Park et al., 2014; Subramanian et al., 2016). Research on increasing resilience to environmental stresses related to climate change has addressed the efficacy of managing stand density (Cescatti and Piutti, 1998; Laurent et al., 2003; Magruder et al., 2013), managing species composition (Cortini et al., 2011; Buma and Wessman, 2013), and utilizing site preparation and vegetation control practices (Cortini et al., 2011). Investigations on the role of silviculture for enhancing adaptive capacity have focused mainly on increasing compositional and structural diversity at stand- to landscape-scales, which is hypothesized to promote a greater range of potential responses to future uncertainty (i.e., enhance response diversity) (Puettmann et al., 2008). An area that has received less attention is how contemporary forest management impacts adaptability to projected changes in climate.

The Ozark Highlands support forest and woodland natural communities that contribute to the ecological and socio-economic well-being of the region. Therefore, effects of anthropogenic climate change on Ozark ecosystems are potentially far-reaching. The Missouri portion of the Ozarks was included in a recent climate change vulnerability assessment for ecosystems of the Central Hardwood Region (Brandt et al., 2014). This effort used a model-based approach to compare recent abundances of tree species with their future abundances projected under two alternative climate change scenarios. Climate projections for the Missouri Ozarks from the periods of 1971–2000 to 2070–2099 indicated a 1–4 °C increase in mean annual temperature, while projected changes in mean annual precipitation were highly variable, ranging from a decrease of 15 cm to an increase of 5 cm. Simulated changes in the abundance of tree species in the Missouri Ozarks were variable with some species increasing, others decreasing, and some showing no change. Assessments such as this one provide resource managers with information on potential species' response to climate change that can be factored into management decisions. The next step in assessing climate change impacts for regions like the Missouri Ozarks is to evaluate the influence of alternative management regimes on the adaptability of forest communities to projected future climate.

The Missouri Ozark Forest Ecosystem Project (MOFEP) afforded a rare opportunity to examine the effects of landscape-scale management on forest dynamics and to assess management impacts on adaptation to climate change. MOFEP is a century-long, landscape-scale forest management experiment designed to evaluate the cumulative effects of even-aged, uneven-aged, and no-harvest management systems on the flora and fauna of upland oak ecosystems. The objectives of this investigation were to evaluate the effects of alternative landscape-scale forest management systems on: (1) structural and compositional dynamics of Missouri Ozark forests and (2) adaptability of the Missouri Ozark tree communities to projected climate change.

2. Material and methods

2.1. Study site and experimental design

Three management systems were initiated as treatments of the MOFEP experiment: even-aged management (EAM), uneven-aged management (UAM), and no-harvest management (NHM). The management systems are applied to MOFEP in the same manner as operationally applied by the Missouri Department of Conservation (MDC) on other managed public lands in the southeast Missouri Ozarks. The MOFEP experiment is located on two MDC-administered Conservation Areas in southeastern Missouri. All MOFEP sites fall within the Current River Ecological Subsection of the Ozark Highlands Section (Nigh and Schroeder, 2002). MOFEP sites are underlain mainly by Ordovician dolomites and sandstones (Meinert et al., 1997). Soils are highly weathered Ultisols and Alfisols derived mainly within loess, hillslope sediments, residuum, and gravelly alluvial parent material (Meinert et al., 1997). For nearly a quarter century, the MOFEP experiment has been a platform for multi-agency, collaborative research on managed forests (Knapp et al., 2014).

The MOFEP experiment employs a randomized complete block design (RCBD) that includes three blocks, with each management system randomly assigned to one of three experimental units per block ($n = 9$). MOFEP units range in size from 314 to 516 ha. Each MOFEP unit is an administrative compartment (hereafter 'site') composed of 44–82 stands, each ranging from 0.2 to 62 ha.

Silvicultural practices under EAM and UAM systems of the MOFEP experiment were first implemented from May 1996 to May 1997. The management cycle of both systems starts with a pre-treatment inventory of a site that is accomplished by inventorying each stand individually. This information is used to prescribe appropriate silviculture practices to each stand that also considers management impacts at the site level. Under MOFEP's EAM system, approximately 12% of the site is regenerated by clearcutting of mature stands every 15 years. Thinning is also applied as an intermediate treatment under EAM. Under MOFEP's UAM system, stands are treated with a combination of single-tree and group selection that tends size classes, similar to the BDq method, on the same 15-year cycle as the EAM system. Approximately 10% of each site was reserved as old growth under both systems prior to the first treatment entry. To date, there have been two treatment entries on MOFEP sites (1996–97 and 2011–12). See Brookshire et al. (1997) and Knapp et al. (2014) for more information about treatment implementation of the MOFEP experiment.

2.2. Woody vegetation monitoring

A network of 648 permanent sampling stations, with 70–76 sampling stations per site, is used to monitor forest vegetation on the MOFEP experiment. Since MOFEP sites are topographically and edaphically heterogeneous, sampling stations were strategically placed to capture topoedaphic variation within each MOFEP site using a stratified random sampling approach. Each station consists of a nested array of fixed-area plots designed to sample vegetation across size classes. Species, diameter at breast height (DBH), and condition (e.g., live or dead, crown class, etc.) of all woody stems $\geqslant$11.4 cm DBH are recorded within a 0.2-ha fixed-radius plot at each sampling station. The species and DBH of all live woody stems from 3.8 to 11.3 cm DBH are recorded within four, 0.02-ha fixed-radius plots located a fixed distance from the center of the 0.2-ha plot in the four cardinal directions. Nested within each 0.02-ha plot is a 0.004-ha fixed-radius plot for tallying live woody stems from 1 m tall to 3.7 cm DBH. This investigation used tree data collected over 18 years (1995–2013) on MOFEP's 0.2,

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