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Fire history, fuels, and overstory effects on the regeneration-layer dynamics of mixed-pine forest ecosystems of eastern Upper Michigan, USA

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ABSTRACT

Mixed-pine forest ecosystems of the northern Lake States were historically dominated by red pine (*Pinus resinosa* Ait.) and eastern white pine (*Pinus strobus* L.). The late 18th and early 19th century logging activities, followed by significant changes in the characteristics of the fire regime altered the structure and composition of these forests. Prior to making decisions about restoration treatments aimed at promoting natural regeneration of red pine and eastern white pine, there is a need to develop a better understanding of the influence of fire history and current stand conditions on the regeneration-layer. To this end, we quantified the seedling and sapling densities of tree species in altered second-growth and reference old-growth stands at Seney National Wildlife Refuge in eastern Upper Michigan. We then related these densities to descriptors of fire history, fuel loadings, and overstory characteristics. Our results indicate lower densities of red pine and eastern white pine seedlings compared to saplings in second-growth stands. Red pine and eastern white pine seedling densities were positively associated with number of fires in the last 142 years, and negatively associated with time since last fire. Time since last fire also influenced red pine and eastern white pine regeneration indirectly through positive correlations with organic matter depth and negative correlations with importance values for these species in the overstory. Jack pine (*Pinus banksiana* Lamb.) seedling density was also positively associated with the number of fires in the last 142 years. Red pine and eastern white pine seedling and sapling densities exhibited negative relationships with most of the descriptors of fuel loadings. Compared to the second-growth stands, the overstory was found to be a stronger driver of regeneration-layer dynamics in the old-growth stands. Our findings suggest that regeneration of red pine and eastern white pine in the second-growth stands is limited due to unfavorable seedbed conditions, abundance of competing species, and an insufficient seed source. The long-term management objective should be to reintroduce fire with characteristics that resemble those of the historical fire regime. In the short-term, however, managers need to explore management options focused on creating favorable conditions for regeneration of red pine and eastern white pine, and on reducing jack pine. Our findings indicate that opportunities exist for restoration treatments that can manipulate successional dynamics to favor red pine and eastern white pine dominance in these stands.

1. Introduction

Fire has shaped the structure and composition of many forest ecosystems across North America. Pine-dominated ecosystem types, including longleaf pine (*Pinus palustris* Mill.) ecosystems of the Southeast, ponderosa pine (*P. ponderosa* C. Lawson) ecosystems of the Southwest, and mixed-pine ecosystems of the northern Lake States were historically maintained by a fire regime generally characterized by low- to mixed-severity surface fires (Covington et al., 1994; Drobyshev et al., 2008a; Ware et al., 1993). In these forest types, fire created conditions necessary for germination, seedling establishment, and dominance of the pine species (Ahlgren,

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1976; Bergeron and Gagnon, 1987; Romme et al., 2009), and played a major role in regulating stand density and functional processes (Fulé et al., 2009; Naficy et al., 2010). Fires occurring within the natural range of severity and return intervals also provided the dominant pine species with a competitive advantage during establishment by reducing competition from other vegetation (Kershaw, 1993). Fire history studies in many of these ecosystem types have, however, revealed significant changes in the historical fire regimes (Covington and Moore, 1994; Drobyshev et al., 2008a; Frost, 1993). As a result, many of these ecosystems face a variety of similar management issues associated with these changes in fire regime (Corace et al., 2009; Fulé et al., 2009; Palik et al., 2005; Wilson et al., 2009).

Within the northern Lakes States region, extensive logging during EuroAmerican settlement, followed by a period of catastrophic slash fires, extended periods of fire-suppression, and even-aged harvesting practices such as clear-cutting have resulted in significant changes in many forest ecosystems (Cleland et al., 2004; Rist, 2008; Stephens and Ruth, 2005). Among these changes are shifts in species composition, inadequate regeneration of historically dominant pine species, structurally simplified stands, and accumulation of fuels outside of the natural range of variation (Corace et al., 2012; Drobyshev et al., 2008b; Frelich, 1995). While extended periods of fire suppression likely favored increases in deciduous species such as red maple (*Acer rubrum* L.), the high intensity slash fires following logging activities in many areas likely destroyed most of the remaining pine seed trees (Barrett, 1998; Whitney, 1987). In eastern Upper Michigan, mixed-pine forests historically dominated by red pine (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) have declined from about 39% of the land area prior to EuroAmerican settlement to only about 13% of the land area (Zhang et al., 2000). Further, many of the current stands have a significant component of jack pine, a species whose regeneration was favored by clearcutting (Rist, 2008), and is of concern for fire management in these stands (Corace et al., 2009).

While changes in fire history have been documented (Cleland et al., 2004; Drobyshev et al., 2008a), the legacy effects of these changes and their interaction with stand characteristics on regeneration have not been studied comprehensively in mixed-pine forests of the northern Lake States. Compared with other pine-dominated ecosystems in the southern and western regions of the United States, relatively little information exist on the effects of fire on stand development processes and ecosystem components for pine-dominated ecosystems of the northern Lake States (Miesel et al., 2012). Recent efforts to improve access to (and exchange of) information about fire and fuel issues (Kocher et al., 2012; Miesel et al., 2012), coupled with increasing public support for ecologically based management activities (Shindler et al., 2009; Wilson et al., 2009), indicate increasing interest in restoring these altered forest ecosystems. If land managers are going to take advantage of these opportunities to develop restoration strategies, especially where management goals include restoring historically dominant species, a better understanding of the important factors that drive regeneration-layer dynamics in current stands is needed.

This study focused on exploring the following question: how do fire history, fuels, and overstory characteristics influence the regeneration-layer dynamics of mixed-pine forest ecosystems of eastern Upper Michigan? We addressed this question by examining seedling and sapling densities (with emphasis on red pine and eastern white pine as restoration target species) in both second-growth (representing altered conditions) and old-growth (representing reference conditions in forest composition and structure) stands. We then related these data to three primary factor groups: (1) fire history; (2) current down fuel loadings; and (3) current overstory characteristics (composition and structure) (Fig. 1). While fire plays a key role on the regeneration and

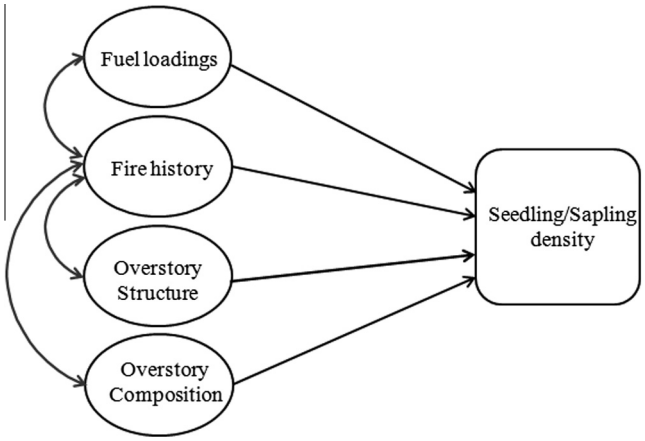

Fig. 1. Conceptual diagram illustrating the factor groups (inferred from measured variables) that likely influence seedling and sapling densities in mixed-pine forest ecosystems of eastern Upper Michigan, USA.

dominance of red pine and eastern white pine (Ahlgren, 1976; Carey, 1993a), we know that there have been changes in the historical fire regime in our study area (Drobyshev et al., 2008a), that might be expected to influence the structure and composition of current stands. We, therefore, focused on fire history, fuels, and overstory characteristics because these are the primary factor groups that we anticipate are important drivers of regeneration dynamics in current stands, and that can be manipulated by management. This important baseline information on the effects of fire history and current stand characteristics on regeneration dynamics will contribute to restoration efforts by facilitating decision-making when selecting and implementing restoration alternatives in this and other similar ecosystem types.

2. Materials and methods

2.1. Study area

The study was conducted within the 38,542-ha Seney National Wildlife Refuge (SNWR), Schoolcraft County, eastern Upper Michigan (N46.271594° W86.057078°) (Fig. 2). SNWR lies within the Seney Lake Plain ecoregion and is characterized by soils and physiographic features that resulted from postglacial erosion and soil formation processes (Albert, 1995). Two major landform types dominate the landscape: glacial outwash channels and a

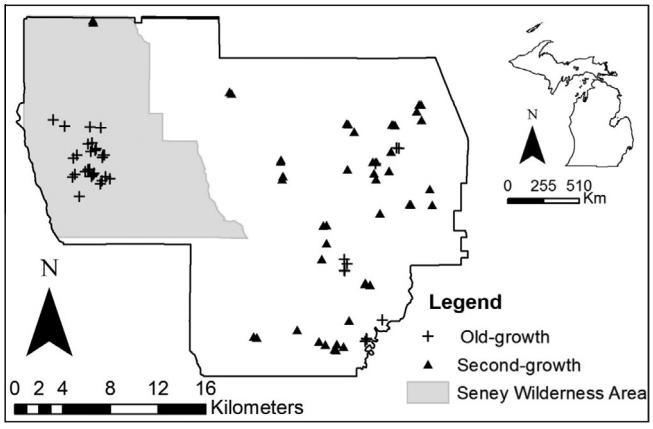

Fig. 2. Study area at Seney National Wildlife Refuge showing study plot locations in old-growth and second-growth stands.