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Ecological restoration and fine-scale forest structure regulation in southwestern ponderosa pine forests

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ABSTRACT

Fine-scale forest patterns are an important component of forest ecosystem complexity and spatial pattern objectives are an increasingly common component of contemporary silviculture prescriptions in dry fire-adapted forests of North America. Despite their importance, questions remain regarding the assessment of silvicultural treatments designed to meet spatial objectives. We initiated a replicated silvicultural assessment of two forest management approaches commonly applied in dense ponderosa pine forests of the Southwest United States: historical evidence-based ecological restoration guidelines (ERG) and northern goshawk (*Accipiter gentilis*) foraging area management recommendations (GMR). We compared stand-level characteristics, global tree location point patterns and tree group-level attributes resulting from the marking of these approaches to current forest conditions and patterns of historical forest remnants in six, 2.02 ha stem mapped plots. We also assessed group-level Vegetative Structural Stage (VSS; a classification of fine-scale forest structural development used to regulate fine-scale spatial patterns in these forests). ERG and GMR-based treatments significantly reduced densities and basal area from the current condition, but did not significantly differ in density from historical forest remnant estimates. GMR-based treatments retained greater stand level basal area than ERG-based treatments, primarily in large, 28–48 cm tree diameter classes. GMR-based treatments approximated global tree location point patterns of forest remnants better than ERG-based treatments, primarily due to a 5–6 m minimum spacing of residual trees, but also likely due to specific aspects of ERG-based marking techniques. Despite this difference, both treatments resulted in group-level characteristics similar to those exhibited by historical forest remnants. Both treatments significantly altered group-level VSS area and reduced variation of tree diameters within classified VSS groups.

Our study provides insight how tree marking techniques using historical forest remnants may have important effects on resulting fine-scale forest structure patterns. We also demonstrate how the use of global point or group-level pattern assessment methods can affect the evaluation of fine-scale spatial pattern objectives. Our analysis of VSS group characteristics highlights implementation and assessment issues associated with group-level spatial pattern identification, classification and regulation. We conclude that group-level classification and regulation is not necessary for maintaining fine-scale spatial patterns in complex ponderosa pine ecosystems subject to frequent fire disturbances and changing future climate conditions and societal demands. Both ERG and GMR-based approaches applied in this study may have utility in maintaining fine-scale spatial heterogeneity and promoting resiliency in Southwest ponderosa pine forests.

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1. Introduction

1.1. Fine-scale forest structure management

Forest spatial pattern heterogeneity at multiple-scales is increasingly recognized as an important component of forest structural complexity (Churchill et al., 2013; Puettmann et al., 2008).

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Variation in tree spatial patterns at scales finer than those associated with forest stands (typically 10–100 ha) is a result of complex interacting biotic and abiotic ecological processes (Franklin and Van Pelt, 2004). Spatial heterogeneity not only influences future tree growth and development, but is also important for the development of understory plant communities (Griffis et al., 2001; Fahey and Puetmann, 2008), fire behavior and effects (Fulé et al., 2001; Heyerdahl et al., 2001; Agee and Skinner, 2005) and wildlife habitat suitability (Reynolds et al., 1992; Turner et al., 1997; Dodd et al., 2006). There is increasing recognition that the maintenance of fine-scale spatial heterogeneity in dry forests increases the capacity of these ecosystems to adapt to a changing future climate and persist and recover from disturbances over time and (Franklin et al., 2007; Churchill et al., 2013).

Management for within-stand spatial heterogeneity, particularly associated with natural disturbance regimes, is an increasingly common objective of contemporary silviculture prescriptions, especially in dry fire-adapted forests of North America (North et al., 2009; O'hara and Nagel, 2013; Reynolds et al., 2013). Management for specific spatial structures occurring under natural disturbance regimes is a common objective of Ecological Restoration and Ecological Forestry practices (Franklin et al., 2007) and is considered essential for the management of forests as complex and adaptive ecosystems (Puettmann et al., 2008). Silvicultural treatments based upon reference conditions are increasingly accepted as capable of increasing forest resilience to disturbance and changing climate (Keane et al., 2009; Spies et al., 2010).

Additionally, forest spatial structure and development requirements form the basis of management guidelines for many threatened, endangered or sensitive bird and mammal species and have been incorporated into public forest management regulations (Hoffman et al., 1993; USDA Forest Service 2008, 2012, O'hara and Nagel, 2013). Guidelines have proposed to create characteristics and patterns associated with specific forest development stages to promote associated nesting, denning, foraging or hiding habitats, depending on the specific organism and landscape (for example Abert's squirrel (*Sciurus aberti*) nesting, Canada lynx (*Lynx canadensis*) denning, or northern goshawk (*Accipiter gentilis*) foraging). The suitability of contemporary forest structure and the success or failure of silvicultural treatments intended to enhance or develop spatial patterns relies on the ability of managers to classify and quantify forest spatial patterns and attributes. Since managers are often legally mandated to manage for fine-scale threatened, endangered or sensitive species habitat characteristics, the ability to evaluate spatial patterns consistently and quantitatively is of great importance to land management in many jurisdictions.

1.2. Importance to southwestern ponderosa pine forests

A legacy of past land management activities such as logging, grazing and fire suppression in many forests in North America that were historically subject to frequent surface fires has been the development of dense, contiguous forested landscapes, highly susceptible to expensive and destructive stand replacing wildfires (Dombeck et al., 2004). Many studies have shown contemporary forests to have relatively homogeneous spatial patterns compared with forests existing at the time of Euro-American settlement circa 1880 (Cooper, 1960; White, 1985; Sánchez Meador et al., 2009; Larson and Churchill, 2012). Within southwestern National Forests there is broad agreement that forest management activities are necessary across large areas of ponderosa pine forest to restore forest densities and spatial patterns similar to those common in the region prior to Euro-American settlement of the region in the late 19th centuries. (Moore et al., 1999; Allen et al., 2002). Ecological Restoration Guidelines (ERG) and Goshawk Management Recommendations (GMR) are two forest management approaches that have been proposed to accomplish this goal (Reynolds et al., 1992; Covington et al., 1997).

Ecological restoration efforts within ponderosa pine forests have often relied on silvicultural treatments designed to reduce tree densities and woody fuel accumulations in order to allow reintroduction of ecologically beneficial surface fires. Restoration of a surface fire regime is anticipated to maintain ecological function and regulate structure in these forests over time (Moore et al., 1999; Allen et al., 2002).

Management for forest structural patterns within the historical range of ecosystem variability is a stated goal of ERGs (Moore et al., 1999). These guidelines draw upon White's (1985) observation in Northern Arizona ponderosa pine forests indicating trees in groups (i.e., two or more trees with interlocking crowns were uneven-aged, ranging in age from 33 to 268 years. ERG-based methods, therefore, often attempt to manage for uneven-aged or multi-aged tree groups (Moore et al., 1999). The ERG-based marking approach uses the location and density of historical forest remnants (old trees, stumps, snags, and stump holes predating settlement of the region by Europeans in the 1870–1880s) as reference for the desired spatial pattern and density of the restored forest. Using this method, treatments typically retain all trees older than approximately 135 years, so-called "presettlement" trees, as well as 1–3 younger "replacement" trees within a predetermined search distance of each dead presettlement forest remnant (Covington et al., 1999) (Fig. 1). The resulting forest structure is intended to approximate the fine-scale forest structure patterns existing in the stand prior to the disruption of the natural frequent-surface fire regimes around the time of Euro-American settlement.

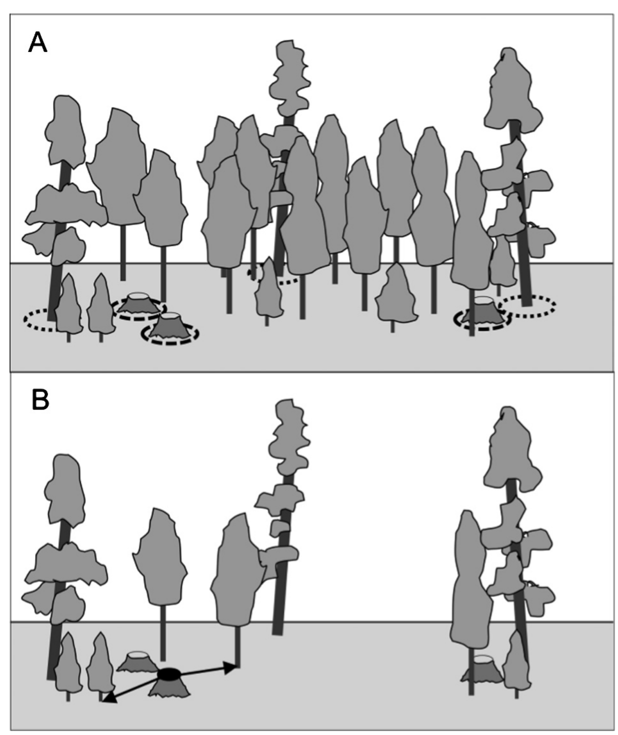

Fig. 1. ERG Historical Evidence-based Marking. (A) Using this approach, all pre Euro-American settlement (~1870–1880) era live trees (A-dotted circles) and presettlement forest remnants (A-dashed circles) are identified. (B) All presettlement era trees are retained and each remnant is replaced with the closest (two in this example) post-settlement era trees within a predetermined search distance (represented by black arrows in B) and the remaining post-settlement trees are thinned.