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Tamm Review

Effects of tree cutting and fire on understory vegetation in mixed conifer forests

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ABSTRACT

Mixed conifer forests of western North America are challenging for fire management, as historical fire regimes were highly variable in severity, timing, and spatial extent. Complex fire histories combined with site factors and other disturbances, such insect outbreaks, led to great variation in understory plant communities, and management activities influence future dynamics of both overstory and understory communities. This variation needs to be considered as part of ecosystem-scale efforts to influence future fires and restore the composition and structure of mixed conifer forests. We undertook a systematic review of published studies evaluating effects of tree cutting and fire on understory vegetation in western North American mixed conifer forests. Forty-one studies, published in 50 articles, met inclusion criteria and encompassed projects in seven states in the USA and British Columbia in Canada. Total understory plant abundance (cover, biomass, or density) commonly declined in the short term within 4 years after treatment. This may result from damage to plants during tree cutting operations or fire, heavy loadings of slash, little change or even expansion of tree canopies after low-intensity treatments, herbivory, or drought. In contrast, all 7 studies measuring understories longer than 5 years since treatment reported increases in understory metrics. Treatments in these long-term studies also persistently decreased tree canopy cover. Most or all native species endured (even if reduced in abundance) through cutting operations or fire. A model of understory response has emerged that treatments generally do not eliminate species, and often benefit species absent or uncommon in untreated forest. Groups of native species (e.g., *Epilobium* spp.) appear fire-dependent, because they are uncommon or absent in unburned mixed conifer forests and after tree cutting alone. Cutting and prescribed fire applied together resulted in the greatest invasion of non-native plants, but non-native cover was minimal compared to native cover. Few studies examined influences of intensity of tree cutting or severity of prescribed fire, but overstory–understory relationships suggest that treatments must substantially reduce overstory density from maximum values (which can exceed 3000 stems ha^{-1} and 80 m^2 ha^{-1} basal area) and tree canopy cover to <30–50% cover to elicit appreciable responses from the forest understory. Few studies examined understory dynamics after wildfire relative to unburned forest, and further work is warranted because wildfire is a likely eventual outcome of passive management in these forests. Across a broad region from the southwestern United States into Canada, prescribed fire and tree cutting consistently increased disturbance-promoted native species in the short term and total understory abundance in the long term. Active management using tree cutting and fire will likely benefit both biodiversity conservation and fire management in current mixed conifer forests.

Contents

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1. Introduction

Conserving forest biodiversity and maintaining ecosystem services is challenging forest managers globally (Honnay et al., 2002; Hart and Chen, 2006; Paillet et al., 2010). Meeting this challenge benefits from a comprehensive understanding of the effects of a range of forest management activities – including passive management – on ecosystem components (Metlen et al., 2004; North et al., 2007; Kalies et al., 2010). Understory plant communities are a critical forest component containing a major proportion of forest species diversity and providing numerous ecosystem functions that can both affect and be affected by forest management activities (Roberts, 2004; Gilliam, 2007; Barbier et al., 2008). Tree cutting and fire are two of the main management activities affecting forest understory dynamics (Selmants and Knight, 2003; Ares et al., 2010; Halpern and Lutz, 2013). For example, different methods of tree cutting can differentially influence understories, and a particular cutting method could affect plant cover differently than it affects species richness (Dodson et al., 2007; Kreyling et al., 2008; Knapp et al., 2013). Similarly, plant groups, such as native and non-native species, could respond differently to management activities (Abella and Covington, 2004; Sutherland and Nelson, 2010; Fiedler et al., 2013). The imprint of major events in forests on understory plant communities can be long-lived, such as persistent effects to plant diversity from Roman clearing of French forests 2000 years ago (Dambrine et al., 2007). Undesirable legacies of forest practices might be avoided if we have a foundation of clear insights on impacts to understory communities.

To help provide such a foundation, systematic reviews are emerging tools for evaluating evidence for ecological questions, including effects of forest management activities (e.g., Rosenvald and Lõhmus, 2008; Verschuyl et al., 2011; Duguid and Ashton, 2013). Systematic reviews are complementary to traditional narrative reviews, but differ by having reproducible methods for locating literature, criteria for including or excluding studies, and an evaluation of evidence from reproducibly synthesized primary data (Pullin and Stewart, 2006). Systematic reviews and statistical meta-analyses are not synonymous: data gathered by a systematic review can be analyzed with or without a statistical meta-analysis, and meta-analysis can be applied to numerous data sets other than those assembled through a systematic review (Koricheva et al., 2013).

Here, we conducted a systematic review of the effects of tree cutting and fire on understory vegetation in mixed conifer forests of interior western North America. Mixed conifer forests are considered among North America's most difficult for fire management, and conservation of these forests is currently of keen interest (Agee, 1993; Klenner et al., 2008; Jain et al., 2012). Contemporary conditions of mixed conifer forests differ from those before or during initial Euro-American settlement (Parsons and DeBenedetti, 1979; Covington et al., 1994; Minnich et al., 1995; Reynolds et al., 2013). Major changes to fire regimes, tree structure and composition, forest floor and light conditions, climate, and introduction of livestock and exotic species may all influence understory vegetation (Battaglia and Shepperd, 2007; Knapp et al., 2013). Except for rare forests such as those with natural fire regimes continued through the 1900s (mostly in Mexico; Minnich et al., 2000) or with managed active fire programs (e.g., Sequoia/Kings Canyon National Parks; Webster and Halpern, 2010), the key evolutionary process of low- and mixed-severity fire has been excluded after settlement (Heinlein et al., 2005; Baker et al., 2007; Falk et al., 2011). Fuel loads accrued during the 1900s support severe, stand-replacing fire regimes in many areas (Freeman et al., 2007; Crotteau et al., 2013; Fornwalt and Kaufmann, 2014). Tree density and basal area have increased on average by orders of magnitude, now often exceeding 1000 trees ha^{-1} and 30–80 m^2 ha^{-1} basal area (Cocke et al., 2005; North et al., 2007; Fulé et al., 2009). Tree composition has generally shifted toward an increased proportion of species with low fire tolerance and higher shade tolerance, at the expense of fire-tolerant species such as *Pinus ponderosa* (ponderosa pine; Barbour et al., 2002; Vankat, 2011; Abella et al., 2012). Concomitant with increased tree density, light reaching the forest floor has decreased, while O horizons have thickened (Bigelow and North, 2012; Lydersen et al., 2013). Stocking levels of livestock (primarily cattle and sheep) peaked in the mid-1800s or early 1900s among regions, with likely profound but poorly understood impacts (Riggs et al., 2000). A suite of non-native species, ranging from tree pests to plants, can dramatically influence mixed conifer forests at local to regional scales (Hessburg and Agee, 2003).

Associated with these land use and forest structural changes, examples of repeat-photography studies and historical records