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The effects of thinning and burning on understory vegetation in North America: A meta-analysis

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ABSTRACT

Management in fire-prone ecosystems relies widely upon application of prescribed fire and/or fire-surrogate (e.g., forest thinning) treatments to maintain biodiversity and ecosystem function. The literature suggests fire and mechanical treatments proved more variable in their effects on understory vegetation as compared to their effects on stand structure. The growing body of work comparing fire and thinning effects on understory vegetation offers an opportunity to increase the generality of conclusions through meta-analysis. We conducted a meta-analysis to determine if there were consistent responses of understory vegetation to these treatments in North American forests that historically experienced frequent surface fire regimes (<20 years fire return interval, FRI). Means and standard errors were extracted from 32 papers containing data on the response of four understory functional groups (herbaceous, shrub, non-native, and total) to thinning and burning treatments to calculate effect sizes. Lack of replication and inconsistent reporting of results hindered our ability to include many studies in this analysis. For each response variable (species richness and percent cover), we compared three treatment pairs: burn vs control, thin vs control and thin vs burn. We calculated standardized mean differences (Hedges' g) for each pair and tested if this differed from zero using a random effects model fit with restricted maximum likelihood to account for variation by site. The most consistent effect of the treatments was the increase in non-native species following mechanical thinning and reduction in shrub cover following a burn. These differences suggest the two treatments may not be surrogates in the short-term (less than 5 years). Increase of non-native species due to disturbance is well established but it is not clear if burning and thinning consistently have differential impacts. Response of non-native plants to disturbance is likely a complex function of a variety of site and landscape factors that cannot be evaluated by the current literature. We conclude that prescribed fire and thinning treatments can be used successfully to restore understory species richness and cover, but they can create different conditions and these potentially different outcomes need to be considered in the planning of a fuels reduction treatment. We discuss management options to reduce negative effects of the treatments and we suggest managers use current decision-making frameworks prior to designing an intervention.

1. Introduction

North American frequent-fire forests have been shaped by fire over evolutionary and ecological time scales. However, for much of the 20th century, land managers concentrated on minimizing amount of land that burned. Compared to presettlement fire regimes in many contemporary forests, fire intervals have lengthened (Cyr et al., 2009; Aldrich et al., 2010; Spetich et al., 2011), although there is evidence for significant variability in historical fire return intervals (Odion et al., 2014). Increased recognition of the central role of fire in maintaining forest structure and function has contributed to a shift from fire exclusion to reintroduction of fire in fire-dependent forests, with the aim of reducing fuels and restoring historic stand structure (Agee and Skinner, 2005). This recognition has prompted U. S. federal initiatives such as the National Fire Plan and Healthy Forest Restoration Act (2003) that mandate federal land managers restore forest structure and function and reduce risk of wildfire on federal lands. Use of widespread (i.e., over a large area) fuel treatments has led to increasing discussion of the effectiveness, suitability and ecological impacts

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of thinning and prescribed fire (Schoennagel et al., 2004; Schwilk et al., 2009; Schoennagel and Nelson, 2011; Stephens et al., 2012).

Although prescribed fire is often the preferred fuel reduction practice, forest managers often face social and economic constraints on burning particularly when human safety and property might be compromised. Additionally, in forests thought to have departed significantly from historical fire return intervals, there is concern that introducing fire may result in unnaturally high intensity fire that may be difficult to manage or may have negative ecological effects (but see Bond et al., 2012; Fontaine and Kennedy, 2012). Therefore, mechanical fuel reduction methods have increasingly been used to reduce fuels or restore historic stand structure (Crow and Perera, 2004). Uncertainty regarding the relative ecological effects of prescribed fire versus mechanical treatments has led to increasing attention on these so-called ''fire surrogates" such as the National Fire and Fire Surrogate study (Schwilk et al., 2009; McIver et al., 2013).

Early forest management emphasized recruiting trees for commercial harvest. However, in the last half of the 20th century, forest management practices shifted focus to include managing for ecosystem services, including biodiversity. In most forests, the majority of plant biodiversity is in the understory herbaceous layer. In addition to harboring high diversity, understory herbaceous communities have profound effects on other ecosystem services such as forest nutrient cycling (reviewed by Gilliam, 2007). Most attention has been paid to the effects of fire and mechanical treatments on forest structure and fuels (e.g., Moghaddas et al., 2008; van Mantgem et al., 2011; Kreye and Kobziar, 2015), and reviewed in Fulé et al. (2012); the extent to which mechanical treatments or thinning approximate effects of prescribed fire on forest understory vegetation is not as well understood. Results from the National Fire and Fire Surrogate study demonstrated that fire and mechanical treatments proved more variable in their effects on understory vegetation as compared to stand structure (Schwilk et al., 2009). This is not entirely surprising: although both fire and thinning remove overstory trees and allow increased light to reach understory plants, extent of canopy removal varies with thinning intensity and fire severity. According to a recent review by Abella and Springer (2015) treatments must reduce tree canopy cover to <30–50% to elicit appreciable responses from the forest understory.

In addition to variable treatment effects on forest cover, fire and thinning modify the abiotic environment differently. Fire restructures microsites and soils that many plants depend on for germination and growth (Bond and van Wilgen, 1996; Gundale et al., 2005, 2006; DeLuca et al., 2006). Thinning, on the other hand, removes or rearranges (as opposed to consumes) vegetation and may alter nutrient dynamics (e.g., Boerner et al., 2006). Many mechanical thinning methods also result in soil disturbance and compaction that fire does not cause (Schwilk et al., 2009). The differences exhibited between fire and fire surrogate treatments may result in differences in responses between native and nonnative species, and in the percent cover and species richness in the herbaceous and shrub layers (Dodson, 2004; Wienk et al., 2004; Metlen and Fiedler, 2006; Collins et al., 2007; Nelson et al., 2008; Zhang et al., 2008b; Fornwalt and Kaufmann, 2014). The growing body of work comparing fire and thinning effects on understory vegetation (recently reviewed by Abella and Springer, 2015) for mixed conifer forests in North America) offers an opportunity to increase the generality of conclusions through meta-analysis.

Our objective was to conduct a meta-analysis of the literature that investigated effects of thin and burn treatments on understory species in North American. Specifically, we were interested in the degree to which thin treatments mimic prescribed burn treatments, and to what extent burning or thinning differ from control treatments. We tested three pairwise comparisons: thinning treatments versus controls, burning treatments versus controls, and thinning treatments versus burning treatments for percent cover and species richness in total species, non-native species, herbaceous species, and shrub species.

We tested the following hypotheses: (1) total species richness and cover of herbaceous understory plants will increase in thin and burn treatments compared to controls as an effect of increasing light availability (Wienk et al., 2004; Metlen and Fiedler, 2006; Fornwalt and Kaufmann, 2014); (2) total cover of understory shrubs will decrease in response to burning, but not to thinning in the short term because burning consumes understory shrubs and these are slower to respond to increased light than are herbaceous species (Nelson et al., 2008; Zhang et al., 2008b); and (3) non-native plant species are often favored by disturbance and we expect both thinning and burning to increase non-native species richness and cover relative to controls with the greatest increases in thinning treatments as a result of greater soil disturbance in thinning relative to burning (Dodson, 2004; Collins et al., 2007).

2. Materials and methods

2.1. Literature search and vetting

In May 2014, we performed a search of the scientific literature investigating effects of prescribed fire and thinning treatments on understory vegetation. We used multiple databases: ISI Web of Science (http://www.webofknowledge.com) and AGRICOLA (http://agricola.nal.usda.gov/) both of which searched literature published since 1970 and Forest Science (http://www.cabi.org/forestscience/) which searched literature published since 1939. We also supplemented these searches with a Google Scholar search (http://scholar.google.com/) which, despite limitations in coverage, includes gray literature publications as well as proceedings. In addition to these search engines, we included additional references gleaned from publications found in the literature search.

We used the following search terms ('*' indicate wild card searches uses to include plural forms, etc.):

- Understory AND native*
- Percent Cover AND native*
- Fire AND Understory*
- Understory AND exotic*
- Percent Cover AND exotic*
- Fire AND Percent Cover*
- Understory AND forb*
- Percent Cover AND forb*
- Burn* AND Understory
- Understory AND graminoid*
- Percent Cover AND graminoid*
- Burn* AND Percent Cover
- Understory AND shrub*
- Percent Cover AND shrub*
- Thin* AND Understory
- Thin* AND Percent Cover.

The literature search from the databases yielded approximately 3500 references, which were then vetted for appropriate material. Documents were eliminated that dealt with medical issues (i.e., new treatments for burn victims), investigations of ecological processes related to fire but not relevant to the scope of this document (e.g., nutrient cycling, insect infestation), or modeling studies with little empirical data. Because North American studies comprise the bulk of the literature and our power to examine larger geographic patterns would be very low, we restricted our analyses to North America. We were specifically interested in studies that collected