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Biodiversity response to intensive biomass production from forest thinning in North American forests – A meta-analysis

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ABSTRACT

Demand for alternative energy sources has led to increased interest in intensive biomass production. When applied across a broad spatial extent, intensive biomass production in forests, which support a large proportion of biodiversity, may alter species composition, nutrient cycling and subsequently biodiversity. Because forest thinning and fuels treatment thinning are viewed as possible wide-spread biomass harvest options, it is important to understand what is known about forest biodiversity response to these practices and what additional information is needed by forest managers and policymakers. Therefore, we summarized documented relationships between forest thinning treatments and forest biodiversity from 505 biodiversity effect sizes (incl. taxa and guild abundance and species richness measures) from 33 studies conducted across North America. We used meta-analysis to summarize biodiversity response by region, taxa and harvest treatments. Biodiversity responses included species richness, diversity, abundance of taxa or groups of species (guilds) and abundance of individual species for birds, mammals, reptiles, amphibians, and invertebrates. Forest thinning treatments had generally positive or neutral effects on diversity and abundance across all taxa, although thinning intensity and the type of thinning conducted may at least partially drive the magnitude of response. Our review highlights the need for more research to determine effects of thinning on amphibians and reptiles and manipulative experiments designed to test the effects of biomass removal on biodiversity.

1. Background and definitions

Forest thinning is a silvicultural treatment that reduces tree density primarily to improve tree growth, to enhance forest health, or for economic reasons (Helms, 1998). Forests naturally thin through tree mortality resulting from competition in dense stands. Stands can be thinned before competitive self-thinning to meet economic objectives as well as objectives related to biodiversity conservation (Hayes et al., 1997, 2003; Carey and Wilson, 2001) and forest restoration (Hayes et al., 2003; Harrod et al., 2009). Wood products resulting from thinning operations are used in a variety of ways, although currently up to 60% of harvested material remains on-site (Parikka, 2004). An increase in availability of biofuels processing facilities may increase removal and use of thinned material (USDA Forest Service, 2005) which may partially offset harvest cost while meeting some of the increasing demand for biofuels (Page-Dumroese et al., 2010).

Thinning can increase structural complexity of young forests, subsequently increasing wildlife species diversity (Spies and Franklin, 1991; Hayes et al., 1997). Thinning produces a variety of short- and long-term changes to forest structure, the most obvious of which is a decrease in tree density and increase in forest canopy gaps and abundance and diversity of mid-story trees (Artman, 2003; Agee and Skinner, 2005; Hayes et al., 2003; Harrod et al., 2009). The more profound effect for wildlife species may be related to development of more complex understory vegetation due to increased light availability below the canopy (Doerr and Sandburg, 1986; Bailey and Tappeiner, 1998; Wilson and Carey, 2000; Garman, 2001; Homyack et al., 2005). Despite the favorable response of many species to thinning treatments, causal relationships between complexity of understory vegetation and increased species abundance or diversity have not been identified (Wilson et al., 2009). In addition, variable thinning intensities and harvest patterns (e.g. variable density thinning, clumped retention, or patch cuts) can produce favorable forest stand conditions for a variety of fauna (Carey and Wilson, 2001; Garman, 2001; Carey, 2003).

Thinning can be represented in three broad categories: pre-commercial thinning; commercial thinning; and fuels treatment

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thinning. The frequency with which each of these strategies is used across a landscape depends on landowner objectives, forest type, physiographic region, and other considerations. Often, a combination of these silvicultural treatments is used to achieve wood fiber, biodiversity, and forest health goals.

Managing regenerating stands often requires thinning of overstocked stands to maximize commercial harvest wood volume. Precommercial thinning (PCT) is the removal of trees, not for immediate financial return, but to reduce stocking density, allowing increased growth of more desirable crop trees (Helms, 1998). Precommercial thinning occurs early in stand development either before or just after canopy closure. The removal of sub-dominant sapling trees allows production of merchantable wood to increase substantially throughout the remainder of the rotation period (Reukema, 1975). Precommercial thinning is commonly used in the Northwest (especially in Douglas-fir forest types [Briggs, 2007]), increasingly used in Acadian forests of the Northeast (Homyack et al., 2007), decreasingly used on industrial forest lands in the Upper Midwest (D'Amato et al., 2008) and not common in commercial forests of the Southeast (Folegatti et al., 2007).

Commercial thinning is a partial-cutting process that produces merchantable material at least equal to the value of the direct costs of harvesting (Helms, 1998). Commercial thinning can occur at any time following canopy closure (Artman, 2003). Two-stage or multiple-entry overstory removal has been used to encourage understory development that simulates late seral forest characteristics at earlier ages (Thysell and Carey, 2001; Poage and Tappeiner, 2002; Hagar et al., 2004). However, few data have been presented to document the success of such techniques in producing the desired outcome (Lindh and Muir, 2004). The extent to which thinning of merchantable trees will be used for biofuels production is also unknown, and will likely depend heavily on fluctuating markets.

A fuels treatment is any manipulation or removal of wildland fuels to reduce likelihood of ignition or to lessen potential damage and resistance to control (Helms, 1998). As a result of decades of fire suppression efforts, fuels treatment forest thinning is increasingly used across the Western U.S. and Canada as a mechanism to reduce forest understory density and restore forest health (Agee and Skinner, 2005; USDA Forest Service, 2005). Mechanical thinning of understory vegetation is becoming commonplace in the dry forests of the Southwest (USDA Forest Service, 2005). Fuels treatments remove dense sapling trees and other woody understory vegetation to reduce ladder fuels that can lead to uncharacteristic stand-replacing wildfire (Agee and Skinner, 2005). However, depending on the length of time that fire has been suppressed from the stand, fuels treatment thinning can include thinning of merchantable trees to decrease crown density and add more wood volume to the timber sale (Skog and Barbour, 2006). As a result, the volume of wood removed in fuels treatment thinning is widely variable, and likely varies significantly by region and forest type. However, the total basal area removed is often less than for commercial and precommercial thinning treatments. Biomass removal as a fuels reduction treatment has been shown to be effective at decreasing near-term fire risk, but results may be mixed over longer time periods (Reinhardt et al., 2010).

Although pilot and experimental biomass harvests have been conducted across North America (Arnosti et al., 2008; Evans and Finkral, 2009), knowledge of how biodiversity responds to forest thinning is incomplete. Although the Southeastern U.S. is the leading timber-producing region of the United States (Prestemon and Abt, 2002), and thinning is a common silvicultural practice in all regions, most research on effects of thinning on wildlife species has been conducted in the Northwest. Reviews of forest thinning effects to date have been regional or local in geographic scope and primarily qualitative in their assessment (Hayes et al., 1997; Harrison, 1999; Muir et al., 2002; Thompson et al., 2003). However, detailed information about biodiversity response to forest thinning has recently been assessed quantitatively for the Southwestern United States (Kalies et al., 2010).

Most current research offers a snapshot assessment of the effect of forest thinning on species diversity and abundance. Effects of forest thinning operations on measures of diversity are often highly dependent on time since harvest, as many harvests will have a negative short-term effect on both species abundance and diversity (Wilson and Puettmann, 2007). The continent-wide meta-analytic approach we use to assess response of wildlife species diversity and abundance to different types of forest thinning represents a more comprehensive assessment of effects of biomass thinning harvests on terrestrial biodiversity across a variety of forest types and taxa.

2. Materials and methods

We reviewed the literature for papers that compared biodiversity responses to various thinning treatments. Definitions of biodiversity are wide ranging, and incorporate several scales of measurement. For the purpose of this work, biodiversity responses included species richness, diversity, abundance of taxa or groups of species (guilds) and abundance of individual species for birds, mammals, reptiles, amphibians, and invertebrates. We included both manipulative experiments (wildlife diversity and abundance measured before and after thinning treatments) and management experiments (stands paired post hoc and thinned areas are compared to unthinned controls). The controls presented were most commonly unthinned harvest-aged stands (30–75 yrs old). We included studies of precommercial, commercial, and fuels treatment thinning.

We used Wildlife and Ecology Worldwide, Web of Science, USDA Forest Service TreeSearch, and Google Scholar databases to search for relevant studies. We searched for the following forestry and biodiversity terms in article abstracts: thinning, precommercial thinning, selection harvest, fuels treatment, shelterwood, amphibian, avian, bird, mammal, reptile, invertebrate, insect, biodiversity, diversity, and richness. We supplemented searches by examining bibliographies of articles for additional references.

We found 33 studies ($k = 33$) relative to effects of forest thinning on wildlife species that provided control and treatment means, sample size and standard deviations for biodiversity responses, making them suitable for meta-analysis (Table 1). Several otherwise suitable studies did not report standard deviations or standard error measures. In some cases, the treatment and control means were provided with an associated two sample t-test statistic, p-value and degrees of freedom. When this occurred, we used the pooled variance in place of individual treatment and control standard deviation measures. When neither standard deviation nor test-statistic/p-values were reported, we contacted the authors and, when the data were available, we calculated error values from the raw data. If error measures could not be back-calculated and the raw data were not available, we did not include the study in analyses, but did include them in the discussion. When studies presented comparisons for a metric in consecutive years, we calculated overall mean effect and standard deviation using the pooled variance.

Because responses to habitat manipulations can vary greatly among taxa and among species within taxa, we considered different biodiversity measures (e.g., diversity, guild abundance, species abundance) from the same study to be independent effects (Bender et al., 1998). For birds, we also calculated 2 separate measures of effect size for species measured in summer and winter, because behavior, habitat requirements, and composition of bird communities often differs during those 2 seasons.