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A meta-analysis of biodiversity responses to management of southeastern pine forests—opportunities for open pine conservation

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ABSTRACT

Open canopy conditions in southeastern pine (*Pinus* spp.) forests were historically maintained by frequent fire and other disturbances, without which midstory hardwoods create closed canopy conditions limiting value of pine stands for many endemic, disturbance-adapted species. Intensively managed pine forests, which comprise 19% of forests in the southeastern U.S., can emulate historical open pine conditions, providing appropriate vegetation structure and composition for many endemic species. However, exact mechanisms for producing and maintaining open pine conditions and subsequent effects on biodiversity have not been examined across regions and stand ages. To better inform managers about options for providing open pine conditions in intensively managed pine stands, we used meta-analyses to examine biodiversity and open pine focal species responses to 5 stand establishment intensities and 4 mid-rotation practices (prescribed fire, selective herbicide, fire and herbicide combination, and thinning). We calculated 1742 biodiversity and 169 open pine focal species effect sizes from 42 publications of manipulative studies at 14 unique study sites in managed loblolly pine (*P. taeda* L.) forests in the Atlantic and Gulf Coastal Plains of the southeastern U.S. We quantified diversity and abundance responses by taxa and management practices for vegetation, birds, amphibians, reptiles, small mammals, and invertebrates. Diversity and abundance responses generally decreased as stand establishment intensity increased, but those reductions appeared to be short-term (<3 years). Birds and open pine focal species responded positively to chemical stand establishment relative to a mechanically-prepared control. Thinning elicited positive diversity and abundance responses from reptiles and small mammals. Effects of prescribed fire, selective herbicide, and their combination on biodiversity responses varied by taxa (e.g., following fire, vegetative and avian diversity increased but amphibian and invertebrate diversity decreased). Further research is warranted on under-represented taxa (e.g., herpetofauna and invertebrates) in literature and long-term effects of forest management on biodiversity. Understanding how silvicultural management practices produce and maintain open pine forest conditions and influence biodiversity responses is necessary to inform opportunities for open-pine wildlife communities in working forested landscapes.

1. Introduction

Pine (*Pinus* spp.) forests of the southeastern Coastal Plain were historically described as open pine woodlands and savannahs with low canopy coverage, variable tree age classes, and floristically rich understories that supported diverse wildlife communities (Mitchell and Duncan, 2009; Van Lear et al., 2005). However, widespread fire suppression following European settlement transitioned many open pine communities to hardwood-encroached, closed-canopy forests followed by subsequent declines in many species of disturbance-adapted wildlife (Mitchell and Duncan, 2009).

Currently, open pine forests occur throughout the southeastern U.S. with most natural and planted pine forests held in private ownership (Oswalt et al., 2014), making them susceptible to fragmentation, parcelization, and land use conversion (Wear and

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Greis, 2012; Zhang and Polyakov, 2010). Connecting open pine forests and increasing area of open pine conditions across the region could benefit myriad open pine species and help meet conservation goals (Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative, 2012). Working forest landscapes can provide open pine conditions during portions of a typical, 25–35 year rotation (e.g., Jones et al., 2009b). Because planted pine comprises approximately 19% (~15.8 million hectares; Wear and Greis, 2012) of forestland in the southeastern U.S., there is potential for it to provide substantial open pine conditions when appropriately managed. However, a comprehensive investigation of how well forest management practices achieve open pine structural and biodiversity conditions is lacking. Thus, there is a need to evaluate potential for managed pine systems to provide habitat conditions conducive to open pine-adapted species.

Managed pine systems provide a dynamic mosaic of vegetation structure and composition across landscapes, ranging from early successional communities following tree harvest, to canopy closure, to post-thin open stands. Managed pine forests receiving at least some mid-rotation management (e.g., thinning, herbicides, burning) can provide habitat for wildlife species adapted to and favoring open pine conditions by altering forest structure and plant community composition (e.g., Iglay et al., 2014b; Burger, 2005; Singleton et al., 2013; Wilson and Watts, 1999). In publications we reviewed, thinned stands receiving some mid-rotation management (e.g., prescribed fire and/or selective herbicide) had basal areas of 68–78 $ft^2\ ac^{-1}$ (15.6–18.0 $m^2\ ha^{-1}$; Smith, 2004; Ulyshen et al., 2012), limited midstory hardwood encroachment and shrub cover (Albaugh et al., 2012; Cain and Shelton, 2003; Sladek et al., 2008), and abundant ground cover by graminoids and forbs (Iglay et al., 2014b; Jones et al., 2009a) with total herbaceous understory coverage ranging from 55% under a thin-only regime (Miller et al., 2004) to 97.7% when prescribed fire follows thinning (Cain and Shelton, 2003). These values of stand structure in managed loblolly pine forests are consistent with pine and hardwood basal area values in old-growth longleaf pine (*P. palustris* Mill.) stands in Alabama and Mississippi (Kush and Meldahl, 2000, Schwarz 1907 as cited in Landers and Boyer, 1999). As managed stands transition from dense, closed-canopy conditions toward open woodland conditions following thinning, avian community composition also shifts toward open woodland and pine–grassland species (Iglay, 2010; Singleton et al., 2013), suggesting that commercially managed pine stands may provide conditions equivalent to open pine for at least part of typical rotations. In addition, young pine stands (2–6 years following establishment) provide early successional conditions, such as dense graminoid bunches, diverse forbs, and singing perches (Hanberry et al., 2013a; Jones et al., 2009a; Lane et al., 2011b), that are used by avian species associated with pine–grasslands (Lane et al., 2011a).

Herpetofauna and small mammal diversity, abundance, and activity have been correlated with changes in microhabitat features such as leaf litter depth, soil moisture, and vegetation structure (deMaynadier and Hunter, 1995; Schurbon and Fauth, 2003), and amount and distribution of coarse woody debris following forest management (Davis et al., 2010; Loeb, 1999; Owens et al., 2008; Riffell et al., 2011). However, few studies address responses of herpetofauna or small mammals to specific management activities with appropriate control stands and these studies have not been pooled for region-wide analysis and management recommendations.

To address our knowledge gap and cohesively examine results of multiple studies, we conducted a comprehensive meta-analysis to evaluate how a gradient of stand establishment practices (mechanical vs. chemical site preparation, banded vs. broadcast herbicide, and number of herbicide applications) and mid-rotation management (thinning, prescribed fire, selective herbicide, and fire and herbicide combination) affect biodiversity (e.g., plants, birds, amphibians, reptiles, small mammals, invertebrates) and open pine focal species within managed loblolly pine (*P. taeda* L.) forests in the Atlantic and Gulf Coastal Plains of the southeastern U.S. We expected biodiversity responses to decrease as stand establishment intensity increased and for ground-nesting birds, herpetofauna, and small mammals to decrease in diversity and abundance in response to the most intense stand establishment practices (i.e., mechanical and chemical site preparation with broadcast herbicide for one or two years). Prescribed fire and thinning are frequently promoted to improve wildlife habitat quality (e.g., Sladek et al., 2008; Thompson, 2002; Wigley et al., 2000; Woodall, 2005), and thus, we expected their application to increase total biodiversity and the diversity and abundance of plants, birds, and small mammals. We expected herbicide to have similar effects as prescribed fire and their combination to have a somewhat additive effect.

2. Materials and methods

We conducted a systematic literature search for publications that compared biodiversity responses to various practices in managed forests. We restricted our literature search to managed, naturally regenerating or planted forests dominated by loblolly pine in the Atlantic and Gulf Coastal Plains due to similarities in management practices and physiographic characteristics (e.g., soil classification) across this region. We searched 11 databases including Wildlife and Ecology Studies Worldwide, USDA Forest Service Treesearch, and Google Scholar for relevant publications. Response variables of interest included diversity metrics (species richness, alpha diversity, and evenness) and abundance of taxa, guilds, and individual species for vegetation, birds, amphibians, reptiles, small mammals, and invertebrates. We searched titles, abstracts, and keywords using 189 combinations of search terms including forestry, biodiversity, taxa, and a list of open pine focal species (Table 1). We supplemented database searches by manually examining references cited in publications from our literature search.

Because responses to forest management can vary substantially among taxa, guilds, and species within a taxon, we considered different biodiversity metrics (e.g., richness, equitability, abundance) from the same publication to be independent effects (Bender et al., 1998; Riffell et al., 2011). We also separated effects by season to account for migration and seasonal differences in activity (Bender et al., 1998; Riffell et al., 2011). For publications presenting data for multiple years, we calculated mean effect and pooled variance across all years or for year subsets according to treatment application frequency (e.g., fire return interval). Most publications compared more than one treatment to the same control. To account for this lack of independence, we calculated cumulative effect sizes for each taxon across all manipulations and for each manipulation type (Borenstein et al., 2009). We contacted authors to obtain standard deviations or raw data to calculate statistics whenever unavailable in the published literature.

Several publications (e.g., Singleton et al., 2013) noted that mid-rotation management appeared to drive a shift in community composition toward species adapted to open canopy, pine–grassland conditions. This shift may occur concomitant to changes in diversity and abundance metrics. Therefore, we evaluated individual open pine wildlife species (Table 1) responses to stand establishment and mid-rotation manipulations using meta-analysis techniques identical to our biodiversity analyses.

We conducted all meta-analyses in MetaWin 2.0 (Rosenberg et al., 2000). We calculated effect sizes (i.e., values that reflect magnitude of a treatment effect) using means, standard deviations, and sample sizes for experimental and control groups. Meta-analyses used log response ratios as an effect size index with log response