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Comparison of short term low, moderate, and high severity fire impacts to aquatic and terrestrial ecosystem components of a southern USA mixed pine/hardwood forest

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ABSTRACT

Historically fire was an important natural disturbance shaping the structure and composition of pine-dominated forests in the southern United States. Longstanding fire suppression policies have resulted in structural and compositional changes, notably accumulation of heavy fuel loads and reduction in vegetation species diversity. Primary goals of forest management through prescribed burning include fuel load reduction and mimicking ecosystem impacts of historically natural wildfires. In addition to the influences of fire frequency and season, the influence of fire severity on ecosystem responses is currently of interest. In this study we sought to quantify the impacts of low, moderate, and high severity fires, and their interaction with prior forest management practices, to several aquatic and terrestrial ecosystem components of a southern U.S. mixed pine/hardwood forest using a before–after, control-impact (BACI) approach. The ecosystem components we assessed were water quality, community composition of aquatic arthropods (wildfire impacts only), forest structure characteristics, community composition of understory vegetation, and community composition of ground-dwelling arthropods. We found that increasing fire severity increased aquatic nutrient levels and productivity, but the magnitude of effects increased with severity. Low and moderate severity fires had weak effects on forest structure characteristics, community composition of understory vegetation, and community composition of ground-dwelling arthropods in the initial years following burns. In contrast, high severity fires dramatically reduced fine and large fuel loads, increased diversity of understory vegetation, and influenced community composition of ground-dwelling arthropods. Further, wildfire severity was reduced in areas with a prior moderate severity prescribed burn, but not in areas with a prior low severity prescribed burn. Our results provide quantitative evidence for the role of fire severity as a primary factor influencing responses of ecosystems to fire, and indicate that forest management practices influence the impact of high severity fires on ecosystems.

1. Introduction

Climatic trends towards warmer and drier conditions, coupled with longstanding broad-scale fire suppression, have resulted in an increase in frequency of high severity wildfires in the southern and western United States (Davis, 2001; Miller et al., 2009), with this trend projected to continue into the next century (Moritz et al., 2012). The increase in wildfires is prevalent in pine-dominated forests (Miller et al., 2009), which are naturally fire-maintained systems (Hartnett and Krofta, 1989; Schulte and Mladenoff, 2005). In the absence of fire, these forests typically progress towards a climax state dominated by hardwood trees (Gilliam and Platt, 1999; Knebel and Wentworth, 2007; Hanberry et al., 2012). Further, suppression-induced increase in fuel loads often creates environments conducive to abnormally high severity wildfires (Davis, 2001; Allen et al., 2002; Collins et al., 2010). Thus, integration and maintenance of fire management is necessary for restoration and sustainability of healthy pine-dominated forests (Agee, 1996). Although the use of prescribed fire for reducing fuel loads and managing forest communities has increased dramatically over the last half century, much of the U.S. remains severely fire-suppressed (Houghton et al., 2000; Shang et al., 2007; Gebert and Black, 2012).

In addition to reducing fuel loads, a common goal of prescribed burning is to mimic ecosystem impacts of historically natural wildfires within a controlled setting (Vose, 2000). Thus, increasing our

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knowledge of similarities and differences between prescribed fire and wildfire is of interest to both ecologists and land managers (Schwilk et al., 2006; Glasgow and Matlack, 2007; Arkle and Pilliod, 2010). This question has resulted in much research being devoted to effects of burn timing and burn frequency, particularly on vegetation (e.g., Cain et al., 1998; Sparks et al., 1998; Taylor, 2000; Webster and Halpern, 2010). However, much less is known about effects of burn severity, given that prescribed burns are typically low or moderate severity fires (Knapp et al., 2009). In contrast, high severity wildfires are unplanned and opportunities for comparative research are more limited.

Fire impacts many terrestrial ecosystem components, ranging from soil properties (Certini, 2005), to habitat selection of large mammals (Long et al., 2009). Fire has also been found to impact aquatic ecosystems in pine-dominated forests (e.g., Spencer and Hauer, 1991; Battle and Golladay, 2003). These aquatic ecosystems provide habitat for a variety of vertebrates (e.g., amphibians and fish) and invertebrates, with many threatened and endangered species dependent upon the presence and quality of aquatic environments in forested landscapes, such as the endangered Houston toad (*Bufo* [*Anaxyrus*] *houstonensis*), and threatened gila trout (*Oncorhynchus gilae*). With the exception of direct effects through increased water temperatures (Hitt, 2003) and burning when aquatic areas are dry (Sacerdote and King, 2009), fire primarily impacts aquatic components indirectly through a variety of impacts to the surrounding and adjacent terrestrial environment (Spencer and Hauer, 1991; Gresswell, 1999). Due to the interconnected nature of aquatic and terrestrial systems, fire research that incorporates effects on both ecosystem types is needed to improve our understanding of fire impacts to ecosystems (Bisson et al., 2003; Rieman et al., 2003).

Previous research suggests there are consistencies with regards to fire impacts on nutrients in both terrestrial and aquatic environments. In the short-term, fire often increases soil nitrogen (N) and phosphorus (P) availability through conversion of organic to inorganic forms, with fire severity positively related to the magnitude of inorganic nutrient increases (Wan et al., 2001; Certini, 2005). Similarly, N and P in both still and flowing waters typically increases after fire (Battle and Golladay, 2003; Earl and Blinn, 2003). In both terrestrial and aquatic environments, nutrient availability tends to decrease to background levels over a period of weeks to a few years (Wan et al., 2001; Earl and Blinn, 2003; Spencer et al., 2003). However, in some cases fire can impact terrestrial and aquatic nutrient levels for decades (McEachern et al., 2000; Duran et al., 2010).

Fire can directly impact biotic communities through both heat-induced mortality (animals and plants) and heat-induced reproduction (plants; Gauthier et al., 1996; Schwilk et al., 2006; Engstrom, 2010). Fire can indirectly impact biotic communities through alteration of nutrient availability (Lewis, 1974; Gilliam, 1988; Battle and Golladay, 2003), structural habitat modification (e.g., removal or addition of debris; Sweeney and Biswell, 1961; Tinker and Knight, 2000; Hall et al., 2006), and alteration of inter- and intra-specific interactions. Thus, fire effects on biotic ecosystem components are inherently complex and difficult to extrapolate from one ecosystem to another. Further, the impacts of high severity fires are typically not short-lived, but rather a given fire can influence an ecosystem from decades to centuries (Hall et al., 2006; Lecomte et al., 2006; Webster and Halpern, 2010).

Fire can influence plant community composition primarily through direct impacts on mortality and reproduction (Gauthier et al., 1996; Simmons et al., 2007), changes in nutrient availability (Wan et al., 2001), and alteration of ground structure (e.g., soil organic matter), which influences spacing of individual plants and light availability (Sweeney and Biswell, 1961; Tinker and Knight, 2000; Hall et al., 2006). Because all of these factors are affected by fire severity, we would expect higher severity fires to have a greater impact on plant communities than low severity fires in fire-suppressed forest ecosystems, where probability of tree survival is heavily influenced by fire intensity (Oosting, 1944; Safford et al., 2012; Thies and Westlind, 2012), and understory plant growth is largely limited by the density of litter and duff layers (Hodgkins, 1958; Glasgow and Matlack, 2007; Wayman and North, 2007).

Compared to nutrient and vegetation impacts, effects of fire on animal taxa are much more equivocal and unpredictable, likely due to more complex trophic interactions and the ability of some taxa to adapt to habitat changes through both movement and behavioral responses (Geluso and Bragg, 1986; Jones et al., 2004; Engstrom, 2010). Animal-based studies often detect minimal or no effects of prescribed fire (Ford et al., 1999; Greenberg and Waldrop, 2008; Dickson et al., 2009; Greenberg et al., 2010). However, studies assessing impacts of fire severity on animals have found that severity is an important factor affecting population and community dynamics. Smucker et al. (2005) reported that some bird species (i.e., hermit thrush [*Catharus guttatus*] and western tanager [*Piranga ludoviciana*]) responded positively to low severity fire and negatively to high severity fire in the same study area, and Roberts et al. (2008) found equivalent responses in small mammals. Alternatively, by meta-analysis on bird and small mammal responses to fire severity, Fontaine and Kennedy (2012) concluded that fire severity did not consistently impact species response direction (e.g., a negative or positive impact), but response magnitude of animals increased with fire severity.

The above ensemble of previous fire research suggests that fire severity is an important, and potentially driving, factor in determining fire impacts to essentially all fire-affected ecosystem components (Knapp et al., 2009). In this study we sought to quantitatively assess the impacts of fire severity and forest management practices (i.e., prescribed fire, historic fire suppression, and their combinations) on both terrestrial and aquatic ecosystem components of a mixed pine/hardwood forest in central Texas. Specifically, we assessed impacts of low severity winter prescribed burns, moderate severity summer prescribed burns, moderate severity summer wildfires, and high severity summer wildfires on water quality, aquatic arthropods (data for wildfire impacts only), vegetation (live and dead), and terrestrial ground-dwelling arthropods. Based on previous research, we hypothesized that impacts to terrestrial components would increase with increasing fire severity, and subsequent effects on aquatic components would also be more pronounced as fire severity increased, and that prior forest management practices would influence the impacts of subsequent wildfires.

In addition to our basic interest concerning fire severity effects, we also have an applied interest specific to the impacts of fire on our study area, the Lost Pines ecoregion of Texas. This ecoregion is the last remaining stronghold for the federally endangered Houston toad, and populations have been declining within the ecoregion for decades, to the point now where the species is at high risk of extinction in the wild (Gaston et al., 2010; Duarte et al., 2011; Brown et al., 2013a,b). Thus, we are interested in fire as a habitat restoration tool in this ecoregion, with particular interest in potential and realized effects on this endangered species (Brown et al., 2011, 2012). To this end, we included a discussion of results of this study with respect to potential impacts on the Houston toad.

2. Methods

2.1. Study area

This study was conducted in the Lost Pines ecoregion in Bastrop County, Texas, USA. The Lost Pines is a 34,400-ha remnant patch of