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Effects of prescribed fire on fuels, vegetation, and Golden-cheeked Warbler (*Setophaga chrysoparia*) demographics in Texas juniper-oak woodlands

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ABSTRACT

The Golden-cheeked Warbler (*Setophaga chrysoparia*) is an endangered songbird that breeds in mature juniper-oak woodlands restricted to Central Texas. This habitat is increasingly susceptible to crown fire due to climate change, land use change, and fire suppression. Prescribed fire is a potential tool to reduce the risk of crown fire and may be a management tool to enhance juniper-oak woodlands for breeding warblers. However, no experimental study has been undertaken to investigate how well prescribed fire can meet these goals. We conducted a before-after control-impact study on three plot-pairs within Balcones Canyonlands National Wildlife Refuge, Texas, from 2012 to 2014 to evaluate the response of fuel loads, vegetation structure, and warblers to prescribed fire. We measured fuel loads and vegetation structure in summer 2012 (pre-treatment) and 2014 (post-treatment). We burned one randomly-chosen plot within each plot-pair during February 2013 and measured fire severity in May 2013. We monitored populations of warblers to determine plot abundance and breeding success each season. Impact of the prescribed fires was highly variable across treatment plots with ~49% of points showing no effects of fire on junipers and ~9% showing high mortality in the juniper canopy. All 12 fuel and vegetation measures responded to fire in the direction expected; however, only juniper seedling density, juniper sapling density, hardwood sapling density, canopy cover, litter cover, and litter depth were significant (i.e., year × treatment effect $P < 0.05$). Warbler density decreased 23% and 40% in the two post-treatment years in response to fire but other demographics did not have significant year × treatment effects. Across all plots and years, 67–93% of males were aged after-second year ("ASY"), pairing success was high (94–100%), average breeding success was 50–63%, and mean daily nest survival was 0.957 (SE = 0.010). Return rates averaged 45% and 35% for control and treatment plots. Discrete choice analysis based on locations of males in treated plots revealed the highest probability of use was in closed-canopy woodlands that experienced low to moderate fire severity effects from the fire (canopy intact but some intermediate level of subcanopy mortality) and the lowest probability of use was where fire severity was high. A single application of prescribed fire achieved many but not all fuel and vegetation objectives. The resulting reductions in warbler densities appeared due to avoidance of areas with high burn severity, whereas areas of low to moderate burn severity had high warbler use.

1. Introduction

Fire is a natural disturbance that can change the vegetation structure at local to landscape scales depending on its severity, intensity, frequency, and extent (Graham et al., 2004). Some forest types, especially woodlands, may require fire for forest health and vigor and to be maintained in their current state (Brose et al., 2013; Ryan et al., 2013). While fire is an important disturbance for maintaining or creating woodland habitat, it can be costly for humans when not effectively managed (Stavros et al., 2014; USDA, 2015). Crown fires, fires that consume tree canopies and kill either the trees or their above ground tissues, are difficult and costly to contain and may have long-lasting impacts to the vegetation structure as well (Reemts and Hansen, 2008; USDA, 2015). The frequency of wildfires is increasing across the United States due to

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decades of fire suppression and a build-up of fuels on the ground and because climate change is causing hotter and drier conditions in many portions of the United States (USDI et al., 2009; USDA, 2015), including central Texas (USFWS, 2014). Increased duration and frequency of drought conditions will lead to higher probabilities of wildfire (Guyette et al., 2014), as already experienced in the central Texas region during the drought of 2011–2012 (Texas A and M Forest Service, 2011).

Crown fires are considered a primary threat to the Golden-cheeked Warbler (*Setophaga chrysoparia*; hereafter, "warbler") (USWFS, 2014), an endangered songbird species that breeds only in the wooded areas co-dominated by Ashe juniper (*Juniperus ashei*; hereafter "juniper") and hardwoods found in central Texas (USFWS, 1992; Ladd and Gass, 1999). Female warblers build nests primarily made of strips of bark collected from the trunks of mature junipers and adults and juveniles forage in junipers and a variety of hardwood species, mostly oaks (*Quercus* spp.) (Ladd and Gass, 1999; Marshall et al., 2013). Therefore, the presence of mature junipers and a variety of hardwood species is required for warbler breeding habitat. A crown fire started by military activities on Fort Hood, Texas, destroyed ~2100 ha of juniper-oak woodlands during February 1996. This fire resulted in many small patches of intact habitat surrounded by large expanses of dead trees. Juniper mortality was severe, with virtually no recovery evident 14 years post-fire and the area is unlikely to be suitable as breeding habitat for several more decades (Reemts and Hansen, 2008, 2013); abundance of warblers within these burned areas was concomitantly low (Baccus et al., 2007; Reemts and Hansen, 2008, 2013). These findings illustrate that reducing the risk of crown fires is a justifiable management goal for warbler conservation.

One of the most widely used management tools to reduce risk of a crown fire is to reduce surface fuel loads and decrease the vertical continuity between surface fuels and canopy fuels with prescribed fire (Graham et al., 2004; Ryan et al., 2013). Little information exists on how prescribed fire alters the fuel loads and vegetation composition in juniper-oak woodlands; yet understanding fire behavior in this area is important in maintaining or improving warbler habitat (White et al., 2010). Yao et al. (2012) reported higher oak recruitment in plots that had experienced high intensity burns and concluded that moderate intensity fire in woodlands dominated by young junipers may promote tree species diversity. Andruk et al. (2014) found controlled surface fires in combination with selective understory thinning in juniper-oak woodlands reduced density of young junipers and increased hardwood re-sprouting while leaving the canopy intact. Thomas et al. (2016) measured the vegetative characteristics of the four dominant tree species in juniper-oak woodlands in relation to crown fire and found that junipers could sustain crown fire under lower wind speeds than the three dominant oak species due to higher leaf mass per unit area and canopy bulk density. They also reported higher canopy mass values closer to the ground for junipers than the oaks, indicating junipers provide more ladder fuels to reach the canopy. Overall, current research indicates juniper-dominated woodlands result in fuel loads that are less amenable to low-intensity fire and at greater risk of crown fire (White et al., 2010; Andruk et al., 2014), and are then slow to recover from such high-intensity fires (Reemts and Hansen, 2008; White et al., 2010).

Besides increasing risk of crown fire, lack of management across the warbler's breeding range could pose significant challenges to maintaining or increasing available breeding habitat. While habitat loss and fragmentation were principal reasons listed by USFWS (1990) for listing this species under the Endangered Species Act, habitat succession through lack of oak recruitment was also cited and may be more important than previously thought (Russell and Fowler, 2002; Groce et al., 2010). Several sites across central Texas were shown to have no or little recruitment of Texas red oak (*Quercus buckleyi*) in the preceding 35–60 years (Russell and Fowler, 2002). Texas red oak is a dominant hardwood in warbler habitat and a favored foraging substrate (Marshall et al., 2013). Lack of oak recruitment may lead to lower diversity woodland stands due to increased juniper composition (Russell and Fowler, 2004; Andruk et al., 2014). These low diversity juniper woodlands support lower densities of warblers than mixed juniper-oak woodlands (Peak and Thompson, 2013; Reidy et al., 2016; Sesnie et al., 2016). Prescribed fire in combination with selective thinning of the juniper understory was effective at killing juniper seedlings and increasing hardwood sprouts but not hardwood seedlings and saplings in juniper-oak woodlands (Andruk et al., 2014). However, fire may be insufficient as a stand-alone management technique to increase hardwood recruitment in areas with high densities of white-tailed deer (*Odocoileus virginianus*) because herbivory by deer is a significant limitation in oak regeneration (Russell and Fowler, 2004; Andruk et al., 2014).

While prescribed fire may be a necessary management tool to promote woodland health and reduce the risk of crown fire, it is unknown how warbler populations will respond to changes to the vegetation structure caused by prescribed fire. Historically, management guidelines in warbler habitat recommended no or little active management such as prescribed fire or understory thinning, instead favoring less aggressive management actions such as invasive plant control, white-tailed deer and feral pig (*Sus scrofa*) culling, and selective tree removal to maintain or enhance juniper-oak woodlands (BCNWR, 2001; BCP, 2007). However, thus far there has been little research investigating warbler response to habitat management or manipulation, including prescribed fire.

Balcones Canyonlands National Wildlife Refuge (BCNWR) was created in 1992 to preserve habitat for endangered species. It is located northwest of the Austin metropolitan area, one of the fastest growing metropolitan areas in the United States since 1990 (Groce et al., 2010; U.S. Census Bureau, 2012). Rapid growth in the area around BCNWR has expanded the exurban-wildland interface along the borders of the refuge increasing risks to human life and property from natural disasters such as crown wildfires (Radeloff et al., 2005; USDI et al., 2009). Beyond the concern of protecting human infrastructure, one of the goals established by BCNWR is to "protect warbler habitat from wildfire and reduce hazardous fuel loads" (BCNWR, 2001). Thus, management actions should reduce the risk of crown fire in juniper-oak woodlands and minimize the negative impacts to breeding warblers. However, land managers need to understand the potential impacts of prescribed fire on warbler populations before its use is recommended on a larger scale. We conducted an experimental study using a before-after control-impact design to investigate the response of fuel loads, vegetation structure, and warblers to prescribed fire on BCNWR. We monitored warbler populations on three control and three treatment plots to compare territory density, age structure and return rates, and pairing and breeding success. Our objectives were to determine (1) changes in fuel loads that may reduce risk of crown fire, (2) changes in vegetation structure in response to prescribed fire, and (3) the short-term response of warblers to prescribed fire in terms of abundance, return rates, productivity, and habitat selection.

2. Methods

2.1. Study area and experimental design

We conducted our study at BCNWR, in Travis and Burnet counties, Texas. BCNWR is ~9900 ha, of which 7700 ha have been identified to be managed for the warbler (BCNWR, 2015). BCNWR