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Climate warming alters fuels across elevational gradients in Great Basin bristlecone pine-dominated sky island forests

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ABSTRACT

Little is known about fuel characteristics and dynamics in GBBP communities, and current monitoring programs inadequately quantify the surface and canopy fuels of this system. Using the Forest Inventory Analysis (FIA) plot variables of tree species, height, diameter at breast height (DBH), canopy base height (CBH), coarse (CWD) and fine (FWD) woody debris counts, and canopy fuels measurements, this paper examines the effects of climate-induced changes to fuel loading, fire hazard and risk on predicted changes in fire behavior and severity. Field transects were installed using FIA protocols along environmental gradients. Plots were located every 22 chains or ~440 m along random transects on Mt. Washington in the Great Basin National Park (GBNP) and in the nearby Mt. Moriah Wilderness, NV. Additional plots were installed at Notch Peak (UT), Cave Mountain (NV), and Wheeler Peak (GBNP, NV). Linear regression showed that all classes of FWD decreased with elevation, and only 1000-h fuels remained constant across elevational transects. This, combined with lower CBH and foliar moisture and increasing temperatures due to climate change, increases fire potential at the Great Basin bristlecone pine treeline, threatening the oldest individuals of this iconic species. New information about discontinuous fuels will aid in management of high elevation alpine treeline forests.

1. Introduction

High elevation five needle pines are declining throughout western North America from climate warming, mountain pine beetle (*Dendroctonus ponderosae* Hopkins), white pine blister rust (*Cronartium ribicola*), and the alteration of naturally occurring fire regimes (Gibson et al., 2008). Climate change effects are especially acute in sky islands, the isolated mountains surrounded by valleys of the Great Basin, as warming temperatures alter tree community distribution and contribute to increased surface fuels. Changing air temperature and precipitation may interact with fire regimes to shorten times to ignition and lower temperatures at ignition from lower moisture content (Gill et al., 1978) of lower elevation populations. Great Basin bristlecone pine (*Pinus longaeva* Bailey) is a high elevation, five needle pine, located near treeline and grows in isolated sky islands of California, Nevada, and Utah. Great Basin bristlecone pine (GBBP) are mainly adapted to survive low-severity surface fires (Zavarin and Snajberk, 1973), however fire-scarred GBBP are found at lower elevations with fire tolerant ponderosa pine (Lanner, 1999). Climate induced changes to the fire regime will alter surface and canopy fuel loading, species composition, fire hazard and risk, and fire behavior and severity on GBBP forests (Schoennagel et al., 2004). Additionally, the amount, arrangement, and continuity of GBBP fuels vary with elevation, community species composition, and time. Fuel loadings are strongly influenced by fire history and site characteristics providing a proxy for temperature change; however, these gradients have yet to be quantified.

1.1. Climate change and fire in treeline communities

GBBP are among the oldest organisms on earth. Their distribution is limited to the highest elevations (2700–3700 m) in mountain ranges of the Great Basin of the western United States. Because populations are isolated, effects of a warming climate are projected to be particularly acute (Bower et al., 2011). Increasing temperatures are expected to result in pine mortality and introduction of invasive weeds and lower elevation conifers, consequently changing surface fuels composition (Flannigan et al., 2000; Gibson et al., 2008). Historically, fire was thought to be infrequent in GBBP communities at high-elevation sites because stands are open and productivity is low. When fires did occur at high elevations, they were usually small, low-severity surface fires (Bailey, 1970; Bradley et al., 1992). Moisture and climate have

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more influence on treeline stand dynamics than fire (Lanner, 1988, 1985). Early studies suggested that low tree density and sparse litter in the sub-alpine GBBP forests near treeline did not contain enough fuels to carry fire (Bradley et al., 1992; Lamarche, 1967; Lanner, 1988). At lower elevation sites, the role of historical fire regimes in dictating past stand characteristics and current distribution is not fully known, yet it is likely GBBP experienced a variable fire regime across gradients of site productivity and fuels connectivity. Fuels can be sufficient to carry fire in denser, low-elevation sites where GBBP occurs in mixed forests with limber pine (*Pinus fexilis* James) and/or Engelmann spruce (*Picea engelmannii* Parry) (Bidartondo et al., 2001). GBBP have a low resistance to fire, due to thin bark and low branches and retain their 2.5–3.5 cm needles up to 25–30 years (Bailey, 1970), increasing needle accumulation in crowns and on the surface under GBBP when compared to lower elevation pine species (Jenkins, 2011).

Limited studies of the closely related Rocky Mountain (RM) bristlecone pine (*Pinus aristata* Engelm.) and limber pine communities have found fire scars indicative of frequent, low intensity surface fires in sites that border grassy openings (Coop and Schoettle, 2011). Stand-replacing fire could be the primary disturbance regime for RM bristlecone pine, with a fire return interval of approximately 300 years (Baker, 1992). Evidence suggests that fire severity for RM bristlecone forest types varied through time and space (mixed-severity fire regime) as climate changed at centennial to millennial time scales (Coop and Schoettle, 2011). Additionally, frequent fire presumably played an important role in restricting RM bristlecone pine at lower elevations in pre-settlement times (Coop and Schoettle, 2011). Physical limitations on forest structure, such as age and density, affect the accumulation of surface fuels and crown fuels. For example, a study from boreal forests in Finland indicates a site's disturbance history is the determining factor for fuels quantity and decay class distribution (Aakala, 2010). While Baker (1992) found that stand-replacing fires in RM bristlecone pine initiated regeneration, little is known of post-fire succession in mixed-conifer forests containing GBBP. It is important to understand the fire history of GBBP/limber pine/Engelmann spruce and other montane forests in the Great Basin to develop appropriate adaptation strategies for managing these systems with a warming climate.

Most wildfire and fuel models were designed for vegetation types that burn frequently, are characterized by continuous surface fuels, or are of interest to fire management (Rothermel, 1972). Thus, discontinuous fuel associated with GBBP are not represented by traditional fuel models, and might be more similar to heterogeneous systems like piñon juniper woodlands. Extensive characterization of piñon juniper woodlands have examined the sparse surface fuels and discontinuous tree canopies that curtail fire spread under low wind conditions (Floyd et al., 2008; Huffman et al., 2009; Miller et al., 2000; Romme et al., 2009). One physics-based fire model was applied to piñon juniper woodlands and results suggest sparse fuels in heterogeneous forests propagate fire because dead needles on the ground provide surface fuels, and allow increased winds through the canopy and sub-canopy (Linn et al., 2013). A fire behavior study in arid vegetation communities in Australia developed models to predict the sustainability of fire spread, fire type (surface or crown), rate of spread and flame height in a discontinuous fuel type (Cruz et al., 2013). They found that sustainability of fire spread was a function of litter fuel moisture with wind speed having a secondary but still significant effect. The continuity of fine fuels was also significant. Initiation of crown fire was primarily determined by wind speed. Cruz et al. (2013) presented the need to find threshold conditions for sustained fire propagation based on wind speed and fine fuel moisture content. While fire spread models could be helpful for assessing fuel changes in GBBP, validation data are unavailable, and therefore are outside the scope of this study.

1.2. Environmental gradients

Environmental gradients relate factors such as elevation, temperature, water availability, light, and soil nutrients, or their closely correlated surrogates. Forest composition usually changes along environmental gradients in predictable ways (Peet, 2000). For example, elevation is often a surrogate variable which approximates changes in temperature and moisture (Peet, 2000). At lower elevations, moisture and temperature may allow for a forest to reach full crown closure, although a mid-elevation site might not reach full crown closure. At upper alpine treeline (the edge of the habitat at which trees are capable of growing, found at high elevations and in frigid environments) tree density and decomposition is typically limited by a short growing season. However, high severity disturbances are rare (low frequency and high intensity) allowing for large tree size diversity (Miller, 1997).

1.3. Fuels composition across environmental gradients

Understanding how fuels structure and composition varies across environmental gradients in Great Basin sky islands is necessary to predict how fire frequency and intensity may change at high elevations with a warming climate. Studies that have modeled severity and length of forest fire season employing general circulation models (GCMs) have estimated that seasonal severity ratings may increase by 10–50% over most of North America, (Flannigan et al., 2000) suggesting that fire is an predominate agent of change and has the potential to overshadow direct effects of climate change on species distribution and migration. Our best tool at estimating the potential fire intensity of vegetation communities, or the amount of energy released during a fire, is fine and coarse woody debris surveys (Brown, 1974), yet fuels vary greatly depending on topography, meteorological influences, fuel type and characteristics of previous disturbance. Warming temperatures, lower humidity, and lower fuel moisture increase the potential for high severity fires (Abatzoglou and Williams, 2016; Littell et al., 2016). Research is needed that will help managers plan for transitions to new conditions and habitats, manage migrations along expected climatic gradients, prepare for higher-elevation insect and disease outbreaks, and anticipate forest mortality events and altered fire regimes (Millar et al., 2007).

The objective of this paper is to quantify spatially discontinuous fuel structure across changing environmental gradients in GBBP stands. This information is useful to understand how climate change affects the fire regime and GBBP health and abundance. We assume that elevation is a surrogate for warming air temperatures. To understand how global climate change will alter wildland fuels, we quantified differences in GBBP fuels and how fuels differ across elevation gradients. We compare the relationship between forest structure and environmental gradients to predict changes in surface and canopy fuels of GBBP communities with increasing temperatures. A comprehensive stand assessment and fuel survey of this iconic species provides a foundation upon which management decisions and dialogue can be based. Consequently, this research is valuable for forest and fire planning and management, as well as prioritization and design of restoration efforts and climate change adaptation strategies.

2. Study site

The geographic extent of sampling was limited to sky islands of the Great Basin of Nevada and western Utah. Sample sites were at Washington Peak, NV (38.90°, −114.31°, 3475 m), Wheeler Peak, NV (39.00°, −114.30°, 3415 m), and Mt. Moriah, NV (39.29°, −114.20°, 3300 m). Additional individual plots were installed at