CHAPTER 10.

Monitoring the Impact of Climate Change on the Frequency and Severity of Fires and Distribution of Great Basin Bristlecone Pine Sky Island Ecosystems

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INTRODUCTION

Great Basin bristlecone pine, *Pinus longaeva* (GBBP), is one of the longest-lived, non-clonal organisms on Earth and is also one of the most highly fragmented high-elevation conifer species. Great basin bristlecone pine ecosystems contain many biodiversity "hot spots" with a high degree of species endemism. Throughout the Great Basin, GBBP communities are being threatened by changing disturbance regimes, invasive species, and climate change. The loss of GBBP can detrimentally impact biodiversity and valuable resources including wildlife habitat, watershed and soil protection, aesthetics, and recreation (Gibson and others 2008).

The impact of climate change may be especially acute in sky islands of the Great Basin as warming temperatures drive montane and alpine ecosystems upslope and result in overstory tree mortality at the lower margins of tree distributions (Bower and others 2011). Overstory tree mortality directly related to warming may induce changes to the fire regime of GBBP communities; however, little is known about their fuel characteristics and fire dynamics.

In this study, we compared the relationship between forest structure and environmental gradients to predict changes in surface and canopy fuels of GBBP communities with increasing temperatures. The results of this study were published in Gray and Jenkins (2017). Land managers can use this information to help plan for transitions to new conditions expected within future climatic gradients and altered fire regimes (Millar and others 2007).

METHODS

Data Collection

In the Great Basin of Nevada and western Utah, mountains and basins create steep environmental gradients which greatly influence the composition and structure of vegetative communities (Peet 2000). We used U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA) program plots (O'Connell and others 2015) that contained GBBP tree species to obtain tree height, diameter at breast height (d.b.h.), canopy base height (c.b.h.), coarse woody debris counts (c.w.d.; >7.6 cm diameter), fine woody debris counts (f.w.d.; 0–7.6 cm diameter), and canopy fuels measurements from stands that were distributed at elevation bands below 3000 m, between 3000 and 3300 m, and above 3300 m. Temperature regimes within these elevational bands reflect those of predicted climatic gradients.

Due to the small number of suitable FIA plots, we also quantified fuel loading of the four major surface fuel components (litter, duff, f.w.d., and c.w.d.) on a total of 76 plots located within additional study sites. We collected these data using Brown's method (also called the line-intersect or planar-intersect method) (Brown 1974).

To quantify the unique patchy and discontinuous distribution of surface and aerial fuels at high-elevation sites, we used tree-specific fuels sampling following methods described in Jenkins (2011). In brief, fuels are measured within the fuel zone (fuels lying within the drip line of a tree) of select trees along the planar transects extending from the tree bole in the four cardinal directions (N, S, E, and W) and within the non-pine fuel matrix (the area between adjacent trees). We only collected litter and duff data from under trees near treeline after initial sampling indicated that these classes comprised the majority of fuels.

We next assessed the relative degree of fuels continuity by utilizing Landsat satellite images. The August 24, 2012 Landsat 7 Enhanced Thematic Mapper Plus (ETM+) image was chosen because it was the cloud-free image closest to the dates of field sampling. The spectral indices Normalized Difference Vegetation Index (NDVI), Brightness, and Greenness estimate both fuels cover and continuity.

To assess live foliar moisture content (f.m.c.), we collected needles from four randomly selected GBBP trees at three different elevations (low = 2640 m, mid = 2910 m, high = 3160 m) during the first week of July, August, and September (n = 36). Approximately 20 g of live needles from each sample were weighed to the nearest 0.01 g and then oven-dried at 105 °C for 48 hours and reweighed to obtain a dry weight (Matthews 2010). Samples were kept frozen until processed. Foliar moisture content was computed as the percentage of the oven-dry weight to dry foliage weight.

Data Analyses

For comparing forest floor c.w.d. and f.w.d. within elevational bands, transect counts were converted to weight of fuel per unit area (kg/m^2) following Brown and others (1982). Litter and duff weight per unit area (kg/m^2) was estimated from depth measurements by using the equation developed for foxtail pine (*P. balfouriana*), a close relative to GBBP (van Wagtendonk and others 1998). Regression coefficients via generalized linear models (GLM) were developed relating forest floor mass to elevation. To characterize surface fuels dissimilarity along environmental gradients, a non-metric multidimensional scaling (NMDS) ordination based on a matrix of Euclidean dissimilarities was calculated on f.w.d, c.w.d., litter, and duff amounts. Non-metric multidimensional scaling collapses information from multiple dimensions to fewer dimensions, so that data can be visualized and interpreted (McCune and others 2002). Stand densities in trees/ha were calculated for each plot using the tree expansion factors (coefficient used to scale each tree on a plot to a per-area basis) in the FIA user manual (O'Connell and others 2015). Regression coefficients were also calculated for stand density (trees/ha) and height to live crown for the same elevational gradients. Post hoc mean comparisons using Tukey-Kramer tests were used when a significant difference among elevation class was identified in canopy fuels.

A GLM with a negative binomial link was fit to the litter and duff measurements made in the four cardinal directions under the sampled individual trees. Generalized linear models are mathematical extensions of linear models that do not force data into unnatural scales, and thereby allow for nonlinearity and non-constant variance structures in the data (Hastie and Tibshirani 1990). We used the negative binomial distribution because data with many zero values cause over-dispersion, or greater variability than would be expected. The negative binomial distribution generates realistic heterogeneity representative of spatial clustering of individuals and other small-scale processes (Bolker 2008). All statistics were completed using R statistical software (R Development Core Team 2015).

RESULTS AND DISCUSSION

Linear regression showed that all classes of f.w.d. decreased with increasing elevation, and only 1,000-hour fuels remained constant across elevational transects. The NMDS ordination supported the results of linear regression analysis with all measurements of fuels except c.w.d. being highly correlated with elevation and slope. All crown fuels metrics varied by elevation. Tree height, c.b.h., and crown length decreased with increasing elevation, while available crown fuel load and canopy bulk density increased with elevation. Canopy base height declined significantly with increasing elevation (p <0.001, $R^2 = 0.74$). Foliar moisture content was significantly less at the upper elevation site (ANOVA with p <0.001), while f.m.c. at the mid and low sites did not differ. Foliar moisture content varied significantly by month. September had the highest f.m.c. and July the lowest with values likely influenced by monsoonal precipitation events (Scalzitti and others 2016).

The results from the Landsat indices of vegetation cover reiterate the findings from c.w.d. and f.w.d. sampling. As elevation increased, NDVI and Greenness decreased, indicating less vegetation and fuels available to carry a surface fire. Conversely, Brightness (a measure of exposed soil) increased with increasing elevation indicating larger gaps between trees, or a decrease in GBBP stand density (trees/ha) and less continuous fuel cover.

Measurements of litter and duff in the four cardinal directions directly beneath GBBP trees showed higher litter and duff fuel loads near the bole of the tree. While there might not be sufficient fuels between individual trees to carry a surface fire, nearly each individual tree had a pocket of litter and duff directly beneath it.

Forest tree distribution data suggest an upward movement of lower elevation species with temperatures of 2–4 °C warmer than historical averages (Scalzitti and others 2016). We expect the structure, composition, and fuel condition of future GBBP stands to more closely approximate those that currently exist in vegetation communities at mid and low elevations. The accumulation of fuels in lower elevation vegetation communities has proven to amplify the effects of fire in the high-elevation/low fire return interval systems. More important than fuel load is a reduction in the size of fuel gaps that typically limit fire propagation. Our research indicates that if climate warming changes fuel conditions, then the frequency of fire in GBBP systems at low and mid elevations could increase where stands are denser and surface fuel is greatest. Two of the recent large fires in GBBP forests resulted from ignitions at low elevations that spread up into pure GBBP stands. Fire spread from ignitions at upper elevations is unlikely to result in crown fires since surface fuels are low and GBBP intercrown distance is large. However, as elevation increased, the branches of GBBP were closer to the ground, which could facilitate the transition of fire into the crown of the trees.

CONCLUSIONS

As climate change continues to impact high-elevation forests, treeline species like GBBP may be extremely important in maintaining forest ecosystems. We characterized fuels within elevational and latitudinal ranges of GBBP communities and showed how alterations in fuels and associated changes in fire behavior may threaten high-elevation GBBP stands in the future, particularly when coupled with climate change and with very low GBBP regeneration in the post-fire environment. Land managers can use this information for planning and improving practices used to sustain high-elevation GBBP forests.

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