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FIRE HISTORY ACROSS FOREST TYPES IN THE SOUTHERN BEARTOOTH MOUNTAINS, WYOMING

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ABSTRACT

Fire is a critical ecosystem process that has played a key role in shaping forests throughout the Beartooth Mountains in northwestern Wyoming. The highly variable topography of the area provides ideal conditions to compare fire regimes across contiguous forest types, yet pyro-dendrochronological research in this area is limited. We reconstructed fire frequency, tree age structure, and post-fire tree growth response in the Clarks Fork Ranger District of the Shoshone National Forest to infer variations in historical fire behavior and stand effects. We collected fire-scarred trees and plot-based tree ages on plots ranging 0.5-5 km^2 in size across two forest types separated by 2 km: a lower-elevation forest of mixed Douglas-fir and lodgepole pine and a higher elevation treeline forest dominated by whitebark pine. Fires occurred in the lower-elevation forest in 1664, 1706, 1785, 1804, 1846, and 1900 with a mean fire return interval of 47 years. The fires in 1804 and 1900 were also recorded in the higher elevation forest, with significant tree mortality at high elevation in the 1900 fire. Both forests were multi-aged with little evidence of tree cohorts in response to severe, stand-replacing events. On average, tree growth increased after fires, with mean ring widths after fire 39% wider in Douglas-fir and 40% wider in lodgepole pine than pre-fire averages, suggesting that some tree mortality likely occurred in association with lower-elevation forest fires. Burns were more frequent in the lower-elevation forest and were occasionally able to spread into the upper-elevation whitebark stand. Although we suspect the transition of fires from low- to high-elevation occurred during drier years, we did not find any relationship between fire years and available climatic reconstructions via superposed epoch analysis. Regeneration during the 20^{th} Century in the whitebark forest documents recovery of this forest after the 1900 moderate-severity fire event. Finally, especially in the lower-elevation Douglas-fir forest, the period since the last recorded fire (1900)

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appears to be longer than any fire-free period in the historical record, suggesting that fire exclusion may be creating changes in landscape and patch-scale stand structures, which will likely impact future fire behavior, especially the extent of crown-replacing fire, in these forests.

Keywords: Shoshone National Forest, dendrochronology, elevation, fire suppression, whitebark pine, Douglas-fir, lodgepole pine.

INTRODUCTION

Fire is a critical ecosystem process that has directly and indirectly shaped modern vegetative communities across the globe for thousands of years (Heyerdahl *et al*. 2001; Whitlock *et al.* 2003; Gavin *et al*. 2007; Bowman *et al.* 2009). This is particularly pronounced in the western United States, where many tree species exhibit a variety of reproductive strategies and physiological adaptations to fire (Pyne 2002; Bond and Keeley 2005; Keeley *et al.* 2011). Fire in these systems has historically acted to modify stand densities via mortality of mature and juvenile trees and is an important component in promoting biodiversity and stand heterogeneity.

However, broad-scale changes in land use, particularly over the past 150 years, have led to alterations in fire regimes throughout many of these ecosystems. Aggressive fire suppression beginning in the early 20th Century has facilitated increased regeneration and biomass accumulation in forests where fire was previously frequent and tree densities were low to moderate (Stephens and Ruth 2005). This has led to generally denser forest stands and a proliferation of fire-intolerant species, resulting in major shifts in stand structure and composition (Nowacki and Abrams 2008; Collins *et al.* 2011). In forest types where fire was historically less frequent, biomass growth during fire-free periods creates conditions that support contiguous patches of stand-replacing fire where most or all trees in a plot were killed (Stevens *et al*. 2017). Increased variability in the climate system, largely resulting from anthropogenic inputs, increases the potential for large and severe fires throughout the western U.S. and has raised important management concerns for adapting to this disturbance (Brown *et al*. 2004; Flannigan *et al*. 2009; Spies *et al*. 2010; Westerling *et al*. 2011).

The Shoshone National Forest, established in 1891, spans 971,000 ha within the Greater Yellowstone Ecosystem (USDA Forest Service 2017). Shoshone encompasses portions of the Absaroka, Wind River, and Beartooth Mountains, with elevation ranging between *ca*. 1400 to 4200 meters above sea level. The National Forest is composed of a wide variety of ecosystems from sagebrush-dominated (*Artemisia tridentata* Nutt.) lowlands to whitebark pine-dominated (*Pinus albicaulis* Engelm.) treeline. The highly variable topography of the area provides ideal conditions to compare fire regimes across various forest types, yet pyro-dendrochronological research in this geographic area is limited. Previous fire history research in the Greater Yellowstone Ecosystem indicates that varied characteristics of the forest composition cause fire to behave differently. Specifically, forest type, topography, fuel load, fuel moisture, and climate are important determinants in fire frequency and severity (Romme and Despain 1989; Renkin and Despain 1992; Higuera *et al.* 2010; Westerling *et al.* 2011). However, our study offers additional evidence of historical forest dynamics from this relatively understudied region of the Greater Yellowstone Ecosystem.

Mid-elevation forests (1400–2700 m) within the Shoshone National Forest are dominated by lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and Douglas-fir (*Pseudostuga menziesii* (Mirb.) Franco). Lodgepole pine is a shade-intolerant species that prefers slightly acidic soil, grows quickly in fire-disturbed soils, and has moderate-to-strongly serotinous cones that open after exposure to high temperatures associated with wildfire (Ryan *et al.* 1992). Lodgepole pine effectively reseeds post-disturbance and can grow in a wide range of moisture conditions (Muir and Lotan 1985). Thus, lodgepole pine growth and reproductive characteristics make it highly resilient to fire disturbance at the stand level. Mortality is often followed by rapid regeneration. Douglas-fir is a moderately shade-tolerant species that occurs across a range of elevations and commonly occupies forests with varied fire regimes. Thick bark and self-pruning branches make Douglas-fir a highly fire-resistant species by insulating cambial tissues and elevating canopy base heights. Fire-resistant characteristics effectively reduce transition of surface fires into the forest canopy, allowing these Douglas-fir to persist in the presence of low- to moderate-intensity fire (Furniss 1941), but Douglas-fir is particularly vulnerable to stand-replacing fire at large spatial scales where patch edge dispersal is limited (Collins *et al*. 2017).

Fire severity of high-elevation whitebark pine ecosystems varies widely across the western United States, ranging from high severity in northern Idaho to relatively low-to-moderate severity in the southern range of whitebark pine in high-elevation Rocky Mountain refugia (Arno and Hoff 1990; Keane 2001; Campbell *et al*. 2010). This variability creates complex landscape patterns, both in cohort recruitment and retention of old-growth trees (Romme and Knight 1981; Murray *et al.* 1998). Historical low-to-moderate fire severity is primarily caused by low productivity and, thus, low fuel availability (Baker 2009). Fire suppression in whitebark pine systems has resulted in the encroachment of fire-intolerant Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) into historically whitebark-pine dominated forests (van de Gevel, 2008).

The objectives of this study are to reconstruct fire frequency, tree age structure, and post-fire tree growth response in the southern Beartooth Mountains to infer variations in historical fire behavior and effects on stand structure. We hypothesize that (1) fire frequency will be greater in lower-elevation stands where fuels are more likely to dry out on a seasonal basis and were more conducive to fire spread, (2) fire will have a direct impact on cohort establishment and stand development, with a decrease in stand density directly following fire, (3) fire will be significantly correlated with climate parameters, with increased fire activity occurring during years of drought, and (4) individual tree growth will increase following fire events, as moderate severity fire will reduce competition for surviving trees.

METHODS

Site Descriptions

We collected fire-scarred trees and plot-based tree ages across two forest types: a lower-elevation forest of mixed Douglas-fir and lodgepole pine and a higher-elevation treeline forest dominated by whitebark pine. We selected two high-elevation mixed-conifer forest stands along an elevation gradient for site-specific reconstruction of fire history in the Clarks Fork Ranger District of the Shoshone National Forest in northwestern Wyoming: Ghost Creek (GHC) and Clay Butte (CLB) (Figure 1). Ghost Creek (GHC) (44°55.5′N, 109°38.7′W; 2382 m a.s.l.) comprises a mixture of Douglas-fir and lodgepole pine, with a small component of Engelmann spruce and quaking aspen (*Populus tremuloides* Michx.). Clay Butte (44°56.5′N, 109°37.9′W; 2850 m) is dominated by whitebark pine with lesser abundance of subalpine fir and Engelmann spruce. CLB and GHC are located 2.3 km apart on the same generally south-facing slope with no major topographic barriers to the spread of fire and were selected to compare the spatial extent of reconstructed fires. None of the sites had been logged historically.

Two additional high-elevation mixed-conifer forest stands, Lily Lake (LLY) and Island Lake (ISL), were selected to provide a regional comparison of age-structure patterns near the elevational transect (Figure 1; Brown 2016). Site LLY (44°56′N, 109°43′W; 2375 m) is characterized by a mosaic of Douglas-fir and high-elevation mixed-conifer woodland, including lodgepole pine, Engelmann spruce, and subalpine fir. Site ISL (44°56′N, 109°32′W; 2925 m) consists largely of Engelmann spruce with a lesser abundance of subalpine fir.

Soils of the area are of the Vanwirt-Taglake-Rubic series, generally classified as gravelly sandy loams derived from glacial till formed from a granite substrate (Soil Survey Staff 2017). Climate for the study region is considered arid to semi-arid, with an average annual precipitation of 640 mm, with most arriving as winter snowfall. The mean maximum temperature ranges from –2.8°C in January to 26.3°C in July with an annual average of 11.4°C (Rice *et al.* 2012). Averages were determined from instrumental data between 1971 and 2000.

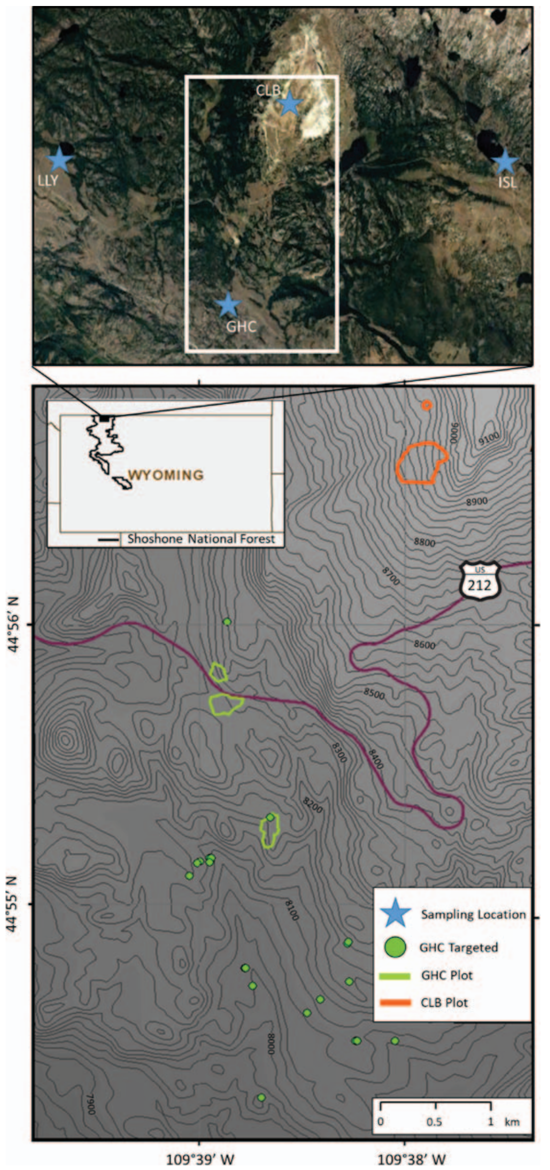

Figure 1. Satellite imagery map of the study sites (upper panel) located in the Clarks Fork Ranger District of the Shoshone National Forest (see inset in lower panel for its position in state of Wyoming). General sampling locations are indicated by stars. Digital elevation map (lower panel) of the extent indicated by the white rectangle in the upper-panel satellite map including the Clay Butte (CLB) and Ghost Creek (GHC) fire-scar sampling stands. Clay Butte (CLB) sampling locations are indicated by orange polygons. Ghost Creek (GHC) sampling plots (polygons) and targeted trees (points) are indicated in green.

Field Methods

We employed two complementary and well-established sampling strategies to evaluate fire history and stand demographics, (1) targeted sampling to locate suitable samples that had been scarred by fire (Van Horne and Fulé 2006; Farris *et al.* 2013) at GHC and CLB, and (2) randomly located plots (Brown *et al.* 2001; Sibold *et al.* 2006), to estimate possible effects of variation in fire severity on stand age structures at CLB, LLY, and ISL. The main criteria for targeted fire-scar sample selection was the presence of well-preserved visible healing scars at the basal surface, with a preference for sections with two or more visible scars (Swetnam and Baisan 1996). Cross-sections were cut with a chainsaw from fire-scarred snags, downed logs, and stumps. Partial, plunge-cut cross-sections were collected via chainsaw to minimize cambial damage in living trees while allowing for collection of an adequate amount of material for analysis. Coordinates were collected with a GPS unit for each sampled still-living fire-scarred tree.

To examine stand age structure and to assist in the dating of the fire events in the fire-scar record at GHC, we extracted two increment cores at 30-cm height above root collar from the four closest large (>20 cm diameter at breast height = dbh) living trees located in each directional quadrant (NE, SE, SW, and NW) from each fire-scar tree sampled. We also collected cores from older fire-scarred trees and non-fire-scarred trees as encountered to assist with chronology development. Cores were obtained either with pith or with tight ring curvature that would suggest the pith was only a few years off the core itself. We also recorded distance from the fire-scarred sample trees to these adjacent living trees to estimate local stand density and basal area metrics. A variable diameter circular plot sampling method (Lessard *et al.* 2002) was conducted at CLB, LLY, and ISL. We randomly located plot centers using a compass bearing and sampled a total of 30 trees per plot above root collar. Plots were sampled to 30 trees because of time constraints.

Laboratory Methods and Analysis

Increment cores and fragile cross-sections were mounted and glued as necessary to ensure sample stability (Grissino-Mayer *et al.* 1994; Speer 2010). At a minimum, increment cores were surfaced first with 320-grit (44.7–47.7 μm) sandpaper on a handheld belt sander and then hand-surfaced with 400-grit sandpaper until cellular structures were clearly visible. Cross-sections were surfaced with a planer and sanded with progressively finer sandpaper including 40 (425–500 μm), 120 (106–125 μm), and 320 (44.7–47.7 μm) grits until cellular structure and fire scar characteristics were clearly visible. Cross-sections were additionally hand-sanded with 400-grit (20.8–22.8 μm), as well as 30 μm and 15 μm micron sandpaper when necessary to facilitate the dating process (Orvis and Grissino-Mayer 2002).

We used both skeleton plots (Stokes and Smiley 1968; Speer 2010) and the list method (Yamaguchi 1991) for crossdating and assigning precise calendar dates to all tree rings. Tree rings on selected radii were measured to the nearest 0.001 mm using a Meiji 40X stereomicroscope and a Velmex measuring stage (Velmex Incorporated 2016) interfaced to a PC workstation running Measure J2X software (Voortech Consulting 2015). Measuring was done to develop a potential climate chronology for the site, to assist in crossdating, and to examine growth responses to fire occurrences. We used the program COFECHA (Holmes 1983; Grissino-Mayer 2001) to verify crossdating and measurement accuracy of annual rings, using 50-year segments lagged 25 years, requiring a Pearson's $r > 0.328$ for statistical significance at $p < 0.01$ with all other segments created from the remaining cores in the data set. A pith locator was used to estimate the number of missing rings to pith on cores where pith was absent, but ring curvature was present (Applequist 1958). Fire seasonality was determined by visual analysis of fire-scar location within the growth ring (Baisan and Swetnam 1990), with dormant season scars assigned to the previous year.

Individual fire events throughout the study area were determined based on coinciding fire-scar dates across multiple (two or more) sampled trees. For GHC, stand-level metrics (basal area in m^2 ha^{-1} and density in trees ha^{-1}) were derived using the point-centered quarter method (Safford *et al.* 2012). Fire and tree demographic chronologies were then compiled in the program FHAES (Brewer *et al*. 2017) for archiving and analyses.

We measured growth during the period around fire events on high-resolution images of 10 cross-sections from GHC. Specifically, we measured raw ring widths for eight years before fire events and 20 years after fire events using CooRecorder (Larsson 2017). Some cross-sections had multiple scars, so we analyzed growth samples from 21 scars over 10 trees. Using raw ring widths, we analyzed tree growth before and after fire events to assess the impact of fire on health using the TRADER package in Program R (Altman *et al*. 2014). We used a 25% increase in mean ring width from the 10 years after a given ring, relative to the 10 years before a given ring over a minimum of five consecutive rings as our threshold for a major growth release, based on previous standards for Douglas-fir (Winter *et al*. 2002).

Next, we conducted a superposed epoch analysis to assess whether various climate factors had a measurable influence on fire activity in the years preceding and including fire events (Swetnam 1993; Schoennagel *et al.* 2005; Harley *et al.* 2014). Variables we evaluated included the Palmer Drought-Severity Index (PDSI) (Dai *et al.* 2004), El Niño-Southern Oscillation (ENSO) (Jones *et al*. 2012), Pacific Decadal Oscillation (PDO) (Zhang *et al.* 1997), and regional streamflow data (Bekker *et al*. 2014), as well as a Northern Hemisphere temperature reconstruction and a local temperature reconstruction, both provided by Wilson and Stachowiak (2017).

RESULTS

We collected a total of 233 samples from 142 trees consisting of 65 full or partial cross-sections and 168 increment cores. Using a tree-ring chronology generated from increment cores collected from living trees, 49 fire scars from 32 dead and living trees were identified. Five fire events were identified (Figure 2), all occurring in the dormant season. Fire was least frequent at the higher-elevation site (CLB), with fires recorded in 1804 and 1900, as well as a single scar sampled in 1693. Fire was more frequent at the lower-elevation site (GHC) with fires recorded in 1664, 1785, 1804, 1846, and 1900. Scars on individual trees also occurred in 1694, 1706, 1717, 1763, and 1873. We found no evidence of fires at any site during the 20^{th} and 21^{st} Centuries. The lower-elevation forest site had

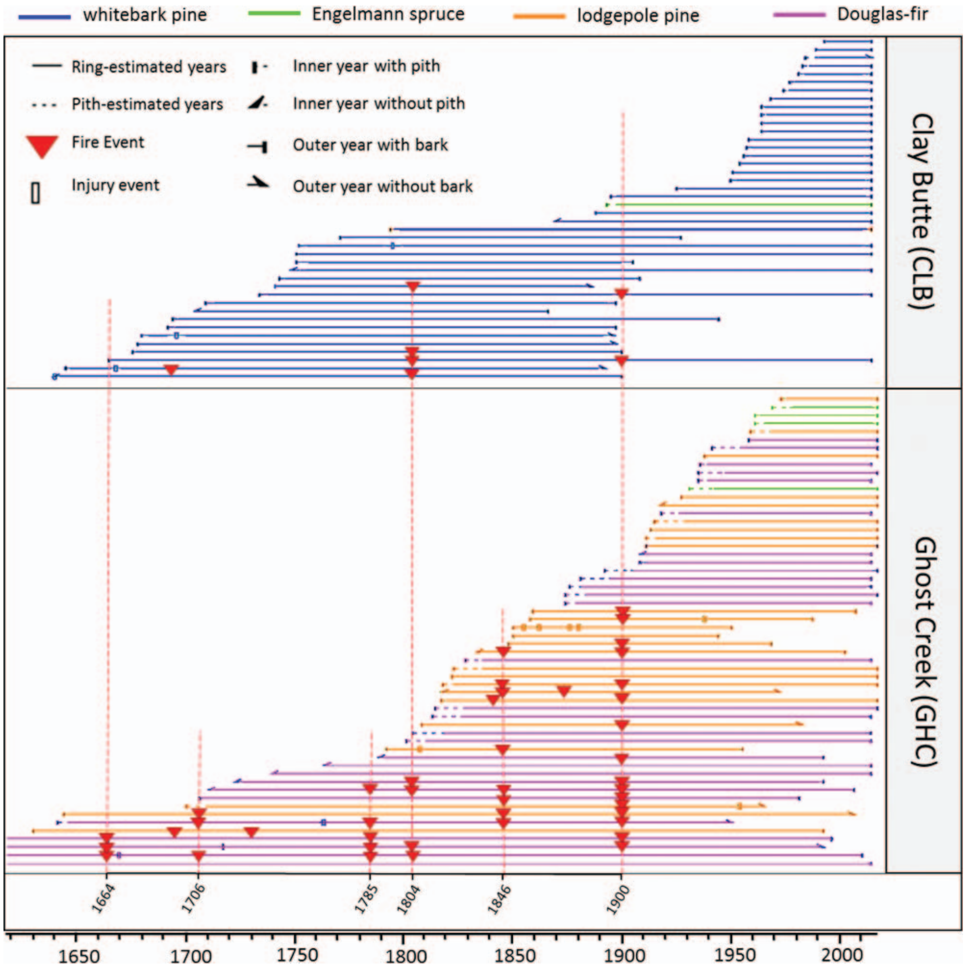

Figure 2. Fire history data for lower-elevation (GHC, lower panel) and higher-elevation (CLB, upper panel) fire history plots along an elevation transect. Each horizontal line represents a tree, with pith ages estimated by ring curvature patterns as dashed lines and pith ages determined from a complete set of rings as solid lines. Verified fire years are reflected by vertical lines at 1664, 1706, 1785, 1804, 1846, and 1900.

a mean fire return interval of 47 years (42 median), and the upper-elevation whitebark pine-dominated site had a longer fire return interval of *ca.* 100 years.

Multi-aged stand structures characterize both CLB and GHC (Figure 2) as well as the plots at sites LLY and ISL (Figure 3). The oldest trees at CLB were all whitebark pine and established in the late 1600s, with constant establishment and little evidence of distinct cohorts until the latter half of the 20th Century. A cohort initiated around 1955 exhibits abrupt establishment timing. Site GHC exhibits gradual establishment of lodgepole pine and Douglas-fir throughout the period of record (AD 1584–2017). These results are similar to regional records at sites LLY and ISL (Figure 3). Establishment occurred gradually at LLY with the oldest living tree dating back to 1811. At ISL, establishment of the modern stand began in 1720, with more than half of living trees originating post-1900.

Average stand density for the GHC study area was 306 trees ha^{-1} with a mean basal area of 21 m^2 ha^{-1}. On average, tree growth increased after fires although the response varied across individual trees and species (Figure 4). For Douglas-fir, mean ring widths increased from 0.77 mm prior

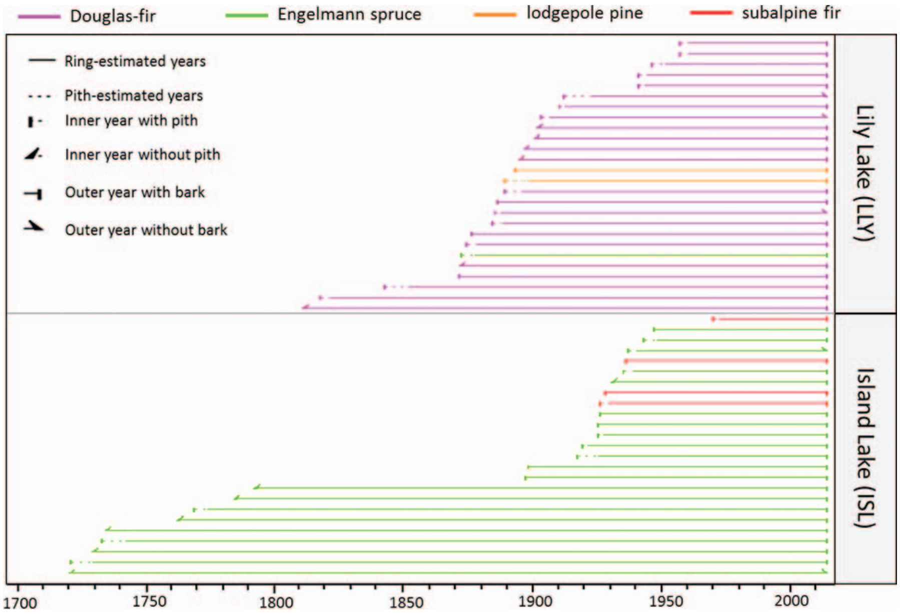

Figure 3. Stand age structure of Island Lake (ISL, lower panel) and Lily Lake (LLY, upper panel) plots. Each horizontal line represents the age of an individual tree, with pith-estimated years shown by dashed lines.

to fire to 1.26 mm post-fire, a difference of 39% (Figure 4a). For lodgepole pine, mean ring widths increased from 0.75 mm prior to fire to 1.25 mm post-fire, a difference of 40% (Figure 4b). For each species, these growth increases were strongest and most sustained after the 1900 fire, where all individuals sampled had a growth increase of greater than 25% for five or more consecutive years (Figure 5).

Using superposed epoch analysis, we did not see any significant climate relationships with fire years. Although our preliminary analysis found no statistically significant influence of climate preceding and including fire years, we plan to explore further relationships in future fire research studies within the Clark's Fork Ranger District of the Shoshone National Forest.

DISCUSSION

Fire frequency and severity varied across elevation and forest types in the southern Beartooth Mountains of northwestern Wyoming. Fires were most frequent in the lower-elevation forest site dominated by Douglas-fir and lodgepole pine, with a mean fire return interval of 47 years based on six fire dates ranging from 1664 to 1900 (Figure 2). In contrast, the upper-elevation whitebark pine-dominated site recorded only two fires during roughly the same period, from 1693 to 1900, with some evidence for a third. Two of the fire dates, 1804 and 1900, were recorded on trees at both sites. Severity varied as well, especially with the 1900 fire, where we sampled numerous whitebark pine trees at Clay Butte, which appear to have perished in response to this fire (Figure 2). It is likely that fire behavior in the lower-elevation Douglas-fir and lodgepole pine also consisted of some overstory mortality, evidenced by growth responses in surviving trees after fires in 1846 and 1900 (Figure 4). We found a larger growth release in the surviving trees following the 1900 fire than the 1846 fire (Figure 5). This suggests that the later fire may have caused mortality of mature competitors, triggering a growth release, whereas the 1846 fire was likely lower-severity, leaving the developing stand relatively undisturbed. Because tree-ring widths were not normalized for climate variability, we cannot exclude more favorable post-fire climate conditions as an explanation for these increases in mean ring width.

Additional evidence for lower-severity fire behavior in 1846 is the survival of numerous young

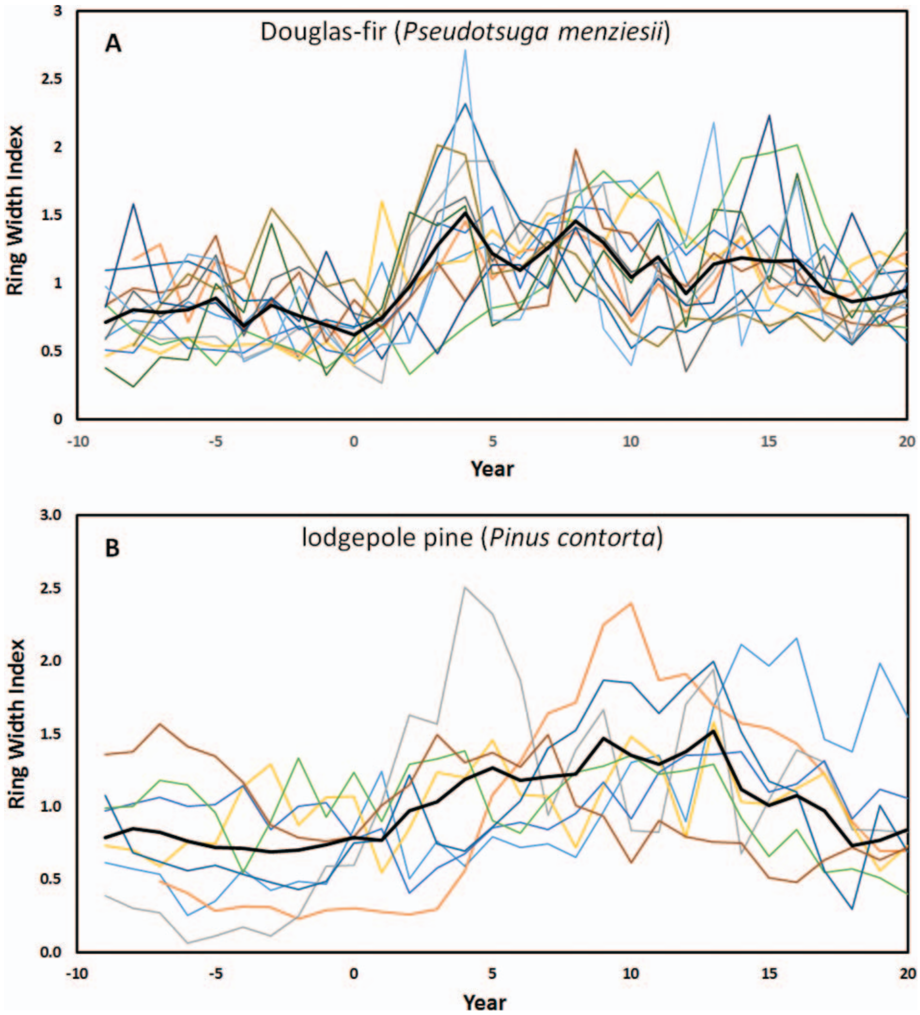

Figure 4. Mean ring widths (mm) for eight years before and 20 years after fires (year zero) for a subsample of Douglas-fir (upper panel A) and lodgepole pine (lower panel B) – 21 fire scars from ten trees – from site GHC. Species average is represented by the bold black line.

(20–30 years old) fire-sensitive lodgepole pine that established after the 1804 fire. The 1900 fire spread into the higher-elevation whitebark pine stand whereas the 1846 fire did not, suggesting that the 1900 fire was generally more intense and able to spread from the lower-elevation stand to the higher-elevation stand where fuel moistures are typically higher and temperatures generally lower. Collectively, the evidence suggests that the 1900 fire event caused mortality over the entire elevation range, although we did not find direct evidence of tree mortality in the lower-elevation stand (Figure 2).

Although the 1900 fire caused extensive mortality in the higher elevation whitebark pine stand, most of the post-1900 recruitment did not begin until after *ca*. 1945 (Figure 3). This delay may derive from unfavorable conditions for whitebark pine recruitment related to a number of factors including seed dispersal by the Clark's nutcracker (*Nucifraga columbiana* (Wilson, 1811; Tomback 1982)), outbreaks of white pine blister rust (*Cronartium ribicola* J.C. Fisch.) and mountain pine beetle (*Dendroctonus ponderosae* (Hopkins, 1902)), fire suppression, or climate limitation for successful

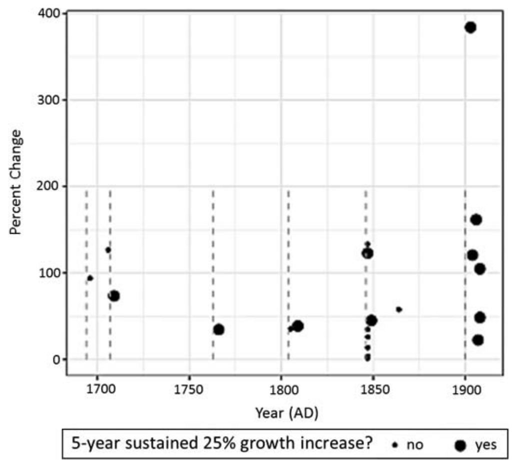

Figure 5. Maximum percent change in ring width (next 10 years relative to previous 10 years of a given ring) at each of 21 fire scar samples from Douglas-fir and lodgepole pine from GHC with each dot representing a tree. Large dots indicate samples where five consecutive rings (r) had a 10-year percent change ($r + 9{:}r - 9$) greater than 25%. Gray dashed lines indicate fire dates 1694, 1706, 1763, 1804, 1846, and 1900.

seedling germination. Historic observations of beetle outbreaks in the Greater Yellowstone Ecosystem during the 1930s correspond with this lag in recruitment (Logan *et al.* 2010). During the 1930s average precipitation in the region was slightly lower than modern averages, which could have potentially impacted whitebark pine recruitment dynamics (Rice *et al.* 2012). Whatever the reason, the stand today appears to be returning to a whitebark pine-dominated forest.

We did not observe any distinct cohort structure that potentially resulted from synchronous tree establishment after stand-replacing fire. All stands, including high-elevation whitebark pine, exhibited uneven-aged structure (Figures 2 and 3). We observed some indication that clusters of trees established after these fires, especially in lodgepole pine stands, but these patterns are ambiguous and do not provide substantial evidence for stand-opening events. This suggests that the presence of lodgepole pine cohorts or those of other species may not be sufficient in isolation to constitute evidence of stand-replacing fire, and that other evidence including mortality dates (*e.g.* Figure 2) or post-fire growth responses (*e.g.* Figure 4) is necessary to best assess fire severity. Additionally, surface fire creates favorable conditions for germination of conifers, particularly pines (Baker 2009), so a stand with previously open or lower-density structure can still experience a pulse of regeneration in the absence of stand-replacing fire. We acknowledge that these data are limited, but provide preliminary insight into broader-scale tree recruitment patterns across the area where we have reconstructions of fire history dynamics.

Although we suspect that trans-elevational fires occurred during dry conditions in the dormant season, we did not find any relationship between fire years and drought indices. However, general late-Holocene trends in PDSI within the Greater Yellowstone Ecosystem include dry conditions in the 1700s and mid-1800s, which are generally consistent with fire events at our study sites (Whitlock *et al.* 2012). Future efforts will be directed to expanding the number of sites across the Beartooth Mountains range to collect additional regional fire data with which to investigate the role of climate on fire occurrence in this portion of the Greater Yellowstone Ecosystem.

Our results are consistent with fire return intervals derived from studies in similar forests in the surrounding area, which have estimated surface fire return intervals as frequent as 25–30 years, with less frequent, higher-severity fires occurring on the order of 200 years for low- to mid-elevation mixed conifer systems and 350+ years for high-elevation areas (Houston 1973; Barrett 1994; Millspaugh *et al.* 1995; Millspaugh *et al.* 2000). General trends in decadal fire activity across this elevation gradient are consistent with fire frequency and timing in Yellowstone National Park (Romme and Despain 1989). Additionally, elevated fire activity in the 19th Century in lower-elevation Douglas-fir sites is consistent with regional records in Jackson Hole (Loope and Gruell 1973) and a cessation of frequent grassland surface fires in southwestern Montana (Heyerdahl *et al.* 2006). These changes in fire activity reflect multidecadal drought conditions in the 19th Century amplified by the interaction of PDO and Atlantic Multidecadal Oscillation (AMO) that favors dry conditions in the northern Rocky Mountains (McCabe *et al.* 2008).

Similar to patterns in forests of the Greater Yellowstone Ecosystem (Loope and Gruell 1973;

Romme and Despain 1989; Millspaugh and Whitlock 1995; Heyerdahl *et al.* 2006), a marked change occurred in fire activity after 1900, with the current fire return interval of 117 years exceeding the observed historical frequency in the lower-elevation Douglas-fir dominated forest. A lack of fires post-1900 may affect changes in stand to landscape overstory structure and fuel dynamics, with feedbacks into fire frequency and severity across the study area. Changes in fire regime, especially lack of fire, alter relationships between fire-dependent and fire-intolerant species, and future fire events are likely to include larger areas of stand-replacing fire behavior than that which occurred historically.

CONCLUSIONS

Fire-scar and tree-age data document variability in both fire frequency and inferred fire behavior across a gradient in elevation and forest types in the southern Beartooth Mountains of northwestern Wyoming. Fires were more frequent and less severe in lower-elevation, mixed Douglas-fir/lodgepole pine stands than in higher-elevation whitebark pine stands, which had both longer fire return intervals and greater evidence for higher-severity fire events. Fires in lower-elevation Douglas-fir and lodgepole pine stands exhibited growth releases after mixed-severity fires, indicating decreased stand density post-fire, though synchronous recruitment pulses were not apparent. Although fire was not significantly correlated with the climate parameters we examined, elevated fire activity in the 19th Century may reflect a regional multidecadal drought. Post-fire whitebark pine recruitment in the 20th Century indicated the resilience of these forest systems to higher-severity disturbance, although the current fire return interval of 117 years is outside the historical range of fire frequency. This suggests that the fire regime is being altered by fire suppression and argues for restoration of prescribed fire or managed fire use in this area to maintain landscape patterns of fuel structures and forest conditions.

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