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Paleofire severity and vegetation change in the Cascade Range, Oregon, USA

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ABSTRACT

Paleoecological research has expanded our knowledge of the relationships between climate, fire and vegetation. Fire can be a significant driver of forest composition and structure change, but identifying and quantifying fire regimes has been elusive. Using high-resolution charcoal analysis and pollen analysis we reconstructed a 13,200-year-old fire and vegetation history from Breitenbush Lake, Oregon, located in the central Cascade Range, USA. Our objective was to examine if fire occurrence and severity may have been a driver of Holocene forest-composition change. The data from this study suggests that while fire can create opportunities for successional process to occur, fire events were not significant catalysts for forest change. Instead, most major transitions at Breitenbush Lake occurred during prolonged fire-free intervals. Our results reinforce the view that climate is the major control of vegetation composition change in the Cascade Range.

Introduction

Disturbances play an important role in determining forest structure, composition and successional processes (Turner and Romme, 1994); yet forest ecosystems have been shown to be resilient under varying disturbance regimes (Holling, 1973; Agee, 1993; Franklin et al., 2002; Minckley et al., 2012b). As global and regional climates change, disturbance regimes, such as fire, are likely to be altered as well (Westerling et al., 2006; Marlon et al., 2012). How forest processes will unfold, either through compositional change or continued resilience, under future climate and fire regimes is unclear. One way to understand how fire influences forest regeneration dynamics is to examine this interaction over multiple iterations with lake sediment records that use charcoal accumulation to reconstruct fire history and pollen accumulation to reconstruct vegetation history at the same location. Analysis of sedimentary charcoal to reconstruct local fire history is a process that has seen rapid refinement over the last few decades (Long et al., 1998; Gavin et al., 2003; Higuera et al., 2009). Inferring the spatial extent and severity, i.e., plant mortality, of fires, has also improved over the last several years (Marlon et al., 2006; Higuera et al., 2011, 2014; Minckley and Shriver, 2011; Shriver and Minckley, 2012; Kelly et al., 2013; Dunnette et al., 2014; Morris et al., 2015).

Direct comparison of the impact of a fire episodes and the resulting change in forest composition is often challenging because of differences in temporal resolution of each record type (Tweiten et al., 2009). Fire-histories derived from charcoal accumulation in lake and bog sediments are sampled contiguously, whereas vegetation histories derived from pollen data are sampled discretely at subcentennial-to-centennial intervals. The resulting interpretations are of fire regime changes based on fire frequency within sub-periods, i.e., pollen zones. Pollen zones can be viewed as periods of prolonged equilibrium (stability) of a vegetation community. In terms of ecological theory, pollen zones are periods when a plant community returns to a stable state in response to disturbances, i.e., the resilience of the plant community (Holling, 1973; Bjune et al., 2015). Fire disturbance identifiable in paleoenvironmental records are those discrete events (charcoal peaks) that occur intermittently through a sedimentary column. Moderate-to-high severity fire events occurring every 35+ yr should also be evident in pollen records as these disturbances result in significant mortality whose effects persist as ecosystems recover floristic composition and soil structure (Agee, 1993; Minckley and Shriver, 2011; Kelly et al., 2013; DeBano, 2000; NWCG, 2008).

Paleoecological identification of fire severity is constrained by what can be measured or observed with proxy data, which is representative of the physical and chemical signature of biomass consumption (Keeley, 2009). Important components of a fire regime, such as severity (low, moderate, high; Fig. 1) and type (surface or crown) are often inferred by the change in charcoal abundance or peak magnitudes (Whitlock et al., 2006; Marlon et al., 2008; Dunnette et al., 2014) or change in charcoal morphology (Jensen et al., 2007; Mueller et al., 2014). Other indicators of fire severity may be inferred from changes in sediment magnetic susceptibility or biogeochemical analyses (Millspaugh et al., 2000; Morris et al., 2014). However, an examination of

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Fire Severity	Description	Apparent Pollen Abundance Response Understory	 Overstory
Low	Associated with surface fires that consume forbs, grasses, and shrubs; soils intact	▼	▲
Moderate	Associated with understory mortality as above, some mortality of fire-sensitive trees; soils intact	▲	▼
High	Mortality of understory and canopy trees; soils altered and susceptible to erosion	▲	▼

Fig. 1. Expected responses of pollen production under different fire severity. Mid- and high-severity response should appear similar in a pollen record based on 5–10 yr recovery times of the plant community, however, high-severity events might take longer to recover from because of the alteration of soils due to prolonged heating (Agee, 1993).

pollen associated with specific fire episodes may provide similar information based on differential mortality in the plant community (Minckley and Shriver, 2011; Shriver and Minckley, 2012).

To identify the past effects of fire on ecosystems, pollen-data sampling strategies need to be modified to accommodate the temporal scale of successional response. The use of pollen data as a proxy for fire severity assumes that fire-induced plant mortality alters pollen productivity for a short period (Fig. 1). Short-term changes (1–20 yr) in pollen production can be apparent in samples associated with, or immediately following a fire episode (Minckley and Shriver, 2011; Shriver and Minckley, 2012). The changes in specific pollen types can then identify which plants, arboreal (canopy) or non-arboreal (understory), were most affected by the fire episode and a fire severity and type can be inferred.

We detail the impact of fire episodes on forest vegetation in this paper. Our goals were to reconstruct Holocene fire regime and vegetation history from Breitenbush Lake in the central Cascade Range of Oregon and gain a better understanding of the impact of fire on forest composition.

Site description

Breitenbush Lake, located in the Central Oregon Cascade Range (Fig. 2) formed as a result of alpine glaciation (Orr and Orr, 2006). The surface area of the lake is 26.3 ha with a maximum depth of 7.6 m and simple bathymetry. The watershed is 270 ha and contains a forest with major canopy species Pacific silver fir (*Abies amabilis*), noble fir (*Abies procera*), and mountain hemlock (*Tsuga mertensiana*) with some Engelmann spruce (*Picea engelmannii*) and lodgepole pine (*Pinus contorta*), all of which are fire sensitive (Agee, 1993). Common understory species include snowbrush (*Ceanothus velutinus*) and pinemat manzanita (*Arctostaphylos nevadaensis*) with western needlegrass (*Stipa occidentalis*) on open slopes. Shrub and herb cover is minimal under closed canopies. The climate of the area is characterized by cool, wet winters and warm, dry summers, with the bulk of annual precipitation coming from low pressure systems moving inland from the Pacific Ocean during winter months. Winter precipitation falls mainly as snow. In summer, high pressure dominates the area and suppresses precipitation (Mock, 1996). The fire season occurs from June to October as fuel moistures drop during the early-summer through early fall months. The fire regime is characterized by fires of moderate to high severity that occur every 100–250 yr (USFS, 2007). In the subalpine forests of the Cascade Range, historic fire size ranged between 700 and 300 ha (Agee, 1993), suggesting that identified fire episodes in our study would be large enough to burn enough of the watershed to produce a robust pollen signal of local vegetation recovery.

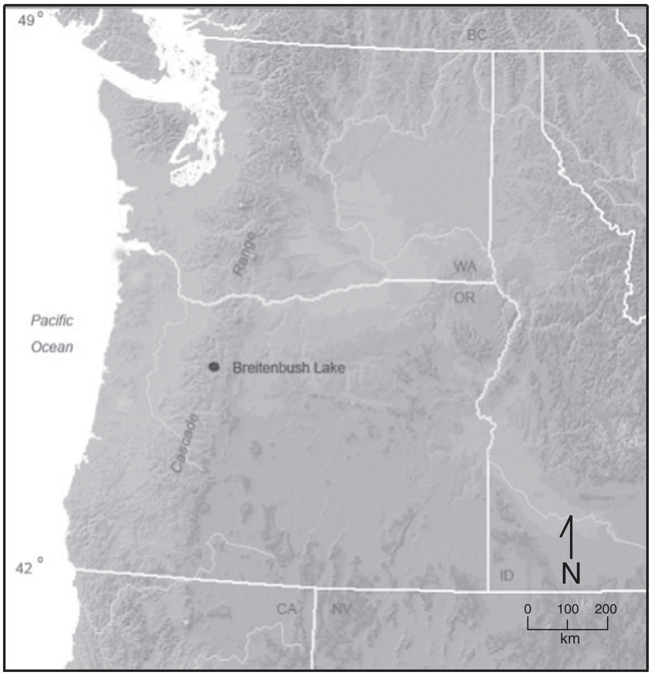

Fig. 2. Location of Breitenbush Lake in the Cascade Range of Oregon.

Methods

Coring

Sediment cores were collected from the deepest part of the lake using a 5-cm-diameter modified Livingstone sampler (Wright et al., 1984). Cores were extruded in the field, wrapped in cellophane and aluminum foil, and transported to the laboratory for analysis.

Determination of age-depth relationships

The chronology for the sediment core was based on five Liquid Scintillation Counts (^{14}C) of sedimentary charcoal and the established age of Mt. Mazama tephra (Zdanowicz et al., 1999), which was recovered in the core (Fig. 3; Table 1). All ages were converted to calendar ages (Reimer et al., 2009: IntCal13.14C dataset) and a smooth spline age-vs-depth model was established with 95% confidence intervals (CI) for each 1-cm section of core (Blaauw, 2010: clam 2.2). The age model curve was based on 10,000 iterations using a spar of 0.67, and resulted in a goodness-of-fit of 38.87. Ages were assigned to the sediment core as calibrated years before present (cal yr BP) with 1950 CE used as 0 cal yr BP and reported in kiloannum (ka).

Charcoal analysis

Variations in the abundance of macroscopic charcoal were used for fire history reconstruction. 3 cm^3 samples for charcoal analysis were taken at contiguous 1-cm intervals along the entire core following standard procedures (Whitlock and Larsen, 2001). Charcoal samples were soaked in 15% solution of hydrogen peroxide for 24 h. Sediments were then sieved and all charcoal particles greater than 125 µm were tallied. Charcoal counts for each sample were converted to concentration (particles/cm) and, using the median sedimentation rate of 34 yr/cm, to charcoal accumulation rates (CHAR, particles cm^2/yr). Conversion of the charcoal record to equal-time intervals was done to minimize the influence of variations in the time represented by each 1-cm sample