Quaternary Research 84 (2015) 348–357

Contents lists available at ScienceDirect

Quaternary Research

journal homepage: www.elsevier.com/locate/yqres

Postglacial vegetation and fire history of the southern Cascade Range, Oregon

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ARTICLE INFO

Article history:
Received 26 March 2015
Available online 2 November 2015

Keywords:
Holocene
Fire history
Climate history
Vegetation history
Pollen
Charcoal
Cascade Range
Oregon

ABSTRACT

The Cascade Range of southwestern Oregon contains some of North America's most diverse forests, but the ecological history of this area is poorly understood. A 7900-yr-long pollen and charcoal record was examined to better understand past changes in vegetation and fire activity in relation to large-scale climate variability. From 7900 to 3500 cal yr BP, the dominance of xerophytic species and the frequent fires are consistent with a climate that was warmer and drier than at present. The period from 3500 cal yr BP to present experienced an abundance of mesophytic taxa and reduced fire frequency, suggesting cooler and wetter conditions. The regional history of *Abies* indicates that it was most widespread during the late-glacial period; its range contracted during the early Holocene thermal maximum, and it steadily expanded during the middle and late Holocene. In contrast, *Pseudotsuga* was restricted in range during the glacial period, became abundant at low-elevation sites in the Coast and northern Cascade ranges during the early Holocene, and was more prevalent in southern mid-elevation sites as the climate became cooler and wetter in the late Holocene. The sensitivity of these species to past climate change suggests that biogeographic responses to future conditions will be highly variable in this region.

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Introduction

Our understanding of the fire, vegetation and climate history of northern California and western Oregon has come from paleoecological records from the Coast Range (Worona and Whitlock, 1995; Long and Whitlock, 2002; Long et al., 2007), the central Cascade Range and its eastern flanks (Sea and Whitlock, 1995; Minckley et al., 2007; Long et al., 2014), and the Klamath and Siskiyou mountains (Mohr et al., 2000; Briles et al., 2005, 2008, 2011; Daniels et al., 2005; Colombaroli and Gavin, 2010; Crawford et al., 2015) (Fig. 1). These records show that vegetation and fire changes throughout the Holocene were strongly governed by large-scale variations in the climate system related to the seasonal cycle of insolation and its effects on the strength of the northeastern Pacific subtropical high-pressure system in summer (Bartlein et al., 1998). Records from the Klamath and Siskiyou mountains also show that past ecological responses were also mediated by topographic gradients and substrate-dependent levels of nutrients (Briles et al., 2011). Native people were present in the Klamath region throughout the Holocene, and population numbers are thought to have been highest in the last 1500 yr (Arnold and Walsh, 2010; Crawford et al., 2015). Their influences on vegetation and fire regimes have been interpreted to be localized to population centers at lower elevations than Hobart Lake (Lake, 2013; Crawford et al., 2015).

One poorly studied area of the Pacific Northwest is the region of the southern Cascade Range, located north of the Sierra Nevada, southeast of the Oregon Coast Range, and northeast of the Klamath region, which includes the Klamath and Siskiyou mountains (Fig 1). The southern Cascades support plant communities composed of many species that are at the northern, southern, eastern or western limits of their biogeographic ranges, and because of the rich forest diversity it is an area of high conservation concern (Whittaker, 1960; 1972; Whitlock et al., 2004; U.S. Geological Survey, 2006; Odion and Sarr, 2007; Olson et al., 2012). This paper describes an 7900-yr-long vegetation and fire history of the southern Cascade Range, based on pollen, charcoal and lithologic records from Hobart Lake (41.09935°N, 122.48170°W, 1458 m, 3.2 ha) (Fig. 1). The record and its comparison with pollen data from other sites in the region help trace the Holocene history of two important conifers, *Abies* (fir) and *Pseudotsuga* (Douglas-fir), in response to past climate variations. These insights have important implications for understanding the range of vegetation responses likely in the future as a result of projected climate change.

Modern setting

Seasonal climate patterns at Hobart Lake are driven by the expansion of the Aleutian Low in winter, which directs frontal storms to

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http://dx.doi.org/10.1016/j.yqres.2015.09.007
0033-5894/ Published by Elsevier Inc. on behalf of University of Washington.

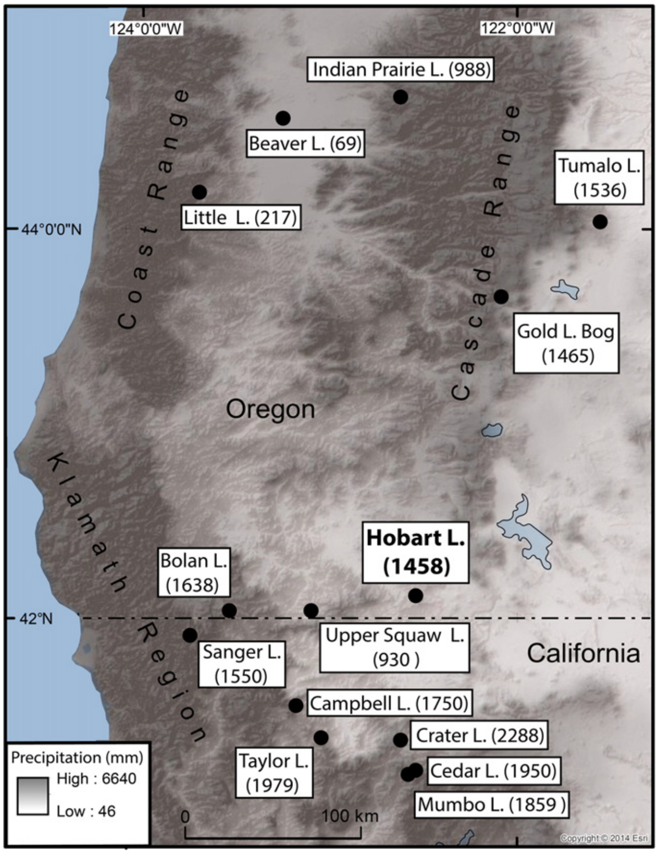

Fig. 1. The location of Hobart Lake and other pollen records in the region on a base map showing average annual precipitation from 1981–2010 (PRISM Climate Group, 2014). Numbers in parentheses are lake elevations in m asl. Beaver Lake and Tumalo Lake are not discussed in this paper.

the region, and the northeastern Pacific subtropical high-pressure system in summer, which creates seasonally dry conditions (Western Regional Climate Center, D. R. I, 2013). At Hobart Lake, winter and summer temperatures average to 1 and 19°C, respectively, and precipitation averages 760 mm/yr (PRISM Climate Group, 2014), of which approximately 50% is received in winter and the remaining amount falls in spring and fall (Western Regional Climate Center, D. R. I, 2013).

The vegetation of the southern Cascade Range, in general, is arrayed along gradients of elevation and climate (Odion and Sarr, 2007). The Interior Valley Zone, dominated by *Quercus garryana* (Oregon white oak) and *Quercus kelloggii* (California black oak), occurs below 800 m elevation and Mixed-Conifer Zone with *Pinus ponderosa* (ponderosa pine), *Calocedrus decurrens* (incense cedar), and *Abies concolor* (white fir) extends from 800 to 1400 m elevation. The *A. concolor* Zone is located from 1400 to 1700 m elevation, and subalpine forests of *Abies magnifica* (Red fir) and *Tsuga mertensiana* (mountain hemlock) in the *T. mertensiana* Zone lie between 1700 and 2500 m elevation. Areas above 2500 m elevation support alpine meadows (Franklin and Dyrness, 1988).

Hobart Lake is a landslide-dammed lake located in the Mixed-Conifer Zone. The watershed supports *Pseudotsuga menziesii*, *A. concolor*, *P. ponderosa*, and *C. decurrens*, although logging in the last 150 yr has favored *A. concolor* and *P. ponderosa*. *Abies procera* and *A. magnifica* hybridize in the region creating *A. magnifica var. shastensis*. Abies lasiocarpa, scattered farther north, does not occur near Hobart Lake. The mixed-conifer and *A. concolor* forests are characterized by low- to moderate-severity fire regimes with lightning ignitions occurring more frequently in these forests than in any other forest type in the Pacific Northwest (Agee, 1993). Based on tree-ring and charcoal studies from similar forests in the Klamath Mountains, fire-return intervals range from 11 to 19 yr (Taylor and Skinner, 1998; Mohr et al., 2000).

Methods

Two sets of 5-cm-diameter long cores were obtained from Hobart Lake with a modified Livingstone square-rod piston corer from an anchored platform in the deepest location of the lake. The first core, measuring 11.47 m long, was obtained in 2004 and the second, measuring 10.01 m in length, was recovered in 2011. A unit of impenetrable clay and silt was encountered at the base of sets of cores. Cores were extruded, packaged in plastic wrap, aluminum foil, and transported to the MSU Paleoecology Lab where they were refrigerated.

In the laboratory, cores were split longitudinally, described, and photographed. One-third of the 2011 core was archived. The top two meters of the 2004 core dried significantly prior to this study, and the 2011 core was used to fill in the upper section. It was correlated with the 2004 core based on litho- and chronostratigraphy (see results). Therefore, the top 2.35 m of the 2011 core and the bottom 9.17 m of the 2004 core were used for all analyses and treated as a single record.

Lithologic analyses

Loss-on-ignition analysis at 5-cm intervals was undertaken to quantify the organic and carbonate content of the lake sediments (Dean, 1974). For each interval, 1 cm^3 of sediment was heated at 80°C for 24 h to dry the material, then placed in a furnace and heated at 550°C for 2 h and re-heated at 900°C for two additional hours. Sample weight loss was measured between each procedural step. Magnetic susceptibility was undertaken for the entire 2011 core and portions of the 2004 core to assist in correlation. Magnetic susceptibility was measured with a Bartington magnetic susceptibility core logging sensor at 0.5-cm increments. Peaks in magnetic susceptibility, expressed in CGS $\times 10^{-6}$ units, record the input of ferromagnetic minerals from allochthonous material (Dearing, 1999) (Fig. 2).

Pollen

Pollen analysis was undertaken on samples, 1-cm^3 volume, extracted at 16-cm intervals. Processing followed standard methods (Bennett and Willis, 2001), including the addition of *Lycopodium* spore tablets of a known concentration to calculate pollen concentration (grains cm^{-3}). Pollen residues were mounted in silicone oil on slides and tallied under a microscope at 400 and 1000× magnification. Reference slides and pollen identification keys (McAndrews et al., 1973; Faegri and Iversen, 1975; Kapp et al., 2000) were consulted to identify each pollen grain to the lowest taxonomic level possible. A minimum of 300 terrestrial pollen grains was counted for each slide. Pollen percentages were calculated as a percent of total counted terrestrial pollen. Aquatic pollen percentages were calculated as a percentage of total terrestrial and aquatic pollen. This information was plotted using C2 and Tilia software, with zone designation determined using a constrained cluster analysis (CONISS) in Tilia (Grimm, 1987). Pollen accumulation rates (grains cm^{-2} yr^{-1}) were calculated by dividing pollen concentration by the sample deposition time.

Pinus pollen was separated into subgenus *Strobus*, subgenus *Pinus* and undifferentiated *Pinus* grains. *Pinus* subg. *Strobus* was attributed to Pinus lambertiana (sugar pine) or Pinus monticola (western white pine). *Pinus* subg. *Pinus* was assigned to *P. ponderosa*, which occurs locally, or Pinus contorta (lodgepole pine), which grows ~20 km east of Hobart Lake. *Abies* pollen is attributed to Abies grandis and *A. concolor* based on their modern phytogeography. *Alnus rubra*-type pollen is referred to Alnus rhombifolia (white alder), Alnus incana subsp. *tenufolia* (thinleaf alder) or *A. rubra* (red alder), all of which grow today in southwestern Oregon and northern California and have similar pollen