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Postglacial fire, vegetation, and climate history across an elevational gradient in the Northern Rocky Mountains, USA and Canada

M.J. Power [a,*], C. Whitlock [b], P.J. Bartlein [c]

[a] Utah Museum of Natural History, Department of Geography, University of Utah, Salt Lake City, UT 84102, USA
[b] Department of Earth Sciences, Montana State University, Bozeman, MT 59717, USA
[c] Department of Geography, University of Oregon, Eugene, OR 97403-1251, USA

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ABSTRACT

A 13,100-year-long high-resolution pollen and charcoal record from Foy Lake in western Montana is compared with a network of vegetation and fire-history records from the Northern Rocky Mountains. New and previously published results were stratified by elevation into upper and lower and tree line to explore the role of Holocene climate variability on vegetation dynamics and fire regimes. During the cooler and drier Lateglacial period, ca 13,000 cal yr BP, sparsely vegetated *Picea* parkland occupied Foy Lake as well as other low- and high-elevations with a low incidence of fire. During the warmer early Holocene, from ca 11,000–7500 cal yr BP, low-elevation records, including Foy, indicate significant restructuring of regional vegetation as Lateglacial *Picea* parkland gave way to a mixed forest of *Pinus-Pseudotsuga-Larix*. In contrast, upper tree line sites (ca >2000 m) supported *Pinus albicaulis* and/or *P. monticola-Abies-Picea* forests in the Lateglacial and early Holocene. Regionally, biomass burning gradually increased from the Lateglacial times through the middle Holocene. However, upper tree line fire-history records suggest several climate-driven decreases in biomass burning centered at 11,500, 8500, 4000, 1600 and 500 cal yr BP. In contrast, lower tree line records generally experienced a gradual increase in biomass burning from the Lateglacial to ca 8000 cal yr BP, then reduced fire activity until a late Holocene maximum at 1800 cal yr BP, as structurally complex mesophytic forests at Foy Lake and other sites supported mixed-severity fire regimes. During the last two millennia, fire activity decreased at low elevations as modern forests developed and the climate became cooler and wetter than before. Embedded within these long-term trends are high amplitude variations in both vegetation dynamics and biomass burning. High-elevation paleoecological reconstructions tend to be more responsive to long-term changes in climate forcing related to growing-season temperature. Low-elevation records in the NRM have responded more abruptly to changes in effective precipitation during the late Holocene. Prolonged droughts, including those between 1200 and 800 cal yr BP, and climatic cooling during the last few centuries continues to influence vegetation and fire regimes at low elevation while increasing temperature has increased biomass burning in high elevations.

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1. Introduction

During the summer of 2006, lightning caused over 420,000 ha to burn in the Northern Rocky Mountains (NRM) (Idaho, Montana, and Wyoming) contributing to one of the largest fire years in U.S. recent history (http://www.nifc.gov/). Research using tree-ring based fire-history suggests that regionally synchronous fire years in the NRM were linked to significantly warmer springs and warmer and drier summers (Heyerdahl et al., 2008; Morgan et al., 2008). Research by Arno (2000) suggests that low-elevation forests in the NRM burned on average every 17–35 years during the 18th and early 19th centuries. To understand if the return interval estimates are characteristic of fire regimes of longer time scales requires examination of lake-sediment records that provide information on climate, fire, and vegetation conditions over several thousand years. Previous paleoecological investigations reveal past changes in forest composition and fire activity have been predominately linked to orbitally-driven variations in regional climate (e.g. see review in Whitlock and Brunelle, 2006; Whitlock et al., 2011). Many of these pioneering studies in the NRM come from middle and high elevation forests (generally >2000 m asl), but relatively little is known about the history of vegetation

* Corresponding author. Tel.: +1 801 581 6520; fax: +1 801 581 8219.
E-mail address: mitchell.power@geog.utah.edu (M.J. Power).

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dynamics and biomass burning at lower tree line. We propose that past changes in vegetation and fire in the NRM are linked to elevation affects of climate forcing with high-elevation records being more responsive to changes in growing-season temperature, whereas low-elevation sites respond to changes in effective precipitation.

To increase our understanding of the environmental history of low-elevation forests, we present pollen and charcoal data from Foy Lake (48° 10′ N, 114° 21′ W, 1006 m elevation asl, 39.9 m water depth, 110 ha surface area) in northwestern Montana (Fig. 1). The water depth of the lake creates anoxic conditions, and the preservation of annual laminations (varves) has enabled high-resolution reconstructions of the paleolimnology (Stevens et al., 2006; Stone and Fritz, 2006). Reconstructions of past lake levels at Foy Lake also indicate large changes in hydrology, including periods of very low lake level (Shuman et al., 2009). The pollen record of the last 3800 years (Power et al., 2006) suggests dynamic shifts in vegetation at lower tree line with late Holocene *Pinus*-dominant forest patches and steppe vegetation being replaced by expanding *Picea, Abies, Pseudotsuga* and/or *Larix* forest between 2000 and 800 cal yr BP. During the last 800 years vegetation became more open with steppe limited to dry exposed slopes and compositionally diverse forests confined to more mesic habitats at low elevation.

1.1. Site description

FoyLake in the Flathead Valley of northwestern Montana was formed following late-Pleistocene retreat of the Flathead Valley sublobe of the Cordilleran Ice Sheet (Smith et al., 2000). The present mixture of forest and steppe near Foy Lake is strongly controlled by slope, elevation, and aspect. Closed forests of *Larix occidentalis* (western larch) (botanical nomenclature follows Hitchcock and Cronquist, 1973), *Pseudotsuga menziesii* (Douglas-fir) with an understory of *Clintonia uniflora* (Queen's cup) and *Symphoricarpus albus* (snowberry) on mesic north and east-facing slopes. Open forests of *Juniperus scopulorum* (Rocky Mountain juniper), *Pinus ponderosa* (ponderosa pine), *Pinus contorta*, and *Pseudotsuga* are present on dry south- and west-facing slopes as well as the valley bottom around the site. Steppe species include *Artemisia tridentata* (big sagebrush), *Chrysothamnus* sp. (rabbit-brush), *Pachistima myrsinites* (mountain-lover), and *Agropyron spicatum* (bluebunch wheatgrass), growing on non-forested areas, including south and west-facing slopes. At higher elevations and mesic settings, *Abies grandis* (grand fir) and *Picea engelmannii* (Engelmann spruce) dominate.

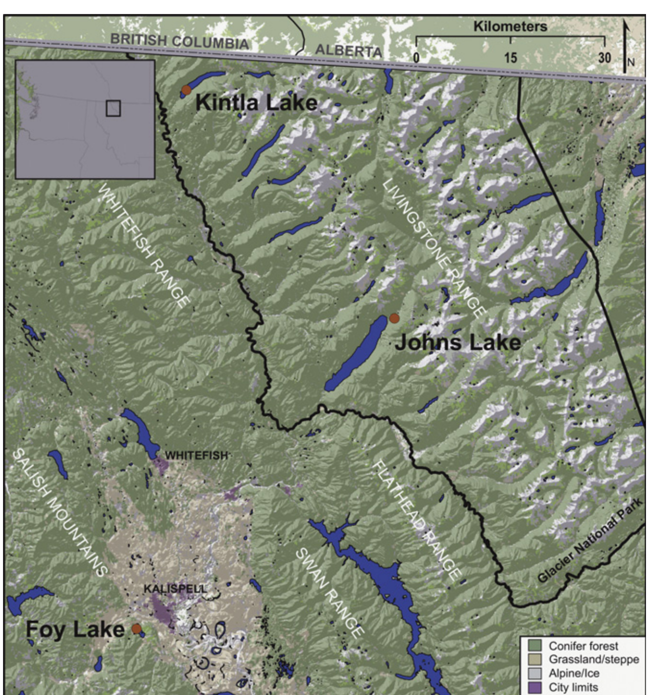

Fig. 1. Map of the Northern Rocky Mountains and Glacier National Park showing the location of three low-elevation pollen records discussed in text and the distribution of major vegetation types (overlain on a 30 m DEM).

Climate data from the Kalispell Airport (A.D. 1899–2003) indicate average maximum and minimum summer temperatures (June–August) of 24.9° and 8.6 °C and average maximum and minimum winter temperatures (December–February) of −0.4° and −8.5 °C, respectively. At a regional scale, the season of precipitation is determined by Pacific storm systems that deliver moisture in winter, the strength of the northeastern subtropical high-pressure system in summer to suppress precipitation, and convectional storms in spring and summer (Mock et al., 1998). Significant summer (JJA) precipitation averages 11.3 cm from June to August, as compared with a winter (DJF) average of 9.32 cm. Winter storms deliver snow to high elevations and the duration of snow cover and snowmelt affects soil and fuel moisture during the subsequent fire season (e.g. Westerling et al., 2006). Lightning from summer convective storms provides an important ignition source for fires (Morgan et al., 2008). Large fires in the last 100 years have been associated with an enhanced ridge over western North America, subsidence, and lower than-normal mid-tropospheric moisture advection into the region in summer (Power, 2006). During the summer months, low-elevation basins may experience weeks of drought, lowering soil moisture and drying fuels (Morgan et al., 2008). As convectional storm activity increases in July and August, forests become increasingly susceptible to lightning ignitions. The patterns of fire in the NRM are largely controlled by fire weather, topography, fuel moisture, and fuel connectivity (Agee, 1993).

2. Methods

2.1. Field

An 11.4-m-long sediment core was taken from the deeper of two basins (39.9 m of water) at Foy Lake with a five-cm-diameter Livingstone piston sampler (Wright, 1967) from the frozen lake surface. Multiple overlapping cores were combined and correlated by lithology. Cores were wrapped in cellophane and aluminum foil, and transported to the University of Nebraska where they were refrigerated. Freeze cores were also collected to obtain the mud-water interface in tact. These cores were kept frozen at the University of Nebraska, Lincoln until sampling.

2.2. Laboratory

The long cores were split longitudinally, photographed, and described. Samples for charcoal analyses were taken from contiguous 3–10 mm intervals, which represented ca 7 varve years on average. The sampling interval was adjusted to maintain this time span through the record. Samples were disaggregated in 5% KOH for 10–20 min and washed through a 125-μm-mesh screen (see Whitlock and Larsen, 2002 for discussion of methods). Macroscopic charcoal particles >125 μm in minimum diameter were identified and tallied at 36× under a stereomicroscope. Charred plant material was generally considered woody, but grass charcoal was identified based on morphological characteristics described by Enache and Cumming (2006) and were separated when possible based on width to length ratios.