

Holocene climate–fire–vegetation interactions at a subalpine watershed in southeastern British Columbia, Canada

Colin J. Courtney Mustaphi^{a,*}, Michael F.J. Pisaric^{a,b,1}

^a Ottawa–Carleton Geoscience Centre, Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6, Canada

^b Department of Geography and Environmental Studies, Carleton University, Ottawa, Ontario K1S 5B6, Canada

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ABSTRACT

Vegetation assemblages and associated disturbance regimes are spatially heterogeneous in mountain ecosystems throughout the world due to the complex terrain and strong environmental gradients. Given this complexity, numerous sites describing postglacial vegetation and fire histories are needed to adequately understand forest development and ecosystem responses to varying climate and disturbance regimes. To gain insight into long-term historical climate–fire–vegetation interactions in southeastern British Columbia, Canada, sedimentological and paleoecological analyses were performed on a sediment core recovered from a small subalpine lake. The pollen assemblages, stomata, and macroremains indicate that from 9500 to 7500 cal yr BP, *Pinus*-dominated forests occurred within the catchment and *Alnus* was also present. Climate was an important control of fire and fire frequency was highest at this time, peaking at 8 fires 1000 yr^{−1}, yet charcoal accumulation rates were low, indicative of low terrestrial biomass abundance. From 7500 to 4600 cal yr BP, *Pinus* decreased as *Picea*, *Abies* and *Larix* increased and fire frequencies decreased to 3–6 fires 1000 yr^{−1}. Since 7500 cal yr BP the fire regime varied at a millennial scale, driven by forest biomass abundance and fuel accumulation changes. Local scale (bottom-up) controls of fire increased in relative importance since at least 6000 cal yr BP.

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Introduction

Fire is one of the most important abiotic disturbances to forested ecosystems, influencing stand age and composition, biodiversity, soil stability, carbon flux and biogeochemical cycling. It is critical to examine historical rates of change and the mechanisms interacting at various spatial and temporal scales to understand how future climate and vegetation changes could affect fire regimes (Whitlock et al., 2010; Hessler, 2011). Fire occurrence in mountainous regions is a patchy phenomenon due to complex interactions between top-down (climatic) and bottom-up (local) controls over multiple temporal and spatial scales. The relative importance of various controls on fire regimes is not static through time (Gedalof, 2011), highlighting the need to develop numerous long-term paleoecological records to fully understand past climate–fire–vegetation interactions. Climate variability, a top-down control, varies on short and long time scales and interacts with vegetation, fuel abundance and conditions, topography and other bottom-up control factors that affect the energy and moisture regimes across the landscape. Over long time scales, in mesic ecosystems with substantial biomass growth and accumulation, temperature is the

most important control of postglacial fire activity (Daniau et al., 2012). In western North America, fire activity has increased in recent decades due to climate warming (Westerling et al., 2006) in combination with the ecological impacts caused by effective fire suppression (Marlon et al., 2012). However, how these influences affect fire regimes at high-elevation forests is less certain. Bottom-up controls, such as vegetation type and density, topography, and aspect, have also been shown to be important influences in explaining the spatial variability of fire activity in western North America (Heyerdahl et al., 2001; Gavin et al., 2006; Heyerdahl et al., 2007; Courtney Mustaphi and Pisaric, 2013). Lake sediment records provide a long-term perspective permitting the examination of Holocene fire regime variability and the relative importance of abiotic and biotic controls on past biomass burning (Whitlock and Larsen, 2001).

Records of vegetation and fire regime variability are necessary to inform land management policy and decision making (Gavin et al., 2007). Long-term fire histories need to be examined to resolve the relative importance of the interactions between top-down and bottom-up influences of fire across the heterogeneous landscape of mountainous southern British Columbia, Canada. Multiple studies have examined the long-term disturbance histories of Engelmann spruce-subalpine fir (ESSF; *Picea engelmannii*, *Abies lasiocarpa*) forests in southern British Columbia, Canada (Wong et al., 2004; Gavin et al., 2006; Courtney Mustaphi and Pisaric, 2013). Previous dendroecological studies in this region have shown that pre-settlement disturbance regime intervals in wet cool ESSF forest stands range from 90 to 807 yr and 105 to

* Corresponding author at: York Institute for Tropical Ecosystems, Environment Department, University of York, Heslington, York YO10 5DD, United Kingdom.

E-mail address: colin.courtney-mustaphi@york.ac.uk (C.J. Courtney Mustaphi).

¹ Current address: Department of Geography, Brock University, St. Catharines, Ontario L2S 3A1, Canada.

508 yr and that fires are the most important disturbance causing mortality over large areas (Dorner, 2001; Wong et al., 2004). Lower elevation sites within 10–40 km of the study site experience mixed severity fire regimes (Nesbitt, 2010), with stand-replacing disturbance intervals of 150–350 yr for ESSF forests (Pollack et al., 1997; Wong et al., 2004). Additional Holocene records are necessary to examine the linked or cascading interrelationships between different types of disturbance, to capture the full variability of fire activity (Courtney Mustaphi and Pisaric, 2013), and to spatially-resolve the controls of fire regimes (Heyerdahl et al., 2001).

Regional synchrony of fire activity is caused by the top-down influences of climate across the Pacific Northwest (Gedalof et al., 2005). Large fires in the interior of British Columbia are associated with blocking circulation patterns resulting in prolonged high-pressure systems causing fuel drying and intermittent convective thunderstorms (Johnson et al., 1990; Johnson and Wowchuk, 1993). Forests of the Kootenay region of southeastern British Columbia tend to burn during warm and dry years with no significant relationship with previous growing season conditions (Heyerdahl et al., 2002; Da Silva, 2009). Fires can occur in any given year, but are more likely to occur in the Pacific Northwest during regional summer drought (Trouet et al., 2010) associated, at decadal and sub-decadal time scales, with El Niño conditions (Heyerdahl et al., 2002). Climatic influences of winter snow accumulation and the rate of spring melting both have implications for the timing of the fire season. At multi-decadal scales, ocean–atmosphere interactions over the Pacific and Atlantic Oceans modulate fire activity in the Pacific Northwest (Kitzberger et al., 2007). It has also been shown, however, that local site factors can override regional climate as the dominant influence on fire regimes at many montane study sites in the Pacific Northwest (Heyerdahl et al., 2002; Gavin et al., 2006; Heyerdahl et al., 2007) and that the relative influence of various top-down and bottom-up controls varies through time (Heyerdahl et al., 2001; Courtney Mustaphi and Pisaric, 2013). For example, Engelmann spruce–subalpine fir forests on north-facing slopes burn less frequently than those on south-facing slopes during the late Holocene (Steventon, 1997; Gavin et al., 2006; Courtney Mustaphi and Pisaric, 2013), with Weibull median fire return intervals of 226–241 yr across north-facing watersheds and 135–190 yr at south-facing sites (Courtney Mustaphi and Pisaric, 2013). These results suggest that bottom-up controls of fire are important regulators of fire regimes in

this region; however, these controls may vary in relative importance through time and be mediated by top-down controls.

We present a postglacial fire and vegetation history study from a north-facing, subalpine watershed covered by a wet and cool ESSF forest. This study aims to investigate how fire regimes at a high-elevation ESSF-forested site have been influenced by Holocene climatic variability, changes to the vegetation assemblages, and the quantity of biomass within the catchment. To provide information on the local and regional vegetation cover variability, we present a pollen and stomata record established from a sediment core collected from the center of Lake NEL03 (unofficial name). We then integrate vegetation data with a high-resolution charcoal record representing historical forest fire activity to investigate Holocene climate–fire–vegetation interactions. Inferences on biomass are based on qualitative interpretations of dominant pollen types and total macroscopic charcoal accumulation rates. Sedimentological and other paleoecological information are also discussed to understand other lake-system changes and their relationships to terrestrial vegetation changes.

Study site

A large portion of the Nelson Range of the Selkirk Mountains is a managed forested land that is crucial to conservation efforts and the continued sustainability of environmental services provided by natural spaces in southeastern British Columbia, Canada. This region contains a large managed area of ESSF forest that has been minimally disturbed by anthropogenic activities and development, such as deforestation, fragmentation and grazing. It is therefore a useful region to examine the natural variability of past ecosystem dynamics; although, since AD 1945, these forests have been influenced by effective modern fire suppression (Nesbitt, 2010; Greene, 2011). A large portion of the population and infrastructure in the region is at the wildland–urban interface and it is one of the most ecologically diverse regions of British Columbia with notable managed lands, including the Harrop-Procter Community Forest, Midge Creek Wildlife Management Area, West Arm Provincial Park, and Kokanee Glacier Provincial Park.

NEL03 (unofficial name; 49°29′46″N, 116°54′17″W; Figs. 1 and 2) has a catchment area of 36 ha and is located near the head of a north–northeast trending, glacially and fluvially incised valley. It is a small (0.35 ha) subalpine, cirque lake (2074 m asl), with a subcircular

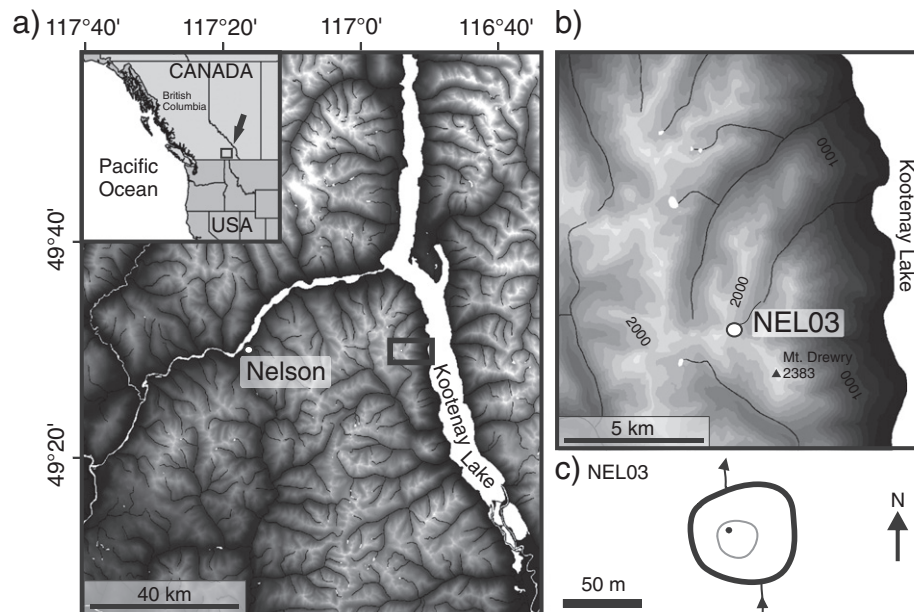


Figure 1. a) Location of study region, black box shows b) the lake site (100 m topographic contours), and c) depicts the lake bathymetry (2 m isobath) and coring location.

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