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Holocene vegetation history and fire regimes of *Pseudotsuga menziesii* forests in the Gulf Islands National Park Reserve, southwestern British Columbia, Canada

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ABSTRACT

Pollen analysis of a 9.03-m-long lake sediment core from Pender Island on the south coast of British Columbia was used to reconstruct the island's vegetation history over the last 10,000 years. The early Holocene was characterized by open mixed woodlands with abundant *Pseudotsuga menziesii* and a diverse understory including *Salix* and Rosaceae shrubs and *Pteridium aquilinum* ferns. The establishment of *Quercus garryana* savanna-woodland with *P. menziesii* and *Acer macrophyllum* followed deposition of the Mazama tephra until ~5500 cal yr BP, when these communities gave way to modern mixed *P. menziesii* forest. Charcoal analyses of the uppermost sediments revealed low charcoal accumulation over the last 1300 years with a mean fire return interval (mFRI) of 88 years. Fires were more frequent (mFRI = 50 yr) during the Medieval Climate Anomaly (MCA) with warm, dry conditions facilitating a higher fire frequency than during the Little Ice Age, when fires were infrequent. Given the projected warming for the next 50–100 years, land managers considering the reintroduction of fire to the Gulf Islands National Park Reserve may want to consider using the mFRI of the MCA as a baseline reference in prescribed burning strategies.

Introduction

Paleoecological studies from coastal British Columbia have provided considerable insight into how macroscale changes in climate since the last glaciation have facilitated the development of modern coniferous rainforests that occupy much of the north Pacific coast (e.g., Mathewes, 1973; Gavin et al., 2003; Brown et al., 2006; Galloway et al., 2009; Lacourse, 2009; Lacourse et al., 2012). Less is known about the paleoecological history of the adjacent dry forests that occupy southeastern Vancouver Island and the Gulf Islands, a comparatively small area in British Columbia. These forests are dominated by *Pseudotsuga menziesii* with *Quercus garryana* savanna present in fragmented patches within this forest matrix (Fuchs, 2001; Vellend et al., 2008). These open forests and savanna communities occur under a relatively dry, mild sub-Mediterranean climate and are unique in Canada, but similar vegetation extends southward into the Puget Lowland of western Washington and into Oregon, particularly in the rainshadow of the Coast Ranges (Thilenius, 1968; Franklin and Dyrness, 1973). Historically, low-severity fire was an important and regular agent of disturbance in these forests and helped to maintain savanna communities, particularly on deep soil sites, by inhibiting conifer encroachment (Tveten and Fonda, 1999; MacDougall et al., 2004; Gedalof et al., 2006; Vellend et al., 2008). These ecosystems in British Columbia have been heavily modified by human disturbance, settlement and the exclusion of fire, with much of this ecoregion converted to urban or agricultural areas (Lea, 2006; Vellend et al., 2008; Bjorkman and Vellend, 2010). Many rare and threatened species occur within remnant *Q. garryana* savanna (Fuchs, 2001), making these ecosystems a focal point of regional conservation efforts (MacDougall et al., 2004; Bjorkman and Vellend, 2010).

Pellatt et al. (2001) provides a well-dated record of Holocene vegetation change for southern Vancouver Island via high-resolution pollen analysis of a laminated marine sediment core from Saanich Inlet (ODP 169S). As with many palynological studies on marine sediments, the paleoecological record from Saanich Inlet documents regional-scale changes in plant communities, with adjacent but highly divergent vegetation types recorded simultaneously due to a large pollen source area. Allen (1995) provides pollen records from two small lakes on southeastern Vancouver Island that show *Pinus* dominated forests starting ~15,000 cal yr BP, followed by the development of *Pseudotsuga menziesii* forests after 12,000 cal yr BP and *Quercus garryana* increasing after ~9500 cal yr BP. Other studies from this region provide limited paleoecological information because of poor to no chronological control, because only major pollen types were identified, or because their records span only the last few hundred years (Hansen, 1950; Zirul, 1967; McCoy, 2006; McDadi and Hebda, 2008). These and other studies (Heusser, 1983; Gedalof et al., 2006) have attempted to clarify the fire history of these dry forests on southern Vancouver Island using charcoal analysis of sediments from the last few hundred years and using dendroecological methods, but these studies lack the long-term perspective needed to understand

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the importance of fire in maintaining forest and savanna communities on southern Vancouver Island on long timescales.

Charcoal analyses of Holocene lake sediment cores from this region (Brown and Hebda, 2002a) suggest that fire was relatively more important in the warm, dry early Holocene, compared to the mid-Holocene when available moisture increased. Determining the natural fire frequency of these forests and the relationship between fire regimes and climate change is critical for informing management strategies, including prescribed burning and restoration efforts, and for making more accurate predictions about the ecological impacts of future climatic change.

Here, we present fossil pollen and charcoal analyses of a ^{210}Pb and AMS radiocarbon-dated sediment core from Roe Lake, a small lake on Pender Island on the south coast of British Columbia (Fig. 1). The primary goal of this study was to reconstruct Holocene vegetation dynamics in the southern Gulf Islands with high temporal and taxonomic resolution. We combine our palynological results with other records from the Pacific Northwest to shed light on the postglacial abundance of *Quercus garryana*. We also use macroscopic charcoal analyses to examine local fire regime changes on Pender Island in relation to climate change over the last 1300 yr and to provide quantitative estimates of fire frequency in the most recent past. We focused charcoal analyses on the late Holocene in order to understand the importance of fire in modern forests on Pender Island. We then make recommendations regarding prescribed burning strategies for the Gulf Islands National Park Reserve.

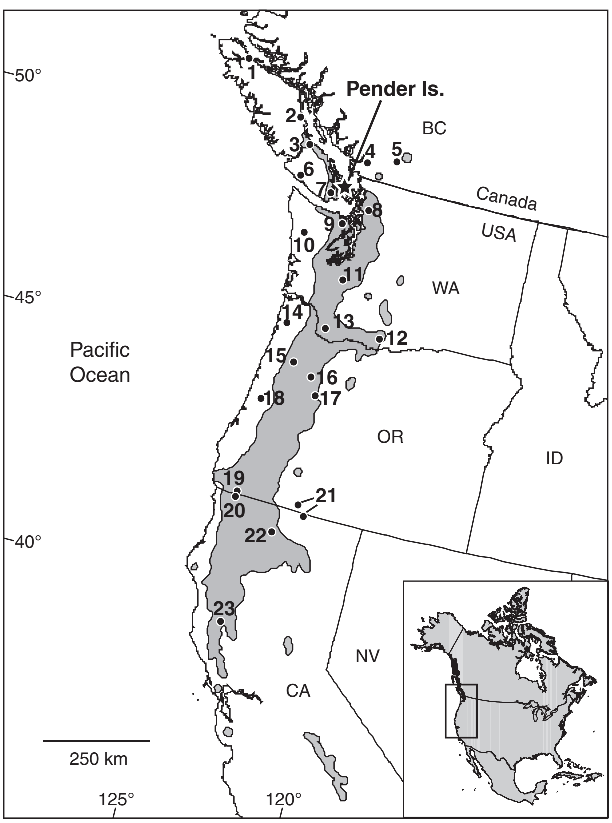

Figure 1. Map of western North America showing the location of Pender Island, the modern range of *Quercus garryana* from Thompson et al. (1999), and other paleoecological studies mentioned in the text: 1. Misty L. (Lacourse, 2005), 2. Black Creek Bog (Hansen, 1950), 3. Qualicum Bog (Hansen, 1950), 4. Marion L. and Surprise L. (Mathewes, 1973), 5. Pinecrest L. and Squeah L. (Mathewes and Rouse, 1975), 6. Pixie L. and Walker L. (Brown and Hebda, 2002b, 2003), 7. Langford Bog (Hansen, 1950), Rithet's Bog (Zirul, 1967), Heal L. and Rhamnus L. (Allen, 1995), Saanich Inlet (Pellatt et al., 2001), East Sooke Fen (Brown and Hebda, 2002b), 8. Mosquito L. (Hansen and Easterbrook, 1974), 9. Manis (Petersen et al., 1983), Cedar Swamp (McLachlan and Brubaker, 1995), 10. Humptulips (Heusser et al., 1999), 11. Davis L. (Barnosky, 1981), Mineral L. (Tsukada and Sugita, 1982), 12. Carp L. (Barnosky, 1985b), 13. Battle Ground L. (Barnosky, 1985a; Walsh et al., 2008), 14. Lost L. (Long et al., 2007), 15. Beaver L. (Walsh et al., 2010a), L. Labish (Hansen, 1942), 16. Indian Prairie Fen (Sea and Whitlock, 1995), 17. Gordon L. (Grigg and Whitlock, 1998), 18. Little L. (Worona and Whitlock, 1995; Long et al., 2007), 19. Bolan L. (Briles et al., 2005), 20. Sanger L. (Briles et al., 2008), 21. Caledonia Marsh and Tulelake (Hakala and Adam, 2004), 22. Bluff L. (Mohr et al., 2000), Mumbo L. (Daniels et al., 2005), 23. Clear L. (Adam, 1988).

Environmental history and setting

Southern Vancouver Island is characterized by rugged topography, modified extensively by the Cordilleran Ice Sheet (CIS) during the last glaciation. During its maximum extent, the Juan de Fuca lobe of the CIS overtopped the region with ~2 km of ice (Clague and James, 2002; James et al., 2009). The retreat of the CIS left the Strait of Georgia ice-free sometime before 14,000 cal yr BP (Barrie and Conway, 2002). There is evidence of extensive marine inundation due to eustatic and isostatic changes in sea level with a sea-level high stand (75 m asl) at 14,250 cal yr BP and a −30 m low stand at 11,200 cal yr BP (James et al., 2009). Modern sea levels were reached by 6000 cal yr BP.

Pender Island is located within the Gulf Islands National Park Reserve, a 62-km^2 reserve established in 2003 that is located immediately east of southern Vancouver Island in one of Canada's most 'at risk' ecoregions. The current management strategy in the Reserve focuses on maintaining the ecological integrity of *Pseudotsuga menziesii* forests and *Quercus garryana* ecosystems by protecting species at risk, managing introduced and invasive species, suppressing wildfire, and protecting cultural heritage (Parks Canada, 2006). Park ecologists are conducting research on historic fire regimes and using an experimental burning approach to assess prescribed burning as a management tool for ecological and cultural restoration.

The Gulf Islands are situated in the rain shadow of the Olympic Mountains and Vancouver Island Ranges, resulting in a dry climatic regime relative to surrounding areas. Temperatures are mild year-round. Climate normals (1971–2000) from nearby Mayne Island indicate a mean annual temperature of 10.2°C and mean annual precipitation of 829 mm/yr, most of which falls as rain during the winter months (Environment Canada, 2012).

Roe Lake (48°46.98′N, 123°18.18′W) is a small (3 ha), low-elevation lake (100 m asl) located on the northwestern side of Pender Island in the Gulf Islands National Park Reserve. The lake formed in a bedrock depression between two northwest-trending ridges (~200 m asl) of Cretaceous-age sandstone that form two limbs of a syncline. Roe Lake has a maximum water depth of 9.5 m and at present there are no inflowing streams. Forests surrounding the lake are dominated by *Pseudotsuga menziesii*, *Thuja plicata*, and *Abies grandis* in the canopy, with *Acer macrophyllum* and *A. glabrum* present along the lake margin and *Gaultheria shallon*, *Symphoricarpos albus*, *Polystichum munitum*, and *Pteridium aquilinum* common in the understory. A stand of *Alnus rubra* is located along the southeastern margin of the lake. Xeric taxa, including *Arbutus menziesii* and *Quercus garryana*, are scattered on the adjacent ridges.

Materials and methods

In total, 9.03 m of sediment was collected from the deepest part of Roe Lake, in 9.14 m of water. The sediment–water interface and the uppermost 47.5 cm were retrieved using a 6.25-cm-diameter Glew gravity corer (Glew et al., 2001), and a 5-cm-diameter Livingstone piston corer (Wright et al., 1984) was used for collecting the remaining sediment. The sediment core chronology is based on a combination of ^{210}Pb and accelerator mass spectrometry (AMS) radiocarbon ages (^{14}C) ages. ^{210}Pb ages were obtained from 17 sediment samples in the upper 30.5 cm of the sediment core (Table 1). Dried sediment samples were analyzed at MyCore Scientific in Deep River, Ontario. ^{210}Pb age determinations are based on the constant rate of supply model (Appleby and Oldfield, 1983). The remainder of the chronology is based on five