Ancient Earth Ovens and their Environment: a Holocene History of Climate, Vegetation, and Fire in Upper Hat Creek Valley, British Columbia, Canada

by

Miranda Brintnell
B.A., Wellesley College, 2007

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

MASTER OF SCIENCE

in the School of Earth and Ocean Sciences

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Supervisory Committee

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Abstract

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Paleoecological analyses of an alkaline fen in the southern Interior Plateau of British Columbia, Canada were undertaken in association with ancient earth ovens. Local and regional vegetation and natural disturbance regimes were reconstructed using pollen, plant macrofossils and macroscopic charcoal.

At White Rock Springs, *Artemisia*-Poaceae steppe occurred in the early Holocene and the inferred climate from this period was warmer and drier than present. Increasing moisture at 6000 ^{14}C yr BP fostered development of open *Pinus ponderosa* forests surrounding the fen, with *Pinus contorta* var. *latifolia* expanding at higher elevations. A slope-wash event likely resulting from root processing activities occurred in the late Holocene that resulted in 13% Asteraceae Tubuliflorae pollen at 2200 ± 80 ^{14}C yr BP. Macroscopic charcoal concentrations increased following this disturbance. Shortly after this time a modern open mixed conifer forest with *Pseudotsuga menziesii* was likely established. A second major ecological disturbance perhaps occurred within the last 200 years as indicated by fluctuating pollen values of *P. ponderosa*, Poaceae, Asteraceae Liguliflorae and wetland species.

The fen's vegetation history is consistent with regional records, but rapid changes during the late Holocene apparently occurred in response to disturbances. These disturbances are most likely linked to human root food harvesting and earth oven use, and later to ranching. Differentiation of *P. ponderosa* and *P. contorta* pollen types reveals intervals of local forest change that were not detected in previous studies. This study is part of a larger research project at Upper Hat Creek Valley including lithics, phytoliths, and patterns of earth oven structure.

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Dedication

To my Mom and Dad, Carolyn and Dave,
To my Brother, Joe,
To my Sister, Gina,
And to the wonderful world of natural history.

“Non ministrari sed ministrare”
(Not to be ministered unto, but to minister)
~Wellesley College, my alma mater

Chapter 1: Introduction

Interactions between past landscapes, environments, and peoples are central to understanding prehistoric cultural changes. Past landscapes cannot be observed or described directly; therefore archaeological palynology, a subdiscipline of paleoecology, is a useful tool to reconstruct cultural landscapes (Birks 1988**)**. Archaeological palynology tracks how landscapes transform amid human occupations and has many possible applications including insight into how humans might have modified a landscape (Hevly 1981**)**. In 1941, Johannes Iversen pioneered the first known detection of human induced landscape changes in prehistoric northern Europe (Pearsall 2000**)**. Arboreal pollen abundance diminished while non-arboreal pollen rose, suggesting land-clearing subsistence activities during the early and middle Neolithic (Bryant and Holloway 1996). Iversen's seminal work provides a basis for modern palynological investigations, especially those with significance local environments signals, made by comparing arboreal and non-arboreal pollen types and proportions.

Paleoecological studies in British Columbia have also combined palynology, archaeology and human history to reveal the influence that prehistoric peoples may have had on the landscape. For example studies of *Thuja plicata* pollen records suggest that the lifeways of coastal peoples were influenced by resource abundance (Hebda and Mathewes 1984; Lacourse *et al.* 2007, 2010). On southern Vancouver Island, Brown and Hebda (2002a) argued that peoples managed the landscape by increasing fire activity in mixed conifer forests during the Holocene. More recently studies on indigenous burning in Oregon and Washington have focused on short and long term trends in charcoal and other paleoecological studies (Scharf 2010; Walsh *et al.* 2010).

The Canadian Plateau Cultural complex refers to populations that subsisted in the Mid-Fraser River region (Figure 1) from 4500 to 200 ^{14}C yr BP (Chatters 1995) as described in Figure A-1. The modern descendants of the Plateau complex are the Secwepmec (Shuswap), Stl’atl’imx (Lillooet) and Nlaka’pamucx (Thompson) cultural groups (Chatters and Pokotylo 1998). Plateau inhabitants relied on the region’s ecological diversity to provide sufficient food to survive harsh winters (Pokotylo and Mitchell 1998). Anadromous salmon, lean ungulate meat, and plant foods, especially wild berries and underground ‘geophyte’ roots, were dietary staples. The pathways by which these resources were used figure prominently in the models of Plateau resource intensification proposed by Thoms (1989) and Peacock (1998).

Archaeological (Pokotylo and Mitchell 1998; Walker 1998; Prentiss and Kuijt 2004) and paleo-ethnobotanical data (Hayden and Cousins 2004) show that many Plateau inhabitants dwelled in at least two large housepit villages. The villages were composed of more than 50 simultaneously-occupied housepits by the late Holocene. At 2400 ^{14}C yr BP, hunter-gatherers resided in a large settlement at Keatley Creek (Hayden 1982, 1997; Hayden and Cousins 2004). A second village site was sporadically occupied at Bridge River from 1600 to 1150 ^{14}C yr BP (Prentiss *et al.* 2005; 2007; 2008).

Fluctuating salmon populations likely contributed to the growth and subsequent abandonment of pit-house villages on the Plateau (Hayden and Mathewes 2009). People lived in housepits along the Fraser River at the most ideal sites for salmon procurement (Hayden 1992; Prentiss *et al.* 2007, 2008). Improved technologies of mass harvesting and salmon storage facilities also developed (Hayden and Cousins 2004). According to Carlson (2010), dry climatic conditions may have limited fish stocks from 2200 to 1600

^{14}C yr BP as the number of freshwater salmon migrations fell. Salmon populations rose again as conditions became wetter from 1600 to 1100 ^{14}C yr BP.

The regional human and salmon populations both declined between 1100 to 900 ^{14}C yr BP (Kuijt 2001). Hayden and Ryder (1991) attributed this loss of salmon to impeded flow of the Fraser River due to a landslide 16 km south of Lillooet. Fluvial aggradation, river downcutting and terraced gravels provide geologic evidence for the destabilizing Texas Creek event (Hayden and Ryder 1991, 2003).

Prentiss *et al.* (2004, 2005, 2008) suggested an alternative reason for the disappearance of pit-house villages. Widespread glacial retreat in the Coast Mountains between 1200 and 1000 ^{14}C yr BP caused by abruptly warm, dry climate is suggested have decimated both salmon and root resources. Human population numbers fell as the newly warmed landscape limited the distribution of main subsistence flora and fauna (Lepofsky and Peacock 2004; Prentiss and Kuijt 2004). Rousseau (2004) favoured an explanation of overexploited ungulate and root resources between middle and high elevations for human population declines. He suggested that the carrying capacity of the Plateau environment was exceeded through technological developments by 1000 ^{14}C yr BP. To this day the debate over the cause of population losses remains unresolved.

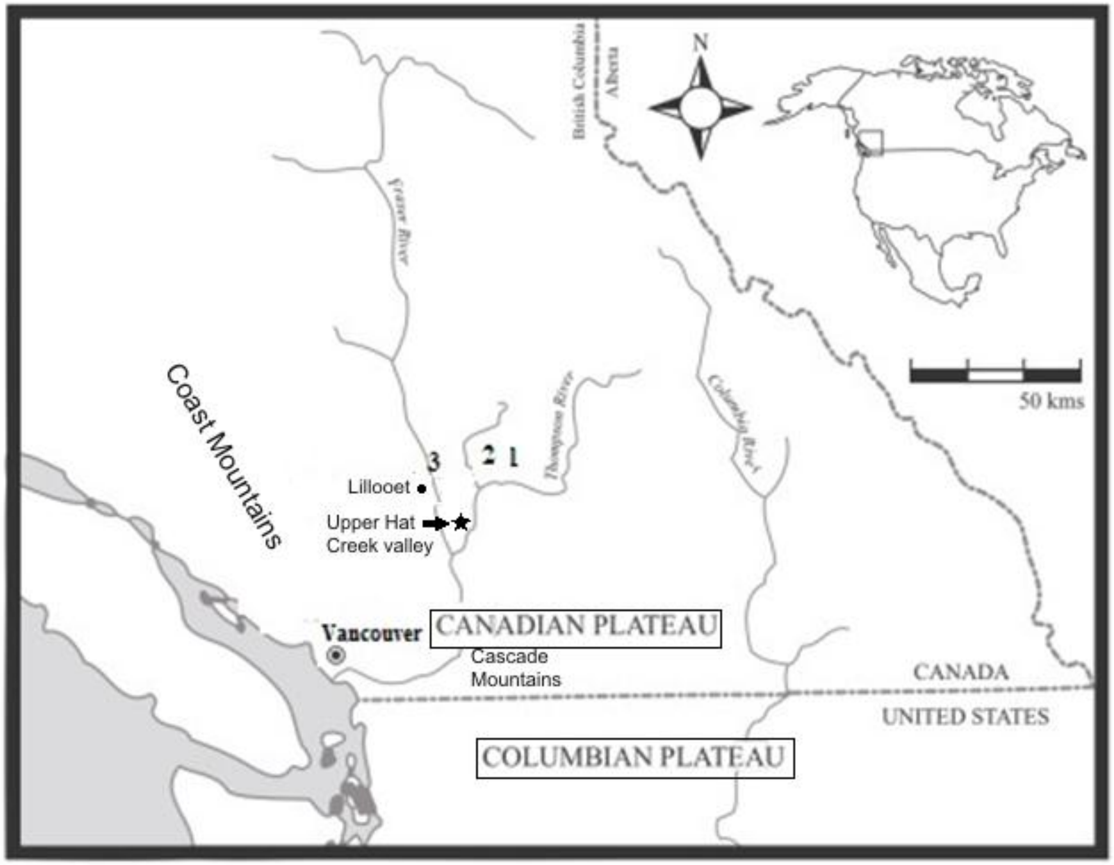

Figure 1. Map of selected traditional root collecting sites in southern interior British Columbia during the Holocene. 1) Komkanetkwa (Peacock 1998); 2) Oregon Jack Creek (Rousseau *et al.* 1991); 3) Potato Mountain (Alexander 1992). Modified from Nicolaides (2010).

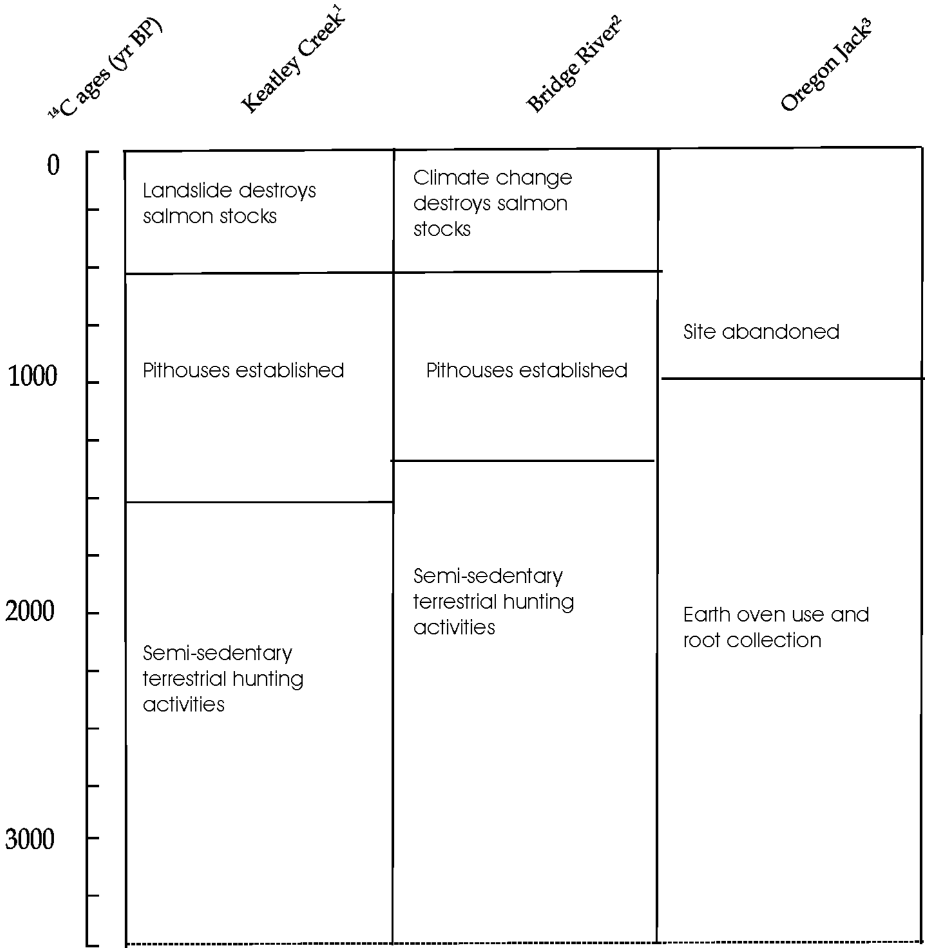

Figure 2. Summary of archaeological events in southern interior British Columbia. 1) Hayden (1982, 1997; Hayden and Cousins 2004); 2) Prentiss *et al.* (2004, 2005, 2008); 3) Rousseau (2004).

Earth Ovens

Small settlements of pithouses aggregated as population numbers grew from 3500 to 3000 ^{14}C yr BP. New subsistence technologies emerged for food procurement such as the bow and arrow along with digging sticks (Rousseau 2004). Another technological development from the same period was the ‘earth oven’ or root-roasting pit. Earth ovens were multi-family, multi-use subterranean baking pits that transformed indigestible root carbohydrates into digestible forms of food (Lepofsky and Peacock 2004). The occurrence of earth ovens implies wild geophyte exploitation and processing but not the domestication of plants (Smith 2001). Peacock (2008) hypothesized that expanded resource exploitation using earth ovens increased the possible carbohydrate energy provided from plant resources. Expanded resource exploitation led to an increase in human populations.

Root foods or edible geophytes are plants with perennial buds borne on subterranean storage organs (Dafni *et al.* 1981). Root foods include bulbs, corms, fleshy taproots, tubers, and rhizomes that are harvested after an extended maturation phase (Turner and Kuhnlein 1983; Thoms 1989; Peacock 1998). They are mainly composed of carbohydrates and provide high contents of dietary fibre and vitamins (Kuhnlein and Turner 1991; Beckwith 2004).

Earth ovens are evidence of a widespread technology used to exploit root foods on the Canadian Plateau (Figure 2). The number of documented earth ovens increased from 50 to over 450 as root processing camps expanded between 2500 and 250 ^{14}C yr BP (Nicolaides 2010). Keatley Creek and Bridge River are situated near four traditional root-collecting sites: Potato Mountain (Alexander 1992), Komkanetkwa (Peacock 1998), Oregon Jack Creek (Rousseau *et al.* 1991) and Upper Hat Creek Valley (Pokotylo and Froese 1983). It is likely that upland earth ovens were constructed near diverse types of desirable geophytes that were most widely available at mid to high elevations (Peacock 1998; Pokotylo and Mitchell 1998; Lepofsky and Peacock 2004).

The Hat Creek Valley Project

Since 2004 three broad areas of paleoethnobotanical research were undertaken at Upper Hat Creek Valley. Under the direction of Dr. Brian Kooyman, the application and development of starch and phytolith analyses has been completed by Nicolaides (2010). Also under Dr. Kooyman, plant tissues have been identified including charred root foods, and carbonized seeds using comparative collections by Croft (2011). This thesis is focused on local and regional paleoenvironment reconstructions of the valley.

Recent work (2004-2010) by Sandra Peacock, Brian Kooyman, David Pokotylo and Richard Hebda (Peacock *et al.* 2007; Peacock *et al.* 2006; Pokotylo *et al.* 2008) has added 24 more ovens to the previously identified 453 ovens. Croft (2011) also examined lithics from Upper Hat Creek Valley to better understand the patterning visible in the earth oven archaeological record and to determine whether there were variable periods of intensive root resource processing. It will also determine whether such periods are linked with changing climates during the Late Prehistoric Period (4500 to 200 BP) on the Canadian Plateau. Earth oven sites located upland in the valley have been discovered in this phase of Upper Hat Creek Valley research and mapped for future study.

Research Questions and Objectives

Hayden and Mathewes (2009) and Prentiss *et al.* (2004, 2005, 2008) both included regional paleoecological data in their analyses of Plateau human population dynamics. Their conclusions on subsistence resources were based almost exclusively on regional sites, not local environmental settings. Both sets of authors discussed the effects of climate change on local vegetation and landscape during the late Holocene. However, no known paleoecological studies have examined environmental dynamics adjacent to earth ovens and presumed root food procurement sites. Paleoecological studies may provide insight into ecological conditions that persisted during the time of earth oven establishment. They also indicate climatic conditions that may have influenced the abundance of root foods. A paleoecological study adjacent to earth ovens may indicate whether the harvesting and processing of root foods itself impacted the landscape.

This thesis addresses the question of landscape conditions and changes to them at the time of settlement intensification and development of earth-oven technology and is the first to collect paleoecological data immediately adjacent to a known root-processing site using higher than conventional sampling resolution. An earth oven site with nearby wetlands in Upper Hat Creek Valley, British Columbia, at White Rock Springs (WRS) was chosen to examine this issue. The White Rock Springs vegetation history record also contributes to a growing body of paleoecological data from the southern interior and provides additional environmental information for the interpretation of the general human history of the region.

Two research questions were initially posed:

1. Did regional and local vegetation and landscape change because of late Holocene climatic changes at the time earth ovens were established and root resource exploitation intensified in Upper Hat Creek Valley?

2. Did vegetation changes and landscape disturbances occur during the late Holocene that might have resulted from human use?

To answer these questions, the main objectives of the study are to:

1. Extract and identify fossil pollen, spores, plant macrofossils and charcoal from a fen sequence at the White Rock Springs site adjacent to earth ovens;

2. Reconstruct the past vegetation assemblages, the timing of changes in vegetation communities and from these data, infer what the climate may have been like in the Upper Hat Creek Valley during the Holocene; and,

3. Correlate the vegetation assemblages with previously established vegetation zones and climate histories from the southern interior of British Columbia and with the local archaeological record.

Chapter 2: Study Region, Area and Site

Regional Physiography and Geology

The physiography of southern British Columbia is composed of three broad units- the western Coast Cascade Mountain region, the Interior Plateau (of the Southern Plateau and Mountain area), and the Columbia Mountains to the east (Holland 1976; Mathews 1986). The Coast Cascade Mountain region is part of a mountain chain of northwest-trending, high-relief granitic and occasionally intruded metamorphic rocks found adjacent to the Pacific Ocean. The region extends over 1100 km in Canada and its mountains cast an extended rain shadow on its leeside (Mathews and Monger 2005). The Interior Plateau is approximately 900 km in length and 376 km in width at its maximum. It includes the Shuswap and Okanagan highlands, Okanagan valley, and Cariboo and Thompson plateaux. The Columbia Mountains extend a distance of 1600 km and include the Cariboo, Selkirk, Monashee, and Purcell mountains, on the west flank of the Rocky Mountains (Figure 3).

The focus of this study is the southern interior of British Columbia, the southernmost intermontane ecoregion of the Montane Cordillera Ecozone (Hebda and Heinrichs 2011). The regional physiography is generally composed of flat plateau expanses and gently rolling foothills (Holland 1976). Notable topographic features in the southern Plateau include the Pavilion Ranges (following Mathews 1986) and adjacent Thompson Plateau to the east. The Pavilion Ranges rise to peaks above 2000 m a.s.l. in the subrange known as the Clear Range within the study area.

As the Cordilleran Ice Sheet stagnated, late-glacial ice-damned lakes formed on the Thompson Plateau and later partially drained (Johnsen and Brennand 2004). Large lakes in the regional watershed include the Kamloops and Shuswap lakes and numerous smaller drainages such as Bonaparte River. The North and South Thompson rivers drain west and then south into the Fraser River.

Duffell and McTaggart (1952) and Blaise *et al.* (1990) provide overviews of the complex geological history of the Interior Plateau. Blaise *et al.* (1990) describe mountain building during the middle of the Cretaceous that is responsible for the region's high relief topography of mountains and valleys. The collision of the Wrangellia Terrane with the western edge of the North American continental plate caused the Coast Range's uplifted metamorphosed and granitic rocks (Duffell and McTaggart 1952).

Volcanism was widespread during the Cenozoic (Souther and Yorath 1992). Basalt flows from the Mio-Pliocene covered the Interior Plateau and later were intensely glaciated and incised by major streams and canyons (Mathews 1989). Several square kilometres of subbituminous coal underlie outcrops of volcanic rocks including dacite, chalcedony, basalt, and ochre in Upper Hat Creek Valley (Duffell and McTaggart 1952; TERA Ltd. 1978).

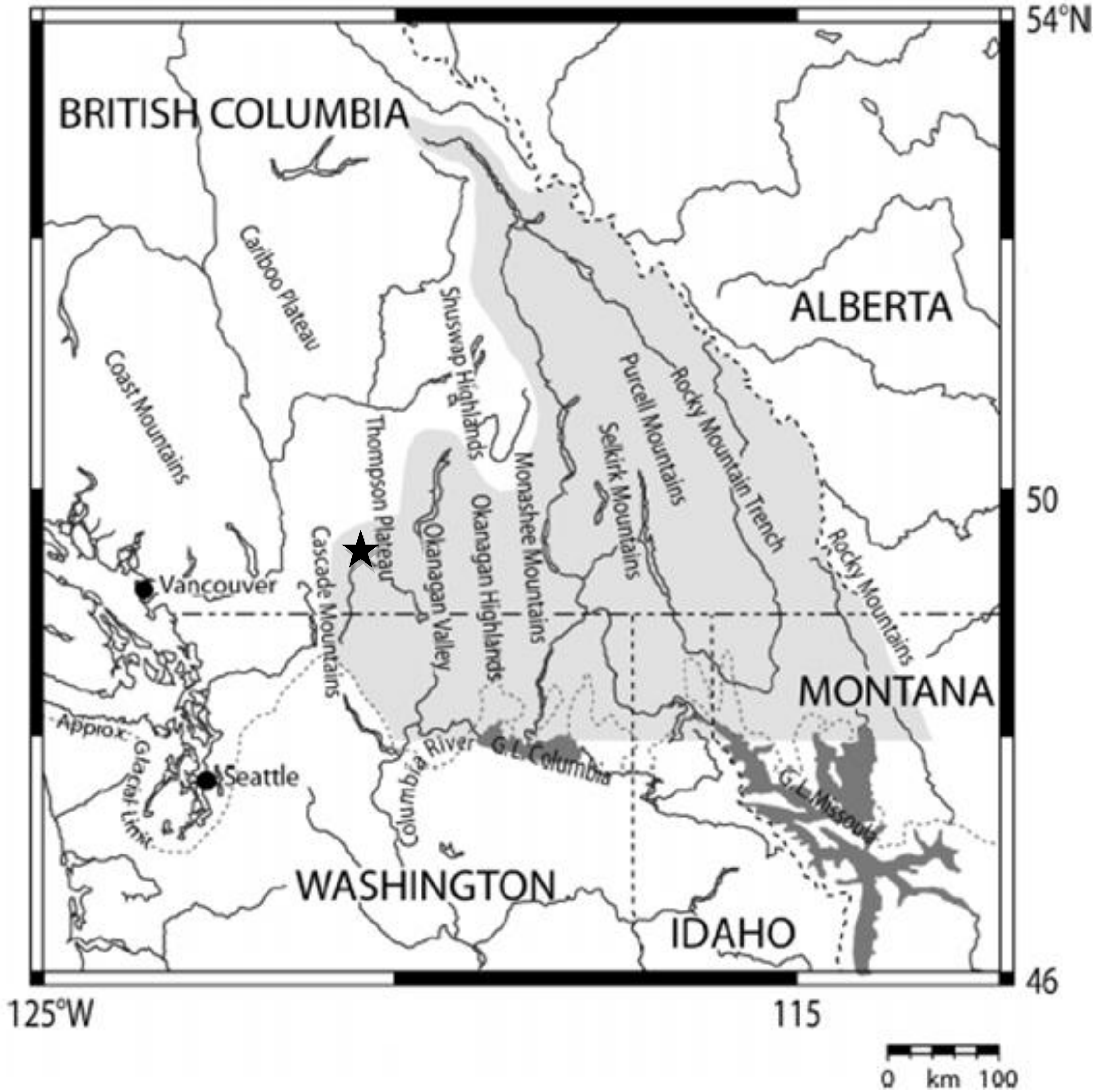

Figure 3. Map of southern British Columbia physiographic units, including the limits of the southern Cordilleran Ice Sheet. The White Rock Springs site is the black star. The grey region denotes the northern and southern Columbia basin. Modified after Walker and Pellatt (2008).

Glacial History

The latest Pleistocene glacial episode, known as the Fraser Glaciation, began more than 30,000 ^{14}C yr BP (Clague and James 2002). The glaciers emerged from the Coast Mountains after 25,000 ^{14}C yr BP and ice slowly coalesced over the Plateau lowlands and formed the Cordilleran Ice Sheet. The Fraser Glaciation reached its maximum extent at 15,000 ^{14}C yr BP. Ensuing glacier melt was rapid, and most of the lowlands were ice-free before 13,000 yr BP (Ryder 1991). The Hat Creek Valley became ice free by 13,170 ± 870 ^{14}C yr BP (Hebda 1996; Hebda and Heinrichs 2011). Stagnant blocks of ice persisted on the Interior Plateau and formed glacial lakes in valley lowlands as ice melted during the late Vashon Stade (Eyles and Mullins 1997). By 10,500 ^{14}C yr BP the remaining alpine glaciers were no more extensive than they are today (Clague 1989).

Glaciers in the Coast Mountains receded and subsequently re-advanced between 8000 and 4200 ^{14}C yr BP with similar advances reported in the Cascade Mountains (Miller 1969; Mathewes 1985; Ryder and Thompson 1986). Ryder and Thompson (1986) define the Garibaldi Phase of ice accretion between 6000 ^{14}C yr BP -5000^{14}C yr BP as detected by radiocarbon-dated buried stumps and detritus wood. Its extent has since been restricted through new evidence from proglacial lakes by Menounos *et al.* (2004) of glacial recession. The earliest of the late Holocene advances, the Tiedemann Advance, demarks a gradual shift toward cooler, wetter conditions in southwest British Columbia with evidence of glacial expansion between 2530±50 and 2280 ±50 ^{14}C yr BP (Pellatt *et al.* 2000; Palmer *et al.* 2002; Hallett *et al.* 2003; Spooner *et al.* 2003; Lamoureux and Cockburn 2005).

By 1000 ^{14}C yr BP, glaciers advanced down slope and achieved their maximal glacial extent in response to the Little Ice Age advance (Ryder and Thompson 1986; Menounos *et al.* 2009). Little Ice Age advances occurred in the Coast Cascade Mountain region between 850 to 750 ^{14}C yr BP and 350 to 250 ^{14}C yr BP (Ryder and Thompson

1986; Koehler 2009). A return to cool wet conditions around 1350 ^{14}C yr BP is documented at Lillooet and Bridge glaciers (Reyes and Clague 2004; Arsenault *et al.* 2007, Menounos *et al.* 2007). Post-glacial down-cutting and valley bottom deposition molded the area. Fluvial, alluvial and lacustrine deposits and processes occurred along valley bottoms.

Climate

The Interior Plateau is one of the warmest physiographic regions in British Columbia (Environment Canada 2012). The region's irregular topography and distance from the coast result in greater temperature ranges from valley bottoms to mountaintops than on the coast. Exceptionally hot dry summers occur on the leeward side of mountain ranges (Table 1). Lillooet, British Columbia, with mean July temperatures of 21.4 ºC holds the highest daily temperature on record for the province at 44.4ºC in 1941. The Highland Valley Mine has mean January temperatures of -6ºC and holds the lowest mean daily temperature of -27ºC in 1936 (Environment Canada 2012).

The climate of the Upper Hat Creek Valley is typically dry because moist, easterly flowing weather fronts are forced to rise and release their moisture over the Coast-Cascade Mountains before reaching the valley. Mean annual precipitation as measured at the Lillooet Climate Station is restricted to 279 mm (Environment Canada 2012). Mean annual rainfall is 312 mm in Upper Hat Creek Valley (TERA Ltd. 1978) and the record snowfall of 133 cm was recorded at Lehman's Ranch in 1960 (Parke 1993). Therefore the greatest amount of precipitation that falls in Hat Creek Valley occurs during the winter months.

Table 1. Climate information based on regional climate stations. Data from National Climate Data and Information Archive. Environment Canada since 1997 (Environment Canada 2012).

Climate Station (above sea level)	**Mean July Temperature ºC**	**Mean Jan. Temperature ºC**	**Annual Temperature ºC**	**Rainfall (mm)**	**Snowfall (cm)**
Highland Valley Mine (1268 m)	14.5	-6.0	4.0	231.5	155.8
Lillooet (198 m)	21.4	-3.6	9.2	297.1	32.4
Lytton (229 m)	21.4	-2.4	9.7	338.7	117.4

Vegetation

The basis for classifying vegetation communities in British Columbia is the Biogeoclimatic Ecosystem Classification (BEC) system (Meidinger and Pojar 1991). In this system, varying moisture, temperature, and soil types translate into characteristic ecosystems. BEC zones are the basic large scale units of classification and are based on plant communities and regional climates. A BEC zone is generally named after the predominant tree or other plants. BEC subzones are subdivided by climatic modifiers derived from relative precipitation and continentality. For example, the BEC subzone IDFxh is a very dry (x) and hot (h) subzone of the Interior Douglas-fir zone. In the study area, this ecosystem is located along middle to lower elevation slopes of the Fraser River and Thompson River valleys and in mid-elevation side valleys. Subzones with slightly wetter or drier, warmer or cooler conditions can be further described as variants and phases to account for further changes in relief (Lloyd *et al.* 1990). The plants and lichens of Upper Hat Creek Valley are listed in Table A-1.

The study area's varying elevation and topography comprises six BEC zones with their subzones and variants (Figure 4). The BEC zones of Upper Hat Creek Valley are Interior Mountain-heather Alpine (IMA), Engelmann Spruce Subalpine-fir (ESSF), Montane Spruce (MS), Interior Douglas-fir (IDF), and Ponderosa Pine (PP). These forested zones represent a range from cool, moist subalpine forests of the ESSF name (dominated by trees of Engelmann spruce and subalpine fir) to dry warm stands of Ponderosa pine in the valley bottom. IMA meadows occur above the forested belt.

The highest elevation BEC zone, the Interior Mountain-heather Alpine (IMA) zone, is found on the highest mountain peaks (Table 2). The zone starts at 2000 m above sea level (a.s.l.) in the southern interior of British Columbia. The timberline defines the lower limits of the IMA; occasional krummholz forms of trees may occur in snow-laden depressions of the IMA zone (TERA Ltd. 1978). Various species of *Phyllodoce*[1], *Carex*, and *Arenaria* persist with dwarf woody shrubs *Betula nana*, *Salix cascadensis,* and *Salix reticulata* under harsh conditions. Lichen genera include *Alectoria, Rhizocarpon* and *Dactylina*, and mosses include *Polytrichum* and *Racomitrium.* The short growing season is due to freezing temperatures, deep snowpack, and intense winds (Lloyd *et al.* 1990; Meidinger and Pojar 1991).The IMA occurs in the Natural Disturbance Type 5, alpine tundra and subalpine parkland ecosystems. The vast majority of areas in Natural Disturbance Type 5 were climax communities that restrict the rate of plant growth following a stand-initiating disturbance such as fires, landslides, and wildlife grazing (*Biodiversity guidebook* 1995).

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[1] Botanical nomenclature for these variants follows the eight volumes of Illustrated Flora of British Columbia (Douglas et al. 1998a;b, 1999a,b, 2000, 2001a,b, 2002) with recent additions from the website E-Flora BC (Klinkenberg 2011).

Two of the four dry Engelmann-Spruce-Subalpine-Fir (ESSF) variants occur in Upper Hat Creek Valley: the Very Dry Cold ESSFxc and Dry Cold ESSFdc. Dominant vegetation in the ESSF contains many overlapping IMA species in subalpine meadows and grasslands along with tall shrubs. The ESSFxc subzone is comprised of continuous mixed forests of *Abies lasiocarpa* var. *lasiocarpa, Picea engelmannii, Picea engelmannii x glauca* and *Pinus contorta* var. *latifolia* (henceforth *Pinus contorta*) with a well-developed shrub and herb layers including *Valeriana sitchensis* and *Vaccinium scoparium*. The ESSFdc subzone is defined by the presence of *Menziesia ferruginea*, *Gymnocarpium dryopteris* and *Streptopus lanceolatus* var. *curvipes* (Lloyd *et al*. 1990). Both the ESSFxc and ESSFdc, like the IMA, occur in the Natural Disturbance Type 5, and share the same natural disturbance regime.

A single Montane Spruce (MS) subzone MSxk variant Very Dry Cool Montane Spruce subzone occurs in Upper Hat Creek Valley. This zone is characterized by short, warm summers and long, cold winters with moderate snow cover. It is distinguished by slightly cooler conditions and moisture deficiencies compared to other MS subzones. Warm, dry conditions generate ideal circumstances for stand-burning fires. Mean annual precipitation is low and ranges from 300 to 900 mm, the majority of which falls as snow. MS forest stands are dominated by *Picea glauca, Picea engelmannii* and its hybrid *Picea engelmannii x glauca* along with *Abies lasiocarpa* and *P. contorta*. Other trees include *Pseudotsuga menziesii* with *Abies grandis* and *Thuja plicata*. Typically the understory is dominated by *Calamagrostis rubescens, Pleurozium schreberi* and *Arctostaphylos uva-ursi*. The MSxk occurs in the Natural Disturbance Type 3, frequent stand-initiating events. These areas experience frequent wind and wildfires of varying magnitude, frequent insect outbreaks, and extensive root disease. Disturbances vary the successional stage of the forest from early seral to climax communities (*Biodiversity guidebook* 1995).

Two variants of the Interior Douglas-fir (IDF) occur in Upper Hat Creek Valley: Thompson Dry Cool IDF (IDFdk) and Thompson Very Dry Hot IDF (IDFxh). The climax species for both variants include *Picea glauca x engelmannii, P. contorta* and *P. menziesii*. Drier sites include *Populus tremuloides* as a seral species. *Calamagrostis rubescens* is a typical grass throughout all subzones. Annual precipitation ranges from 295-750 mm and mean annual temperatures ranges between 1.6-9.5 ℃. A diverse herb/low shrub layer includes *Pteridium aquilinum, Rubus ursinus*, and *Symphoricarpos hesperius. Eurhynchium oreganum* and *Rhytidiadelphus triquetrus* are often present in a well-developed moss layer. IDFdk and IDFxh occur in the Natural Disturbance Type 4, frequent stand-maintaining fires. Low intensity fires are frequent and rare crown fires occur at intervals of 150 to 250 years or more in the IDF. Historically introduced weeds and unregulated livestock grazing have significantly altered the region’s biodiversity (*Biodiversity guidebook* 1995).

One variant of Ponderosa Pine (PP) occurs in the Upper Hat Creek Valley as the variant PPxh Thompson Very Dry Hot Ponderosa Pine. It is characterized by *P. ponderosa, Pseudotsuga menziesii* and *Festuca campestris*. The PPxh is distinguished from IDF subzones by more *P. ponderosa* and the absence of the grass *Pseudogoeneria spicata*. Summers are generally warm and dry while winters are mild and wet with less than half of precipitation falling as snow (Lloyd *et al.* 1990). The PPxh, like the IDFxh and IDFdk, occurs in the Natural Disturbance Type 4 and shares the same natural disturbance regime (*Biodiversity guidebook* 1995).

IMAun	⬜	Interior Mountain-heather Alpine
ESSFxcp,xcw,xc3	🟪 ▨ 🟦	Very Dry Cool Engelmann-Spruce Subalpine fir
MSxk3	🟪	Very Dry Cool Montane Spruce
IDFdk1a,xh2	🟨	(Very) Dry Interior Douglas-fir
PPxh2	🟧	(Very) Dry Hot Ponderosa Pine.

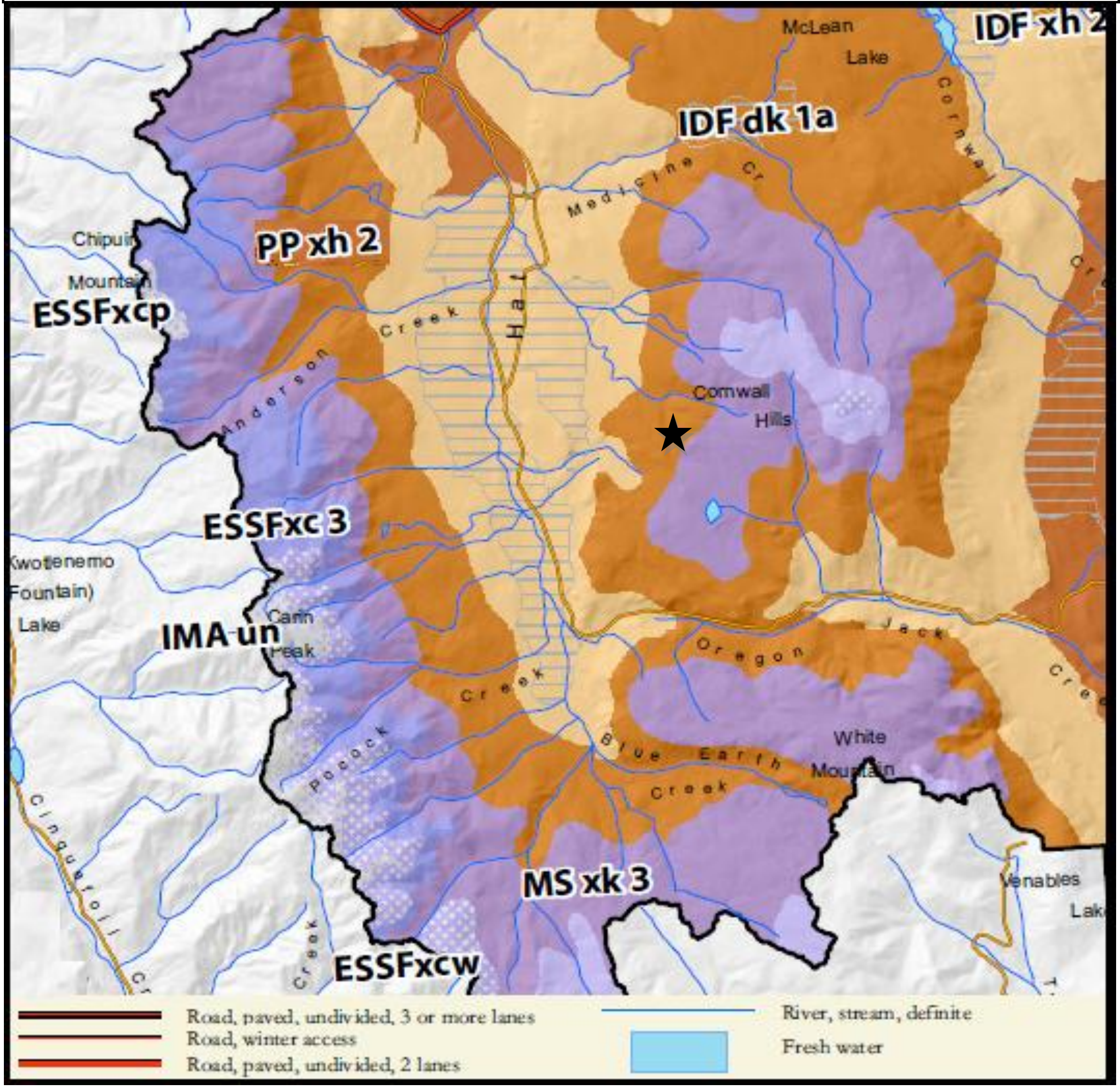


Figure 4. Site map of Thompson biogeoclimatic subzones in Upper Hat Creek Valley, British Columbia. The White Rock Springs site is the black star. Modified after BC Ministry of Forest and Range (2008).

Table 2. Biogeoclimatic subzones/variants in Upper Hat Creek Valley, British Columbia, after Lloyd *et al.* (1990).

Zone Name	Major species	Understory and Secondary Species	Location
IMA Interior Mountain-heather Alpine zone	*Abies lasiocarpa*, *Picea engelmannii*, *Picea glauca*, *Tsuga heterophylla*, *Pinus albicaulis*	*Salix* and *Betula* shrubs; sparse layer of bryophytes and lichens.	Variant occurs on high mountaintops throughout BC. It occurs above the ESSFxc and ESSFdc.
ESSFxc Very Dry Cold Engelmann Spruce-Subalpine Fir subzone	*Abies lasiocarpa*, *P. engelmannii* and *Pinus contorta* var. *latifolia*	*Valeriana sitchensis*, *Vaccinium scoparium*, *Juniperus communis*, *Rubus pedatus*, *Pseudogoeneria spicata*, *Anemone occidentalis*, *Koeleria macrantha* and *Calamagrostis rubescens*	Variant is located on isolated mountaintops across the Thompson Plateau. It occurs above the MSxk.
ESSFdc Thompson Dry Cold Engelmann Spruce-Subalpine Fir variant		*Menziesia ferruginea*, *Gymnocarpium dryopteris*, and *Streptopus lanceolatus* var. *curvipes*.	Variant occurs on the upper slopes along the North Thompson river. It occurs above the MSxk.
MSxk Very Dry Cool Montane Spruce subzone	*Picea glauca*, *P. engelmannii*, *A. lasiocarpa*, *P. contorta*, *Pseudotsuga menziesii*, *Abies grandis*, *Thuja plicata*.	Moderate shrub cover of *Arctostaphylos uva-ursi*, *Vaccinium scoparium*, *Lonicera utahensis* and *Spiraea douglasii* ssp. *menziesii*	Variant occurs at mid-elevations in the central Thompson Plateau. It occurs above the IDFdk and below the ESSFxc.
IDFdk Thompson Dry Cool Interior Douglas-fir variant	*P. ponderosa*, *P. menziesii*, *P. glauca x P. engelmannii* and *P. contorta*	Moderate shrub layer of *Spiraea betulifolia* ssp. *lucida*, *Hesperostipa comata*, *Paxistima myrsinites*, *Acer glabrum* and *Rosa* spp.	Variant is found at lower elevations of the central Thompson Plateau. It occurs above the IDFxh and below the MSxk.
IDFxh Thompson Very Dry Hot Interior Douglas-fir variant		Moderate shrub layer of *Spiraea betulifolia ssp. lucida Hesperostipa comata*, *Paxistima myrsinites*, *Acer glabrum* and *Rosa* spp.	Variant occurs in the valley bottoms and lower slopes of the Thompson and Fraser rivers. It occurs above the PPxh and below the IDFdk.
PPxh Thompson Very Dry Hot Ponderosa Pine variant	Open climax stands of *P. ponderosa* with minor *Pseudotsuga menziesii*	Sparse cover of *Symphoricarpos albus*, *Artemisia tridentata*, *Ericameria nauseosa*, *Penstemon fruticosus* and *Festuca campestris*.	Variant found in valley bottoms. It occurs below the IDFxh.

Study Area and Site

Glacial and fluvial erosion of landscapes in the Interior Plateau have produced broad to deep valleys including the Upper Hat Creek Valley (Ryder 1976; Eyles and Mullins 1997). The Upper Hat Creek Valley is located in a relatively broad north-south trending depression between the Clear Range to the west and the Cornwall Hills to the east on the Thompson Plateau. The valley is about 20 km long and 4 km at its widest points, narrowing at its northern end. The lower flanks of the mountains and hills slope gently toward the valley axis that descends from about 1200 m a.s.l. in the south to 950 m a.s.l. at the north end. The nearest high point is Chipuin Mountain at 2142 m a.s.l. located in the Clear Range. Eastward the Cornwall Hills reach about 2000 m a.s.l.

Upper Hat Creek is connected to the South Thompson River by the Bonaparte River (Figure 4) forming a long tributary of the Bonaparte River that flows mainly over surficial deposits (TERA Ltd. 1978). The hummocky terrain of Upper Hat Creek Valley supports roughly 80 small ponds and lakes including Finney Lake and Houth Meadows Lake (Holland 1976). The northern end of Upper Hat Creek encounters a Paleozoic upland at Highway 99, where it turns northeastwards and flows to the Bonaparte River.

The bedrock of Upper Hat Creek Valley is primarily Palaeozoic limestone. Metavolcanic rocks are overlain by Tertiary basalts, dacites and rhyolites from the Kamloops Group (Clague 1991) and coal/lignite formations (Pokotylo and Froese 1983). The Kamloops Group also includes lenses of siltstones, sandstones and clastic volcanic rocks dating to the Eocene (Duffell and McTaggart 1952). Pleistocene surficial deposits consist of recessional moraines capped by loess deposits up to 2 m thick (TERA Ltd.

1978). The outcrops of volcanic rocks include dacite, chalcedony and basalt in Upper Hat Creek Valley.

The White Rock Springs (WRS) study site consists of a fen located downslope from the main cluster of earth ovens and a second smaller wetland near the base of a west-facing bedrock cliff of limestone of the Cornwall Hills (Figure 5). The fen is located at 1200 m a.s.l. within hummocky topography near the point where glacially-derived valley fill abuts the bedrock walls and slopes of the east side of the valley. The terrain rises between the bedrock and the fen relatively steeply in a series of hummocks to the base of bedrock bluffs at 1220 m a.s.l. reaching 1400 m a.s.l. To the west progressively subdued hummocks lead to the valley floor about 1 km away.

The mostly treeless fen is oval in outline with dimensions of roughly 65 m by 115 m; White Rock Creek borders the fen to the south and drains it to the west. During times of extreme precipitation or snow melt, the creek water floods from the edge of the fen toward the middle over the surface (Figure 6). Fens are restricted to sites with high, stable water tables and high base cation availability (MacKenzie and Moran 2004). They can be slightly acidic but typically have a pH greater than 5.0. Unlike bogs, they receive nutrient bearing groundwater (Waller *et al.* 2005).

Carex spp. remains accumulate and decompose into peats and often combine with brown mosses such as *Campylium stellatum*, *Scorpidium scorpioides* and *Warnstorfia exannulata* (MacKenzie and Moran 2004). Species of *Scirpus* and *Juncus* also occur. Fibric and mesic peats are common in moister openings.

The vegetation of the WRS fen is a *Carex lasiocarpa-Drepanocladus* spp. site association of MacKenzie and Moran (2004). *Equisetum arvense* is also common. In addition to the sedges, a low-diversity herbaceous component includes *Triglochin maritima* and *Viola nephrophylla*.

A narrow forested band of hybrid spruce (*Picea engelmannii x glauca*) (Strong and Hills 2006) surrounds the wetland immediately upslope from the shore. On the fen's south border, deciduous trees predominate over conifers and persistent flooding limits broadleaf species to *Alnus viridis* and *Populus balsamifera* ssp. *trichocarpa*. Park-like stands of *Pseudotsuga menziesii* surround the fen on rolling upland sites.

Scrubby *Salix, Rosa* and *Juniperus* spp. are interspersed with *Shepherdia canadensis* in dry and dappled forest openings. The forest understory includes native *Cirsium drummondii* and *Cirsium undulatum* with *Thalictrum occidentale* and *Sedum* spp. on rocky substrates.

Shrubby *Betula occidentalis* predominates in the well-developed shrub layer of *Symphoricarpos albus* and *S. occidentalis* immediately east of the fen. Clones of *P. balsamifera* ssp. *trichocarpa* form pure stands on floodplains adjacent to *Picea engelmannii x glauca* along the fen's south border.

Southern exposures on moderate slopes above the site have meadows in which earth ovens are located. These are typified by native *Achnatherum richardsonii, Balsamorhiza sagittata, Festuca campestris, Festuca idahoensis,* and *Koeleria macrantha*. *Artemisia frigida* and *Geranium viscosissimum* occur in clumps. Prolific patches of *Antennaria rosea, Fragaria virginiana, Lithospermum ruderale* and *Achillea millefolium* are evident in spring. *Arabis* spp., *Prunella vulgaris, Geum triflorum, Ribes* spp. and *Erigeron* spp. are also common.

With overgrazing, the IDF zone has become occupied by introduced species including *Bromus tectorum*, *Tragopogon pratensis* and *Centaurea scabiosa*. Invasive species also begin to replace native *Poa spicata, Poa secunda* and *Sporobolus cryptandrus*. *Hesperostipa comata* and *Salsola tragus* are common as are invasive *Cirsium vulgare*.

Steppe-like communities dominate the rolling hills at slightly lower elevations to the west of the fen. At 1150 m a.s.l open stands of *P. ponderosa* occur, now mostly dead or dying from infestations by *Dendroctonus ponderosae* (Ponderosa pine beetles). Native grasses of *Poa spicata* and *Leymus cinereus* are gradually replaced by *Poa pratensis* in the PP zone. The shrub layer is composed of *Arctostaphylos uva-ursi, S. albus, Amelanchier alnifolia,* and native *Aconitum columbianum* and *Delphinium nuttallianum.*

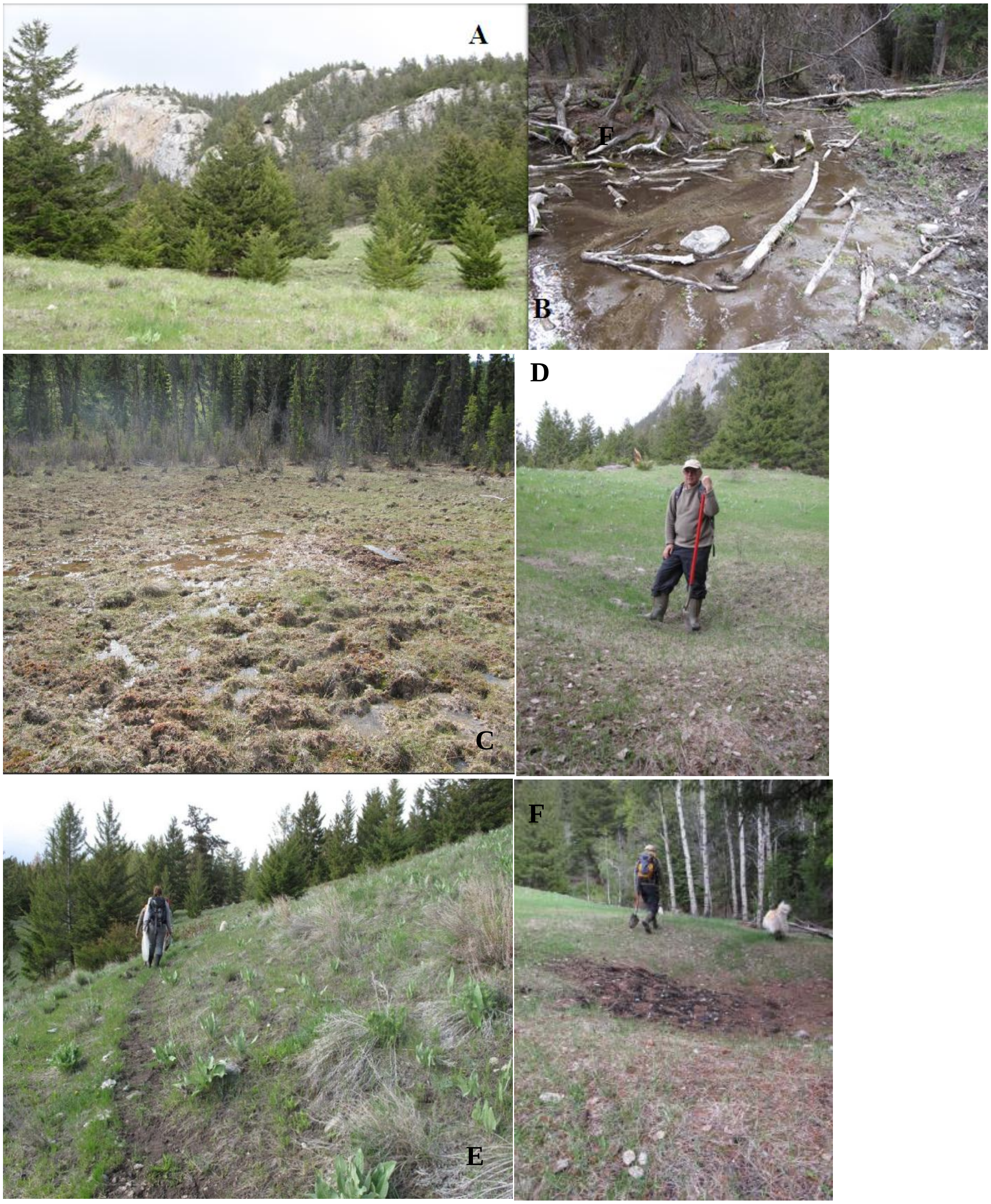


Figure 5. Landscapes in the vicinity of the study site: A) Grass and forb meadows with trees of *Pseudotsuga menziesii*. Cornwall Hills in background looking north from White Rock Springs (average peak elevation is 1890 m a.s.l.); B) White Rock Springs, the site's namesake and main source of water, is located to the southeast. C) The thesis study site. D) A photo of an unexcavated earth oven. E) Slopes above the fen covered in *Balsamhoriza sagittata* and *Lithospermum ruderale*. F) A photo of an excavated earth oven.

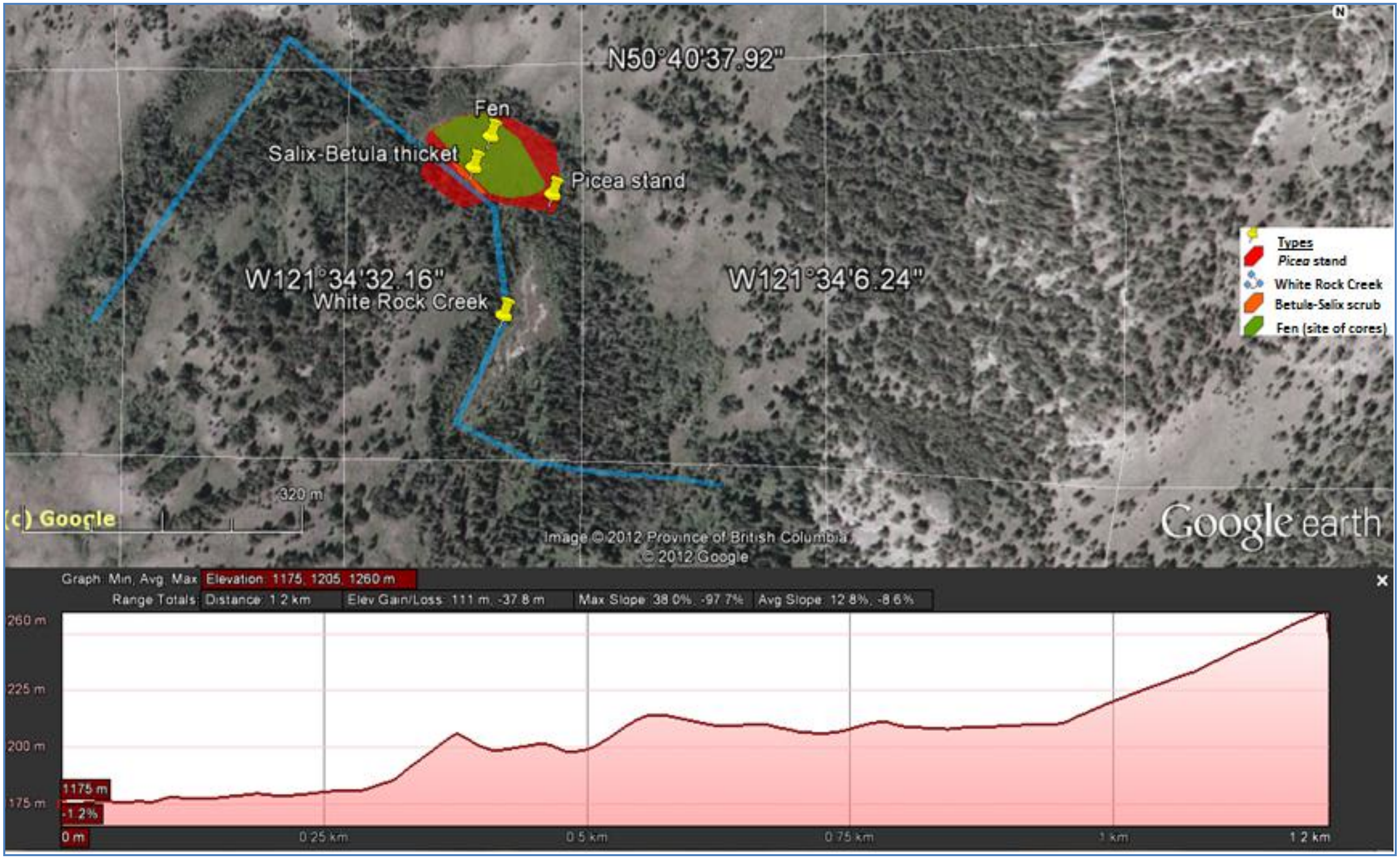


Figure 6. Ecological map and slope profile of the study site in the Upper Hat Creek Valley (Google Earth 2011).

Regional and Local Paleoecology

Background

Chronologically and stratigraphically constrained Quaternary paleoecological studies of lake sediments have been highly successful at reconstructing past regional plant communities (Moore and Webb 1978). Sample sites representing small spatial scales such as bogs, fens, and ponds may reflect local vegetation more closely than lakes. When considering the interpretation of pollen assemblages it is especially important to calibrate fossil assemblages with pollen from surface samples that represent modern plant communities and environments (Bradshaw and Webb 1985). Comprehensive paleoecological reconstructions also include plant macrofossils where possible to help identify plant species and establish their local occurrence of it at the site of study (Faegri and Iversen 1975; Birks and Birks 1980). Plant macrofossils can also provide information about species that are poorly reflected in pollen record e.g. species that produce small amounts of pollen or whose pollen is poorly dispersed or preserved.

Ecological Disturbances

Detecting signs of ecological disturbances using proxies is central to achieving this study’s objectives. Other paleoecological reconstructions from the interior of British Columbia have detected fires, disease, herbivory, grazing, windstorms and volcanism that alter the structure and composition of interior forests, savannahs and grasslands (e.g. Heinrichs 1999; Gottesfeld *et al.* 1991; Parminter 1998). Disturbances occur on many timescales, making them difficult to tease apart from broader climatic trends (Gottesfeld *et al.* 1991). For example, volcanic eruptions can destroy vegetation while its ash simulatenously decreases incoming solar radiation, together triggering a variety of biotic and abiotic landscape changes (Agee 1998). A shift from dry to wetter conditions favouring more trees near mid-elevation southern interior lakes has been reported by Smith (1997), Heinrichs (2001) and Mathewes and King (1989) following the eruption of Mt. Mazama at 6730 ± 40 ^{14}C yr BP (Hallett *et al.* 2003). Volcanism resulted in a large-scale disturbance in the early Holocene but severe, recurring stand-destroying fires were much more common in the rest of the Holocene on the Plateau (Hebda and Heinrichs 2011).

The pre-European fire regime of forest stands of *P. ponderosa* included persistent burning that prevented the buildup of fuel and lessened the severity of fires (Turner and Romme 1994). Fires can produce abundant charcoal fragments that are deposited mostly at the fire's centre (Long *et al.* 1998). The preservation of charcoal, especially as macroscopic fragments, steadily decreases moving away from the fire's edges (Clark *et al.* 1997). Charcoal accumulation rate studies of macroscopic and microscopic from southern British Columbia by Hallett *et al.* (2003), Wainman and Mathewes (1987), and Enache and Cumming (2006) demonstrate regional and their respective site's local fire activity. Subsampling of soils, sediments, and deposits can often detect short-lived and/or low intensity fires (Dunwiddie 1986; Clark 1990; Whitlock and Millspaugh 1996, Parish *et al.* 1999).

Studies in southern interior British Columbia

Paleoecological reconstructions from lakes in southern interior British Columbia provide a regional history of the Plateau. Studies of Finney Lake, in Upper Hat Creek Valley (Hebda 1982a,b), Phair and Chilhil lakes (Mathewes and King 1989), Crater Lake and Mount Kobau in the Okanagan valley (Heinrichs 2002a,b) were the basis for the recent synthesis of the Montane Cordillera Ecozone by Heinrichs and Hebda (2011). This synthesis is placed in the context of a provincial summary by Hebda (1995) and a broad review of the Columbia River Basin by Walker and Pellatt (2008).

Ecosystem dynamics in southern interior British Columbia that are based on palynological studies remain understudied to date. The foci of these studies have been dramatic shifts in climate following regional temperature and precipitation trends. The late-glacial climate was dry and cold, and rapidly warmed by 10,000 ^{14}C yr BP (Hebda 1995). The following warmer, drier ‘xerothermic’ climate persisted until about 7000 ^{14}C yr BP (Hebda 1982a,b). The mid-Holocene was moister and the warm ‘mesothermic’ climate persisted until about 4000 ^{14}C yr BP. The late Holocene was the beginning of climatic stabilization when modern cooler, wetter conditions emerged in southern interior British Columbia (Hebda 1995).

Climate influenced vegetation changes in southern interior British Columbia are began with initially warm, dry conditions in the early Holocene that gave way to wetter climate between 9000 and 7800 ^{14}C yr BP (Hebda 1995). Mathewes and King (1989) suggest deepening water levels at Chilhil Lake and the establishment of Phair Lake after 7000 ^{14}C yr BP based on macrobotanical and midge fossils. Rosenberg *et al.* (2003) reconstructed summer temperatures of two subalpine lake using fossil midges. They report initial warm temperatures during the early Holocene followed by cooler mean temperatures oscillating between 8.7ºC and 13.1ºC until modern conditions established by 4200 ^{14}C yr BP. Heinrichs (1999) also reports changing salinity values in montane lakes at Mount Kobau.

Vegetation composition within these climatic intervals appears stable. Forests and stand dynamics may change more quickly, especially when exposed to disturbances. Close interval sampling, which yields higher temporal resolution, is useful to determine decadal-scale rate changes in vegetation over small spatial scales (Williams *et al.* 2004). Slight "time-transgressive" vegetation changes also depend on a site's location within an ecotone, as shown by Mathewes (1985).

Chapter 3: Methods

Field Work

The focus of the study required a site with strong local and extralocal pollen and spore signals (e.g. Heinrichs 1999; Rosenberg *et al*. 2003) in order to describe changes in the immediate vicinity of the earth ovens and detect disturbances that may have resulted from earth oven construction and use. Several small wetlands occur within the Upper Hat Creek Valley near the earth oven complex. One small wetland is directly downslope about 200 metres away from three well developed earth ovens known as cultural features numbered 15, 16, and 18 (Peacock n.d.). The ovens are clearly visible as they are more than 3 m in a diameter, and their large size was the reason for macrobotanical analyses of their contents by Nicolaides (2010). Also the middle of the wetland was relatively undisturbed; however cattle tracks were observed at its edges.

In August 2009, preliminary sampling focused on removal of the top 200 cm. The samples are inferred as including the Late Prehistoric occupation interval of the valley (Peacock 2002). In addition, three 0.25 x 0.25 square by 0.6 metre deep blocks representing the upper 60 cm of fen were collected. The deposits were recovered from the pit in the wetland adjacent to White Rock Creek. Samples were scraped off using a clean spade and knife to avoid contamination from modern material. Peat blocks were kept intact and further subsampled in the laboratory.

In May 2010 nine uncompressed core segments measuring 3.6 m in total length were obtained using a Russian peat corer. An impenetrable layer was reached at 4 m. All recovered material from the cores was bagged separately in the field, cut into 1 cm to 5 cm segments for this study.

Surface samples were obtained in May 2010 from plant communities in and around the fen. Samples of moss polsters were placed into individual plastic bags upon collection to avoid contamination (for methods see Hebda and Allen 1993; Pellatt *et al.* 1997). The percent of plant species cover was visually estimated. Surface sample locations and elevations were recorded using a Global Positioning System (GPS) unit for each sample.

Laboratory Work

Standard pollen and spore preparation techniques were used to process all surface and fen samples with modifications due to varying deposit types (Faegri and Iverson 1975; Bennett and Willis 2001; Berglund and Ralska-Jasiewiczowa 2003). Treatments were conducted at the Royal BC Museum Paleoecological Laboratory. The interval of sampling became larger as the age of the deposit increased. Every 5 cm was subsampled between the 400 and 200 cm in the core. From 200 to 20 cm, the estimated period of use of the earth oven complex, samples were taken every 2 cm. In the immediately pre-historic and historic interval from 20 cm to the surface, samples were spaced at 1 cm intervals. In each case 1cm^3 of sample was processed for analysis. If the quantity of pollen and spores did not reach 300 pollen and spores, a new sample was prepared.

Wet organic and calcareous samples were sieved at 212 µm to remove large macrofossils. The screened material was subsequently treated with 5% hydrochloric acid (HCl) overnight to remove carbonates and washed three to four times in water after the samples were centrifuged. Samples containing a visibly high portion of macroscopic plant matter were stirred and boiled for 5 to 10 minutes in 5% potassium hydroxide (KOH). After boiling, the samples were centrifuged and their supernatant fluids were decanted. The residual material was treated with 5% potassium carbonate (K_2C0_3) for neutralization and removal of humic material and then repeatedly washed in water.

Eight moss polsters were collected at surface samples locations. The polsters were processed in a similar manner using 3 cm^3 of the dried, crushed moss and sieved at 212 µm to remove large plant debris. These were treated with cold hydrofluoric acid (HF) overnight to remove silicates. The residual material was washed in distilled water.

One or two tablets of *Lycopodium* spores were dispersed into all samples. A single exotic tablet contains a known number of palynomorphs; in Batch # 938934 there were 10,679 ± 953 *Lycopodium* spores used to calculate pollen and spore concentrations and accumulation rates (Stockmarr 1971).

After dehydration in glacial acetic acid, samples were subjected to acetolysis (a ratio of 9:1 acetic anhydride to sulfuric acid while bathing the samples in a boiling water bath) for 7 to 10 minutes. Anhydrous samples were repeatedly centrifuged and washed with distilled water following two glacial acetic acid washes.

The resulting residue was mixed with glycerin jelly and mounted on glass slides for microscopy. Slides were scanned using a Nikon Biophot microscope at 400 to 1000x magnification. A minimum of 300 pollen and spores were identified for each depth; pollen was identified to the lowest possible taxonomic classification. Excess material was placed in labelled vials for future work. Samples and microscope slides are deposited in the collections of the Royal British Columbia Museum.

Radiocarbon Dating

Macroscopic charcoal and plant remains were isolated for radiocarbon dating in the lab. All six samples were cleared of loose surface material to avoid contamination and submitted for accelerator mass spectrometry radiocarbon dating to Beta Analytical Inc. in Miami, Florida. Although attempts were made to extract samples for radiocarbon dating from key deposit horizons, the infrequent occurrence of datable material at depth limited the choice of samples. Radiocarbon (^{14}C) years before present were used to compare the WRS results to regional records. Before present is defined as the year 1950 A.D. and the program CALIB 4.3 via the standard INTCAL98 Database was used for calibration (Stuiver and Reimer 1993). Sediment accumulation rates were calculated on the basis of calendar years and radiocarbon years, for ease of comparison with paleobotanical results from earth ovens obtained by Nicolaides (2010). General dating conversions are listed in Figure A-2.

Identifying Pollen Types

Common pollen and spores types were identified with reference to standard keys (Moore and Webb 1978; Kapp *et al.* 2000) and by using the pollen and spore reference collection at the Royal BC Museum Paleoecological Laboratory. Particular effort was made to distinguish several generic groupings such as *Pinus* to improve the interpretation of the local and extralocal pollen signal. The efforts were meant to gain insight into potential impacts of human activity on the adjacent landscape.

This study distinguishes between species of diploxylon *Pinus* pollen types. *Pinus* pollen grains differed greatly in their preservation throughout the sequence including entire grains, separated bladders and degraded grains. Diploxylon pine pollen were assigned to *Pinus ponderosa*, *Pinus contorta* or undifferentiated categories following visual inspection using criteria described below. Reference slides of *P. ponderosa* and *P.*

contorta were consulted repeatedly. Measurements were used to verify and differentiate between species.

The criteria of Hansen and Cushing (1973) were used to visually separate pollen grains of the two *Pinus* species. Their differentiation is based upon three characteristics beyond that *P. contorta* pollen grains are distinguished from those of *P. ponderosa* pollen grains by the latter's denser ornamentation that is raised and irregular in shape. 1) This feature is known as the marginal frill of the bladders (Jacobs 1985); 2) *Pinus ponderosa* is typically much larger than *P. contorta*; in polar view, the range of bladder heights of *P. ponderosa* is 56 to 65.5 µm and the overall length is 50 to 60.5µm. The bladder height of *P. contorta* is 35 to 53 µm and the length is 30 to 45.9 µm. Generally the equatorial outline of *P. contorta* bladders is more spherical that the bladders of *P. ponderosa*. 3) *P. ponderosa* bladders attached to the corpus and furrows are more elongate and larger than those of *P. contorta*. These features are described in Figure 7.

Separately there is some overlap between overall grain body and bladder sizes for *Pinus* pollen grains; yet the overall grain sizes of both species do not overlap very much. Notably the length of the intersection of bladder to the corpus in *P. contorta* is short relative to that in *P. ponderosa* grains. The overall length of *P. contorta* pollen is slightly shorter than that of *P. ponderosa*. The study of scanning electron microscopy by Weir and Thurston (1977) showed similarities in the size ranges of *Pinus* species. Attempts to differentiate *Pinus* pollen were made by King (1985) at Chilhil and Phair lakes in British Columbia. King (1985) was unable to differentiate between *Pinus* species because of the poor state of their preservation and the limited orientations of the grains on the slides.

The two most common non-arboreal species of *Betula* in the southern interior are *Betula nana* and *Betula occidentalis*. The most common arboreal species in the southern interior is *Betula papyrifera* (Parish *et al.* 1996). Tree and shrub *Betula* pollen types have overlapping morphological traits. It is possible to distinguish *Betula neoalaskana* and *B. papyrifera* from the pollen of shrubby *B. nana* and *B. occidentalis*. The mean diameter of a *Betula* pollen grain and its mean pore-depth distinguish between shrub and tree *Betula* pollen (Clegg *et al.* 2005). Previous studies of *Betula* in the southern interior (Heinrichs 1999, 2002a,b) have favoured *B. papyrifera* as the principal pollen producer in southern interior. In his synthesis paper, Hebda (1995) interprets *B. papyrifera* as the main contributor of pollen at Pemberton Hill Lake (northeast of Kamloops) with similar climatic associations. All recovered *Betula* pollen at WRS were assigned to the category of arboreal pollen (AP).

The local species of *Alnus* in the southern interior are shrubby *Alnus incana* ssp. *tenuifolia* and *Alnus crispa* (Thompson *et al.* 1999). The morphological traits of tree and shrub *Alnus* overlap, making them difficult to differentiate. May and Lacourse (2012) show that *Alnus rubra* and *A. viridis* ssp. *sinuata* pollen can be differentiated into two distinct morphologies that are analogous to species separation based on annulus width, arci strength, exine thickness and overall diameter, but that *A. incana* cannot be distinguished from *A. crispa*. Mayle *et al.* (1999) report that differentiating *Alnus* species is difficult based on the pollen grains alone. All recovered *Alnus* pollen at WRS were assigned to the category of non-arboreal pollen (NAP).

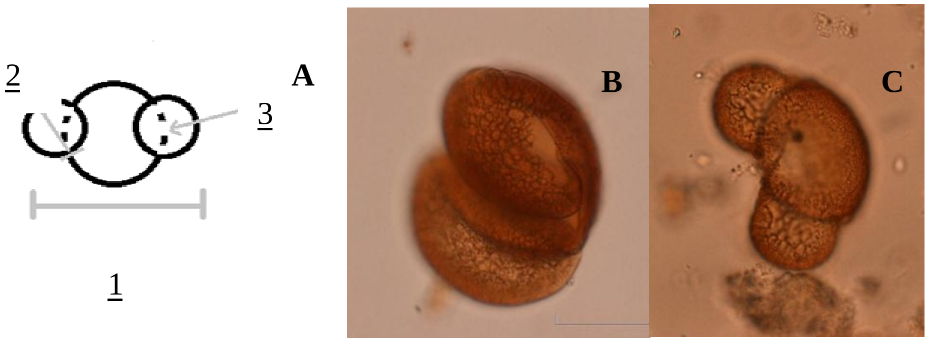


Figure 7. Features of A) *Pinus* pollen grain include (1) Grain length, (2) Bladder height and (3) Intersection of bladder to body furrow membrane; pollen grain of B) *Pinus ponderosa* and C) *Pinus contorta* from reference material.

Pollen and Spore Analyses and Data Representation

Raw pollen and spore data were tabulated and converted into percentages and accumulation rates. PSIMPOLL 4.10 software was used to generate relative and absolute pollen curves and diagrams using pollen and spore concentrations and accumulation rates (Bennett 2002). Several numerical zonations were tested.. Five palynological zones were identified as most plausible using a broken-stick model and following visual inspection. A minimum value of 1% was required for all pollen and spores types for inclusion in pollen zonation. Charcoal concentration, macrofossils and deposit lithology were included along with the pollen zones.

Macrofossil and Charcoal Analyses

Together the combined analyses of plant macrofossils with pollen and spores improve paleoecological reconstructions (Birks and Birks 1980). Needles, seeds, achenes, and cones are important to confirm the local presence of certain taxa whose pollen dispersal is poor and to distinguish between taxa whose similar pollen indicates contrasting paleoenvironmental conditions (Birks and Birks 1980; Warner 1990). Macrofossils often occur in small quantities; therefore percentages are less meaningful than for pollen counts. Plant macrofossils were identified using keys in Schofield (1992) and Parish *et al.* (1996), as well as Royal British Columbia Museum reference material. Given their relatively low abundance, macrofossils are reported as being found in a given sample, rather than as a percentage.

Charcoal analysis methods were adapted after Whitlock and Millspaugh (1996). Charcoal is produced between 280.0 to 500.0ºC temperatures during pyrolysis, generating opaque and angular charred wood fragments. Highly reflective fragments that are often visible in soils and wetland sediments may be evidence of past fire regimes. Charcoal fragments were extracted from depths corresponding to those used for pollen and spore analyses. A gridded petri dish and dissecting microscope at 50X magnification was used to count charcoal fragments. Careful treatment of charcoal retrieved from the sieves limits fractionation of pieces (Rhodes 1998). Size categories of fragments, >3 mm^2, 2 mm^2 to 3 mm^2, 1 mm^2 to 2 mm^2, 0.5 mm^2 to 1 mm^2, 0.25 mm^2 to 0.5 mm^{2}and 0.125 mm^2 to 0.25 mm^2, were based upon the number of squares taken up on the petri dish's surface area. The sum of these fragment yields the total concentration of charcoal in cm^2 charcoal per cubic centimetre of material (Waddington 1969).

Stratigraphic levels with abundant charcoal were inferred to be evidence of past fire or fires, potentially from more than one episode per year (Clark 1990; Clark *et al.* 1997; Whitlock and Millspaugh 1996; Long *et al.* 1998). Emerging charcoal size methodologies by Brown and Hebda (1998), Gavin *et al.* (2007) and Brubaker *et al.* (2009) demonstrate that particle sizes greater than 1.25 mm^2 indicate local fire events since charcoal of this size does not move far from its source. Only local fire activity or extreme fire events were likely recorded in the stratigraphy because of the small size of the fen.

The duration, intensity, and spatial extent of a fire as well as fuel types and quantities influence charcoal deposition. Extralocal sources may affect charcoal production and deposition (Patterson *et al.* 1987) and charcoal may be reworked from floodplains or upstream and redeposited (Wainman and Mathewes 1987). The fen is inundated seasonally by White Rock Creek which may be the principal source of charcoal.

Dendrochronology

In June 2011, 19 wood discs were removed using a chainsaw from recently downed *Picea engelmannii x glauca* surrounding the fen to establish the age of the stand. Annual tree rings were sampled by removing cross sectional discs to determine the age(s) of the stand. Healthy looking trees were sampled to avoid further damage to the stand and avoid missing rings associated with scarring (Parish *et al.* 1996). Annual growth rings were counted at 25X magnification using a dissecting microscope following Stokes and Smiley (1968). Parish *et al.* (1999) explain the sampling procedure and counting of tree rings for dendrochronological samples.

Chapter 4: Results

Stratigraphy, Chronology and Sediment Accumulation Rates

The palynological record for Upper Hat Creek Valley was obtained by sampling a spring-fed fen. The system is a palustrine small basin depression that had soil and sediment develop and accumulate. The record for the fen was constructed by correlating identical sedimentary layers in four overlapping blocks and 12 core segments into a single stratigraphic sequence. The record is a sequence from White Rock Springs that extends to 390 cm below the surface.

The bottom of the record is composed of light grey marl deposits from 390-225 cm. The marl deposits consist of grey to beige fine-grained calcareous material with layers of intact and broken mollusc (mostly gastropod) shells. At 225-220 cm a short lens of grey organic-rich mud (gyttja) occurs. The sequence sharply transitions to dark brown crumbly peats composed mainly of *Drepanocladus* spp. t from 220-195 cm. The profile returns briefly to marl from 205-210 cm then reverts to medium brown peat from 195-190 cm. The remaining deposit consists mainly of medium brown limnic peat. Thin lenses of dark grey marl occur at 165-160 cm and grey gyttja occurs at 84-80 cm. The deposit continues upward from a clayey to silty-peat between 75-65 cm. Transitions from sedge peat to brown mosses at various stages of decomposition occur between 65-30 cm to the tussock top of the fen. The top 5 cm is almost exclusively brown moss peat.

Six AMS radiocarbon ages were obtained from the WRS cores and block sections with corresponding calendar dates (Table 3). The near basal organic samples submitted for dating were clearly contaminated by dragged down debris, several thousand years younger than overlying dates. It is difficult to determine whether the rate of deposition was continuous from 390 to 235 cm as the material is consistently marl. The rejected dates retrieved for WRS are italicized in Table 3.

The lowest reliable age of 5690±40 ^{14}C yr BP was obtained from carbonized wood retrieved from a peat layer at 214-212 cm. Carbonized wood was also retrieved *in situ* from fibrous brown peat at 134-132 cm and 100-98 cm. The wood yielded ages of 3580 ± 40 ^{14}C yr BP and 2220±40 ^{14}C yr BP. Moss fragments from 40-41 cm are 500 ± 40 ^{14}C yr BP.

A fifth radiocarbon age is available from a fine-grained tephra layer visible between 315-310 cm. This ash is likely the Mazama tephra, a widely recognized layer in many lake sediments throughout in southern British Columbia and adjacent Washington and Oregon. The tephra dates to as 6730 ±40 ^{14}C yr BP or 7550 cal. yr BP in recent literature (Hallett *et al.* 2003). The tephra layer is placed at 312.5 cm for establishing the chronology.

The sedimentation rates corresponding to their lithology and radiocarbon ages are summarized in Table 4. The ages are based upon linear interpolation between radiocarbon ages (Figure 8) and linear extrapolation to the base of the core. Based on the current extrapolation, which does not account for possible losses in the record, the basal age of the core at 390cm is 7640 ^{14}C yr BP. The top of the fen has an age of -60 ± 20 ^{14}C yr BP. This model gives a conservative estimate of the ages in Table 4.

In comparison to sampling and time resolutions of previous studies at Phair and Chilhil lakes, the White Rock Springs site generally has the highest sampling and time resolution in the region (Table 5).

Table 3. Radiocarbon ages from White Rock Springs Fen. Italics indicate dates not included in the thesis.

Laboratory Number	Depth below surface(cm)	Material	Sample Environment	AMS Radiocarbon yr BP (1σ)	Cal yr BP (2σ)
Beta-272766	40-41	Moss	Brown peat	550 ± 40	650 to 580 and 570 to 520
Beta-272767	*65-66*	*Wood*	*Marl*	*330 ± 40*	*510 to 310*
Beta-280689	98-100	Wood	Brown peat	2220 ± 40	2340 to 2130
Beta-280690	132-134	Wood	Brown peat with marl	3580 ± 40	3980 to 3730
Beta-280691	212-214	Wood	Dark brown peat	5690 ± 40	6560 to 6400
n/a	312-313	Tephra	Marl	6730± 40	7590 to 7510
Beta-280693	*380-385*	*Wood*	*Marl*	*3940 ± 40*	*4510 to 4470*

Table 4. Sediment accumulation rates of the White Rock Springs fen based on radiocarbon ages.

Depths (cm)	Sediment accumulation rates (cm/^{14}C yr BP)
0-40.5	0.066
40.5-99	0.035
99-133	0.025
133-213	0.058
213-312.5	0.096
312.5-390	0.096

*the above rate is inferred to be the same

Table 5. Sampling and time resolution of sites in southern interior British Columbia with data from King (1985).

Site Name	Depth below surface (cm)	Sampling Resolution (cm)	Time Resolution: yr per sample
Chilhil Lake	390-302	10	158
	302-210	5-10	113-225
	210-0	5-10	108-215
Phair Lake	340-302.5	10	67
	302.5-285	5-10	168-335
	285-143	5-10	125-250
	143-106	5-10	52-104
	106-0	5-10	96-192
White Rock Springs	390-240	5	305
	240-213	2	111
	133-99	2	76
	99-40.5	2	60
	40.5-0	1-2	19-38

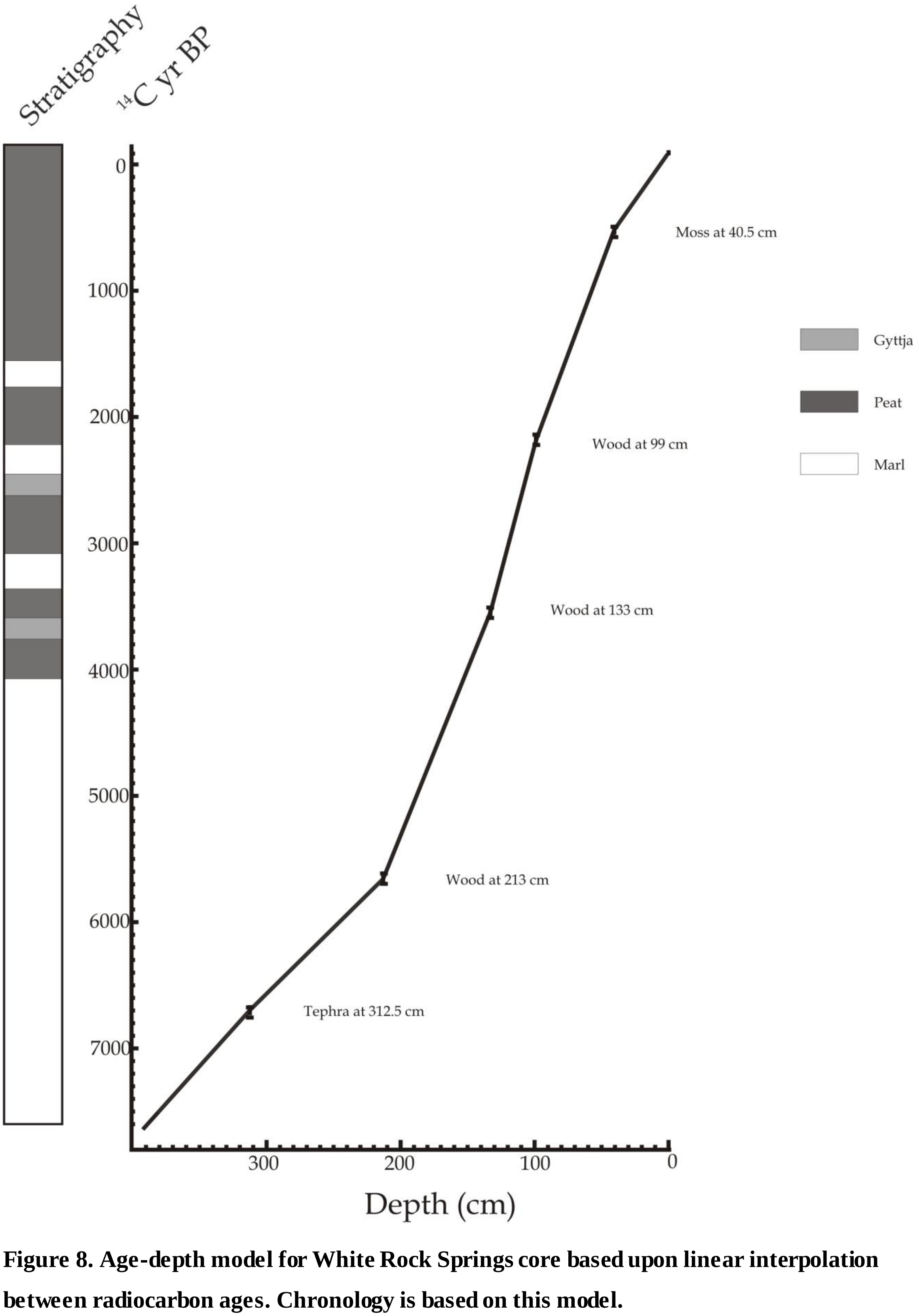
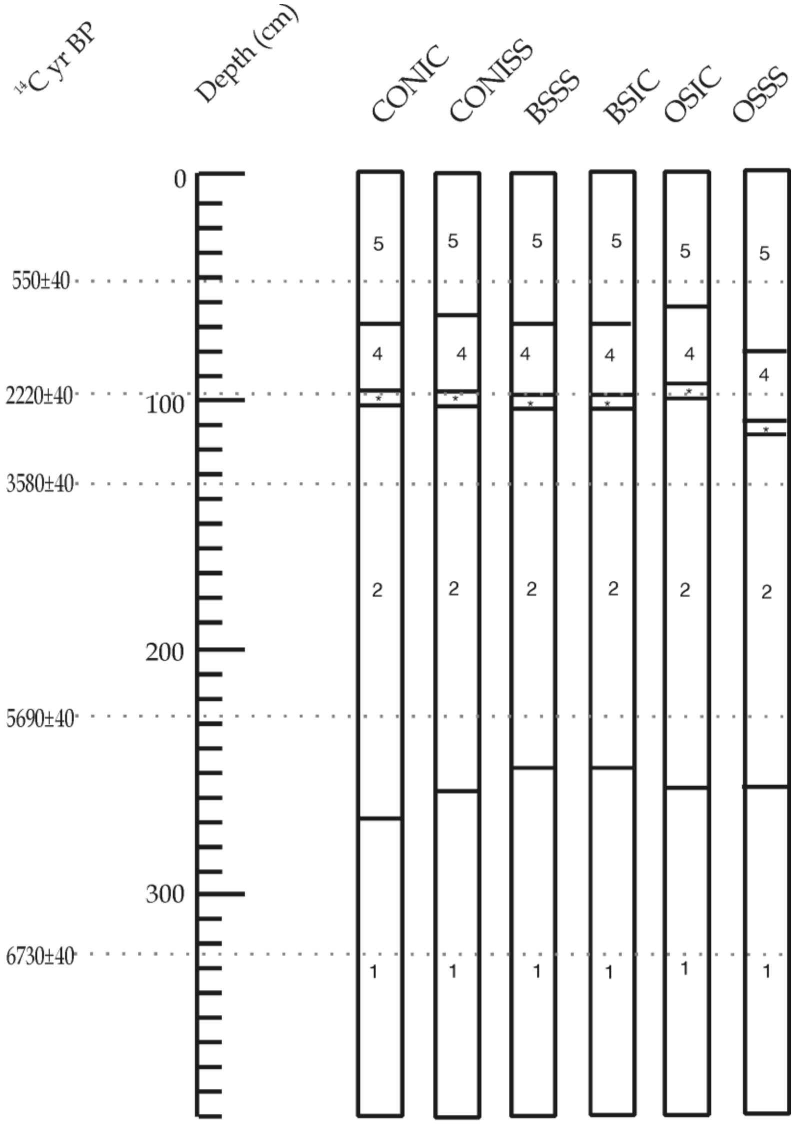


Figure 8. Age-depth model for White Rock Springs core based upon linear interpolation between radiocarbon ages. Chronology is based on this model.

Pollen Analysis

Pollen assemblage zones are generated in paleoecological studies to help describe and correlate pollen and spore data (Grimm 1987). Five major pollen zones were identified at WRS; zone boundaries were established by visual inspection in combination with stratigraphically constrained cluster analysis (CONISS). Multiple pollen zone iterations were attempted using freeware PSIMPOLL 4.10 including constrained cluster analysis by information content (CONIC), optimal splitting by sum of squares (OSSS), binary splitting by information content (BSIC) and binary splitting by sum of squares (BSSS). All possible zone boundaries derived from PSIMPOLL 4.10 are included in Figure 9 as recommended by Bennett (1996).

Pollen zone boundaries are based on arboreal pollen (AP), non-arboreal pollen (NAP) percentages. Wind-pollinated taxa are consistently over-represented relative to those with other vectors of pollination (Hebda and Allen 1993) and because the focus was on nearby landscape changes, NAP types were given special consideration in drawing zone boundaries. Consequently there are several short but distinct zones. Pollen and spore percentages, macrofossil data, charcoal concentration, and pollen and spore accumulation rate (recorded as grains/cm^2/year) are summarized for each zone (Faegri and Iversen 1989; Bennett and Willis 2001).



%

Figure 9. Comparison of six different zonation techniques using PSIMPOLL 4.10 (Bennett 2002) on pollen taxa from White Rock Springs occurring at >1%. * denotes zone 3. CONIC is constrained cluster analysis by information content; CONISS is stratigraphically constrained cluster analysis; OSSS is optimal splitting by sum of squares; BSIC is binary splitting by information content; BSSS is binary splitting by sum of squares.

Pollen and Spore Zones

WRS-1: 390-260 cm, >7640- 6000 ^{14}C yr BP, *Pinus contorta-Artemisia*

This zone is dominated by AP types with AP percentages increasing from 61% to 91% while NAP percentages fall (Figure 10). Pollen and spore influx varies from its lowest level of 435 grains/cm^2/yr to 3833 grains/cm^2/yr (Figure 11). *Pinus* pollen concentration peaks at 285cm in the middle of the zone to 640 *P. contorta* grains/cm^2/yr. The sequence begins with abundant *Pinus contorta* pollen between 43% and 73%. *Pinus ponderosa* type increases from 2% to 35% at the end of the zone. Other trees include *Picea* (ca. 1-3%) and *Abies* (ca. 1-3%). Minor instances of *Tsuga heterophylla*, *T. mertensiana*, and Cupressaceae occur at less than 3% combined. *Betula* increases from 2% to 10% in the middle of the zone.

Artemisia is the most abundant NAP type (3-21%). *Salix* rises from 1% to 4% and *Alnus* from 4% to 10%. Poaceae pollen occurs between 1% and 8%. Liliaceae and Tubuliflorae pollen occur between 2% and 5%. Chenopodiaceae, Cyperaceae and *Typha latifolia* pollen also occur in low percentages (<5%). *Shepherdia canadensis* occurs at a peak value of 5% in the early part of the zone.

WRS-2: 260-100 cm, 6000-2200 ^{14}C yr BP, *P. ponderosa-Picea*-NAP

This zone is characterized by high percentages of AP comprised predominantly almost entirely of *P. ponderosa* which rarely dips below 40%, and having notable values of NAP (Figure 10). One major peak of pollen and spore influx of 19760 grains/cm^2/yr is associated with crumbly brown peat to marl boundary (Figure 11). *Pinus* pollen concentration peaks at 144 cm to 5800 *P. ponderosa* grains/cm^2/yr. *Pinus contorta* percentages drop markedly to 36% from the highest value of 82% in the upper third of the zone. *Picea* and *Abies* increase from WRS-1 up to 8% and 4%, respectively. *Pseudotsuga menziesii* first occurs at the beginning of the zone, reaching 5%. *Betula* percentages decline from 10% near the beginning of the zone to 1%.

Alnus percentages fluctuate from 4% to 8%. Rosaceae, *Shepherdia canadensis, Acer, Salix* and *Sarcobatus* all occur at less than 5%. *Artemisia* and Poaceae values decrease from WRS-1 then remain relatively constant throughout the zone (8% and 7% respectively). Apiaceae, Chenopodiaceae and Liguliflorae occur at 3% from the middle to end of the zone. Cyperaceae percentages increase from WRS-1 and reach 8%. Near the end of the zone, *Triglochin maritima* pollen values reach to 33% in a single sample and Liliaceae pollen increases briefly to 12%.

WRS-3: 100-97 cm, 2200-2160 ^{14}C yr BP, *P. contorta*- Tubuliflorae

This brief zone is characterized by exceptionally high (22%) and diverse NAP (Figure 10). Pollen and spore influx declines considerablyfrom the previous zone to 1800 to 2600 grains/cm^2/yr between the two samples (Figure 11). At the same time, *P. ponderosa* rapidly declines from almost 80% to 8% and *Pinus contorta* jumps from 10% to 76%. The percentages of *Picea* (ca. 7%) and *Abies* (ca. 3%) pollen remain consistent with the previous zone. *P. menziesii* pollen values decline nearly to zero. All other arboreal species are nearly undetectable. *Salix, Betula* and *Alnus* show slight increases in their abundance from the previous zone.

Asteraceae Tubuliflorae values reach 13% occurring in unprecedented abundance. *Artemisia*, Poaceae, Rosaceae, and Liliaceae levels each occur at 2-4%. *Acer, Sarcobatus* and Chenopodiaceae are recorded in the middle of the zone at 2-3%.

WRS-4: 97-63 cm, 2160- 1170 ^{14}C yr BP, *P. ponderosa-Picea*

AP percentages rise sharply due to increasing *P. ponderosa* to the point where there is little expression of NAP (Figure 10). Pollen and spore influx in general decreases from the previous zone, with values ranging from 300 grains/cm^2/yr to 5358 grains/cm^2/yr (Figure 11). *Pinus* pollen concentration is sustained early in the zone up to 1200 *P. ponderosa* grains/cm^2/yr. *P. ponderosa* values fluctuate between 30-87% and *P. contorta* between 2-29%. *Picea* reaches 16% during this zone. *Abies* percentages remain unchanged from previous values. *Pseudotsuga menziesii* rises substantially towards the end of the zone (0-11%).

The relatively low NAP component consists mainly of Poaceae to 4%, *Artemisia* to 2% and Tubuliflorae to 2% towards the middle and end of the zone. Cyperaceae percentages remain low (2%). *Triglochin maritima* and *Typha latifolia* are mostly absent.

WRS-5: 63-0 cm, 1170 ^{14}C yr BP to Present, *P. ponderosa-Picea*-NAP

The proportion of AP remains high in this zone though less than in WRS-4 and includes reduced values for *P. ponderosa* and *P. contorta* (Figure 10). Pollen and spore influx decreases slightly from the previous zone, ranging from 180 grains/cm^2/yr to 5620 grains/cm^2/yr (Figure 11). *Pinus* pollen concentration is sustained throughout the zone up to 1200 *P. ponderosa* grains/cm^2/yr. *Pinus ponderosa* ranges from 22-62% and *P.*

contorta from 2-36%, having exceptional single sample peaks. *Picea* percentages range from 16% to 31% varying widely. *Abies* largely maintains percentages as in WRS-4.

NAP values vary substantially but are much greater than in the previous zone. Except for *Alnus* (1-3%), pollen from shrubs occur infrequently. Herbaceous types however are relatively abundant including Tubuliflorae. In the uppermost 10 cm, strong peaks of Liguliflorae occur (3%). Poaceae pollen values rise to 21% in this zone; Poaceae pollen grains in the top 5 cm were almost entirely transparent. Cyperaceae percentages increase to 7% from the previous zone occurring with *Typha latifolia* (1-15%) both of which persist throughout the upper half of the zone.

Macrofossils and Charcoal

In zone WRS-1, sedge achenes and seeds were recovered throughout the marl along with freshwater gastropod shells. Macroscopic charcoal is absent from this zone (Figure 11). In zone WRS-2, a Juncaceae seed was recovered at 138-136 cm likely belonging to *Juncus* spp. or *Luzula* spp. Fragments of mollusc shells are prolific throughout zone WRS-2; the marl is composed primarily of tan coloured calcareous deposits and is distinguished from zone WRS-1 by its lack of whole shells. Recovered charcoal fragments between 0.125-2.0 mm^2 in size were recovere mainly at 234-232cm with a maximum concentration of 0.5 cm^2cm^{-3}. The charcoal is mainly scattered towards the middle of the zone. In zone WRS-3 no macrofossils were recovered in the marl or peat sediments. Little or no charcoal fragments were recovered. In zone WRS-4 achenes and leaf blades of *Carex* spp. were recovered in the fibrous peat of the zone. Recovered charcoal fragments between 0.125-0.25 mm^2, 0.25-0.5 mm^2 and 1-2 mm^2 in size were recovered mainly near the beginning of the zone at 90-88cm with a maximum concentration of 25 cm^{2}cm^{-3}. In zone WRS-5, macrofossils of brown mosses including parts of the sporophytes and gametophytes of *Warnstorfia exannulatus*, *Scorpidium revolvens*, and *Drepanocladus spp.* dominate the fibrous peat zone. Achenes of Cyperaceae were also recovered. Recovered charcoal fragments between 0.125-0.25 mm^2 in size were recovered mainly near the beginning of the zone at 55-53cm with a maximum concentration of 20cm^{2}cm^{-3}.

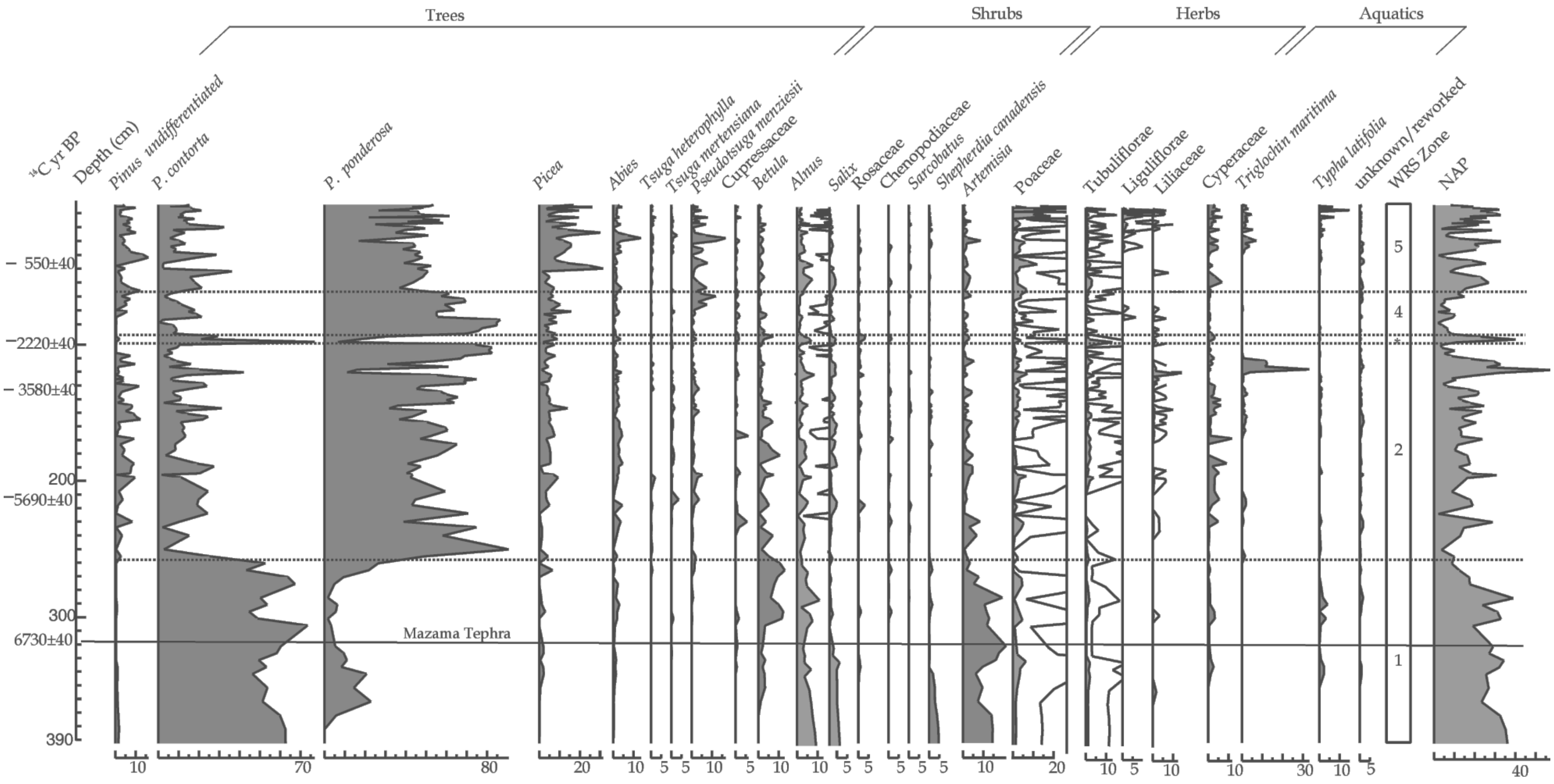


Figure 10. Pollen percentages of selected pollen taxa for White Rock Springs with 10x exaggeration applied to infrequent taxa. The asterisk (*) is WRS Zone 3.

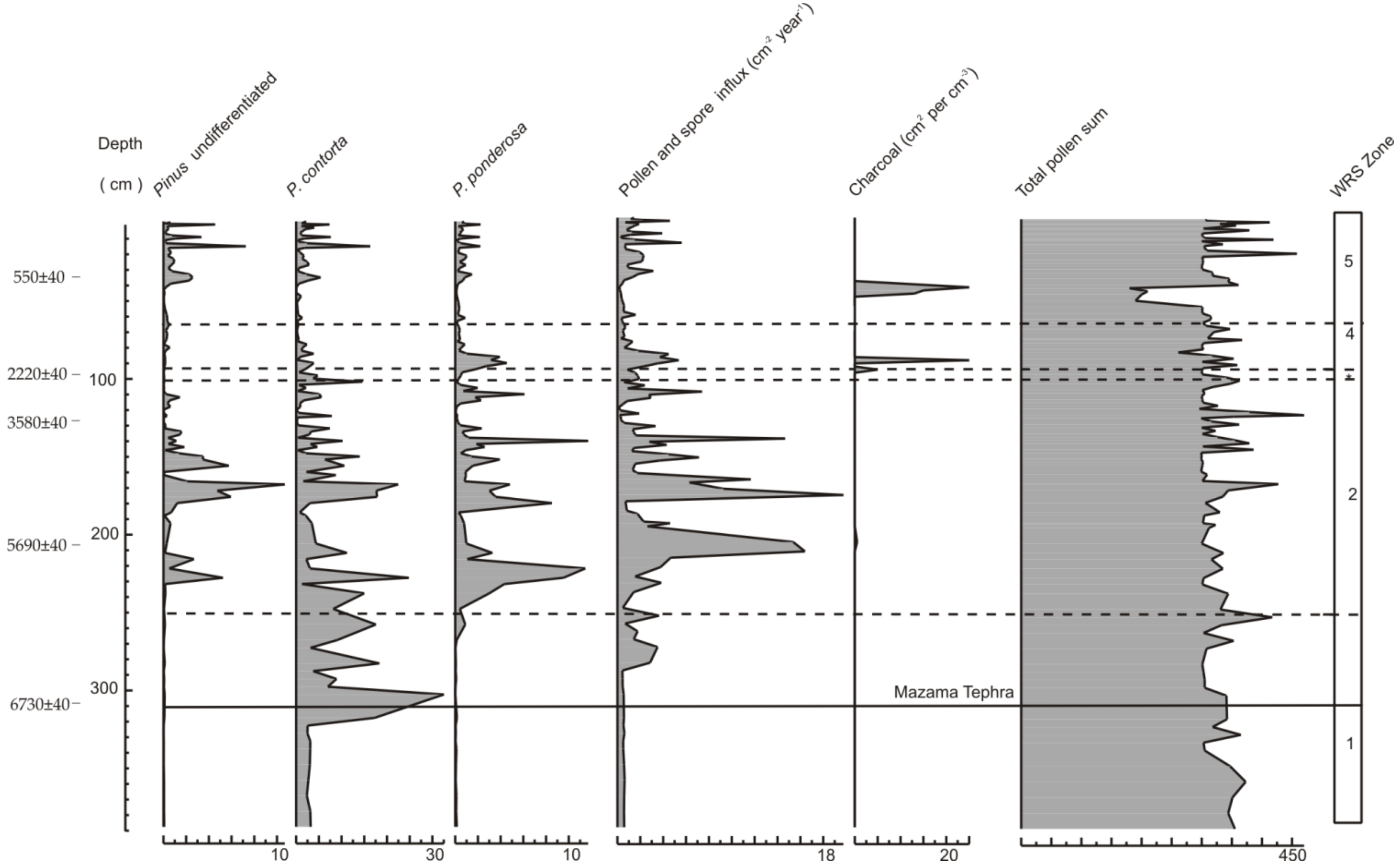


Figure 11. Concentrations of *Pinus* pollen, pollen and spore influx, charcoal concentration, and pollen sum from White Rock Springs. The solid line represents the Mazama ash layer. The asterisk (*) is WRS Zone 3.

Dendrochronology

Tree sections from 19 *Picea engelmannii x glauca* trees were used to establish stand age and history. The trees designated as 'alive' were trees upright and intact at the time of removal in June 2011 (Table A-2). The trees designated 'Very Recent Root Throw' are trees that fell within last 2 to 4 years. The trees designated as 'Recent Root Throw' are trees that fell over 4 years prior to the removal of discs from their trunks. The trees designated as 'Snag Dead' are dead trees or snags that were still upright and rapidly decaying at the time of their removal. The time of death for the snags is unknown.

The 10 largest trees had discs showing 150 to 200 annual growth rings (Figure 12). They predate the first known land-clearing conducted by Euro-Canadian settlers in Upper Hat Creek Valley in 1886 A.D. The remaining nine trees have 110 to 140 annual growth rings and demonstrate that the stand dates back to 1871 to 1880 A.D. One explanation is the suppressed growth of smaller *Picea engelmannii x glauca* trees as they were possibly shaded out by neighbouring trees. The survival of relativley old *P. engelmannii x glauca* trees suggests that ranching and agricultural activities by land tenants Alexander McDonald and Tong Sing may not have removed the *P. engelmannii x glauca* stand, and it is therefore a long-term ecological feature, as suggested by the *Picea* pollen curve.

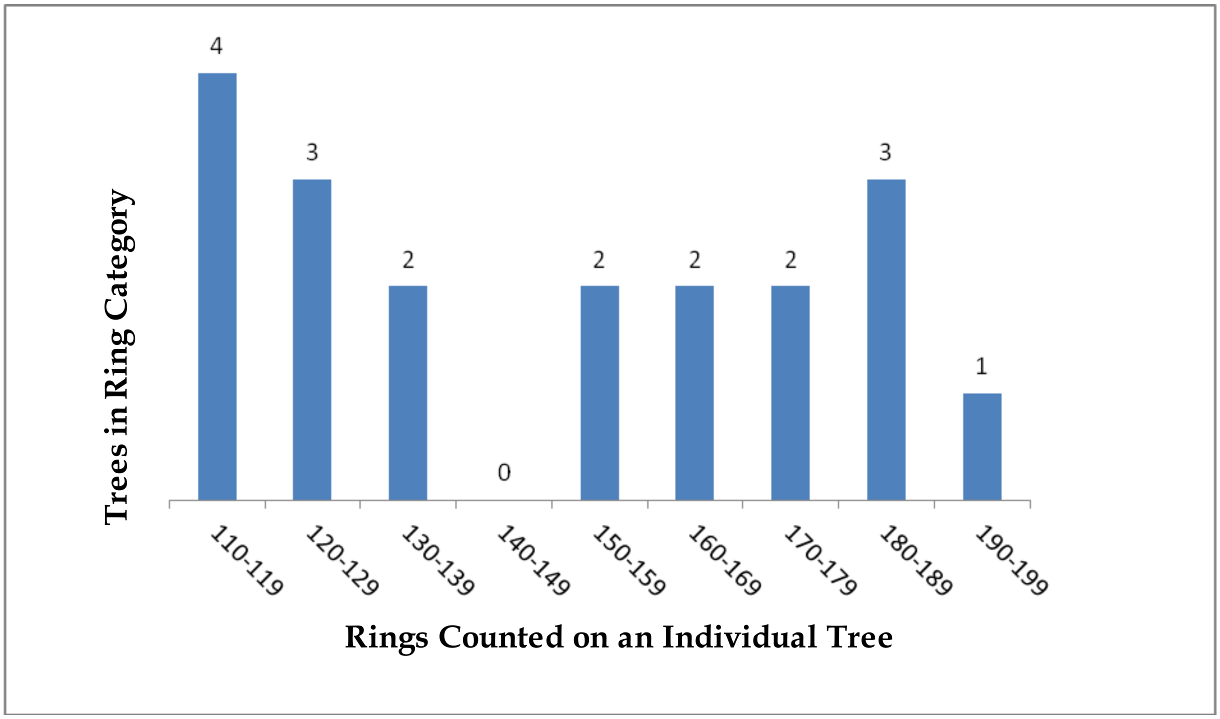


Figure 12. Number of rings on *Picea engelmannii x glauca* trees surrounding the west side of the White Rock Spring site.

Surface samples

Surface sample pollen spectra provide representative comparisons of modern local plant community assemblages. Surface samples were collected from the fen (S10-1 Fen), shrub thickets and stands S10-3 Alder thicket, S10-4 Willow-Birch thicket, and S10-5 Scattered Douglas-fir stand upland herbaceous opening S10-6 Grasslands & forb savannah, and forested regions S10-2 Spruce Stand, S10-7 Aspen parkland, and S10-8 Forest clearing (Figure 13). The surface samples are not intended to provide statistically replicable observations. Nevertheless they establish the overall character of modern pollen assemblages and highlight notable differences among plant communities.

Surface sample results show pollen type abundance changing between closed forest stands to open canopy forests in the Ponderosa Pine Biogeoclimatic Zone (Table 6). Spectra from open sites in general have higher non-arboreal pollen values than those from closed canopy sites.

The highest pollen percentages from White Rock Springs surface samples consist mainly of *P. ponderosa*, *Pinus contorta* and *Picea* pollen. *Pinus ponderosa* is locally present around the site at mid elevations in the Ponderosa Pine Very Dry Hot subzone (PPxh) and *P. contorta* surrounds the site at higher elevations (Olivier and Ryker 1990). Samples from the closed forest collection sites show higher percentages of locally abundant *P. ponderosa* compared to long-distance transported pollen from *Pinus contorta* (Hebda 1997). All surface samples contain less than 5% values of *Abies* (Figure 13). The pollen signal is likely regional as there is no *Abies* species are present in the species cover. The scattered Douglas-fir S10-5 and Forest clearing S10-8 surface samples consist of high local *Pseudotsuga menziesii* percentages; it is not surprisingly both sites show *P. menziesii* at its highest values (17% and 22 % respectively). Furthermore, shrub and herbaceous pollen (the NAP) in high in open canopy sampling areas. There are notable amounts of pollen of Poaceae, *Artemisia*, *Shepherdia canadensis*, Liliaceae and Tubuliflorae in open canopy settings. Cyperaceae pollen values are highest at the fen (1.5%) as well as *Collinsia parviflora* spp. (1%) and *Triglochin maritima* (2%) although they are not shown in the diagram. All three taxa are indicative of shallow waterbodies whose presence declines in the open canopy.

Table 6. Summary of White Rock Springs surface samples location, material, habitat & vegetation.

Sample No. ID and Name	Elevation	Sample type	Habitat	Overstory Structure	Understory Structure	Other Species Present
S10-1 Fen	N50°40’57.7, W121º34’.41.7 1200 m a.s.l.	Brown moss peat	Top 0 to 0.5 cm of moss from middle of fen	None	Few shrubs of *Salix* and *Betula*; groundcover is tussocks of brown mosses *Campylium stellatum, Scorpidium scorpioides* and *Drepanolcadus,*	*Equisetum arvense, Triglochin maritima, Viola nephrophylla*
S10-2 Spruce stand	N50°40’57.7, W121°34.41.7 1200 m a.s.l.	Moss	Spruce stand at edge of fen	Closed canopy of full sized and dwarf *Picea engelmannii x glauca* and occasional *Populus tremuloides*	sparse *Salix and Poaceae;*	*Cornus stolonifera*
S10-3 Alder thicket	N50°40’57.7, W121° 34’41.7 1200 m a.s.l.	Moss	Alder thicket around fen	Open canopy of full sized and dwarf *P. engelmannii x glauca*	dense *Alnus* and *Salix* shrubs*;* groundcover is tussocks of Poaceae and *Carex*	N/A
S10-4 Willow-Birch thicket	N50°40’57.7, W121° 34’36.7 1205 m a.s.l.	Moss	Willow-birch thicket around fen	Open canopy with occasional dwarf *P. engelmannii x glauca*	dense *Betula* and *Salix* shrubs; groundcover is *Carex*	*Acer glabrum*

Sample No. ID and Name	Elevation	Sample type	Habitat	Overstory Structure	Understory Structure	Other Species Present
S10-5 **Scattered Douglas-fir stand**	N50°40’55.9, W121° 34’31.4 1215 m a.s.l.	Lichen	Scattered Douglas fir with grass and forb savannah	Open canopy of occasional *Pseudotsuga* and *Pinus contorta*	few shrubs; groundcover is mainly *Juniperus scopulorum* and Poaceae	*Juniperus communis, Calochortus macrocarpus*
S10-6 **Grasslands & forb savannah**	N50°40’50.8, W121°34’23.3 1226 m a.s.l.	Lichen	Open forb and grass savannah adjacent to large earth ovens	None	few shrubs; groundcover is mainly Poaceae	*Fritillaria pudica, Collinsia parviflora, Geocaulon lividum, Ribes cereum, Potentilla spp,. Lomatium spp.*
S10-7 **Aspen Parkland**	N50°40’38.6, W121°34’24.5 1240 m a.s.l.	Lichen	Aspen parkland next to fen	Closed canopy of *Populus tremuloides* and some *Pinus contorta*	no shrubs; sparsely developed layer of *Shepherdia canadensis*	*Delphinium nuttallianum, Erigeron compositus* var. *glabratus*
S10-8 **Forest clearing**	N50°40’57.7, W121°34’13.3 1246 m a.s.l.	Moss	Forest clearing around fen	Open canopy of *Pseudotsuga* and occasional veteran *Picea glauca x*	few shrubs; groundcover is mainly *Juniper scopulorum* and Poaceae	Rosaceae spp., *Allium cernuum, Fragaria virginiana, Aquilegia formosa, Taraxacum, officinale*

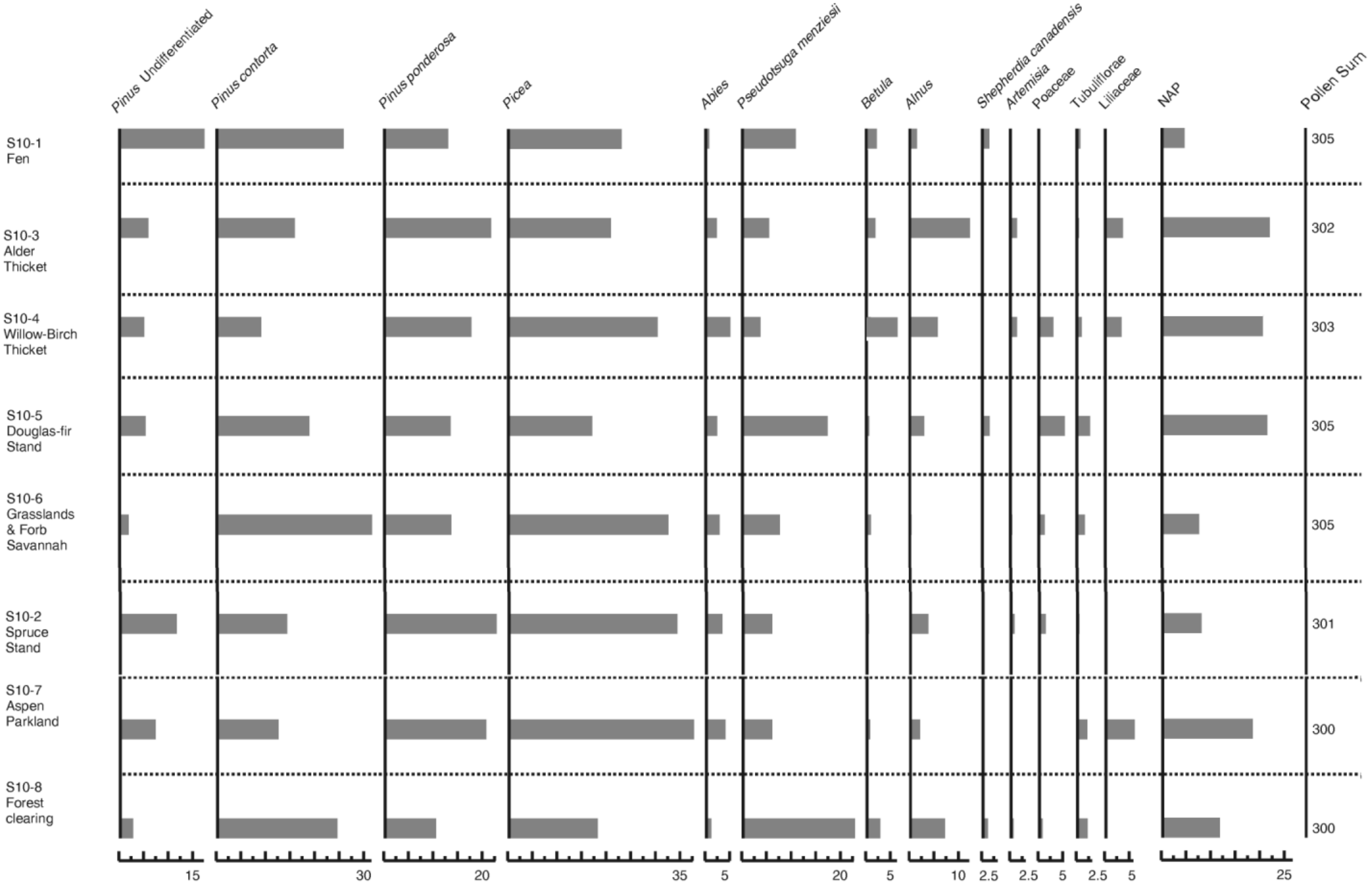


Figure 13. Pollen percentages for surface sample from Fen (S10-1), Alder Thicket (S10-3), Willow-Birch Thicket (S10-4), Douglas-fir stand (S10-5), Grassland & Forb Savannah (S10-6), Spruce Stand (S10-2), Aspen Parkland (S10-7), and Forest clearing (S10-8).

Vegetation and Landscape History

At the beginning of zone WRS-1 (about 7640 ^{14}C yr BP) high *Artemisia* and Poaceae percentages coupled with low overall concentrations of pollen suggest that open, shrubby grasslands surrounded the wetland in the early Holocene (Table 7). *Pinus contorta* also occurs. *Salix* probably indicates wet conditions in the local environment as suggested by modern occurrences of *Salix* at the site. Locally there were species of Cyperaceae with *Typha latifolia* at the wetland. High percentages of *Artemisia* indicate that the valley was arid during the early Holocene period. The absence of charcoal from this zone is consistent with an absence of large fires on the landscape, possibly due to a lack of fuel (Figure 13).

Low pollen concentrations (Lichti-Fedorovich and Ritchie 1965) and relatively low *Pinus ponderosa* percentages confirm the absence of forest at the site (Pellatt *et al.* 1998). The relatively high abundance of *P. contorta* may reflect initial pine parkland communities with scrub thickets following deglaciation. Similar pioneering species are seen elsewhere in southern British Columbia (Hebda 1982a,b; King and Mathewes 1989). *P. contorta* is the most easily established and hardy coniferous tree in British Columbia (Klinka 1989). Its high abundance in the WRS spectra may be a consequence of regional input from adjacent high elevations including Mount Chipuin and the Cornwall Hills.

High proportions of *Betula* during the early and middle Holocene have been noted by Hebda (1995). Considering the relative abundance of *Betula* at WRS, its growth in a moist zone is likely associated with the nearby spring and creek. Most likely as mentioned earlier these were stands of *Betula papyrifera*. *Tsuga heterophylla* and *Tsuga mertensiana* are nearly absent from the site, as expected since both are mostly coastal species (Parish *et al.* 1996). Their pollen may be from small, isolated populations in the Cascade Mountains to the west.

At the beginning of zone WRS-2 (at 6000 ^{14}C yr BP), stands of *Pinus ponderosa* became quickly established and the species came to dominate the landscape by the end of the zone (Table 7). The decline in *P. contorta* likely reflects relative reduction of regional input. Non-arboreal pollen declines from the previous zone, suggesting that a tree canopy developed surrounding the wetland and reduced the abundance of open site species.

The decline in *Alnus* pollen in zone WRS-2 likely resulted from relative decreased regional input as *Pinus ponderosa* became more abundant. Occurrences of *Salix* and *Acer* also suggest moistening conditions (Klinka *et al.* 1989). The decline of *Betula* is notable since *B. papyrifera* may have played a significant role in parkland stands in zone WRS-1. The increase in *Picea* pollen suggests *Picea glauca* and/or its hybrid *Picea engelmannii x glauca* began to grow near the site. At the same time, low but consistent occurrence of *Pseudotsuga menziesii* may indicate that scattered trees of Douglas-fir had become established in the vicinity of the site.

Treeless steppe vegetation dominated by *Artemisia* and Poaceae may have persisted in patches; however the decrease in *Artemisia* pollen from the previous zone suggests a major decline in grassland openings. Instead more savannah-like parklands of *P. ponderosa* likely occurred. Modest Cyperaceae values and high abundance of *Triglochin maritima* pollen (32%) near the end of the zone reflect the establishment of the calcareous fen at the site. Meanwhile the persistent charcoal values in the zone suggest fires near the site (Figure 13).

The short duration of zone WRS-3 likely represents a disturbance event (Table 7). Low charcoal concentrations indicate that the disturbance was likely something other than a stand-burning fire despite the steep decline in *P. ponderosa*. The increases in regional *P. contorta* imply more relative pollen from distant sources. Likely fewer *P. ponderosa* trees near the fen reduced the pollen input from the species. Pollen influx values of *P. ponderosa* for the zone clearly show a real decline in its pollen abundance (Figure 11).

The high values of Tubuliflorae pollen in the zone are unexpected, especially for this group of perennial, insect pollinated plants. The disturbance event at the start of this interval, somehow introduced greater amounts of Tubuliflorae into the basin. According to values in preceding zone WRS-2, Tubuliflorae were a low but consistent part of the pollen input to the basin. Surface samples indicate similarly low occurrences of Tubuliflorae pollen (Figure 13). The Tubuliflorae pollen in the zone likely came from sources upslope from the fen as habitat characteristics of the group favour warm, dry slopes. The explanation and significance of WRS-3 is discussed further in Chapter 5: Discussion.

The conditions at the beginning of WRS-4 resemble the conditions of WRS-2 including open stands of *Pinus ponderosa* with other coniferous species (Table 7). Towards the latter half the zone, the stand structure and composition became essentially modern as *Pseudotsuga menziesii* pollen abundance increased. Both *Picea* and *Abies* are adapted to relatively cooler conditions, suggesting modern climate was well established at this time.

Macroscopic charcoal rises to its highest abundance at the beginning of the zone as grey gyttja is deposited. Fires seem to have been widespread including those that consumed the forest stand (Figure 11). A marked decline in *P. ponderosa*, an increase in *Picea* and Poaceae with little persistent change in *P. contorta* percentages suggests that local changes in vegetation in WRS-5 (Table 7)

Local forest structure and composition is established in zone WRS-5, likely including the ring of spruce trees around the wetland as reflected by the increase in *Picea* in the zone (Table 7). One possible explanation for fluctuating *Pinus* values is the invasion of trees by

Dendroctonus ponderosae that kill living trees in a stand (Carroll *et al.* 2003). Arboreal species *Picea*, *Pseudotsuga* and *P. contorta* persist as *P. ponderosa* percentages decrease.

A rise in local non-arboreal, especially herbaceous pollen types suggests an opening of the understory. Unlike WRS-1 *Artemisia* is not abundant. The arrival of Liguliflorae pollen in the late Holocene is notable and is likely tied to historic settlement. The increase in Poaceae pollen may be related to this event yet it predates the rise in Liguliflorae. These changes are discussed further in Chapter 5: Discussion, Regional Vegetation History section.

Table 7. Summary of pollen zones and interpreted vegetation from White Rock Springs site.

White Rock Springs Zone	Depth (cm) Years ^{14}C yr BP	Characteristic Vegetation Type	Interpretation of Vegetation
1	390-260 >7640-6000	*Pinus contorta*-*Artemisia*	Mosaic of *Pinus contorta*-Poaceae-*Artemisia* steppe
2	260-100 6000-2200	*Pinus ponderosa*-*Picea*-NAP	Forest of the Ponderosa Pine subzone (PPxh) are established and expand
3	100-97 2200-2160	*Pinus contorta*-Tubuliflorae	Sudden and brief appearance of *Pinus contorta* and Tubuliflorae
4	97-63 2160-1170	*Pinus ponderosa*-*Picea*	Forests of *P. ponderosa* and *Pseudotsuga* becomes established
5	63-0 1170-Present	*Pinus ponderosa*-*Picea*-NAP	*Pseudotsuga* and Poaceae increase like from modern agriculture and/or invaded species.

Chapter 5: Discussion

Regional Vegetation History

The WRS site provides a local record of vegetation dynamics as is typical of small sized basins (Jacobson and Bradshaw 1981; Prentice 1985; Mathewes 1988). The general patterns revealed by the site also lend themselves to comparison to the regional paleoecological framework. Knowing these general changes helps address the question: Were there climate-driven vegetation and landscapes changes in the late Holocene as proposed by Hayden and Mathewes (2009) at the time that earth ovens were established and root resource exploitation intensified in Upper Hat Creek Valley?

Six records from the southern interior of British Columbia were selected for comparison within the framework of a regional synthesis of the Montane Cordillera by Hebda and Heinrichs (2011) (Figure 14). These records occur in similar broad ecological settings to the study site. Two records at Crater Lake and Mount Kobau are more distant and are at higher elevations such as those immediately to the east in the Cornwall Hills, whose pollen rain contributes to WRS assemblages. A study at Cabin Lake by Pellatt *et al.* (2000) is not included specifically since it deals with high subalpine zone and treeline changes in a relatively moist climate. None of these previous regional studies distinguish between diploxylon *Pinus* pollen types.

Four southern interior sites, Chilhil, Fishblue, Horseshoe and Phair lakes were analysed for pollen by Mathewes and King (1989). Chilhil and Phair lakes are directly comparable to the WRS sequence because of their proximity; Phair Lake is located 22 km west of WRS at 715 m a.s.l. and Chilhil Lake is located 16 km west of WRS at 915 m a.s.l. in the Clear Range (Figure 15). Both sites are currently located in the Interior Douglas-fir (IDF) Biogeoclimatic Zone. Horseshoe Lake is 160 km southeast of WRS at 411 m a.s.l. and Fishblue Lake (or Blue Lake) is

110 km south of WRS. Both are located in the coast to interior transition in the IDF Biogeoclimatic Zone, not a strictly interior climate. A third comparative site at Finney Lake (Hebda 1982a,b) is located in the Hat Creek Valley itself 10 km northwest of WRS at 1190 m a.s.l., also in the IDF. The fourth site Pemberton Hill Lake (Hebda 1995) is located at 1020 m a.s.l. and 130 km east of WRS northeast of Kamloops in the IDF, not far from stands of *Pinus ponderosa* and patches of grassland.

The two high elevation sites are also used in the regional comparison to White Rock Springs: Mount Kobau at Buckbean Bog is 215 km southeast of WRS at 1810 m a.s.l. and Crater Lake at Crater Mountain is 170 km southeast at 2120 m a.s.l. Today both sites are in the Engelmann Spruce Subalpine-fir Biogeoclimatic Zone but are not far from high elevation grasslands (Figure 14). Their history involves arboreal and non-arboreal pollen types similar to those at WRS.

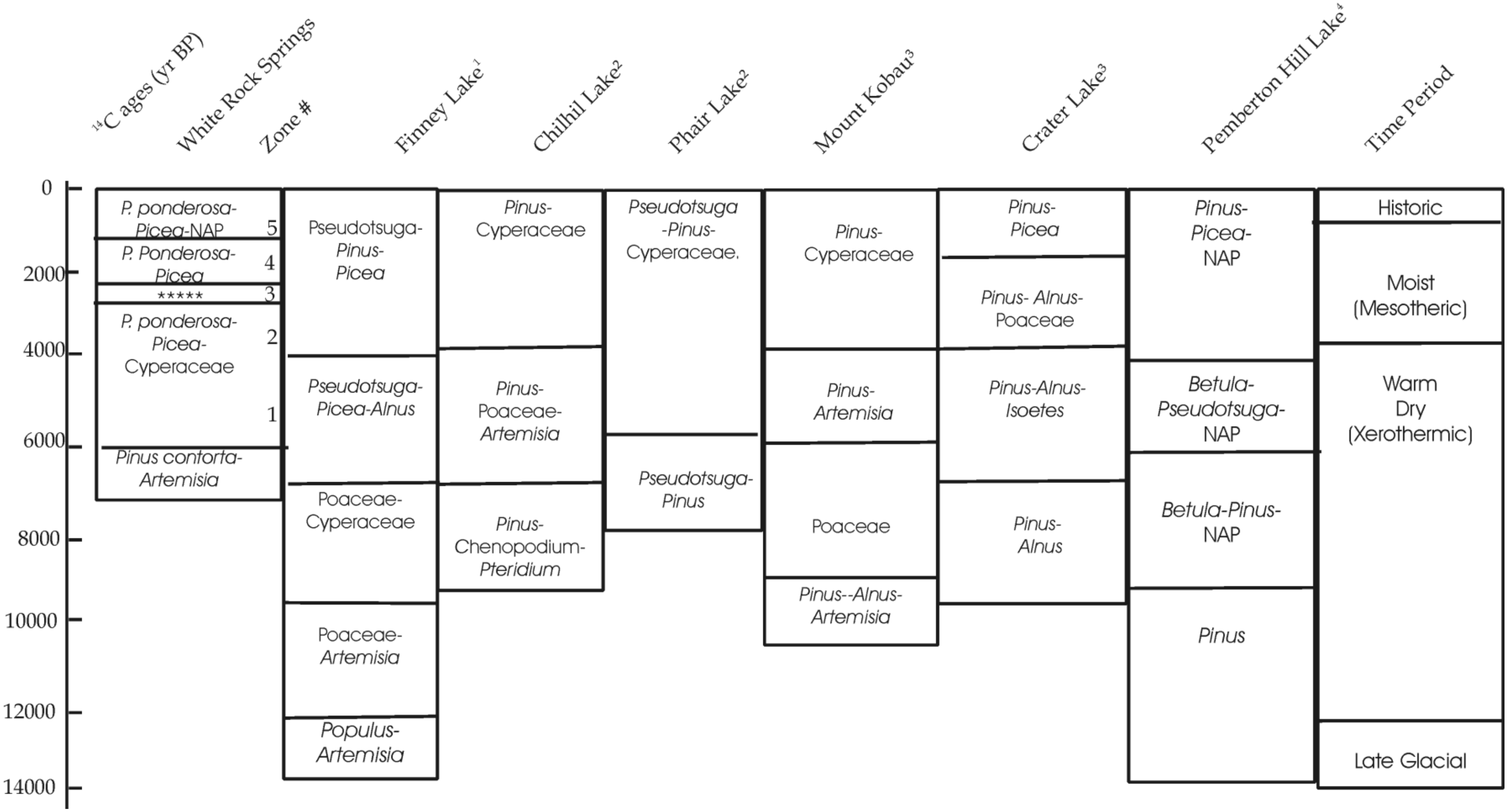


Figure 14. Summary of pollen zones and climatic conditions for selected sites in southern interior British Columbia during the Late glacial and Holocene time. 1) Hebda (1982a,b); 2)Mathewes and King (1989); 3) Heinrichs (1999); Hebda (1995). *** is *Pinus contorta* and Tubuliflorae.**

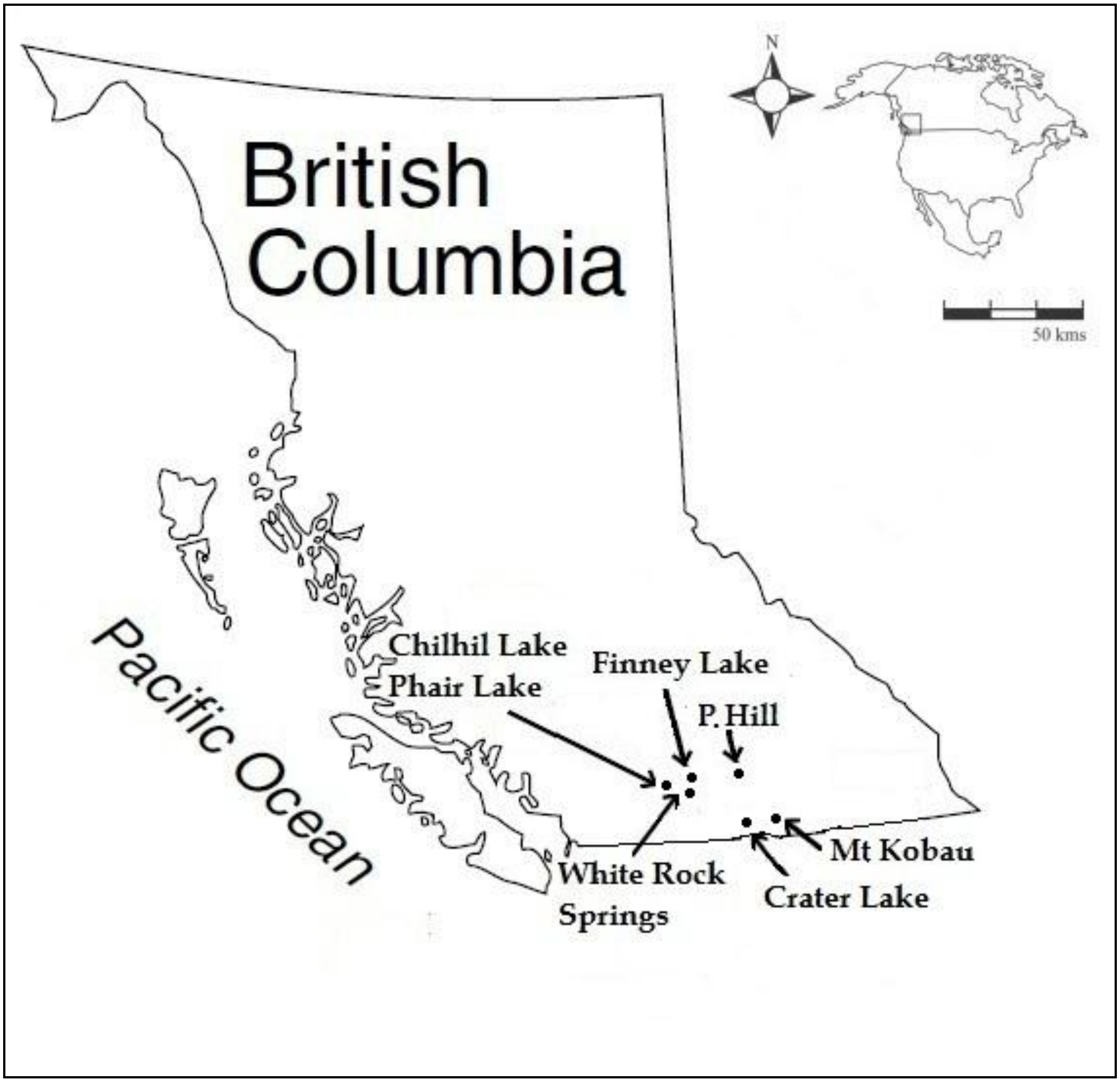


Figure 15. Locations of previous paleoecological studies in southern interior British Columbia. Finney Lake (Hebda 1982a,b); Chilhil and Phair Lakes (Mathewes and King (1989); P. Hill for Pemberton Hill (Hebda 1995); Crater Lake and MountKobau (Heinrichs 1999) and White Rock Springs is the thesis study site.

Late glacial and Warm Dry (Xerothermic) Early Holocene

Broadly speaking, open vegetation occurred in the region from 13,000-7000 ^{14}C yr BP (Figure 14). The earliest postglacial ecosystems at Finney Lake and Pemberton Hill Lake that followed deglaciation were mainly treeless (Souther *et al.* 1987; Hebda 1982a). *Typha latifolia*, Tubuliflorae and Cyperaceae grew around the lakes, likely immediately after glaciers left the sites of deposition (Hebda 1982b). Following initial colonization, a brief phase dominated by a species of *Populus*, occurred after which *Artemisia* and *Poaceae*-dominated grasslands persisted for millennia in the region at mid elevations. *Shepherdia canadensis* played an important role in this early vegetation (Hebda 1995). *Populus* may have formed closed or parkland stands with diploxylon *Pinus* (likely *P. contorta*) dominating at higher elevations in the late glacial. At Pemberton Hill Lake, an interval of high *Pinus, Populus, Artemisia* and *S. canadensis* is seen at 9750 ± 190 ^{14}C yr BP (Lab number WAT-916, Hebda 1995). At Finney Lake, an interval of high *Pinus, Populus, Artemisia* and *S. canadensis* is seen at 10290 ± 190 ^{14}C yr BP onwards that in part persisted as a zone of *Betula-Pinus*-NAP from 9800 to 7000 ^{14}C yr BP. *Pinus*, assumed to be *P. contorta*, grew widely in the region most likely at the upper elevations.

The late glacial communities may have included krummholz forms of *Picea* and *Abies* at higher elevations as visible at Mount Kobau and Crater Lake (Heinrichs 1999). At Crater Lake, *Pinus* percentages (inferred to be diploxylon) were relatively low between 11,400 and 9700 ^{14}C yr BP as the *Artemisia*-steppe-tundra was widespread (Heinrichs 2002a,b). The high NAP values (especially of *Artemisia*) at all sites including the WRS site reflect climatic conditions much drier than today. Open vegetation occurred even at high elevations as demonstrated by the grasslands seen between 9000 to 7700 ^{14}C yr BP at Mount Kobau (Heinrichs 1999; Heinrichs *et al.* 2004).

The bottom of the WRS core suggests a pioneer community of *Shepherdia canadensis* and *Pinus contorta*. It may represent colonizing vegetation at the site following receding glaciers and unstable soils. If so, the vegetation assemblage at WRS could extend as far back as 10,000-9000 ^{14}C yr BP and be synchronous with older levels at Finney Lake. The true basal date of WRS may occur after the *Populus* record at Finney Lake at 11,000 yr ^{14}C BP. *Shepherdia canadensis* is particularly notable as a nitrogen fixer preferring moist to wet soils (Meidinger and Pojar 1991; Rhodes 2008). The absence of *Populus* in basal marl sediments at WRS indicates that only a short portion may be represented. Other regional records at Finney Lake (Hebda 1982a,b) and Pemberton Hill (1995) suggest that *P. contorta* likely grew at high elevations and reached the WRS site through long-distance transport. *Artemisia* steppe landscape with *Betula, Alnus* and *Salix* spp. reflects a dry open landscape with local stands of birch with understory willow and alder that surrounded the site.

Low water levels at Fishblue, Horseshoe, and Chilhil Lakes demonstrate regionally warm and dry climate (King 1981) in the early Holocene. The sediments of Phair Lake and Chilhil Lake did not begin to accumulate until around 7000 ^{14}C yr BP and 8000 ^{14}C yr BP respectively due to dry climate conditions (Mathewes and King 1989). At WRS, moistening conditions may be signalled by relatively high *Betula* values (~10%) at the end of the early Holocene as shown in other records (Hebda 1995).

Warm Moist (Mesothermic) Mid-Holocene

Regionally the period between 7000 and 4000 ^{14}C yr BP is interpreted as one of increased moisture availability and/or decreased temperatures, compared to the preceding interval (Hebda 1995). Lake gyttja accumulated over earlier marl deposits in WRS. Grasslands shrank at Finney Lake as forests of *Pseudotsuga* and *Pinus* expanded and diversified. The understory however remained open as suggested by high NAP. At Pemberton Hill Lake open vegetation surrounded the lake as Poaceae and *Artemisia* remained abundant. Predominantly *Pseudotsuga* forests with a significant *Betula* component thrived between 7000 and 4000 ^{14}C yr BP at Finney Lake and Pemberton Hill (Hebda 1995).

Meanwhile at Phair Lake there is an overall increase in *Pinus, Abies, Betula, Alnus* and *Pseudotsuga* (Mathewes 1985). Open marsh communities eventually became inundated as water levels increased to form lakes at 7000 ^{14}C yr BP. The extent of mudflats at Chilhil Lake lessened as indicated by reduced NAP (Mathewes and King 1989). These vegetation communities persisted until 3800 ^{14}C yr BP. The forests and parkland were largely dominated by *Pinus, Betula, Pseudotsuga* and possibly shrubby *Alnus* (Hebda 1995). At high elevations by 7000^{14}C yr BP forests replaced parklands at Crater Lake under slightly moister conditions than in the early Holocene and parklands replaced open steppe at Mount Kobau (Hebda and Heinrichs 2011).

WRS-2 roughly spans the mesothermic interval of warm and moistening climate. In Upper Hat Creek Valley, forb and grass meadows persisted between 7600 based on Finney Lake (Hebda 1995) and 4000 ^{14}C yr BP while a fen of Cyperaceae, and *Triglochin maritima* developed at the WRS site. The main feature of WRS-2 is exceptionally high values of *Pinus ponderosa* (20-86%), indicating *P. ponderosa* grew in stands locally and on the nearby surrounding landscape. It is likely that in this interval development of the Ponderosa Pine Biogeoclimatic Zone occurred as had been suggested at Finney Lake (Hebda 1995). Locally the site became sufficiently moist for *Picea* to grow. It is notable that *Pseudotsuga* developed into an important forest component at Finney Lake in this interval but did not do so at WRS only 10 km to the south. Most likely Finney Lake is climatically moister and possibly cooler than WRS. Finney

Lake is a large basin adjacent to gentle north- and east-facing slopes thus broadly moister whereas WRS is west-facing on steeper slopes; also WRS is located in one IDF variant drier than at Finney Lake. Therefore the WRS site is more similar climatically to the Ponderosa Pine Biogeoclimatic Zone than Finney Lake.

Late Holocene

Regionally grassland/steppe ecosystems reached their minimum extent between 4500-3000 ^{14}C yr BP (Figure 14) (Hebda and Heinrichs 2011). Forests of modern mixed composition in which *Pseudotsuga* played a key role developed at mid-elevations at the expense of grasslands as a result of cooling and moistening conditions (Hebda 1995; Mathewes 1985). The treeline at Finney Lake declined as late as 1000 ^{14}C yr BP as *Pinus* and *Pseudotsuga* descended below the elevation of the lake (Hebda 1982b). At Phair Lake *Pseudotsuga* pollen does not exceed 15% of the total sum (Mathewes and King 1989) although its pollen rarely disperses well with 90% falling within 800 m of source (Tsukada 1982). At Chilhil Lake, upland-tree abundances remain largely stable, but *Tsuga heterophylla* is more consistently represented than before suggesting moister conditions at least to the west. Diploxylon *Pinus* and Cyperaceae peak with *Myriophyllum* as a prominent aquatic (Mathewes and King 1989). Climate was moist and moderate at Pemberton Hill Lake as *Artemisia* and open grasslands disappeared. Forests of *Picea*, *Pseudotsuga,* and *Betula* expanded and closed in after 4000 ^{14}C yr BP with lesser contributions of diploxylon *Pinus*. *Pinus monticola* expanded at moist montane elevations (Hebda 1995).

By 4000 ^{14}C yr BP forest closure at Finney Lake is characterized by more *Pseudotsuga* trees, unlike the dominance of *P. ponderosa* at WRS during this interval. *Tsuga mertensiana* arrived late to other high elevation regions after 3500 ^{14}C yr BP further indicating increased moisture and possibly cooling (Rosenberg *et al.* 2003).

At high elevation sites, modern ESSF forests developed by about 4000 ^{14}C yr BP as climate cooled (Heinrichs 1999). A closed ESSF forest developed at Crater Lake by 3800 ^{14}C yr BP. Heinrichs *et al.* (2002a,b) infers that fires burned during short warm periods and re-growth of forests occurred during cooler intervals between 3800 and 1600 ^{14}C yr BP. By 1600 ^{14}C yr BP, the forest composition was essentially modern (Heinrichs *et al.* 2002a,b). From about 3800 ^{14}C yr BP to present, Mount Kobau vegetation was composed of young *Pinus* stands with notable amounts of *Picea* and *Abies*. Crater Lake, a wetter ESSF site, endured less vegetation shifts and is less sensitive to climatic changes (Heinrichs *et al.* 2004).

Notably the vegetation at WRS remained stable through the climatic cooling 4000 ^{14}C yr BP (later part of zone WRS-2) associated with Neoglacial conditions (Hebda 1995). The modern forests of *Pinus ponderosa* at WRS were already established by the mid Holocene.

Few major vegetation changes are evidenced at WRS after the onset of the relatively cool and moist climates of the Late Holocene beyond the arrival of *Picea* to the site. No known event such as that recorded in zone WRS-3 is detected in the southern interior of British Columbia. Likewise the switch from *P. ponderosa* to *P. contorta* within 150 years is the first known detection; the two pine species are not distinguished in British Columbia beyond the WRS study. Notably there is no significant increase in regional *Pinus* elsewhere in the regional record so presumably there is little change in regional *Pinus* pollen production. Since no other record differentiated the two *Pinus* pollen types, such a switch would not have been detected had it occurred. This synchronous decline in *P. ponderosa* and rise in Tubuliflorae is best interpreted as a local disturbance event.

The dominance of *P. ponderosa* returns after the local disturbance event. *Pseudotsuga* rises at about 2100 ^{14}C yr BP. This rise is a reflection of the establishment of the IDF zone at the site. This pattern, as mentioned earlier, is markedly different than at Finney Lake to the north and Phair Lake to the west where *Pseudotsuga* was a major element of the vegetation since the start of the mid Holocene (Figure 14).

The late appearance of *Picea* and *Pseudotsuga* at WRS is not seen regionally. The late rise of both species seems exceptional. Non-arboreal pollen values, especially Poaceae, increase around the same time that *Pinus* significantly decreases. Human activity and/or fire may be better explanations for the curious appearance of charcoal late in the record. Perhaps it is part of cultural landscape management such as regular burns. The large size of the fen may prevent charcoal from reaching its centre, beyond large-scale or erosional events.

Despite their close proximity, WRS does not respond ecologically in the same manner as Finney Lake. Differences in the timing of vegetation responses may extend beyond the small basin size of WRS; topographic features used by Heinrichs *et al.* (2004) to separate ESSF sites (i.e. relief, aspect, and elevation) may also explain the effects of climate at WRS. WRS likely occurs in a drier, cooler IDF variant than Finney Lake. Therefore the less steep climactic gradient of IDF variants explains the late, limited appearance of *Pseudotsuga* at WRS (Lloyd *et al.* 1990). The WRS site occurs in a small basin on a west-facing slope, therefore experiencing warmer conditions compared to the larger basin northeast-facing slope of Finney Lake. Therefore vegetation at WRS may show greater sensitivity to changes during the Holocene.

Historical times

Regional records of Hebda (1995) and Heinrichs and Hebda (2011) reveal little about historical changes in southern British Columbia. By 1600 ^{14}C yr BP, the forest composition at

Crater Lake was essentially modern and a brief dry phase was observed at Mount Kobau by 1700 ^{14}C yr BP (Heinrichs 2001). At Phair Lake and Chilhil Lake, changes in Poaceae and *Betula* pollen occurred over the past 3000 years (Mathewes and King 1989).

The high temporal resolution of the WRS sequence reveals new details on the historical period that are not resolved in any other coarser regional sequences. Land survey records from Upper Hat Creek Valley by a land tenure company describe large veteran *Pseudotsuga* amongst less ‘bull pine’/*Pinus ponderosa* and occasional ‘jack pine’/*Pinus contorta* (Parke 1993) on the valley bottoms. In the words of Parke (1993), “in his younger days of his father, Ponderosa pine and Douglas Fir trees were scattered, not dense as they are on much of the range.” Perhaps the more open vegetation and smaller populations of *Pinus* were the result of regular burning by First Nations in immediately pre-contact times.

Upper Hat Creek Valley was first settled by in 1885 and agricultural activities flourished by 1895. Historic settlement changed the landscape. Irrigation channels were constructed and altered to sow “good fields of barley, oats and wheat [that] were observed although grain does not always ripe[n]” (Calder 1915). Cattle grazing and removal of surface vegetation likely rendered the lower slopes more prone to erosion. When trees and shrubs are removed, their absence reduces the interception of rain fall. Therefore the potential for gullying and spring overflow as more porous soils reduce its infiltration capacity (MacKenzie and Moran 2004). In this context the prevalence of surface degraded pollen grains of Poaceae in zone WRS-5 could be explained by slope wash and erosion. The impacts of historical agricultural development through the increase in NAP are also seen at WRS.

Implications for Archaeological History

Two landscape-culture questions were initially asked concerning events recorded in the Canadian Plateau archaeological record since 3500 ^{14}C yr BP. Did regional vegetation and the landscape change in response to climatic changes at the time of earth oven establishment and intensification in Upper Hat Creek Valley? Did the human use of the White Rock Springs site leave a record in the fen deposit that might shed light on resource use and its significance in culture history?

With respect to the first question, climatic changes at WRS in the last 4000 years may have occurred as *Pseudotsuga* became more abundant and *Picea* proliferated at the site in the late Holocene at about 1000 years ago, as discussed in the previous section on regional history. However up until that point the pattern is consistent with Hayden and Mathewes' (2009) argument that the lake and pollen records recovered over the past 3000 years and associated with Plateau archaeology are stable. The diagrams provided for Phair Lake, Chilhil Lake, Finney Lake, Buckbean Bog and Crater Mountain and now WRS demonstrate this point (Figure 14). Therefore it may be inappropriate to tie climatic changes to population fluctuations and cultural changes in this interval (3000-1000 BP) and rather to look for other explanations.

However there is strong evidence for rapid ecological change at the WRS site in the interval of interest. Zone WRS-3 demonstrates a profound local disturbance around 2200 ^{14}C yr BP when the earth ovens appear to be established. At this time, there is rapid and profound decline in tree pollen abundance both relative and influx and exceptional and unique increase in non-arboreal types notably pollen of Tubuliflorae. The pollen may be derived from Balsamroot (*Balsamorhiza sagittata*) the most prolific pollen producer and grower from the Tubuliflorae group in the region today (Cane 2005). This burst of Tubuliflorae pollen is short-lived and spans about 60 years. It is followed more or less by a return to pre-disturbance conditions. One explanation for zone WRS-3 may be the repeated intensive use of the adjacent slope by root harvesters to the point where the resource was overexploited and the site largely abandoned.

Earth oven use at WRS began at the start of the Plateau cultural horizon (Figure A-1) about 2500 ^{14}C yr BP. Nicolaides (2010) and Peacock (n.d.) note a period of intensive use of earth ovens between 2250 to 1650 ±80 ^{14}C yr BP (two standard deviations) based on cultural features 15,16, and 18. According to Pokotylo (1983) and others work at Hat Creek Valley, radiocarbon dates collected from adjacent earth ovens appear to cluster mainly in two time spans. The intervals are roughly 2400 to 2100 ^{14}C yr BP (timespan 'A') and 1050 to 450 ^{14}C yr BP (timespan 'B'). Radiocarbon dates have been obtained for the basin and toss zones at WRS but not yet published (Nicolaides 2010). For this thesis a major horizon of earth oven use is deemed as a time when more than three large earth ovens were active at one time. The local disturbance event represented by WRS-3 occurred between 2220 and 2160 ^{14}C yr BP and seems to reflect the first time of major occupation at WRS as indicated by the 'A' timespan. The second major period of earth oven use, the 'B' timespan, occurs sometime after 1300 ^{14}C yr BP and is correlated with the beginning of zone WRS-5 where there is again a rise in Tubuliflorae. Both of these timespans are remarkably close to the start of the key cultural intervals in the Interior Plateau region (Figure 14).

One interpretation is that during zone WRS-3, Canadian Plateau inhabitants came to the site, dug up roots and cooked them in the large earth ovens. The fuel for the earth ovens was likely the most widely available local wood. It is possible that collecting that fuel reduced tree cover as indicted by pollen influx decline (Figure 11). Digging, cutting and repeated root oven construction destabilized the slopes immediately above the fen, and increasing slope-wash that would have brought the pollen of balsamroot into the basin in unprecedented large quantities.

Possibly the resource was over-exploited and people ceased to visit the site. It is one explanation for the short duration of the zone. It is important to note that no exceptional charcoal peak occurs at this time. Consequently a major fire cannot be held responsible for the decline in arboreal pollen and sharp peak in a specific type of non-arboreal pollen.

The model for technological development as proposed by Thoms (1989) might explain in part the cultural shifts at this time as indicated by the onset of the Plateau Horizon. Of course, the observations are for only one site and for this interpretation to be strengthened, more sites require investigation to determine the regional timing of earth oven establishment and evidence of disturbance of adjacent areas with abundant root foods such as *Balsamhoriza sagittata*.

This peak of earth ovens in timespan 'A' is followed by a recovery to previous environmental conditions at WRS. Therefore the site was likely abandoned or less intensive land use (Turner *et al.* 1990). Interestingly there is the establishment of relatively abundant fire-resistant *Pseudotsuga* after timespan 'A' with what may appear to be an open understory of grasses and other herbs. Perhaps the grasses are local, that is growing in the fen, but there are few such grasses growing there today. Possibly a different landscape management regime occurred at WRS after 2220±40 ^{14}C yr BP, one of low intensity fires without the over-exploitation that occurred the first time the site was occupied.

The timing of the second Tubuliflorae peak is also interesting because it correlates with timespan 'B' of earth oven use and the onset of the Plateau Horizon. This match may be simply a coincidence or it may reflect a return to consistent occupation of the site and use of root resources, this time without their overexploitation.

In general, inferring human behavior from paleoenvironmental records is inherently difficult. However observations for this site would seem to be more in keeping with cultural changes associated with the development of new technology for exploiting root resources. This study demonstrates a strong chronological relationship between landscape disturbances at the time of earth oven building and a time of relative climatic stability. This relationship answers the second cultural question posed in the thesis-Plateau people that used earth ovens may have indeed impacted the local landscape through the harvesting and use of root foods and left a signal in the paleoecological record.

Higher Resolution Sampling and Distinguishing Pine Species

In addition to the contribution to understanding regional vegetation, climatic and cultural history, this study advances pollen analysis in the region in two ways: its application of increased temporal resolution in southern interior paleoecological studies and its differentiation of diploxylon pine pollen. First, the greater number of sampling intervals reveals high frequency ecological changes on the landscape that may not have been detected through traditional interval sampling typical of previous paleoenvironmental studies in the region (e.g. as was used at Chilhil and Phair Lakes by Mathewes and King (1989). The brief but intense change of zone WRS-3 could have been completely missed had 5 cm intervals been used. High Tubuliflorae values (13%) likely would have been diluted by high *Pinus contorta*. Increased resolution sampling is especially important when trying to uncover local events. A human disturbance effect/event such as intense exploitation and overharvesting of a root crop may only last a few decades. During the period of archaeological interest (2200 to 200 ^{14}C yr BP) it is estimated that the interval represented by each centimeter of the samples is 28 years. The Tubuliflorae peak represents at most one hundred years, with an estimated error of one interval of 28 years on either side of it. Subsequent events such as the second Tubuliflorae peak at and the historical disturbance of the local area likely would not have been detected at all or would have been very weak and ambiguous.

The increased sampling resolution is combined with differentiated diploxylon *Pinus* thus providing more insight into the character of zone WRS-3. Not only was a Tubuliflorae peak detected but it was associated with a presumed local deforestation. The total *Pinus* curve would not have changed very much had the two *Pinus* species not been separated. Instead an obvious short-lived decline in *Pinus ponderosa* was detected with a concomitant sharp rise in regional *P. contorta* pollen type. This feature could be interpreted as a removal of a variety of local trees to heat earth ovens. Perhaps small local burns kept the young trees from recolonizing the slopes, at least during the time of most intense occupation to favour the growth of *Balsamhoriza sagittata* (Peacock and Turner 2000).

There was no repeat of the intense disturbance of zone WRS-3 in subsequent centuries. There were rapid shifts in vegetation composition up to modern times. The quick change of *Pseudotsuga* and *Picea* curves between single samples is an example. Since this variation is not really associated with high charcoal concentrations, it seems that major stand-destroying fires did not play a major role and other factors were involved. These might have included small local ground fires, insect outbreaks, human removal of trees, successional dynamics of plant communities, and possibly high frequency climatic variation.

The surprisingly dynamic nature of the WRS vegetation has important implications in the study of paleoecology in southern interior of British Columbia and Plateau archaeology. Ecosystems and presumably food resources such as root foods may have varied greatly in time and space, much more than we have previously expected. Human responses to such variation may have operated on much finer times scale than has so far been contemplated. High frequency vegetation dynamics has also been demonstrated on southern Vancouver Island by Fitton (2000), McDadi and Hebda (2008) and in the Okanagan valley by Pellatt *et al.* (2000). Increasing the temporal resolution of sampling areas should become the norm when considering archaeological investigations.

More studies need to be carried out to confirm high frequency variation in the vegetation of the interior of southern British Columbia. The potential to gain insight into the interrelationship between human history and environment seems to be high.

Chapter 7: Conclusions and Recommendations

This study addressed two questions:

1. Did regional and local vegetation and landscape change because of late Holocene climatic changes at the time earth ovens were established and root resource exploitation intensified in Upper Hat Creek Valley?

2. Did vegetation changes and landscape disturbances occur during the late Holocene that might have resulted from human resource use?

These questions were addressed by paleoecological analyses (pollen, charcoal, macrofossils) of wetland deposits immediately downslope from a major cluster of earth ovens. The analyses spanned most of the Holocene and high-resolution sampling techniques were used to focus on the last 3500 years. The pollen of *Pinus ponderosa* and *Pinus contorta* were distinguished to reveal a clearer picture of vegetation dynamics than in previous paleoecological investigations.

The study began by noting the importance of understanding environmental history, attempts to interpret changes in archaeological deposits and the reasons for them. A key point is that cultural changes, such as technological advances or social developments, cannot be inferred without understanding natural landscape changes. Environmental changes are often viewed as having an overriding nature, including macro-environmental climate shifts that transform ecological zones and resource abundance. These broad changes have to be tied directly to particular subsistence resources that might limit or provide opportunities for human populations.

The prehistory of the Canadian Plateau exhibits changes that have been attributed to climatic change, resource over-exploitation, and non-environmental factors such as social inequality (Teit 1900, 1909; Hayden 1991, 1997; Prentiss *et al.* 2005, 2007, 2008; Hayden and Mathewes 2009). In particular the changes at the Shuswap Horizon and Plateau Horizon boundary around 2400 years ago have received attention partly due to the well-studied excavations of Keatley Creek and Bridge River (Rousseau 2004). This transition and the intensification of settlement is especially interesting because it occurs at the same time as the widespread proliferation of earth ovens, a technology tied to specific plant resources (root foods) in montane environments (Peacock 1998, 2002; Wollstonecraft 2000; Nicolaides 2010). An extensive earth oven complex in the Upper Hat Creek Valley affords an opportunity to examine landscape and resource history spanning the time of cultural change.

During the Holocene, the White Rock Springs record broadly reflected regional climatic phases and trends and corresponding vegetation responses. A warm, dry *Artemisia* steppe persisted during the early Holocene (zone WRS-1); Ponderosa Pine forest–savannah developed and persisted during the warm moist Mesothermic mid-Holocene (zones WRS 2-4 from 6000 years ago until 1200 years ago); Local stands of *Pinus- Picea-Pseudotsuga* developed only during the last 1200 years (WRS-5). The late Holocene expansion of *Pseudotsuga* lagged well behind a similar spread at Finney Lake in the northern part of the valley. The reconstructed vegetation and climatic events reveal that there were no major macro-environmental climatic changes at White Rock Springs between 3500 and 1200 ^{14}C yr BP an interval that includes the horizon of building of the earth ovens from 2400-2200 ^{14}C yr BP and the transition from the Shuswap Horizon of 3500 to 2400 ^{14}C yr BP to the Plateau Horizon of 2400 to 1200 ^{14}C yr BP (Stryd and Rousseau 1996).

The vegetation and landscape of WRS did change at the time earth ovens were established and root resource exploitation intensified. However these phenomena were apparently not associated with significant climatic shifts and ecological responses. The vegetation changes and landscape disturbances that occurred during the late Holocene (3500 to the present) likely resulted from human use.

The short-lived event in zone WRS-3 strongly suggests that local changes occurred on the landscape near the boundary between the Shuswap and Plateau horizons at about the time of construction of the earth ovens. Over a 4 cm interval (two samples) at 2220 ^{14}C yr BP, high amounts (13% at its peak) of Tubuliflorae pollen were preserved in the wetland sediments. Based on morphological comparisons of the species the Tubuliflorae pollen is likely derived from *Balsamorhiza sagittata*, a plentiful root crop in Upper Hat Creek Valley that today grows abundantly on the slope above the fen (Peacock 2008). The short duration of zone WRS-3, and return to previous vegetation communities, suggests a local landscape disturbance event. Coupled with a decline in *P. ponderosa* and low charcoal concentration, this zone is interpreted as an intense exploitation of the root foods adjacent to the site at the time of the first uses of the earth ovens. A similar but less marked rise in Tubuliflorae may be a response to another major re-occupation of the site about 1200 ^{14}C yr BP.

These results demonstrate that markedly increased resolution paleoecological analyses can shed light on local landscape history and provide information to test the models of intensification proposed by Peacock (1998) and Thoms (1989). This thesis demonstrates the importance of small sedimentary basins to discern the local pollen signal. This thesis is an improvement on other paleoecological studies in the region as it addresses and sheds light on questions relating to environmental and cultural history through a study immediately adjacent to a well-dated archaeological resource site.

The large areas represented by previous paleoecological studies sites limit Plateau archaeologists from reaching clear conclusions on earth oven use. This is the first known study conducted next to an earth oven site. More paleoecological sites, especially sampled at fine resolution, may help understand the pattern of intensification of plant resource use discussed by Turner (1997). However it is necessary that the chosen sampling sites be close to places near human subsistence activity.

Technological advancements in the harvesting, roasting and possibly storage of root foods as reflected by the earth ovens may be associated with the cultural shift at the Shuswap/Plateau boundary. There is no conclusive proof of this explanation. A well-dated comprehensive record of artifacts and features would be necessary to support this hypothesis.

Recommendations

The results and their interpretation in this study open opportunities for future work to improve the understanding of vegetation and climate history in the region. They also point to further research to understand the relationship between humans, the landscape and resource use and availability in the late Holocene in the Interior Plateau of British Columbia.

First, future studies in the region should differentiate the two diploxylon pine types. The separation of the two types may not be definitive in all cases yet it aids in determining the migration of *Pinus* spp. and dynamics of the Ponderosa Pine Biogeoclimatic Zone in the region. By differentiating *Pinus ponderosa* and *Pinus contorta*, insights might be gained into local stand dynamics and high frequency disturbance events such as fires and possibly insect outbreaks. It may be of interest to return to past study sites (e.g. Finney Lake, Chilhil Lake, Pemberton Hill Lake and Phair Lake) to determine whether their diploxylon pine pollen is distinguishable and what insights may be derived from the differentiated pine curves.

Second, additional studies of Late Holocene sequences, especially those that relate to human use of the landscape, would benefit from improved temporal resolution (Table 5). Increased resolution is critical to determining short-term disturbances and identifying local fires, human removal of trees or even disruption of the landscape through root harvesting.

Third, further studies need to be carried out at other root harvesting sites. At present no paleoecological investigations have been conducted at other known earth oven locations in southern interior British Columbia. Such investigations might clarify the relationship between root food abundance and vegetation dynamics to see if similar short-lived disturbances are detected for the same time horizon as at White Rock Springs. The Plateau region extends as far south as 65 km south of the Canada –United States border (Pokotylo and Mitchell 1998). It is highly likely that more earth oven and root processing sites are associated with wetland and lake sediments in the region.

Fourth, a more comprehensive study of charcoal might be helpful from deposits of uniform character rather than fen deposits. Charcoal particles accumulate well in lake and pond sediments (Long *et al.* 2002). It might be possible to distinguish local charcoal signals from regional background charcoal (Brown and Hebda 2002b). A study of geometric shape and other features might help differentiate woody from herbaceous charcoal (Enache and Cumming 2006). It is plausible that the large peaks in charcoal found at WRS are visible at regionally representative other sites. Coring other nearby lakes (Hammond Lake or Houth Lake in Upper Hat Creek Valley) may provide further insight into background regional and local fires.

Likewise, charcoal resulting from slope-wash might be recognized (Clark 1990; Millspaugh and Whitlock 1996).

The results reported in this thesis demonstrate that people likely had a significant role in using and transforming the landscape on a local scale in the southern interior of British Columbia. The study demonstrates that markedly increased resolution paleoecological analyses have considerable potential to reveal much about the relationship between humans and the use of resources prior to European settlement and perhaps to provide insights into the broad patterns of cultural history in the region.

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Appendices:

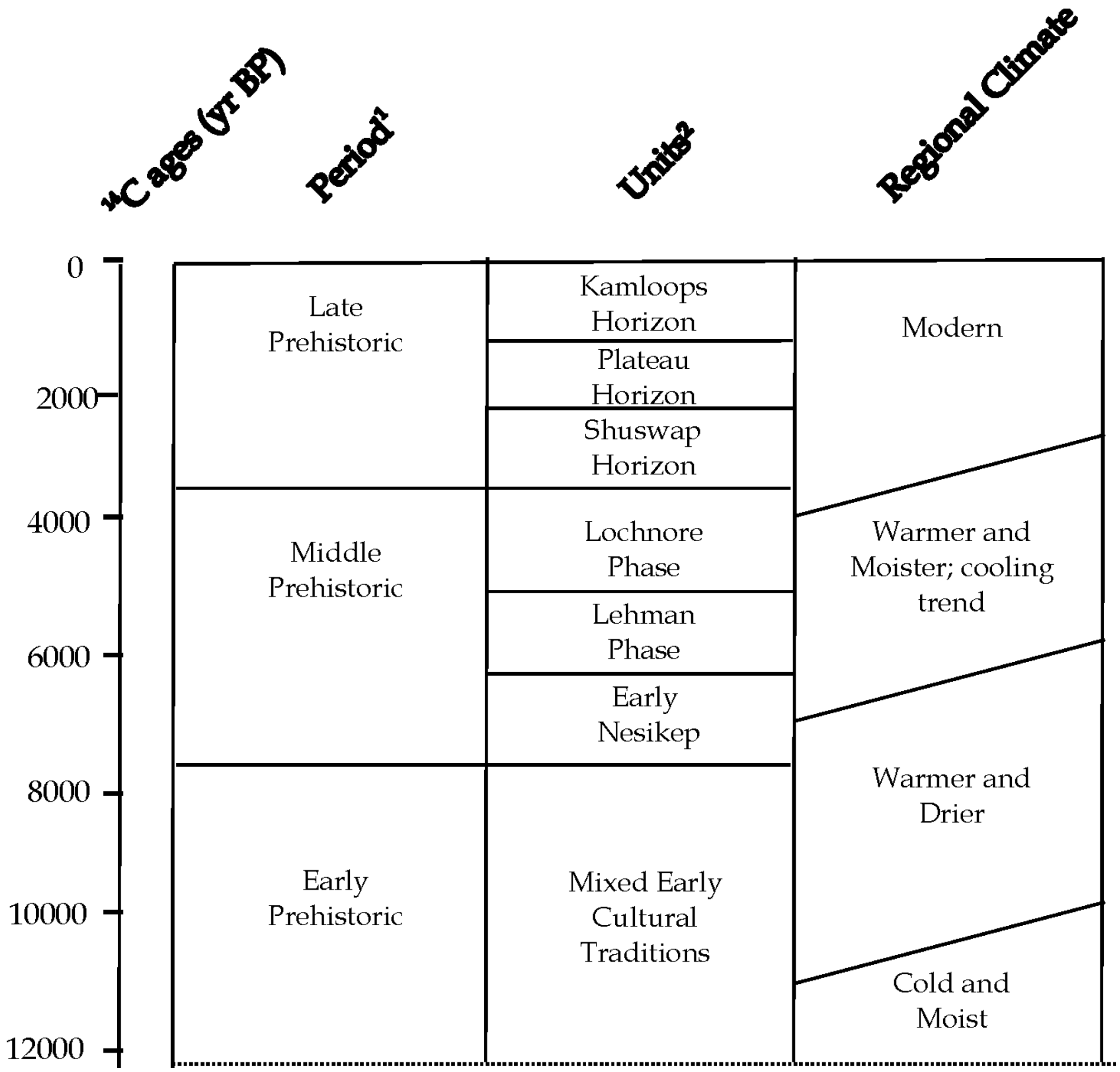


Figure A-1. Archaeological units of the Canadian Plateau. (1) and (2) are generalized time periods of regional occupation after Stryd and Rousseau (1996). Regional climate after Hebda (1995).

Table A-1. Plants and lichens of Upper Hat Creek Valley (Lloyd *et al.* 1990; Parish *et al.* 1996).

Scientific Name and Taxonomic	Common Name	Family
Abies grandis (Douglas ex D. Don) Lindl.	Grand fir	Pinaceae
Abies lasiocarpa (Hook.) Nutt. var. *lasiocarpa*	Subalpine fir	Pinaceae
Acer glabrum Torr. var douglasii (Hook.) Dippel	Douglas maple	Aceraceae
Achillea millefolium L.	Yarrow	Asteraceae
Achnatherum richardsonii (Link) Barkworth	Richardson's needlegrass; spreading needlegrass	Poaceae
Aconitum columbianum Nutt. ssp. *columbianum*	Columbian monkshood	Ranunculaceae
Actaea rubra (Ait. Willd.)	Baneberry	Ranunculaceae
Alectoria Ach.	Witch’s hair lichen	Alectoriaceae
Allium acuminatum Hook.	Hooker’s onion	Liliaceae
Allium cernuum Roth var *cernuum*	Nodding onion	Liliaceae
Alnus incana (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung	Mountain alder	Betulaceae
Alnus rubra Bong.	Red alder	Betulaceae
Alnus viridis (Chaix) DC. ssp. *sinuata* (Regel) A. Löve & D. Löve	Sitka alder	Betulaceae
Amelanchier alnifolia (Nutt.) Nutt. ex M. Roem.	Saskatoon or serviceberry	Rosaceae
Anemone multifida Poir.	Cut-leaf anemone	Ranunculaceae
Anenome occidentalis S. Watson	Western pasqueflower	Ranunculaceae
Antennaria rosea Greene	Rosy pussytoes	Asteraceae
Apocynum androsaemifolium L.	Spreading dogbane	Apocynaceae
Aquilegia formosa Fisch. ex DC.	Sitka or red columbine	Ranunculaceae
Arabis L.	Rockcress	Brassicaceae
Aralia nudicaulis L.	Wild sarsaparilla	Araliaceae
Arctostaphylos uva-ursi (L) Speng.	Kinnikinnick; bearberry	Ericaceae

Arenaria L.	Sandwort	Caryophyllaceae
Argentina anserina (L.) Rydb.	Common silverweed	Rosaceae
Aristida purpurea Nutt.	Red three-awn	Poaceae
Arnica cordifolia Hook.	Heart-leaved arnica	Asteraceae
Artemisia campestris L.	Northern wormwood	Asteraceae
Artemisia dracunculus L.	Tarragon	Asteraceae
Artemisia frigida Willd.	Prairie sagewort	Asteraceae
Artemisia ludoviciana Nutt.	Western mugwort	Asteraceae
Artemisia tridentata Nutt.	Big sagebrush	Asteraceae
Astragalus miser Douglas ex Hook.	Timber milk-vetch	Fabaceae
Balsamorhiza sagittata (Pursh) Nutt.	Arrowleaf balsamroot	Asteraceae
Betula nana L.	Scrub birch; resin birch	Betulaceae
Betula occidentalis Hook.	Water birch	Betulaceae
Betula papyrifera Marsh.	Paper birch	Betulaceae
Bromus tectorum L.	Cheatgrass	Poaceae
Bryoria fremontii (Tuck.) Brodo & D. Hawksw.	Fremont's horsehair lichen	Parmeliaceae
Calamagrostis rubescens Buckley	Pinegrass	Poaceae
Calochortus macrocarpus Douglas	Mariposa lily	Liliaceae
Campylium stellatum (Hedw.) C.E.O. Jensen	Star campylium moss	Amblystegiaceae
Carex lasiocarpa Ehrh.	Woollyfruit sedge	Cyperaceae
Ceanothus sanguineus Pursh	Redstem ceanothus	Rhamnaceae
Ceanothus velutinus Douglas ex Hook.	Snowbrush	Rhamnaceae
Centaurea scabiosa L.	Greater knapweed	Asteraceae
Cerastium fontanum Baumg.	Mouse ear chickweed	Caryophyllaceae
Chenopodium L.	Goosefoot	Chenopodiaceae
Cicuta douglasii (DC.) Coult. & Rose	Douglas's water hemlock	Apiaceae
Cirsium undulatum (Nutt.) Spreng.	Wavyleaf thistle	Asteraceae
Cirsium vulgare (Savi) Ten.	Bull thistle	Asteraceae
Claytonia lanceolata Pall. Ex Pursh	Western springbeauty	Portulacaceae

Clematis ligusticifolia Nutt.	White clematis	Ranunculaceae
Collinsia parviflora Lindl.	Maiden blue eyed mary	Scrophulariaceae
Comandra umbellata (L.) Nutt.	Pale comandra; bastard toadflax	Santalaceae
Cornus stolonifera Michx.	Red-osier dogwood	Cornaceae
Corylus cornuta Marshall	Beaked hazelnut	Betulaceae
Crepis atribarba A. Heller	Slender hawksbeard	Asteraceae
Dactylina Nyl.	Dactylina lichen	Parmeliaceae
Delphinium nuttallianum Pritz. Ex Walp.	Upland larkspur	Ranunculaceae
Dodecatheon pulchellum (Raf.) Merr.	Few-flowered shooting star	Primulaceae
Draba L.	Draba	Brassicaceae
Drepanocladus (Müll. Hal.) G. Roth	Drepanocladus moss	Amblystegiaceae
Elymus glaucus Buckley	Blue wildrye	Poaceae
Equisetum arvense L.	Common horsetail	Equisetaceae
Equisetum hyemale L.	Scouring rush	Equisetaceae
Ericameria nauseosa (Pall. ex Pursh) G.L. Nesom & Baird	Common rabbit-bush; rubber rabbitbrush	Asteraceae
Erigeron compositus Pursh	Cutleaf daisy	Asteraceae
Erigeron linearis (Hook.) Piper	Desert yellow fleabane	Asteraceae
Eurhynchium oreganum (Sull.) Jaeg.	Oregon beaked-moss	Brachytheciaceae
Festuca campestris Rydb.	Rough fescue	Poaceae
Festuca idahoensis Elmer ssp. *idahoensis*	Idaho fescue	Poaceae
Festuca occidentalis Hook.	Western fescue	Poaceae
Festuca saximontana Rydb.	Rocky mountain fescue	Poaceae
Fragaria vesca L.	Woodland strawberry	Rosaceae
Fragaria virginiana Duchesne	Wild strawberry	Rosaceae
Fritillaria affinis (Schult.) Sealy var. *affinis*	Checker lily; Chocolate lily	Liliaceae
Fritillaria camschatcensis (L.) Ker Gawl.	Northern riceroot	Liliaceae
Fritillaria pudica (Pursh) Spreng.	Yellow bell	Liliaceae

Gaillardia aristata Pursh	Brown-eyed susan; blanketflower	Asteraceae
Galium boreale L.	Northern bedstraw	Rubiaceae
Gentianella amarella (L.) Boerner	Northern gentian; dwarf gentian	Gentianaceae
Geocaulon lividum (Richardson) Fernald	False toad-flax	Santalaceae
Geranium viscosissimum Fisch. & C.A. Mey ex C.A. Mey	Sticky purple geranium	Geraniaceae
Geum macrophyllum Willd.	Large-leaved avens	Rosaceae
Geum triflorum Pursh	Purple avens	Rosaceae
Gymnocarpium dryopteris (L.) Newman	Western oakfern	Dryopteridaceae
Heracleum maximum W. Bartram	Cow parsnip	Apiaceae
Hesperostipa comata (Trin & Rupr.) Barkworth	Needle and thread	Poaceae
Heuchera cylindrical Douglas ex Hook.	Round-leaved alumroot	Saxifragaceae
Heuchera glabra Willd. Ex Roem. & Schult.	Smooth alumroot; alpine heuchera	Saxifragaceae
Heuchera micrantha Dougl. Ex Lindl.	Small-flowered alumroot	Saxifragaceae
Hieracium cynoglossoides Hook.	Hounds-tongue hawkweed	Asteraceae
Juncus mertensianus Bong.	Merten’s Rush	Juncaceae
Juniperus communis L.	Common juniper	Cupressaceae
Juniperus scopulorum Sarg.	Rocky mountain juniper	Cupressaceae
Koeleria macrantha (Ledeb.) Schult.	Junegrass	Amblystegiaceae
Lathyrus nevadensis S. Watson	Purple peavine	Fabaceae
Lathyrus ochroleucus Hook.	Creamy peavine	Fabaceae
Ledum groenlandicum (Oeder) Kron & Judd	Labrador tea	Ericaceae
Letharia vulpina (L.) Hue	Wolf lichen	Parmeliaceae
Lewisia rediviva (Pursh)	Bitterroot	Portulacaceae
Leymus cinereus (Scribn. & Merr.) A.	Giant wildrye	Poaceae
Lilium columbianum Pursh	Tiger lily	Liliaceae
Lithospermum ruderale Douglas ex Lehm.	Lemonweed	Boraginaceae

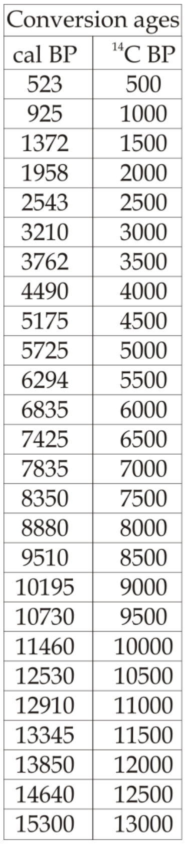
Lomatium ambiguum (Nutt.) J.M. Coult. & Rose	Swale desert parsley	Apiaceae
Lomatium dissectum (Nutt.) Mathias & Constance	Fern-leaved desert parsley	Apiaceae
Lomatium geyeri (S. Watson) J.M. Coult. & Rose	Geyer's desert parsley	Apiaceae
Lomatium macrocarpum (Nutt. Ex Torr. & A. Gray) J.M. Coult. & Rose	Large-fruited desert parsley	Apiaceae
Lomatium triternatum (Purhs) J.M. Coult. & Rose	Narrow-leaved desert-parlsey; nineleaf	Apiaceae
Lonicera involucrata (Richardson) Banks ex Spreng.	Black twinberry	Caprifoliaceae
Lonicera utahensis S. Watson	Utah honeysuckle or red twinberry	Caprifoliaceae
Lupinus sericeus Pursh	Silky lupine	Apiaceae
Maianthemum racemosum subsp. *amplexicaule* (Nutt.) LaFrankie	False Solomon's seal	Lilaceae
Maianthemum stellatum (L.)Link	Star-flowered false Solomon's seal	Lilaceae
Matricaria discoidea DC.	Pineapple weed	Asteraceae
Mentha arvensis L.	Field mint	Lamiaceae
Menziesia ferruginea Sm.	Rusty menziasia	Ericaceae
Opuntia fragilis (Nutt.) Haw.	Brittle prickly-pear cactus	Cataceae
Osmorhiza berteroi DC.	Moutain sweet-cicely	Apiaceae
Oxytropis campestris (L.) DC.	Field locoweed	Fabaceae
Paxistima myrsinites (Pursh) Raf.	Falsebox	Celastraceae
Penstemon fruticosus (Pursh) Greene	Shrubby penstemon	Scrophulariaceae
Phalaris arundinacea L.	Reed canarygrass	Poaceae
Phyllodoce Salisb.	Mountain-heather	Ericaceae
Picea engelmannii glauca x var. *glauca x*	Hybrid white spruce	Pinaceae
Picea engelmannii Parry ex Engelm.	Engelmann spruce	Pinaceae
Picea glauca (Moench) Voss (white spruce)	White spruce	Pinaceae
Pinus albicaulis Engelm.	Whitebark pine	Pinaceae
Pinus contorta Douglas ex Loudon var. *latifolia* Engelm. Ex S. Watson	Lodgepole pine	Pinaceae

Pinus monticola Douglas ex D. Don	Western white pine	Pinaceae
Pinus ponderosa Lawson & C. Lawson	Ponderosa pine	Pinaceae
Plantago major L.	Common plantain	Plantaginaceae
Pleurozium schreberi (Brid.) Mitt.	Red-stemmed feathermoss	Hylocomiaceae
Poa secunda J. Presl	Sandberg's bluegrass	Poaceae
Polemonium occidentale Greene subsp. *Occidentale*	Western Jacob's-ladder	Polemoniaceae
Polygonum amphibium (L.) A. Gray	Water knotweed	Polygonaceae
Polytrichum Hedw.	Polytrichum moss	Polytrichaceae
Populus balsamifera ssp trichocarpa Torr.& A. Gray	Black cottonwood	Salicaceae
Populus tremuloides Michx.	Trembling aspen	Salicaceae
Prosartes trachycarpa S. Watson	Roughfruit silverbells	Liliaceae
Prunella vulgaris L.	Self-heal	Lamiaceae
Prunus emarginata (Dougl. Ex Hook.) Eaton	Bitter cherry	Rosaceae
Prunus virginiana L.	Choke cherry	Rosaceae
Pseudoroegneria spicata (Pursh) A. Love	Bluebunch wheatgrass	Poaceae
Pseudotsuga menziesii (Mirb.) Franco	Douglas fir	Pinaceae
Pteridium aquilinum L. (Kuhn)	Bracken fern	Pteridaceae
Pyrola asarifolia Michx.	Pink wintergreen	Pyrolaceae
Racomitrium Brid.	Racomidtrium moss	Grimmiaceae
Ranunculus glaberrimus Hook.	Sagebrush buttercup	Pinaceae
Rhizocarpon Ramond ex DC.	Map lichen	Rhizocarpaceae
Rhytidiadelphus triquetrus (Hedw.) Warnst.	Electrified cat's-tail moss	Amblystegiaceae
Ribes cereum Douglas var. *cereum*	Squaw currant	Grossulariaceae
Ribes lacustre (Pers.) Poir.	Prickly currant	Grossulariaceae
Ribes oxyacanthoides L.	Canadian gooseberry	Grossulariaceae
Ribes triste Pall.	Red swamp currant	Grossulariaceae
Ribes viscosissimum Pursh	Sticky currant	Grossulariaceae

Rosa acicularis Lindl.	Prickly rose	Rosaceae
Rosa gymnocarpa Nutt.	Dwarf rose	Rosaceae
Rosa woodsii Lindl.	Woods' rose	Rosaceae
Rubus idaeus L.	Red raspberry	Rosaceae
Rubus leucodermis Douglas ex Torr. & A. Gray	Black cap	Rosaceae
Rubus parviflorus Nutt.	Thimbleberry	Rosaceae
Rubus ursinus Cham. & Schltdl.	California blackberry	Rosaceae
Rumex crispus L.	Curly dock	Polygonaceae
Salix barclayi Andersson	Barclay's willow	Salicaceae
Salix bebbiana Sarg.	Bebb's willow	Salicaceae
Salix cascadensis Cockerell	Cascade willow	Salicaceae
Salix exigua Nutt.	Narrowleaf or Coyote willow	Salicaceae
Salix reticulata L.	Netleaf willow	Salicaceae
Salix scouleriana Barratt ex Hook.	Scouler's or mountain willow	Salicaceae
Salsola tragus L.	Prickly Russian thistle	Chenopodiaceae
Sambucus racemosa L.	Red elderberry	Adoxaceae
Sarcobactus vermiculatus (Hook.)Torr.	Greasefoot	Chenopodiaceae
Scirpus microcarpus J.Presl & C.Presl	Small-flowered bulrush	Cyperaceae
Scorpidium scorpioides (Hedw.) Limpr.	Scorpidium moss	Amblystegiaceae
Sedum lanceolatum Torr.	Lance-leaved stonewcrop	Crassulaceae
Senecio L.	Groundsel	Asteraceae
Shepherdia canadensis (L.) Nutt.	Soapberry	Elaegnaceae
Sium suave Walt.	Hemlock water-parsnip	Apiaceae
Spiraea betulifolia ssp. *lucida Pall.* (Douglas ex Greene) Roy L. Taylor &	Birch-leaved spirea	Rosaceae
Spiraea douglasii Hook.	Spirea	Rosaceae
Sporobolus cryptandrus (Torr.) A. Gray	Sand dropseed	Poaceae
Streptopus amplexifolius (L.) DC	Clasping twistedstalk	Liliaceae
Streptopus lanceolatus (Aiton) Reveal var. *curvipes* (Vail) Reveal	Twistedstalk	Liliaceae
Streptopus roseus var. *roseus* Michx.	Rosy twistedstalk	Liliaceae

Streptopus streptopoides (Ledeb.) Frye & Rigg	Small twistedstalk	Liliaceae
Symphoricarpos albus (L.) S.F. Blake	Snowberry	Caprifoliaceae
Symphoricarpos hesperius G.N. Jones	Trailing snowberry	Caprifoliaceae
Symphyotrichum campestre (Nutt.) G.L. Nesom	Meadow aster	Asteraceae
Taraxacum officinale F.H. Wigg.	Common dandelion	Asteraceae
Tetradymia canescens DC.	Grey horsebrush	Asteraceae
Thalictrum occidentale A. Gray	Western meadowrue	Ranunculaceae
Thuja plicata Donn ex D. Don	Western redcedar	Pinaceae
Tragopogon pratensis L.	Meadow salsify	Asteraeae
Triglochin maritima L.	Seaside arrowgrass	Juncaginaceae
Tsuga heterophylla (Raf.) Sarg.	Western hemlock	Pinaceae
Tsuga mertensiana (Bong.) Carr.	Mountain hemlock	Pinaceae
Typha latifolia L.	Common cattail	Typhaceae
Urtica dioica L.	Stinging nettle	Urticaceae
Vaccinium caespitosum Michx.	Dwarf bilberry	Ericaceae
Vaccinium membranaceum Douglas ex Torr.	Black huckleberry	Ericaceae
Vaccinium ovalifolium Sm.	Oval-leaved blueberry	Ericaceae
Vaccinium scoparium Leiberg ex Coville	Grouse whortleberry	Ericaceae
Valeriana sitchensis Bong.	Sitka valerian	Valerianaceae
Veratrum viride Aiton	Indian hellebore	Liliaceae
Vicia americana Muhl. Ex Willd.	American vetch	Fabaceae
Viola adunca Sm. Var. *adunca*	Early blue violet; hookedspur violet	Violaceae
Viola nephrophylla Greene	Northern bog violet	Violaceae
Warnstorfia exannulata (Schimp.) Loeske	Ringless hook-moss; warnstorfia moss	Amblystegiaceae
Zigadenus Michx.	Deathcamas	Melanthiaceae

Figure A-2. Conversion ages and age scales as cal BP and ^{14}C dates. Calendar ages are at regularly spaced intervals with the radiocarbon age scale. It is adjusted to match every 500 14C years as per the conversion ages in the table. Age conversions were estimated using Calib 4.3 (Stuiver *et al.* 1993, 1998).



Conversion ages	
cal BP	^{14}C BP
523	500
925	1000
1372	1500
1958	2000
2543	2500
3210	3000
3762	3500
4490	4000
5175	4500
5725	5000
6294	5500
6835	6000
7425	6500
7835	7000
8350	7500
8880	8000
9510	8500
10195	9000
10730	9500
11460	10000
12530	10500
12910	11000
13345	11500
13850	12000
14640	12500
15300	13000

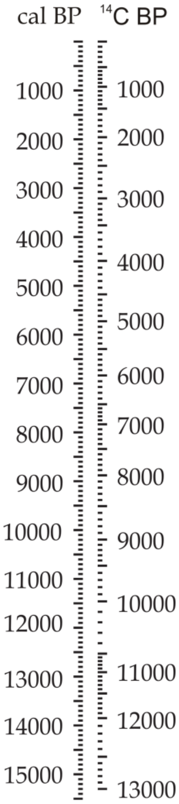


Table A-2. Ages of *Picea engelmannii x glauca* trees removed at White Rock Springs.

Condition of *Picea engelmannii x glauca* during Removal in June 2011	**Age**
Alive	159
Alive	177
Alive	122
Very Recent Root Throw	156
Very Recent Root Throw	113
Very Recent Root Throw	175
Very Recent Root Throw	131
Very Recent Snag	120
Recent Root Throw	195
Recent Root Throw	186
Recent Root Throw	185
Recent Root Throw	167
Recent Root Throw	130
Recent Root Throw	115
Recent Root Throw	111
Recent Root Throw	110
Standing Dead	180
Standing Dead	160
Snapoff	124

Legend

Alive:	Tree upright and intact at time of removal
Very Recent Root Throw:	Tree fell within last 2-4 years
Recent Root Throw:	Tree fell over 4 years prior to disc removal
Standing Dead:	Dead tree (snag) still upright and rapidly decaying.
Snapoff:	Broken tree rapidly decaying.