Late Quaternary History of Vegetation, Climate, and Fire on South Central Vancouver Island, British Columbia, Canada

by

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Abstract

Pollen, macrofossils and charcoal from Turtle Lake (80 m above sea level) and Harris Lake Ridge Bog (1300 m above sea level) were used to reconstruct the late-Quaternary history of vegetation, climate, and fire disturbance on south central Vancouver Island, British Columbia. A non-arboreal community was present in lowland areas around Turtle Lake before 12, 000 ^{14}C ybp, and represents parkland environments growing in the cold conditions near glaciers. From 12,000-11,500 ^{14}C ybp open *Pinus* forests with *Alnus* grew in lowland areas. A mixed conifer forest of *Abies, Tsuga heterophylla* and *Tsuga mertensiana* replaced *Pinus* from 11,500-10,700 ^{14}C ybp. *Pinus* regained dominance, and *T. mertensiana* increased from 10, 700-10,200 ^{14}C ybp. Open *Pseudotsuga menziesii* forests with *Alnus* and *Pteridium* expanded in lowland areas from 10,200-7,800 ^{14}C ybp in response to warm and dry conditions. Later, moistening from 7,800-6300 ^{14}C ybp produced a transitional forest with *T. heterophylla*, Cupressaceae and *Pseudotsuga menziesii*. From 6,300-0 ^{14}C ybp forest were similar to modern lowland forests except for a brief rise in Cupressaceae from 3,000-1,900 ^{14}C ybp, and climate was like that surrounding Turtle Lake today. Vegetation composition, timing of change, and climatic patterns were similar to other records in the Pacific Northwest. At high elevation around Harris Lake Ridge Bog, *Abies* and *T. mertensiana* forest characterised the landscape from 10, 270-6,640 ^{14}C ybp. *T. mertensiana* and *T. heterophylla* expanded in the mid-late Holocene from 6,640-1,970 ^{14}C ybp as moisture increased and temperatures decreased. *Abies* and *Pinus* increased from 1,970-1,260 ^{14}C ybp, as a result of fire. *Phyllodoce empetriformis* communities replaced tree cover from 1,260-520 ^{14}C ybp, after which modern subalpine forest developed. Climate during the last 2,000 years at Harris Lake Ridge Bog is interpreted as cool and moist. Plant communities however were strongly shaped by fire. The record from Harris Lake Ridge Bog is unlike other subalpine sites on Vancouver Island and reveals dynamic local changes in subalpine ecosystems. Fire played a role in forest development at both high and low elevations but fire history from Turtle Lake and Harris Lake Ridge Bog is not clearly associated with climate. Paleoecological results from the study have application to forest management on south central Vancouver Island and shed light on biodiversity issues related to Garry Oak ecosystems, and the Vancouver Island marmot (*Marmota vancouverensis).*

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Dedication

To my mom, Barbara
To my dad, Derek
and
To my brother, Stephen

Chapter 1

Introduction

Future global climate change will have serious impacts on vegetation communities and biodiversity (Houghton et al. 1990, 2001 Hebda 1998, 1997b, Lenihan and Nielson 1995, Rizzo and Wiken 1992). Under the present rates of greenhouse gas emissions General Circulation Models (GCM's) predict an increase in mean global temperatures of 3°C by the end of the next century (Houghton et al. 1990, 2001).

British Columbia has an economy based on renewable resources such as forestry. Potential impacts of climate change on the ecosystems that support these resources are of concern. Climate change can result in profound changes to plant communities, including changes in species ranges, the development of new vegetation communities, and the extinction of species (Lenihan and Nielson 1995, Rizzo and Wiken 1992, Hebda 1998, 1997b). In addition, climate change will result in changing disturbance regimes and plant-plant interactions that will effect vegetation distribution and structure (Suffling 1995, Fitter and Fitter 2002). In light of the potential impacts of future climate change on vegetation it would be beneficial to be able to predict the response of forests on Vancouver Island to future atmospheric change so that more informed management decisions for forest resources could be made. For example, it would be beneficial to know that a certain species may not thrive in a particular area under future conditions so that appropriate decisions can be made regarding forest re-stocking.

Loss of biodiversity as a result of human effects on the atmosphere is also a serious concern (Ehrlich and Wilson 1991). Maintenance of biodiversity is important for three major reasons (Ehrlich and Wilson 1991): 1) biodiversity is translated into economic benefits in the form of medicines, foods, and industrial products, 2) ecosystems provide a range of services, such as maintaining the atmospheric composition, that directly influence the survival of the human population 3) ecosystems and species hold cultural and aesthetic value. We are intrinsically connected to natural ecosystems as we have evolved within them and have an ethical responsibility to protect them. Protection and maintenance can be achieved with a greater understanding of ecosystems and constituent species. On Vancouver Island, protection of the Garry Oak ecosystem requires research that aids in the recovery of the many endangered plant and animal species (GOERT 2003). Knowledge of the past extent and ecology of the constituent species will help to maintain the Garry Oak ecosystem and contribute to the maintenance of biodiversity. It has been proposed that under future climates the Garry Oak ecosystem may expand and replace extant Douglas-fir forests on Vancouver Island (GOERT 2003). Understanding the potential extent and direction of the expansion will aid in reducing human imposed barriers and will help to understand how we can facilitate the expansion and maintenance of biodiversity.

Understanding the role of disturbance is also important for the protection of ecosystems and species, and for prediction of future vegetation response to changing climate. Fire disturbance plays a large role in shaping ecosystems and contributing to biodiversity (Barbour et al. 1999). Understanding the past relationship of fire activity to climate can lend insight into possible future fire regimes. Furthermore, it has been proposed that First Nations may have influenced past fire regimes through land management (Brown and Hebda 2002b), and thus reconstructing past fire activity could lend new archaeological insight into First Nations culture.

One method of looking at the possible future impacts of climate change on natural ecosystems is through paleoecological analysis (Hebda 1998). The basis for this method is that past climatic conditions can be used as analogues for future climate states and trends (Hebda 1998). By doing this, the response of a selected ecosystems, and constituent species, to past climatic change can be assessed, and used to gain insight into possible future response.

One particularly useful paleoecological tool for the reconstruction of past vegetation and climate is pollen analysis (Faegri and Iverson 1975). The pollen and spore contents within a sedimentary sequence can be identified, counted, and used to reconstruct vegetation that grew around a site through time. Through an understanding of modern ecological tolerances of vegetation it is possible to infer climatic conditions from the reconstructed vegetation. To more accurately interpret fossil pollen and spore assemblages surface samples from modern vegetation communities can be used (Allen et al. 1999). In addition, by examining other fossil remains such as macro-plant parts more precise identification of the composition of past vegetation can be revealed (Dunwiddie 1985, 1986, 1987, Birks and Birks 1980).

Identification and counting of macroscopic charcoal particles extracted from a sedimentary sequence is useful in gaining insight into the history of fire disturbance (Whitlock and Millspaugh 1996). This information can be compared to climate interpretations to look at past relationships between climate change and fire disturbance, and can be used to more accurately interpret past vegetation from pollen and spores by considering the effects of fire (Brown and Hebda 2002a,b, Brown 2000).

A combined methodology of pollen, charcoal and macrofossil analysis has been successfully used by a number of workers to gain important insight into the relationship between climate change, vegetation and disturbance in the Pacific Northwest of North America (Hebda 1997a, b, 1998, 1995, 1983, Hebda and Mathewes 1984, Hebda and Brown 2002a, b, c, Cwynar 1987, Gavin et al. 2001, Pellatt et al. 2000, Heinrichs et al. 2002a,b 2001, Barnosky 1981). Previous studies on Vancouver Island have focused on the north of the island (Hebda 1997, 1983), the west central coast (Walker 2001), and the south (Allen 1995, Hebda and Brown 2002 a, b, c, Brown 2000, Heusser 1983, Pellatt et al. 2001), leaving the vegetation, climate and fire history of the central portion of Vancouver Island largely unknown. Results from this study, therefore, fill a gap in the paleoenvironmental coverage of Vancouver Island and can be compared to the results from previous studies to provide a more complete picture of the regional changes in vegetation, climate and fire disturbance since the end of the last glaciation. Allen (1995), and Pellatt et al. (2002), found that Garry oak expanded on southeast Vancouver Island in the Mid-Holocene. The present study from the dry south central interior of Vancouver Island provides insight into whether Garry oak expanded in this region as well. In addition, results from this study can be used to provide insight into the possible impacts of future climate change on current vegetation communities in south central Vancouver Island. Of particular interest are vegetation changes during the early Holocene, as regional climate reconstructions reveal that this was a time of warmer and drier climate on Vancouver Island and in the region and may be analogous to predicted future changes in climate (Brown 2000, Hebda 1995, 1998).

Recently, Brown and Hebda (2002b) found evidence on south Vancouver Island that fire activity may not have been strictly controlled by climate, possibly being strongly influenced by First Nation populations. The sample sites for the present study are located in dry areas similar to those studied on south Vancouver Island and therefore provide a useful comparison to south Vancouver Island sites. Reconstructed fire activity from sedimentary charcoal helps to determine whether fire activity was dominantly controlled by climate or whether First Nations influenced fire patterns. Long-term human occupation in central Vancouver Island (McMillan 1996) makes this area ideal for investigating possible human influence on fire regimes.

The purpose of this study was to reconstruct the post-glacial vegetation, climate, and fire disturbance history from south central Vancouver Island using pollen and spore analysis, plant macrofossils, and charcoal from two sedimentary sequences. Surface samples of pollen and spores from modern vegetation communities were used to more accurately interpret paleovegetation, and add to a growing database of surface samples from Vancouver Island (Brown 2000). Specifically, the study sought to answer the following questions: 1) what is the history of vegetation and climate at low and high elevations on South Central Vancouver Island? 2) Are vegetational and climatic inferences similar to other adjacent sites? 3) How does fire history compare with other fire records from the region and what relationship does fire activity have with climatic states and trends? 4) Did Garry Oak ecosystems expand into the central Vancouver Island during post-glacial time?

Analyses were carried out on lake and peat bog sediments from a lowland and a subalpine site on south central Vancouver Island. A lowland and subalpine site were selected to gain a better understanding of post-glacial change at both low and high elevations, allowing comparisons to be made between the two as well as to other lowland and subalpine sites from adjacent areas. Furthermore, vegetation, climate and disturbance records of coastal subalpine sites have received little attention on Vancouver Island (Hebda and Brown 2002c). The high elevation site provided an opportunity to gain more insight into post-glacial vegetation dynamics in such sites. Finally, both sites are located close to the transition from the Coastal Douglas Fir (CDF) and Coastal Western Hemlock (CWH) zones and lend insight into how biogeoclimatic zone boundaries have changed in the past, and how vegetation responded in this climatically sensitive transition (Allen 1995).

Botanical names used in this study follow Hitchcock and Cronquist (1973)

Chapter 2

Study Area

Introduction

Vancouver Island is located on the northwest coast of North America and is the largest island in the eastern Pacific Ocean. The island is approximately 450 km long and 125 km wide at it widest point (fig. 2-1). The physiography of the island can be broken up into three broad regions: mountainous, plateau and lowland.

The highest mountain regions occur in the south central portion of the island extending north of Port Alberni to Quatsino Sound, southwest of Port Hardy. Mountains in these ranges reach peaks of more than 2000 m (Holland 1964). Mountain ranges south of Port Alberni are smaller and less rugged, having peak elevations of up to 1800m. The west coast of the island, between the north of the island and the Alberni Inlet, is also mountainous and is characterised by a complex shoreline of steep sided fjords that dissect the coast.

Plateau areas are characteristic of the northwestern tip of the island as well as the area surrounding the City of Victoria and west of the city of Nanaimo. The plateaus are of moderate elevation (200-1000m), and in the case of the Victoria and the Nanaimo Highlands are transitional areas between the south mountain ranges and the Nanaimo lowland.

The Nanaimo Lowland region on Vancouver Island occurs in the east between Campbell River and the city of Victoria, and includes most of the Gulf Islands. The area is an important agricultural region, contains most of the major transportation routes and supports much of the population of the island. Other notable lowland areas in terms of size are the Alberni valley and a narrow lowland strip along the west coast of the island.

Tectonically, Vancouver Island lies above an active subduction zone. Presently the Juan de Fuca and Explorer plates are being subducted below the North American plate and have created a large accretionary prism composed of sediments scraped from the subducting slabs (Davis and Hyndman 1989). The area is seismically active as stresses built up through subduction processes are released through earthquakes.

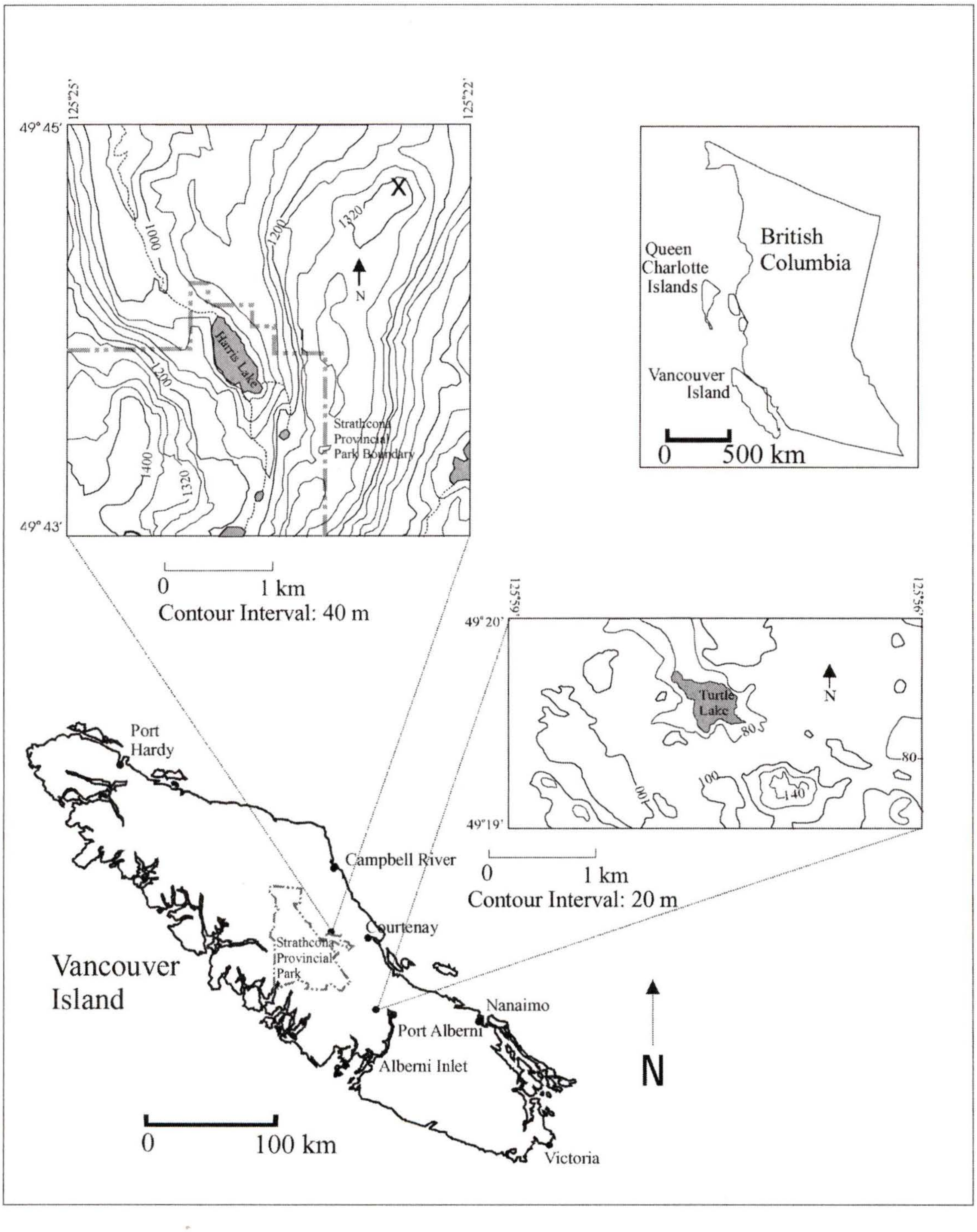

Fig 2-1. Location of Vancouver Island and study sites. "X" denotes location of Harris Lake Ridge Bog

Geology

Pre-Quaternary

Yorath and Nasmith (1995), and Brown and Yorath (1985) provide an overview of Vancouver Island's pre-Quaternary development. Vancouver Island is made up mostly of Wrangellia Terrane accreted to the western edge of the North American plate. This terrane is formed of Paleozoic and Mesozoic volcanic and sedimentary rocks (fig 2-2). The oldest unit (approximately 380 Ma) comprising Vancouver Island is the volcanic rocks of the Sicker Group, a relict of a broad submarine lava plain supporting a system of island arcs. These arcs were characterised by explosive volcanic activity that deposited tuffs and volcanoclastic sediment on the seafloor. Approximately 360 Ma, erosion of the arc volcanoes had formed a submarine plateau that hosted a variety of carbonate secreting organisms and led to the accumulation of a limestone unit known as the Mt. Mark Formation. In the Triassic Period, renewed volcanic activity resulted in the deposition of thick basaltic units over the limestone. The sequence of basalts, named the Karmutsen Formation, is the thickest and most widespread unit on Vancouver Island. Still submarine, the basalts built up to sea level and again created a suitable environment for the accumulation of carbonates that make up the Quatsino Formation. Volcanic activity was renewed in the Jurassic and led to the subaerial eruption of the Bonanza Group volcanics. At the same time, plutonic intrusions formed irregular masses of granodiorite in the crust of Vancouver Island. Older units of the Sicker Group, exposed to temperatures and pressure associated with the intrusions, were metamorphosed into the Colquitz and Wark gneiss.

Moving northward, Wrangellia accreted to the western margin of the North American plate at approximately 100Ma. At approximately 85 Ma, in the region of the Strait of Georgia, a basin accumulated the sands, gravels, muds and organics of the Nanaimo Formation. These deposits make up most of the Gulf Islands and the Nanaimo Lowland.

In the Tertiary, the construction of Vancouver Island was completed with the accretion of two terannes, the Pacific Rim Terrane and the Crescent Terrane, along the southwestern margin of Wrangellia. The Pacific Rim Terrane is composed largely of submarine landslide deposits and was emplaced along the West Coast Fault and the San Juan Fault. Later, at approximately 42 Ma, the Crescent Terrane, composed of sea floor volcanic rocks, was wedged beneath the Pacific Rim Terrane along the Leech River Fault. The Olympic Mountains to the south of Victoria are comprised of the Crescent Terrane volcanic rocks. The emplacement of these two terranes caused Wrangellia to be uplifted, initiating erosion that exposed Colquitz and Wark Gneiss. Also, terrane accretion lead to the folding and faulting of the Nanaimo Group sediments, forming the Gulf Islands.

Quaternary

Two major Quaternary glaciations are recognised on Vancouver Island in the last 75-100 ka, the early Wisconsin Semiahmoo glaciation, and the Late Wisconsin Fraser glaciation (Clague 1991). Presently, deposits of the Late Wisconsin (Fraser glaciation) are more widespread than older glacial deposits and are often found at the surface throughout much of British Columbia (Clague 1991). At the height of Fraser glaciation, the Vashon Stade (approximately 15, 000 ybp), ice had separated into two lobes, with one advancing into the Puget Lowland and the other moving northwest through the Juan de Fuca Strait. Outwash from advancing glaciers lead to the accumulation of a widespread coarse sand unit known as the Quadra Sand, which is often capped by Vashon till, deposited when it was overridden by ice. In the Cowichan Valley an alpine phase of glaciation preceded the Vashon stade and lead to the development of an extensive ice tongue that flowed out of the valley (Halstead 1968). This ice tongue was later overridden by Vashon ice as it moved southward, unconfined by the topography that had constrained the earlier ice tongue in Cowichan Valley. Ice thickness progressively thinned toward the west coast of Vancouver Island where the western edge of the Cordilleran ice sheet was believed to terminate. Paleoecological studies on Brooks Peninsula (NW Vancouver Island), and the Queen Charlotte Island suggest that these areas may have been partially ice free during the last glacial maximum (Hebda 1997, Warner et al. 1982)

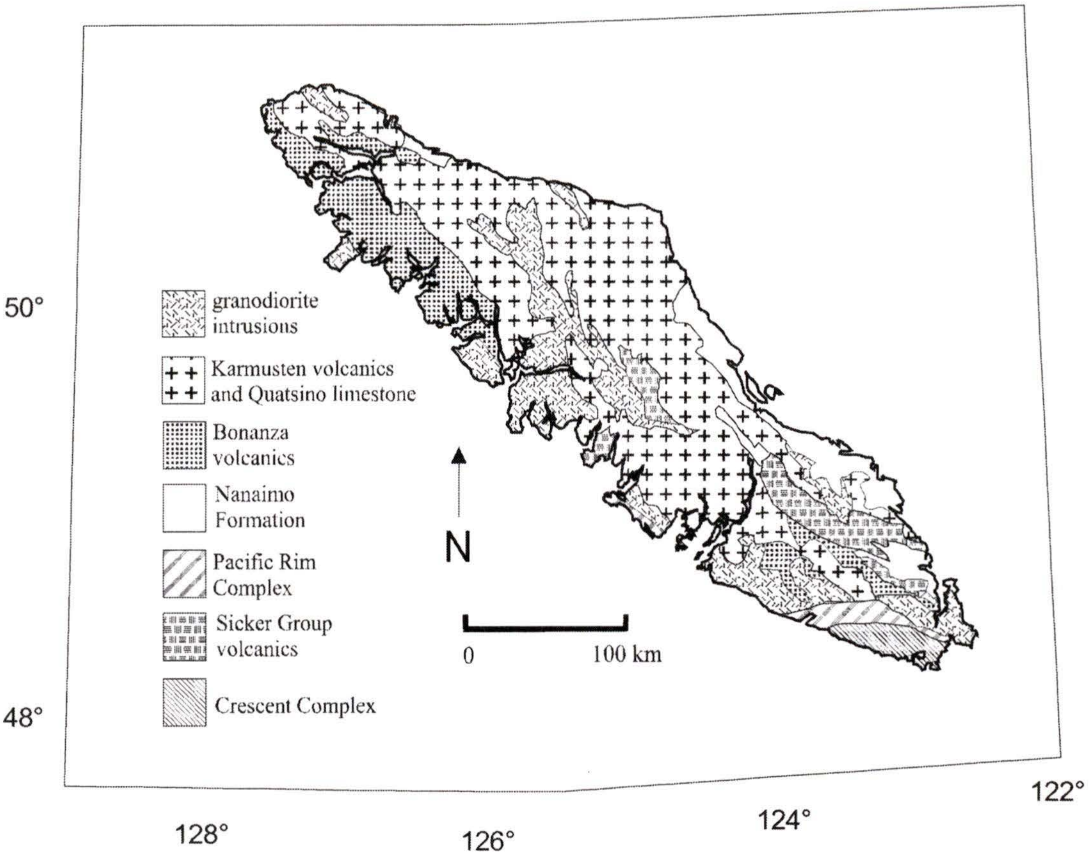

Fig. 2-2 Geological map of Vancouver Island (modified from Yorath and Nasmith 1995)

Deglaciation proceeded by glacial downwasting, uncovering mountain ridges first and leaving a network of glacier ice within valleys. A brief resurgence in glacier advance or halt in downwasting occurred within the Sumas stade. Based on evidence from northwest trending striations along the Juan de Fuca margins, kame terrace deposits and the deposition of lacustrine deposits within the Loss Creek Valley (Alley and Chatwin 1979), it has been suggested that ice in the Strait of Juan de Fuca began to advance again at this time. Deglaciation is thought to have been mostly complete and areas ice-free on Vancouver Island by 13ka (Alley and Chatwin 1979, and in Clague 1991, Hebda 1983, Hicock et al. 1982).

Clague et al. (1982), Clague (1991), and Friele and Hutchinson (1993), provide an overview of the sea-level history and associated mechanisms for coastal British Columbia, which are summarized below. Before deglaciation, the weight of the overlying ice had isostatically depressed the crust, causing sea levels to be higher than at present immediately adjacent to the ice, even with the eustatically depressed sea levels associated with water storage in ice. Isostatic rebound of surfaces formerly covered with ice occurred rapidly after removal of glacial cover and caused sea levels to decline to below present positions. On eastern Vancouver Island and the lower Mainland (Fraser Lowland) sea levels were lower than present by as much as 12m at 8000 ybp. In the Fraser Lowland, transgression occurred at approximately at 7500 ybp, followed by renewed aggradation of the Fraser Delta. On the east coast of Vancouver Island sea levels had reached their present levels by about 5000 ybp, being slightly lower than present before this time. Sea levels on western Vancouver Island were higher at the close of glaciation but not as high as on the inner coast (Fraser Lowland, east coast Vancouver Island) probably because of smaller isostatic depression due to thinner ice accumulation in this area. On the west central coast of Vancouver, sea levels were lower than present at 8,000 ybp. The period from approximately 8,000-4,800 ybp was characterised by submergence of the land surface by rising relative sea levels. Steady emergence in the late Holocene from 4,800 ybp to the present is likely due to tectonic uplift. (Friele and Hutchinson 1993, Hebda and Rouse 1979).

Climate and Vegetation

The Northwest Pacific coast is one of the wettest portions of Canada (Environment Canada 2003). Air masses moving east over the Pacific Ocean are forced up over mountain ranges releasing precipitation on windward slopes. The western coast of Vancouver Island, as a result, is wet, while leeward of mountain ranges there is a rainshadow effect making these areas drier. Winters are cool and wet, whereas summers are generally mild and dry. The Pacific Ocean exerts a considerable moderating effect over the climate of Vancouver Island leading to equable summer and winter temperatures.

The Biogeoclimatic Ecosystem Classification (BEC) provides the basis of vegetation classification in British Columbia (Meidinger and Pojar 1991). This system describes ecosystems in terms of vegetation and soil, both of which are primarily determined by climatic conditions. In this system, the basic working unit is the biogeoclimatic subzone. This can then be broken down further into variants or grouped together into zones to form a broader classification. Zones are named by the dominant vegetation component preceded by a climatic modifier, for example the Coastal Western Hemlock (CWH) zone. Division of zones into subzones is a result of smaller scale climatic variations within the zone. Subzones contain the name of the zone followed by two modifiers representing relative precipitation and continentality, for example CWHxm, represents the xeric (x), maritime (m) subzone of the CWH. Subzones are further divided into variants, to recognize areas that are slightly wetter, drier, warmer or colder within the subzone. Variants are labeled by a number (generally 1 or 2) following the subzone modifiers, for example, CWHxm1, CWHxm2.

Vancouver Island is mostly comprised of three biogeoclimatic zones the Coastal Douglas Fir zone (CDF), the Coastal Western Hemlock zone (CWH), and the Mountain Hemlock Zone (MH). A fourth zone, the Alpine Tundra zone is poorly represented on the island, occurring only on the highest peaks in the central part of the island.

The Coastal Douglas Fir zone occupies a narrow portion of southeastern Vancouver Island in the rainshadow of the Olympic and the Vancouver Island Mountains below elevations of 150 m. Climate is characterised by warm, dry summers and mild, wet winters. Mean annual temperature ranges from 9-10.5 °C, with monthly averages that do not fall below 0°C. Mean annual precipitation ranges from approximately 650 to 1260 mm, with little precipitation falling as snow. There is only one subzone in the CDF zone, CDFmm (moist maritime) subzone, and no variants.

CDF is dominated by stands of *Pseudotsuga menziesii* (Mirbel) Franco. (hereafter *Pseudotsuga*), accompanied to various extents by *Thuja plicata* Donn., *Abies grandis* (Dougl.) Lindl., *Alnus rubra* Bong., *Arbutus menziesii* Pursh., and *Quercus garryana* Dougl. depending on site moisture and nutrient availability. On xeric sites within the CDF zone, there exists a distinctive ecosystem characterised by woodlands and meadows of *Quercus garryana*. These woodland sites contain many rare species as well as species with more southern distribution (Fuchs 2001). On zonal sites the CDF zone is comprised of open forests of *Pseudotsuga menziesii*, with *A. grandis* and *T. plicata*. A well-developed shrub layer consists of *Gaultheria shallon* Pursh. (salal), *Mahonia nervosa* Pursh(Oregon-grape), *Vaccinium parvifolium* Sm. (red huckleberry) and *Rosa gymnocarpa* Nutt. (baldhip rose). A less well developed herb layer commonly consists of *Pteridium aquilinum* L. (Kuhn) (bracken fern), *Rubus ursinus* Cham. and Schlecht (trailing blackberry), and *Symphoricarpos mollis* Nutt. (trailing snowberry). *Kindbergia oregana* (Sull.) Ochyra (Oregon beaked moss), *Hylocomium splendens* (Hedw.) B.S.G. (step moss), and *Rhytidiadelphus triquetrus* (Hedw.) Warnst. (electrified cat's tail moss) are often present in a well developed moss layer.

The Coastal Western Hemlock zone (CWH) is the most widespread zone on Vancouver Island, occurring from sea level up to approximately 1000 m asl. Climate in this zone is characterised by cool summers and mild, wet winters. Mean annual temperature ranges from 5-10.5 °C, with warm monthly averages above 10°C for 4-6 months and coldest mean monthly temperatures that range from approximately –7°C to 4.7° C. Mean annual precipitation ranges from approximately 1000 to 4400 mm, with up to 50% falling as snow in the north. Four of seven CWH subzones occur on Vancouver Island, CWHxm, CWHmm, CWHvm, and CWHhm. Of these CWHxm and CWHmm subzones are relatively drier than the wet and very wet CWHvm, and CWHhm.

Tsuga heterophylla (Raf.) Sarg. predominates in the zone, accompanied most often by *Thuja plicata*. *Pseudotsuga, Abies grandis, Pinus monticola* Dougl. ex D., *Acer* *macrophyllum* are common in drier southern areas and, *Abies amabilis* (Dougl.) Forbes, and *Chamaecyparis nootkatensis* (D. Donn) Spach. in western, wetter areas, and at upper elevations. *Pinus contorta* Dougl. Ex Loud. is common on boggy (wet) or very dry sites, whereas *Alnus rubra* is common on disturbed sites. *Picea sitchensis* (Bong.) Carr. is also a widespread species occurring along shorelines.

Zonal hypermaritime forests (CWHhm) are dominated by *Tsuga heterophylla, Thuja plicata*, and *Picea sitchensis.* Wet maritime forests (CWHvm) are similar with additional cover from *Abies amabilis*, and *Chamaecyparis nootkatensis* at upper elevations. A well developed shrub layer consists of *Vaccinium alaskaense* Howell (Alaska Blueberry), *V. parvifolium*, *Gaultheria shallon,* and *Oplopanax horridus* (J. E. Smith) Miq. (devil's club). The herb layer is poorly developed in these subzones consisting typically of the fern *Blechnum spicant.* A well-developed moss layer may consist of *Hylocomium splendens*, *Rhytidiadelphus loreus*, and *Kindbergia oregana.*

The dry subzones (e.g., CWHxm, CWHmm) of the CWH contain a notable component of *Pseudotsuga menziesii* along with *Tsuga heterophylla* and *Thuja plicata.* The shrub layer is moderately developed in these subzones and is typified by *Gaultheria shallon*, *Mahonia nervosa*, and *Vaccinium parvifolium.* Herb layers may contain *Polystichum munitum* (Kaulf.) C. Presl. (sword fern), and *Pteridium aquilinum.* A well-developed moss later consists of *Hylocomium splendens*, *Rhytidiadephus loreus*, *Kindbergia oregana*, and *Plagiothecium undulatum* (Hedw.) Schimp. (flat moss).

The Mountain Hemlock zone (MH) lies elevationally above the CWH zone occupying elevations of 900-1800 m asl in the south and 400-1000 m asl in the north. Climate in this zone is characterised by short, cool, dry summers and long, cool, wet winters, with abundant snow cover. Mean annual temperature ranges from 0°C to 5°C, with average monthly temperatures being below 0°C for 1- 5months and above 10°C for 1-3 months. Mean annual precipitation is high and ranges from 1700 to 5000 mm, 20-70% of which falls as snow. A deep winter snowpack is common in the MH zone and influences the length the growing season. One subzone with a single variant, the MHmm1, occurs on Vancouver Island.

Forest stands are dominated by *Tsuga mertensiana* (Bong.) Carr., *Abies amabilis*, and *Chamaecyparis nootkatensis.* Other tree species include *Tsuga heterophylla* and

Thuja plicata at lower elevations throughout, *Pseudotsuga* and *Pinus monticola* at lower elevations in the south, and *Picea sitchensis* and *Pinus contorta* to the north and on dry sites respectively. Forest cover thins progressively with increased elevation, the vegetation becoming a parkland of isolated tree patches within subalpine heath, wet sedge fens and/or herbaceous meadow.

Ericaceous shrubs are characteristic of the MH zone. Typical species include, *Vaccinium ovalifolium* Sm. (oval leaved blueberry), *V. alaskaense, V. membranaceum* (Dougl.) (black huckleberry), *V. deliciosum* Piper (blue-leaved huckleberry), *Cladothamnus pyrolaeflorus* Bong. (copperbush), *Menziesia ferruginea* Smith. (false azalea), *Rhododendron albiflorum* Hook. (white-flowered rhododendron), *Phyllodoce empetriformis* Sm. (Don.) (pink mountain-heather), and *Cassiope mertensiana* (Bong.) G. Don. (white mountain-heather).

Herbaceous parkland settings occur in seepage areas or stream edges, and on steep south-facing slopes in the south. Typical herbaceous species include *Veratrum viride* Ait. (Indian hellebore), *Valeriana sitchensis* Bong. (Sitka valerian), *Senecio triangularis* Hook. (arrow-leaved groundsel), *Petasites frigidus* var. *frigidus* L. Fries. (sweet coltsfoot), *Caltha leptosepala* DC. (white marsh-marigold), *Leptarrhena pyrolifolia* R. Br. (leatherleaf saxifrage), *Ranunculus eschscholtzii* Schlecht. (subalpine buttercup), *Mimulus lewisii* Pursh. (pink monkey-flower), *Epilobium latifolium* L. (broad-leaved willowherb), *Erigeron peregrinus* (Banks ex Pursh.) Greene. (subalpine daisy), *Parnassia fimbriata* K. D. Koenig. (fringed grass-of-parnassus), *Mitella pentandra* Hook. (five-stamened mitrewort), *Pedicularis ornithorhyncha* Benth. (bird's beak lousewort), *Castilleja miniata* Dougl. (common red paintbrush), *C. parviflora* Bong. (small-flowered paintbrush), and *Arnica latifolia* Bong. (mountain arnica).

In areas where snow persists well into the growing season, sites dominated by *Carex nigricans* C. A. Mey. (black alpine sedge) are characteristic. These occur in snow basins or cool sites where snow lies on the surface for 9 months or longer each year.

Study Sites, and Site Selection

Two study sites were selected to investigate the south central Vancouver Island region with respect to Late-Quaternary vegetation, climate and fire history (fig. 2-1). A lowland and high elevation site were chosen to gain insight into how Late-Quaternary changes were expressed in two environments that differ with respect to local climate and vegetation.

The lowland record for the study was obtained from cores of lake sediments from Turtle Lake, located approximately 15 km northeast of the city of Port Alberni (fig. 2-1). The lake covers approximately 16.2 ha, and has an irregular perimeter and a shallow profile (fig. 2-3). Turtle Lake is located within the Alberni valley, which is surrounded by mountains. The lake is adjacent to the Stamp River, which flows into the nearby Alberni Inlet, an extensive fjord that extends north-eastward from the Pacific Ocean. Turtle Lake currently lies within the CWHxm1 variant in the biogeoclimatic classification (Meidinger and Pojar 1991). It is surrounded to the north, south and east by the CWHxm2 variant and to the west by the wetter CWHmm and CWHvm subzones.

Locally the lake is surrounded by a marginal bog and second growth forests dominated by *Pseudotsuga*. This site was chosen because it provides insight into Late-Quaternary changes on south central Vancouver Island. Also, the site lies in a dry subzone of the CWH (CWHxm), and provides a comparison site for a previous study of Rhamnus Lake focused on the CWH-CDF transition on southeastern Vancouver Island (Allen 1995). This previously investigated site lies within the modern CDF-CWH transition and is of the same subzone as that at Turtle Lake (CWHxm). In contrast, Turtle Lake lies in dry pocket 50 km to the west of the CDF, separated by an area of CWH. It provides a good opportunity to look at the similarities and differences in the history of both sites to obtain a better understanding of regional changes at the ecotone between the CWH and CDF.

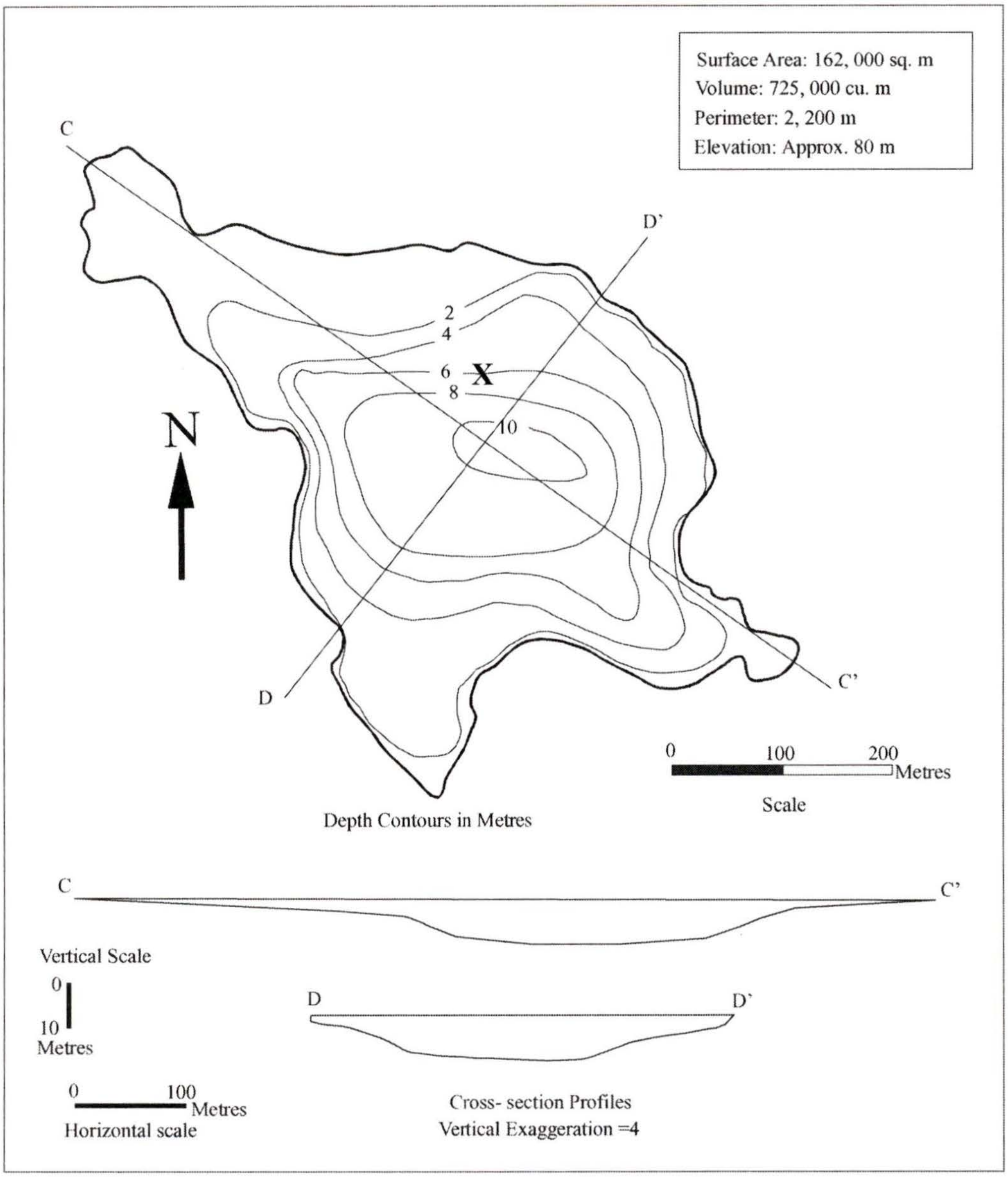

Fig. 2-3. Turtle Lake bathymetry and transects (modified from J. F., Burns 1978). "X" denotes core location

The subalpine record was obtained from peat sediments from a small (50 m^2) bog that had been exposed by the construction of a logging road. The bog was informally named Harris Lake Ridge Bog (R. Hebda 2000) (fig. 2-1). The bog lies at an elevation of 1300 m and is located west of the town of Courtney, in the Forbidden Plateau area, on the nose of the northeast trending Harris Lake Ridge. To the south is the Strathcona Park boundary and across the valley to the east is the Mt. Washington ski area.

The site currently lies within the MH zone and is surrounded by mature forest of *Tsuga mertensiana, Abies amabilis*, and *Chamaecyparis nootkatensis.* Patches of *Phyllodoce empetriformis* and species of *Vaccinium*, as well as moist openings with species of *Carex*, *Eriophorum*, and *Juncus* occur at the site.

This site was chosen because it provides another site within south central Vancouver Island to study late-Quaternary vegetation, climate and fire disturbance, and provides a comparison with Turtle Lake. In addition, the site provides insight into subalpine processes and responses, which presently are less well understood relative to lowland sites on Vancouver Island. Finally, the record from Harris Lake Ridge Bog can be compared to Porphyry Lake and Walker Lake, two previously studied subalpine sites on Vancouver Island (Brown and Hebda 2002 c), to gain a better understanding of late-Quaternary environmental change at subalpine sites.

The Harris Lake Ridge Bog site was also chosen for ease of accessibility, and the rare opportunity to sample sediment from a section rather than a core.

Lake sediments are often re-suspended and laterally re-distributed evenly over the whole basin (Moore and Webb 1978). This justifies the use of a single lake core as a representation of the entire basin and thus as a record of surrounding vegetation. Peat bogs, however, often have irregular surface topography and may accumulate peat such that stratigraphy is not laterally continuous (Moore and Webb 1978). A single section of a peat bog therefore may not be completely representative of the entire basin at a given time interval. However, peat bog sediments do develop in a stratified sequence and are thus temporally ordered (Moore and Webb 1978). Although perhaps not representative of the entire basin the peat bog sediments do provide a record of paleoenvironmental changes through time surrounding the site and satisfy the scope of this study.

Chapter 3

Background: Basis of Terrestrial Paleoecological Analyses

Introduction

This chapter provides background information on the methods used in the study, as well as previous work on the history of vegetation, climate and fire from the Pacific Northwest. The chapter begins by outlining and justifying the use of pollen analysis, macrofossils and charcoal to reconstruct vegetation, climate and fire disturbance. Following this, a summary of the regional paleovegetation and paleoclimate, derived from a number of studies in the Pacific Northwest, provides the framework against which this study will be compared.

Pollen Analysis

The analysis of pollen and spore assemblages, extracted from sedimentary sequences, has long been recognised as a powerful tool for reconstructing paleoenvironmental conditions (Moore and Webb 1978). In British Columbia many have used pollen and spore analysis to infer the history of vegetation and climate change from the late-glacial to present (e.g., Brown and Hebda 2002 a, c, Pellatt et al. 2002, Heinrichs et al. 2001, Hebda 1995, 1983, Mathewes and King 1989, Banner et al. 1983, Kearney and Luckman 1983, White and Mathewes 1982, Mathewes and Clague 1982, Hebda and Rouse 1979, Alley 1976, Mathewes and Rouse 1975, Mathewes 1973)

A number of reasons make pollen and spores useful tools for paleoenvironmnetal investigations and are summarized below.

1) Pollen and spores have a high potential for preservation as the outer wall, or exine, is composed of complex polymers known as sporopollenin. Preservation is excellent where oxidation and microbial activity is minimal (Faegri and Iverson 1975). As a consequence, lake and peat sediments are ideal for pollen and spore preservation.
2) Pollen and spores are produced in large numbers and are deposited from the air onto wetland surfaces.
3) Pollen and spore are easily concentrated from sediments.
4) The small size of pollen and spores allows them to be transported and mixed in

the atmosphere and thus provide a proxy of vegetation from a wide source area, the signature of which varies with the size of the wetland area (Prentice 1985).

5) Pollen and spores from different plants have different structural and sculptural characteristics (for example, pores, furrows, ornamentation, size) making them recognizable and distinguishable from each other (Moore and Webb 1978, Kapp et al. 2000)
6) A large number of pollen and spores are deposited into accumulating sediments, allowing them to be identified and counted within a relative stratigraphic-time sequence.

As with other paleoecological tools pollen and spore analysis has some limitations that must be considered in order to make meaningful interpretations (Moore and Webb 1978, Birks and Birks 1980, Faegri and Iverson 1975). Below is a summary of some of the key limitations to pollen and spore analysis.

1) *Differential production and dispersal of pollen and spores by different plants.* Some plants rely on insects to disperse their pollen while others rely on wind. As a consequence, pollen from wind pollinated taxa is both more widely dispersed and greater in number than insect pollinated taxa (West 1971). To complicate this problem, different wind-pollinated plants produce different amounts of pollen (West 1971, Moore and Webb 1978). Furthermore, the efficiency of dispersal differs among different species due to the stature of the plants themselves (Moore and Webb 1978). More pollen will be entrained into the air from a tree within the forest canopy than one of smaller size in the forest understory, solely because air movements differ in these two locations.

   Long distance transport can provide a source of error in palynological interpretation because pollen from distant sources may be deposited at sites where the taxon is locally absent. Fortunately, insight gained from surface sample studies can reveal the dispersal efficiency and production for different species. From these surface sample studies dispersal and production effects can be taken into consideration, minimizing the difficulties in interpretation.
2) *Differential preservation of pollen and spores.* The pollen and spores of some species preserve better than those of other species. For instance, *Populus* pollen is more

easily corroded and less readily preserved compared to fern spores (Mott 1978). This effect contributes to producing an incomplete representation of species and an incomplete picture of the paleovegetation.

3) *Reworking, resuspension, and vertical mixing of pollen and spores once deposited.* Erosion and transport of pollen and spores from older sediments introduces non-contemporaneous palynomorphs into a sequence. In some instances reworked grains can be separated from the pollen and spore assemblages based on evidence of mechanical or chemical corrosion, especially if the pollen and spores are from a substantially older deposit (Hebda 1977). Post-deposition resuspension of pollen grains and spores by water currents or seasonal turnover can average pollen and spore assemblages from many years and thus reduce the variability within a given sample interval (Moore and Webb 1978). Also, vertical mixing of palynomorphs by bioturbation or down-washing can act to average pollen contents over a longer time-interval than that in which they were deposited (Moore and Webb 1978). Mixing of sediment through biological activity such as feeding or burrowing may disturb the sediment to the point where stratigraphic layering is lost.
4) *Lack of taxonomic precision.* Many pollen and spores are only identifiable to the genus or family level rendering precise interpretations of plant communities difficult. This imprecision can be overcome by using macrofossils and ecological judgement based on modern plant associations and study area characteristics.

Macrofossil Studies

One major limitation to pollen and spore data is the lack of taxonomic precision. To aid this situation macrofossil remains of both aquatic and terrestrial plants are used to narrow taxonomic determination. Terrestrial plant macrofossils (e.g., conifer needles) are particularly useful as they are often identifiable to the species level and help to pinpoint the species contributing to pollen input in an assemblage. If the sampling site is forested and receives no major stream input, then recovered macrofossils have likely not been transported far from their source and are reliable indicators of local forest vegetation (Warner 1990, Dunwiddie 1986, 1987, Birks and Birks 1980). It is especially important to confirm the local presence of certain taxa whose pollen dispersal is poor (not well represented in the sediments). It is also important to distinguish taxa with similar pollen if those taxa indicate contrasting paleoenvironmental conditions, e.g., *Abies lasiocarpa* (Hook.) Nutt. versus *Abies amabilis* (Heinrichs et al. 2002a). Furthermore, macrofossils can reveal the local presence of a plant even though no pollen or spores from the plant were registered in the record (Birks and Birks 1980).

One of the potential problems with macrofossil interpretation is that the material can be transported some distances by water, wind or ice, such that they are removed from their original context, complicating paleovegetational reconstructions (Warner 1990). Fortunately, this limitation can often be overcome by selection of sampling sites that are forested and where input streams are absent (Warner 1990, Dunwiddie 1987). Even with some stream transport however, the distance from the source vegetation is often small (<10 kilometers) compared to pollen transport (>10 kilometers) (Hebda pers comm), emphasizing the local rather than regional vegetation.

A second potential problem with macrofossils is preservation. As with pollen and other fossil remains macro plant remains must be deposited in an environment where preservation is good and degradation by mechanical, chemical or biological agents is limited (Warner 1990). Peat and organic lake sediments generally provide conditions that are conducive to preservation as the energy and aerobic activity is often minimal.

Used together the combined analysis of macrofossils and pollen leads to a less biased paleovegetational reconstruction than if used separately (Birks and Birks 1980).

Fire Studies

According to Whitlock and Millspaugh (1996) the use of charcoal preserved in sediments as a tool for reconstructing fire history relies on the following assumptions:

1) Peaks in charcoal abundance within sedimentary horizons are evidence for increased fire activity.
2) Charcoal is deposited mostly from fallout in the event of fire. Secondary transport and re-deposition is minor in comparison to primary fallout.
3) Larger charcoal particles are indicative of local fire activity.

Each of these assumptions can be addressed to validate the use of macroscopic charcoal fragments to infer fire history.

The first assumption, that peaks in macroscopic charcoal reflect fire activity on the landscape, has been validated by a number of workers (e.g., Whitlock and Millspaugh 1996, Gardner and Whitlock 2001, Blackford 2000). These authors found that in modern settings charcoal was more abundant in sediments from sites within burned areas than from outside these areas. This suggests that as sediments accumulate and compact fire events will be expressed as peaks in charcoal abundance. The size of the charcoal peak depends on the time taken for charcoal to accumulate and the number of individual fires that burned within the time represented by a given sampling interval.

The second assumption, that charcoal is mostly from primary deposition without substantial transport and re-deposition, is debatable. Whitlock and Millspaugh (1996), found that secondary charcoal from mass wasting, both terrestrial and underwater, wind blown charcoal, and fragments from fallen burned trees may contribute to the deposition of charcoal some time after a fire event. In addition, Whitlock and Millspaugh (1996) found that charcoal tended to concentrate in littoral environments and was gradually transported to deeper waters in lakes. Despite secondary transport however, these authors found that sites within the burned areas had more charcoal than unburned sites.

Brown and Hebda (2002b) speculated that increased charcoal in mid-Holocene sediments from southern Vancouver Island may have been the result of influx of particles by overland flow due to increased moisture as opposed to increased fire activity. Overland flow was not demonstrated to be a significant factor in introducing secondary charcoal in the Charlton Burn area in central Oregon (Gardner and Whitlock 2001). In areas where adjacent slopes are gentle, introduction of charcoal through overland flow may be minimal (Gardner and Whitlock 2001).

The present study is not concerned with identifying individual fire events or fire frequency (as sampling resolution is likely not high enough) , but instead simply attempts to infer times of increased fire activity on the landscape as another tool to reconstruct post-glacial vegetation and climate. Therefore, the accumulation of secondary charcoal for some amount of time after a fire event does not pose a problem. Furthermore, because both sites examined in this study have no input stream or are not surrounded by steep slopes, the input of secondary charcoal from stream input or mass movements is minimized.

The third assumption, that large charcoal particles are derived mostly from local fires, has been demonstrated by a number of workers (e.g., Clark and Royall 1995, Whitlock and Millspaugh 1996, Laird and Campbell 2000, Gardner and Whitlock 2001, Blackford 2000). Clark and Royall (1995) found that macroscopic charcoal fragments (>50 μm) reflect local fires whereas microscopic (5-50 μm) record regional fire activity. These authors used petrographic thin sections (thin slices of sediment embedded in epoxy and placed on a microscope slide) to count macroscopic (defined by Clark and Royall (1995) as >50 μm) charcoal fragments, and fragments identified in pollen slides to count microscopic fragments. Whitlock and Millspaugh (1996), and Gardner and Whitlock (2001) counted macroscopic fragments (defined as >125 μm by Whitlock and Millspaugh 1996) and concluded that fragments above 125 μm is representative of local fire activity. Blackford (2000) adopted the technique from Whitlock and Millspaugh (1996) and reported that in burned and unburned heath in England, "large" (>125 μm) particles were more abundant in burned areas and thus represented local fires. Laird and Campbell (2000) also followed the method outlined by Whitlock and Millspaugh (1996) and found that large charcoal fragments record fires that had burned at the lake's edge but were less responsive to fire burning elsewhere in the watershed.

The sieving method outlined by Whitlock and Millspaugh (1996) for counting macroscopic (>125 μm) charcoal has the advantage that it is less time consuming than counting smaller charcoal fragments. In addition, the >125 μm fragments are easier to identify than microscopic particles in pollen slides (Whitlock and Millspaugh 1996). Also, larger fragments extracted by sieving do not endure the same chemical and physical processing as pollen slide processing, a procedure that may affect particle size and identification (Whitlock and Millspaugh 1996, Clark and Royall 1995).

Numerous studies in the Pacific Northwest of North America have relied upon the identification and counting of macroscopic charcoal fragments to reconstruct fire histories (e.g., Brown and Hebda 2002b, 1998, Heinrichs et al. 2001, 1999, Millspaugh et al. 2000, Mohr et al. 2000, Long et al. 1998). On southern Vancouver Island, Brown and Hebda (2002a,b) and Heinrichs et al. (1999) outlined the general sequence of fire history along a west-east transect. All sites initially show low charcoal accumulation immediately after deglaciation, followed by a rise in the accumulation during the late

Pleistocene. This rise is interpreted as a response to increased fuel accumulation as forests dominated by *Pinus* changed to closed mixed conifer forests. In the early Holocene warm and dry conditions may have influenced charcoal accumulation regimes. On the east side of Vancouver Island, charcoal accumulation declined slightly from the late Pleistocene, perhaps reflecting the openness of the vegetation and low charcoal production from ground fires. Toward the west, in contrast, charcoal abundance increased slightly, reflecting a response to early Holocene warming. In the mid-Holocene charcoal influx was relatively low in all lowland sites with the exception of East Sooke Fen, where persistent charcoal accumulation may have been due to forest closure, resulting in greater charcoal production. In the late-Holocene charcoal accumulation was generally low but increased notably at East Sooke Fen and Boomerang lakes at 2000 ybp. This increase in charcoal accumulation, in spite of regional climate reconstructions that suggest increasing moisture and cooling, is attributed to First Nations burning as a land management tool (Brown and Hebda 2002b). Turner (1999) notes that First Nation peoples of coastal British Columbia used fire to clear land for deer hunting and to encourage berry growth.

Paleovegetation

Vancouver Island

Numerous studies have reconstructed the vegetational history of Vancouver Island from the end of the Fraser glaciation to the present (Hebda 1997, 1983, 1995, Brown and Hebda 2002a, c, Allen 1995, Heusser 1983, Pellatt et al. 2001). From these studies, broad generalizations regarding the history of vegetation change on Vancouver Island are revealed (Hebda 1995).

Studies on southern Vancouver Island (Brown and Hebda 2002a,c, Allen 1995, Heusser 1983, Hebda 1995) reveal the vegetation history of this area and also demonstrate the similarities and differences between lowland and subalpine sites. Brown and Hebda (2002c) studied two subalpine sites in southern Vancouver Island (Porphyry and Walker Lakes). To generalize, from >13,000-11,500 ybp late-glacial vegetation in lowland areas consisted of open *Pinus contorta* woodlands that colonized the recently deglaciated immature soils (Brown and Hebda 2002a, c, Allen 1995, Hebda 1995, Heusser 1983). At higher elevations, an NAP zone, recorded in Porphyry Lake, characterises the early late-glacial, before 13, 000 ybp. Later, from 13,000-12,225 ybp, both subalpine sites record open *Pinus* woodlands with *Picea*, *Abies* and *T. mertensiana*. In the late Pleistocene, a closed mixed conifer forest consisting of *Picea*, *Abies*, *T. mertensiana*, and *T. heterophylla* largely replaced the *Pinus* woodlands from 11,500 ybp-10,000 ybp in lowland areas and from 12,225-10,000 ybp at higher elevations (Brown and Hebda 2002a, c, Allen 1995, Heusser 1983).

Forest composition and structure changed dramatically for sites lowland and subalpine on southern Vancouver Island at the beginning of the Holocene. The early Holocene change was, however, expressed differently between west and east Vancouver Island sites, and in lowland and subalpine sites (Brown and Hebda 2002a, c, Allen 1995, Heusser 1983). In lowland areas, on the southeast side of Vancouver Island, from 10,000- 7000 ybp, early-Holocene vegetation was characterised by the expansion and dominance of *Pseudotsuga*, and increases in *Alnus* (Allen 1995, Brown 2002a, Heusser 1983). Forest canopies opened and understories contained notable proportions of *Pteridium*, along with grasses and other non-arboreal taxa. In contrast, in the moister southwestern lowland of Vancouver Island, early Holocene vegetation was characterised by closed forests of *T. heterophylla*, *Picea*, *Alnus*, and minor *Abies*. By comparison, in the subalpine, *T. heterophylla* and *Pseudotsuga* influence increased while *T. mertensiana* values decreased (Brown and Hebda 2002c) paralleling the southeast lowland areas. Both subalpine sites were more open than during the late-Pleistocene (Brown and Hebda 2002c).

In the mid-Holocene, from approximately 8000–3000 ybp, *T. heterophylla* followed by *Thuja plicata* expanded and gave rise to forests of *T. heterophylla*, *Thuja plicata*, and *Pseudotsuga* in the southeast (Brown and Hebda 2002a). In the west, *T. heterophylla*, and *Thuja plicata* also expanded but *Picea* was much more important in these forests than in eastern lowland areas (Brown and Hebda 2002a). The importance of *Pseudotsuga* in forests decreased from east to west (Brown and Hebda 2002a). On the extreme southeastern-most area of Vancouver Island (Saanich Peninsula) mid-Holocene vegetation is characterized by increased *Quercus garryana*, indicative of oak meadow development (Allen 1995, Heusser 1983, Pellatt et al. 2001).

At higher elevations, in the mid-Holocene, from 6600-4400 ybp, *T. heterophylla*, *T. mertensiana*, *Abies* and *Picea* forests expanded at both Porphyry and Walker lakes (Brown and Hebda 2002c). From 3000 ybp -present, late Holocene vegetation resembled modern forests (Brown and Hebda 2002a, c, Allen 1995, Heusser 1983). In the west, forests of *T. heterophylla* and *Thuja plicata*, with some *Picea* developed in the lowlands, whereas *T. heterophylla* and *Pseudotsuga* forests developed in the southeast (Brown and Hebda 2002a, Allen 1995). At higher elevations from the mid-late Holocene, 4400-0 ybp, closed forests dominated by *T. mertensiana*, *T. heterophylla*, and *Chamaecyparis nootkatensis* developed (Brown and Hebda, 2002c).

The post-glacial history of vegetation from the north Vancouver Island differs substantially from southern Vancouver Island (Hebda 1983, 1997). At Bear Cove Bog on northeast Vancouver Island open *Pinus contorta* and *Alnus* with an understory of *Pteridium* colonised the post-glacial landscape (Hebda 1983). Later, species of *Tsuga* (initially *T. mertensiana*, and later *T. heterophylla*) and *Picea* replaced *Pinus* from 11, 500-8800 ybp. The persistence of *Tsuga-Picea* forests until 8800 ybp, well into the early Holocene is in contrast with southern Vancouver Island, where *Pseudotsuga* had already started to expand. From 8800-7000ybp *Pseudotsuga* expanded and became an important forest species with *Picea* around Bear Cove Bog, forming open *Picea-Pseudotsuga* forests that are not known from Vancouver Island today. The mid-Holocene, from 7,000-3,000 ybp, is characterised by the expansion of *T. heterophylla*, forming forests of *Picea* and *T. heterophylla*. In the late-Holocene, from 3000 ybp-present, *Thuja plicata* and possibly *Chamaecyparis nootkatensis* trees expanded, replacing *Picea*, and becoming co-dominant with *T. heterophylla*. These mid and late-Holocene changes are largely contemporaneous with vegetational changes on southern Vancouver Island.

Hebda (1997) studied of a series of five wetland and lake cores from Brooks Peninsula, on the northwest coast of Vancouver Island. Vegetation immediately after deglaciation, from 13,000-11,500 ybp was dominated by *Pinus contorta*, forming open woodlands at some sites and closed stands at others. From approximately 11,500-10,000 ybp mixed conifer forests of *Tsuga* (*T. mertensiana* plus *T. heterophylla* later), *Abies amabilis*, and some *Picea sitchensis* replaced *Pinus* woodlands at all sites with the exception of Cassiope Pond, where groves of *T. mertensiana* and *Abies amabilis* were scattered among open shrubby and herbaceous vegetation. In the early Holocene, from 10,000-9,000 ybp, *Abies amabilis* expanded and shared forests with *T. heterophylla* and *Picea sitchensis*. Scattered *Pseudotsuga* trees occurred in lowland regions. *Picea sitchensis* stands that extended inland and were not solely restricted to ocean shoreline zones have no modern analogue in British Columbia. At approximately 9,000 ybp, vegetation changed once more and gradually began to resemble modern cover up to the present. Forests on the south coast of Brooks Peninsula were characterised by closed forests of *T. heterophylla* and *Abies amabilis*, with minor *Picea sitchensis*. In the lowland forests of the northwest side, *Abies* declined in importance, *Picea* became restricted to the shoreline and forests became dominated by *T. heterophylla* and *Thuja plicata*. Upper slopes and ridges were characterized by groves of *T. mertensiana*, *Abies amabilis*, and extensive heath and meadow communities. Gradual adjustments in vegetation occurred from 4,000-0 ybp; *T. heterophylla* and *Thuja plicata* typified lowland forests, whereas *Abies amabilis* became restricted to well drained sites. Upper slopes were characterised by groves of *T. mertensiana*, *Abies amabilis*, and *Chamaecyparis nootkatensis* with heath and meadow communities continuing to occupy the northwest-facing upper slopes.

Walker (2001), provides insight into the post-glacial history of vegetation on the central west coast of Vancouver Island, through examination of a record from Effingham Bog, a lowland bog located in Barkley Sound, Vancouver Island. Before 12,260 ybp a *Pinus* woodland, possibly with a mixed conifer component of *Picea*, *Abies*, *T. heterophylla*, and *T. mertensiana* developed on the recently deglaciated landscape. In the late glacial, from 12,260-11,400 ybp *Pinus* dominated woodlands were replaced by mixed conifer forests of *Picea*, *Abies*, *T. heterophylla* and *T. mertensiana*. From 11,400-7,450 ybp *Alnus* and *Pseudotsuga* cover increases although *T. heterophylla* and *Picea* remain as important members of the forests. Also, increased Rosaceae in the understory suggests that forests were more open than previously. Toward the mid-Holocene from 7,450-5,700 ybp, forests closed and *T. heterophylla* dominated. From approximately 5,700-4,700 ybp *Picea* cover increased and replaced *T. heterophylla* as the dominant canopy taxon. Better-drained sites may have supported *Abies amabilis*. From 4,700-0 ybp *T. heterophylla* returned to dominance, sharing the forest canopy with *Picea* and *Thuja plicata*.

Notable among all records from Vancouver Island are the similarities in both timing of change and vegetation composition in post-glacial vegetation assemblages. Most sites record initial colonization by *Pinus* woodlands followed by the replacement of these stands by mixed conifer forests. In contrast, early-late Holocene vegetation patterns diverge and take on unique characteristics based on geographic location on Vancouver Island. Southern Vancouver Island shows increased *Pseudotsuga* followed by *T. heterophylla* and Cupressaceae, whereas more northern and western areas exhibit more *Picea* with *T. heterophylla* in the early –Holocene followed by forests of *T. heterophylla* and Cupressaceae in the late-Holocene. *Pseudotsuga* played a reduced role in these locations. Similar timing of vegetation change suggests that Vancouver Island vegetation has responded mostly to regional climatic forcing. Differences in the composition of vegetation assemblages in the Holocene between southern sites and north and western sites illustrates that regional climatic forcing is modified by climatic gradients from west to east and north to south that produce distinctive vegetation assemblages.

Fraser Lowland

Mathewes (1973) study of Marion and Surprise Lakes in the University of British Columbia Research Forest reveals the post-glacial history of vegetation for the lower mainland of British Columbia. Surprise Lake lies in the CWHmm zone whereas Marion Lake is in transition between the moist and dry CWHmm and CWhxm subzone. Major tree species around both lakes include *T. heterophylla, Pseudotsuga* and *Thuja plicata.* Before 12,350 ybp vegetation was dominated by *Pinus contorta* with an understory of *Salix*, *Shepherdia canadensis*, and *Alnus*. The late Pleistocene, from 12,400-10,500 ybp was characterised by decreasing *Pinus* and simultaneous increases in *Picea*, *Abies*, species of *Tsuga* (*T. mertensiana* plus *T. heterophylla* later) and *Alnus*. In the early Holocene, from 10,500-6,800 ybp, *Pseudotsuga*, *Alnus* and *Pteridium* expanded, with *T. heterophylla* cover increasing later in the interval from 8,300-7,300 ybp. From 6,800-0 ybp *T. heterophylla* and *Thuja plicata* expanded to dominate forests.

To the east, in lower Fraser River canyon, palynological records from Pinecrest and Squeah lakes reveal the vegetational history from the transition of Coastal Western Hemlock Zone to the Interior Douglas fir Zone (Mathewes and Rouse 1975). Open *Pinus contorta* and *Alnus* woodlands with lesser amounts of *Abies*, and *Picea* dominate the earliest recorded vegetation in the area, from 11,140-10,000 ybp. In the early Holocene, from approximately 10,000-6,800 ybp, open *Pseudotsuga* forests with an understory of *Pteridium*, and Poaceae, and *Selaginella* on rocky knolls, expanded and replaced *Pinus*. *T. heterophylla* and Cupressaceae (probably *Thuja plicata*) began to increase their cover near the end of this interval. Mid-late Holocene vegetation was characterised by the continued expansion of *T. heterophylla* and *Thuja plicata* forests, with *Pseudotsuga* and *Abies* as important components.

Adjacent US Pacific Northwest

Many studies provide insight into the history of post-glacial vegetation of western Washington State (e.g., Barnosky 1981, Baker 1983, Heusser 1976, 1983, 1985, McLachlan and Brubaker 1995, Hansen and Easterbrook 1974). These records show similarities in the timing of vegetation change among different regions (Heusser 1985, 1983, Baker 1983). In addition, because some sites lie south of the maximum extent of Fraser glaciation, they provide much longer paleoecological records, several extending into full glacial and previous interglacial time (Heusser 1985, 1983).

At Davis Lake, southeast of the Olympic peninsula (Barnosky 1981), *Pinus contorta* woodlands with *Picea*, *T. mertensiana* and *Abies* characterise the late-glacial vegetation between 16,000-10,500 ybp. In the early Holocene, *Pseudotsuga*, *Alnus* and *Pteridium* expanded producing open *Pseudotsuga* forests with disturbed sites occupied by *Alnus*, and understories of *Pteridium*. *T. heterophylla* and Cupressaceae also are important components of the early Holocene vegetation surrounding Davis Lake. In the late Holocene, from approximately 6,800-0 ybp, Cupressaceae (probably *Thuja plicata*) expanded and formed closed forests with *T. heterophylla*. However, *Pseudotsuga* was probably still an important component of the late Holocene forests.

The Hoh-Kalaloch section from the western side of Olympic Peninsula (Heusser 1977), records *Pinus* dominated vegetation with *Picea*, *Abies* and *T. mertensiana* during the late Pleistocene. During the early Holocene, *Pseudotsuga* and *Alnus* expanded along with *Picea*, followed by an increase in *T. heterophylla* and decreasing *Picea* in the mid-late Holocene.

McLachlan and Brubaker (1995) provide a regional picture of the post-glacial vegetation history of the northeastern Olympic Peninsula through examination of a record from Crocker Lake. Late-glacial vegetation, before 11,000 ybp was characterised by open woodlands dominated by *Pinus contorta*, *Abies*, *T. mertensiana*, *T. heterophylla*, and *Picea*. From 11,000-7,000 ybp, open *Pseudotsuga* and *Alnus* forests with understories containing *Pteridium*, Poaceae, and *Artemisia* replaced the late-glacial woodlands. In the mid-late Holocene from 7,000-0 ybp, *T. heterophylla* and *Thuja plicata* forests expanded, while *Pseudotsuga* decreased in abundance.

Notable in these records from western Washington State, as in British Columbia, is the similarity of both paleovegetation composition at similar times and the synchronous timing of vegetation changes in different geographic locations. In particular, late glacial assemblages are regional in extent consisting of *Pinus* woodlands, which are later replaced by closed mixed conifer forests of *T. mertensiana*, *T. heterophylla*, *Abies* and *Picea*. Also, vegetation change close to the transition to the early Holocene is relatively contemporaneous with expansion of *Pseudotsuga* and *Alnus* in most regions

Paleoclimate

Paleoclimatic interpretations in the region can be derived from palynological and other paleoenvironemental investigations (e.g., Hebda 1995, Gascoyne et al. 1981, Heinrichs et al. 1999, Heusser 1985, Walker and Mathewes 1989, Heusser et al. 1980). In the Pacific Northwest of North America a broad pattern of post-glacial climate change has been inferred from numerous palynological records (e.g., Brown and Hebda 2002a, c, Hebda 1997, 1995, McLachlan and Brubaker 1995, Sea and Whitlock 1995, Heusser 1985, Heusser et al. 1980, Heusser L., 1983, Baker 1983, Barnosky 1981, Hansen and Easterbrook 1974, Mathewes and Rouse 1974, Mathewes 1973, 1993, Mathewes and Heusser 1981). The following is a summary of the post-glacial climatic patterns. From approximately 14,000-11,500 ybp, climate was inferred to be cool to cold and dry. From 11,500-10,000 ybp the late Pleistocene climate is believed to have remained cool but to have moistened relative to the past. Rapid climate change at the beginning of the Holocene, from 10,000-7,000 ybp, led to conditions that were warmer and drier than today. From 7,000-4,000 ybp, climate moistened and began to gradually cool, although initially temperatures were probably warmer than today (Hebda 1995). After 4,000 ybp, conditions continued to cool and moisten and modern climate was established.

Mathewes and Heusser (1981), and Heusser et al. (1980) used mathematical functions relating modern pollen assemblages to climate to convert fossil pollen data into mean July temperature and mean annual precipitation. Full glacial climate was cool and dry and subsequently warmed and moistened from approximately 12,000 -10,000 ybp. Temperature and precipitation changed rapidly at the onset of the Holocene and the highest mean July temperatures, and lowest mean annual precipitation values were noted for the interval between 10,000-7,500 ybp. Mean temperatures declined until 4,000 ybp, whereas precipitation increased to modern values around 6,000 ybp.

Chapter 4

Methods

Field Sampling

Lake sediments from the Turtle Lake core was recovered using a Livingstone corer deployed from a wooden raft. The peat bog samples from Harris Lake Ridge Bog were obtained from a cleaned face of the exposed section using a spade and trowel. For each sample care was taken to remove the outer surface of sediment to minimize possible contamination from modern material. All material was sampled and bagged in the field at 1-5 cm resolution with the exception of a small core piece (490-507 cm in the record) from Turtle Lake, which was left intact and sampled at 0.5-2 cm intervals in the laboratory at the Royal British Columbia Museum.

Surface samples were obtained in July and September 2001 from around the margin of Turtle Lake and from old growth forests, and subalpine meadows along an elevational transect on Mt. Arrowsmith. Samples were placed into plastic bags upon collecting and consisted of moss, forest litter, or mud with woody detritus. At each sample site, plant species within a 10 m x10 m plot were identified and species percent-cover visually estimated.

All samples were stored in sealed plastic bags at room temperature at the Royal British Columbia Museum.

Pollen Analysis

From each sediment sample horizon, a measured amount (1-2 cm^3) of sediment was sub-sampled and physically and chemically processed to concentrate the pollen contents. For surface sample approximately 20 cm^3 of material were processed. All surface and sediment samples were processed using standard pollen and spore preparation techniques (Faegri and Iverson 1975).

Material with visible mineral content, such as clay, silts, or sands, was first treated with hydrochloric acid (HCl) to remove any carbonates, stirred with a magnetic rod to remove magnetic minerals, and finally transferred to plastic beakers for silicate mineral digestion in hydrofluoric acid (HF). Sediment containing larger coarse sand to pebble-sized rock fragments was washed through a sieve (e.g. 250 μm) to remove the coarse fraction and then prepared for HF treatment. After mineral digestion (from1-10 hours), the acid was decanted and the residual material washed several times.

Sediment containing humic materials was boiled for 5 minutes in 5% KOH and then screened if coarse organic material (e.g., twigs, moss) was present. Remaining plant detritus was removed through standard acetolysis (9:1 acetic anhydride to sulfuric acid in boiling water bath) for 5-10 minutes. Following a glacial acetic acid wash, samples were then repeatedly centrifuged and washed with water. One or two tablets, containing known amounts of *Lycopodium* spores, were dispersed into each sample before acetolysis in order to calculate pollen concentrations and influx rates. No exotic marker (*Lycopodium*) was added to surface samples.

For microscope work, processed material was mixed with glycerin jelly and mounted on glass slides. Slides were scanned using a Nikon Biophot microscope at 400x-1000x magnification and a minimum of 300 pollen and spores were identified, counted and tallied. Pollen identification was facilitated through the use of reference collections at the RBCM and from published and unpublished keys (Kapp et al 2000, Moore and Webb 1978).

Raw pollen and spore counts were tabulated and converted to percentages and influx values. TILIA 2.0 and TILIAGRAPH 2.0 software (Grimm 1993) were used to create pollen diagrams. In Harris Lake Ridge Bog samples, undifferentiated monolete fern spores often made up much of the material on the slides. As a result, this spore-type was not included in the minimum 300 pollen and spore total, and was also excluded from the pollen sum when percentages were calculated for other pollen and spore types. Percentages of undifferentiated monolete fern spores were calculated using the pollen sum of all other palynomorphs, plus the undifferentiated monolete spore counts. The exclusion of undifferentiated monolete spores from the total pollen sum was to enhance percentage trends in other pollen types.

Pollen concentration (grains/cm^3) was calculated using the relation:

$$\frac{E}{[E]} = \frac{P}{[P]}$$

Where E equals the exotic spores counted (number of *Lycopodium* counted), [E] equals the concentration of the exotic (known from tablet and amount of sediment processed), P equals the pollen of any type counted (e.g., *Pinus*, *Abies*, Total), and [P] is the concentration of that pollen type. Influx (grain/cm^2/yr) was calculated by multiplying pollen concentration by the sedimentation rate calculated from ^{14}C radiocarbon dates.

Three pollen types were selected to be used in two climatic indices of temperature and precipitation. The three pollen types were *Pseudotsuga* because it is a low-elevation drought tolerant taxon, *T. heterophylla* because it is a low-elevation moisture requiring taxon, and *T. mertensiana* because it is common in cool subalpine settings. Following Brown (2000), Allen (1995), and Allen et al. (1999), a ratio of the counts of *Pseudotsuga* and *Tsuga heterophylla* was used as an index of precipitation and a ratio of the counts of *T. mertensiana* and *T. heterophylla* was used as an index of temperature. The precipitation index is referred to as DWHI (Douglas fir-Western hemlock Index), and the temperature index is referred to as THMI (*T. heterophylla-T. mertensiana* Index) (Allen 1995, Brown 2000). The equations for DWHI and THMI are given by:

$$\text{DWHI} = 1 - (\textit{Pseudotsuga} \,/\, \textit{Pseudotsuga} + \textit{T. heterophylla})$$

$$\text{THMI} = 1 - (\textit{T. heterophylla} \,/\, \textit{T. heterophylla} + \textit{T.mertensiana})$$

Each ratio varies between 0 and 1. Low DWHI ratios of 0-0.5 indicate dry conditions and values of 0.5-1 indicate moister conditions. Similarly, low THMI ratios between 0-0.5 indicate relatively warm conditions while values of 0.5-1 suggest relatively cooler conditions. Use of the two ratios is useful in that they distinguish precipitation from temperature trends.

Charcoal Analysis

Charcoal analysis methods were adapted from Whitlock and Millspaugh (1996). Sediment sub-samples of 2.5 cm^3 were washed through nested sieves of 500μm, 250μm, and 150μm. This sequence separated charcoal fragments into three size classes: 150-

250µm, 250-500µm, and >500µm. Material passing through the 150µm sieve was not used for the charcoal analysis and was discarded.

Material from each size class was placed into a gridded petri dish and examined under a binocular microscope at 20x-40x magnification. Fragments identified as charcoal were tallied for each size class. Following Brown (2000), charcoal was identified as black, opaque, and highly reflective fragments that often showed cellular structure. Charcoal from each size class was later summed for each horizon, providing an estimate of the total charcoal greater than 150µm within each sample horizon. Separation of charcoal into three size classes reduced the variability of fragment size in each sample, making the charcoal easier to identify and count.

Macrofossil Analysis

Sediment sub-sampled for macrofossil analysis was gently washed through a 250µm sieve and the coarse material retained in vials. Sample sizes ranged from 5-25 cm^3 with less material being processed for samples with abundant visible needle fragments and woody remains. Retained material was examined under a binocular microscope at 20x-40x magnification and recognizable macro-remains were identified using reference material from the Royal British Columbia Museum and from published keys (Dunwiddie 1985). The main aim of the macrofossil analysis was to identify conifer needles or other plant parts that would aid in identifying species contributing to the pollen and spore spectra, and to detect the presence of species not recorded in the pollen spectra. Macrofossil data are presented as number of fossil specimens found in each sample. Macrofossil data was not converted to concentrations or percentages and hence no interpretation of relative plant cover from macrofossil abundance was made.

Chapter 5

Surface Sample Results

Introduction

Surface samples were collected in the floating bog surrounding Turtle Lake, from the adjacent forest (fig 2-1), and from an altitudinal transect in old growth forests on Mt. Arrowsmith (fig. 5-1), east of the Alberni Valley. Samples from the floating bog consisted of *Sphagnum* peat and pond detritus. Forest samples from stands adjacent to Turtle Lake and from the altitudinal transect consisted of moss and litter from the forest floor and detritus from wet depressions. Samples were processed using standard palynological techniques (Faegri and Iverson 1975), as outlined in Chapter 4.

Results are divided into two sections. The first section deals with the lowland bog and forest samples from Turtle Lake, and are divided into "Turtle Lake Bog", and "Turtle Lake Forest". These samples provide a comparison of pollen assemblages from bog environments and disturbed second growth *Pseudotsuga* forests. In addition, these samples add to a growing database of surface samples collected to interpret fossil pollen assemblages on Vancouver Island (Brown 2000).

The second section deals with pollen from samples along an altitudinal transect on Mt. Arrowsmith, south of Port Alberni (fig. 5-1). The data provide information on pollen assemblage change with elevation, as biogeoclimatic boundaries are crossed. Specifically, these samples show characteristic pollen assemblages from the CWHmm, the transition from CWH to MH, the lower MH and the upper parkland areas of the MH. This information aids in interpreting fossil assemblages from subalpine sites where shifts in the relative position of boundaries may have occurred in the past. In addition, THMI ratios can be calculated from *T. mertensiana* and *T. heterophylla* pollen counts to contribute to a database of high elevation sites such that paleotemperatures may be reconstructed in a GIS (Brown 2000). In addition, THMI trends can be observed and applied to the interpretation of the record at Harris Lake Ridge Bog. Although no surface samples were obtained directly in the vicinity of Harris Lake Ridge Bog, samples from Mt. Arrowsmith provide useful information on subalpine pollen assemblages on Vancouver Island.

Two pollen diagrams consisting of percentages of pollen and spores, THMI and DWHI values and the sample environment is provided for Turtle Lake and Mt. Arrowsmith in fig. 5-2 and fig. 5-3 respectively. A summary table of sample type (e.g., moss, pond detritus, litter), habitat, elevation and characteristic pollen is provided (Table 5-1). Vegetation cover estimates for surface sample sites are given in Appendix A.

Turtle Lake

Bog

Samples from this environment consisted of *Sphagnum* peat and pond detritus. *Myrica gale* L. (hereafter *Myrica*) (8-32%) and Cyperaceae (<1-14%) pollen distinguish this environment from adjacent forest sites. Abundant *Salix* pollen and *Lycopodium* spores are evident in one sample. Low values of Ericaceae (<1%) are also recorded in the bog samples, and were likely derived from individuals of *Kalmia microphylla* (Hook.) and *Vaccinium oxycoccos* L. that grew at the sites. Arboreal components include *Pinus contorta* (ca. 6-11%), *T. heterophylla* (ca. 20-39%), *Pseudotsuga* (ca. 6-27%), and *Alnus* (ca. 7-21%). Percentages of *Pinus monticola*, *Abies*, *T. mertensiana* and Cupressaceae are low (ca. <5%). These trees are either absent in the adjacent forest (*T. mertensiana*) or occurred infrequently (*Pinus monticola,* Cupressaceae, *Abies*).

Forest

Samples were taken from the forest floor of a second growth *Pseudotsuga* forest immediately adjacent to Turtle Lake. Relatively high *Pinus* values (8-18%), *Alnus* (12-45%) and Ericaceae (7-11%) characterise this environment and distinguish it from the bog samples. Both *Gaultheria shallon* and *Vaccinium parvifolium* are abundant (5-13% relative cover) in the understory of sample plots and account for the relatively high Ericaceae values. Other arboreal taxa are similar to those in the bog samples and include *T. heterophylla* (30-35%), and *Pseudotsuga* (4-18%). Percentages of *Pinus monticola*, *Picea*, *Abies*, *T. mertensiana* and Cupressaceae are low (<5%), similar to values in the bog samples. *Pinus monticola* values are low despite the occurrence of the tree in the stand. Relative cover of *Picea* reached 4% in one site but was not recorded in the surface

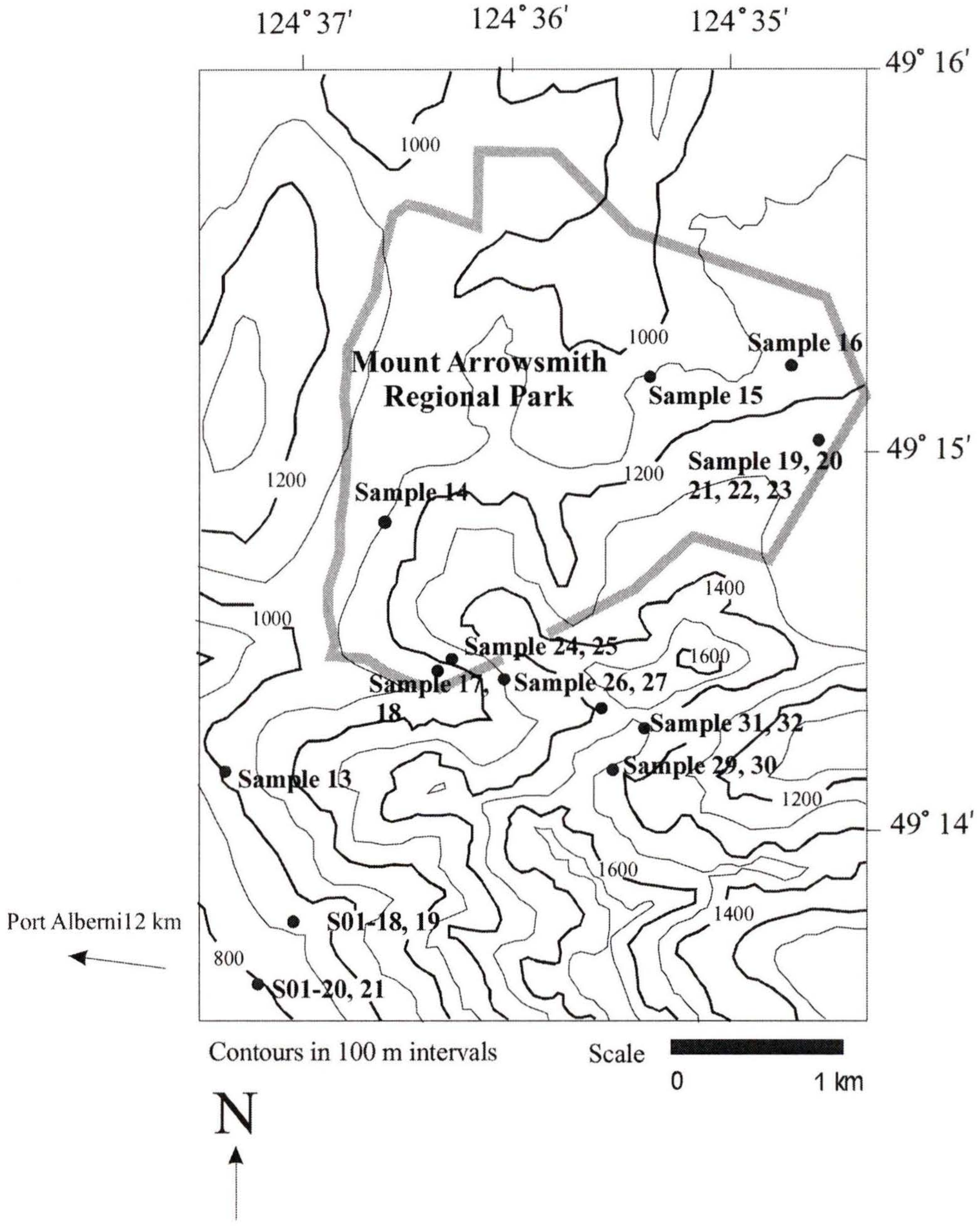

Fig. 5-1. Mt. Arrowsmith surface sample locations. Map reference: 92/F7, 92 F/2

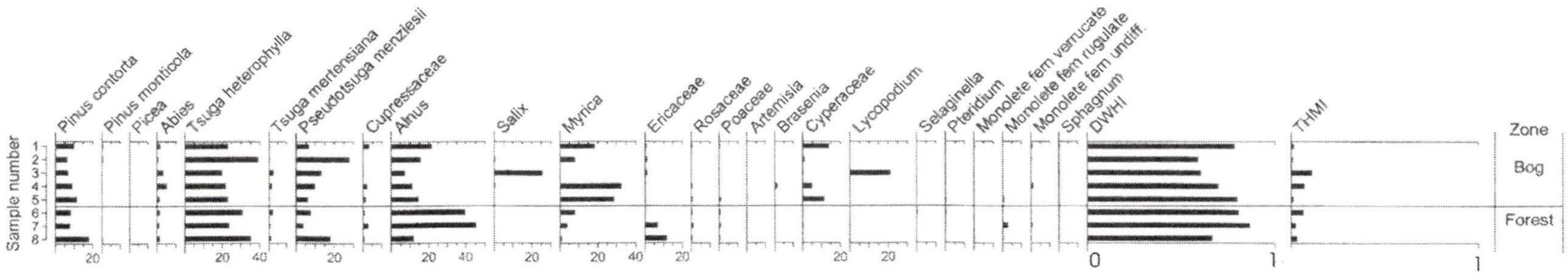

Fig. 5-2. Surface sample pollen and spore percentages from Turtle Lake

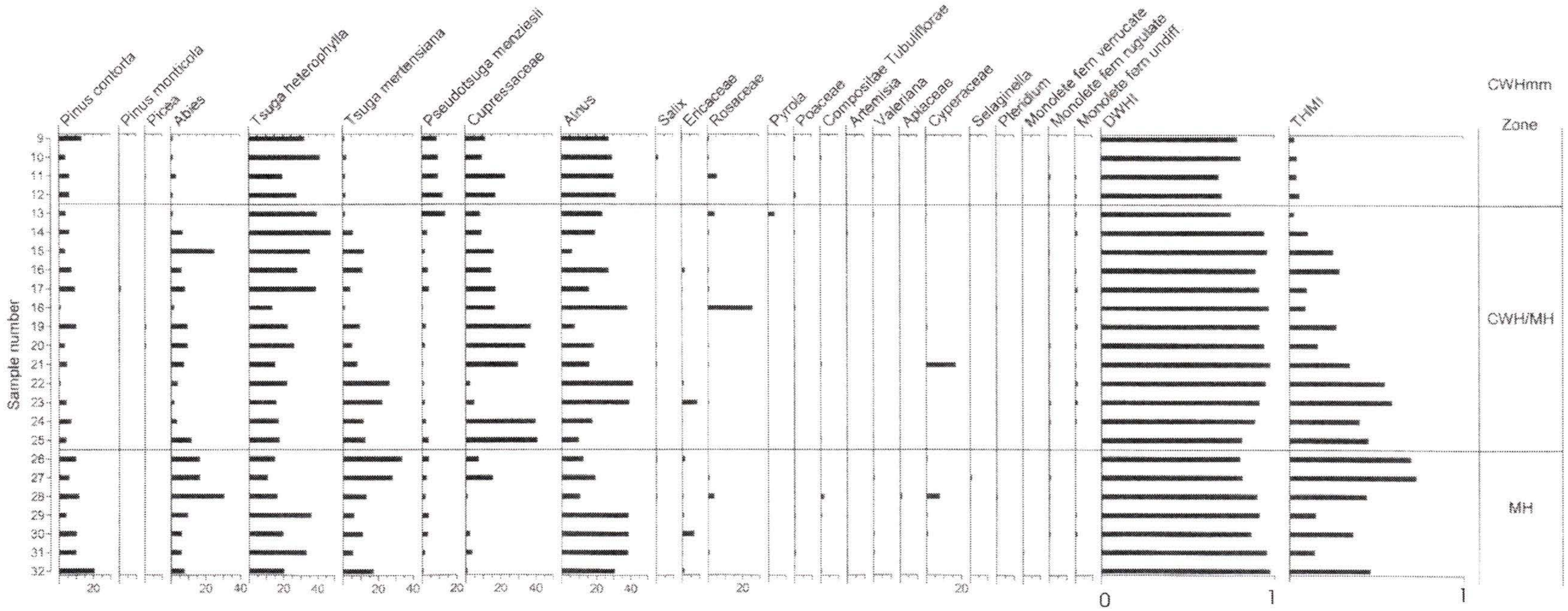

Fig. 5-3. Surface sample pollen and spore percentages from Mt. Arrowsmith, Vancouver Island. Arranged by elevation (top to bottom of diagram=lowest to highest elevation)

Table 5-1. Summary of surface sample material, habitat, elevation and major pollen taxa

Sample No.	ID	Sample type	Habitat	Elevation (m)	Pollen assemblage	Zone
1	S01-1	Sphagnum peat	floating bog at lake margin	80	*Pinus contorta, T. hetrophylla, Pseudotsuga, Alnus; Salix, Myrica*, Cyperceceae. Comments: High *Salix* and *Myrica* relative to forest	Turtle Lake bog CWHxm
2	S01-2	Sphagnum peat	floating bog at lake margin	80		
3	S01-3	Sphagnum peat	floating bog at lake margin	80		
4	S01-4	Pond detritus	Pond in bog	80		
5	S01-5	Pond detritus	Pond in bog	80		
6	S01-6	Moss	2nd growth *Pseudotsuga* forest at lake edge	80	*Pinus contorta, T. hetrophylla, Pseudotsuga, Alnus*; Ericaceae. Comments: high Ericaceae and reduced *Myrica* and *Salix* relative to bog	Turtle Lake forest
7	S01-7	Moss	2nd growth *Pseudotsuga* forest at lake edge	80		
8	S01-8	Moss	2nd growth *Pseudotsuga* forest at lake edge	80		
9	S01-20	Moss crust on bedrock	Open *Abies-Tsuga* forest	800	*Pinus contorta, T. heterophylla, Pseudotsuga*, Cupressaceae; Rosaceae. Comments: Cupressaceae increases up-slope	CWHmm
10	S01-21	Moss and litter	Creek bottom forest	800		
11	S01-18	Moss	*Pseudotsuga-T. heterophylla* forest	920		
12	S01-19	Moss and litter	*Pseudotsuga-T. heterophylla* forest	920		
13	S01-17	Moss and litter	open *Tsuga-Chamaecyparis* forest	1000	*Pinus contorta, Abies, T. heterophylla, T. mertensiana*, Cupressaceae, *Alnus*; Rosaceae, Ericaceae. Comments: *Abies, T. mertensiana*, and Cupressaceae increase; *T. heterophylla* decreases slightly up-elevation and *Pseudotsuga* decline markedly	CWH/MH transition
14	S01-16	Moss and litter	open *Abies-Tsuga* forest	1080		
15	S01-15	Moss	*Tsuga-Chamaecyparis* forest	1100		
16	S01-14	Moss crust and litter	*Tsuga-Chamaecyparis* forest	1120		
17	S01-A	Moss and litter	*Tsuga-Chamaecyparis* woodland	1160		
18	S01-B	Moss and litter	*Tsuga-Chamaecyparis* woodland	1160		
19	S01-9	Moss and litter	*Tsuga-Chamaecyparis-Abies* forest	1220		
20	S01-10	Moss and litter	*Tsuga-Chamaecyparis-Abies* forest	1220		

Table 5-1 Cont'd

						CWH/MH transition Cont'd
21	S01-11	Moss and sedges	Fen	1220		
22	S01-12	Moss crust over bedrock	open *T. mertensiana* forest	1220		
23	S01-13	Moss crust over bedrock	open *T. mertensiana* forest	1220		
24	S01-C	Moss and litter	*Chamaecyparis-Abies* forest	1234		
25	S01-D	Moss and litter	*Chamaecyparis-Abies-Tsuga* forest	1234		
26	S01-E	Moss and litter	*T. mertensiana-Chamaecyparis-Abies* woodland	1340	*Pinus, Abies, T. heterophylla, T. mertensiana,* Cupressaceae, *Alnus* ; Ericaceae, Cyperaceae. Comments: *Abies, T. mertensiana* decline and *T. heterophylla* and *Alnus* increase in bottom samples, because of transition from woofland to parkland. Cupressaceae declines markedly.	MH
27	S01-F	Moss and litter	*T. mertensiana-Chamaecyparis-Abies* woodland	1340		
28	S01-K	Moss crust on bedrock	*T. mertensiana-Abies* woodland	1422		
29	S01-I	Moss and litter	Subapline parkland with *T. mertensiana-Abies* dwarfs	1511		
30	S01-J	Moss and litter	Subapline parkland with *T. mertensiana-Abies* dwarfs	1511		
31	S01-G	Moss and litter	Subapline parkland with *T. mertensiana-Abies* patches	1514		
32	S01-H	Moss and litter	Subapline parkland with *T. mertensiana-Abies* patches	1514		

samples. *Myrica* is present in some of the samples, indicating that pollen from this lakeshore shrub was transported from the bog into the forest.

DWHI and THMI

DWHI values for the Turtle Lake surface samples range from 0.6-0.9, and do not show any difference between bog and forest samples. According to Allen et al. (1999) these DWHI values correspond to mean annual precipitation values of approximately 1700-2500 mm. This agrees well with a value of 1910 mm for Port Alberni for the years 1971-2000 (Environment Canada 2003).

THMI values are mostly <0.1, and reflect the lack of *T. mertensiana* trees growing around the site.

Discussion

Surface sample pollen spectra from Turtle Lake reflect the vegetation that was observed growing in the vicinity of the collection sites (Appendix A). In the bog environment, samples recorded high values of *Myrica* and Cyperaceae, consistent with the presence of these taxa at the sites. The arboreal pollen components were similar from both sample sites and consisted mainly of *Pinus*, *T. heterophylla*, *Pseudotsuga* and *Alnus*. In comparison to cover estimates *T. heterophylla* pollen is over-represented relative to *Pseudotsuga*, whereas *Alnus* and *Pinus* were not observed in plot areas used to estimate cover values. This agrees with the findings of Allen et al. (1999) that show overrepresentation of *Alnus* and *Pinus* and the potential for relatively high *Alnus* pollen counts despite local absence of the species.

Mt. Arrowsmith

CWHmm

The CWH is represented by the samples collected from 800-920 m. These represent the lowest elevation samples collected in the Mt. Arrowsmith transect. CWHmm is characterised by high values of *T. heterophylla* (20-42%), *Pseudotsuga* (9-12%), Cupressaceae (9-23%), and *Alnus* (28-32%). Both *Thuja plicata* and

Chamaecyparis nootkatensis occurred in sample plots and contribute to the Cupressaceae signal. *Pinus* contorta (6-13%) pollen was also observed. Percentages of *Picea*, *Abies* (*amabilis*), and *T. mertensiana* were low (<3%). Cover of *Abies amabilis* trees was 9% at one site but this abundance was not reflected in the pollen spectra for the sample. Rosaceae values are relatively high in one sample. *Rosa gymnocarpa* was observed in one of the sample plots and was likely the species responsible for at least some of the Rosaceae pollen.

CWH/MH transition

The CWH/MH transition was delineated based on typical elevations of CWH and MH boundaries (Meidinger and Pojar 1991; from 900-1800 m in southwestern British Columbia), and on field observations of sites at time of collection. The CWH/MH transition zone incorporated the upper CWH and the lower MH (Meidinger and Pojar 1991). The spectra from the CWH/MH transition are characterised by *Abies* (1-25%), *T. mertensiana* (1-26%), *T. heterophylla* (14-48%) Cupressaceae (8-41%) and *Alnus* (6-41%) pollen. *Abies* (*amabilis*) values are higher than in the CWHmm below. *T. mertensiana* and Cupressaceae (*Chamaecyparis nootkatensis*) values are also greater than in the CWHmm. In contrast, *T .heterophylla* and *Alnus* maintain values similar to CWHmm. Other arboreal components include *Pseudotsuga* (1-13%) and *Pinus contorta* (1-10%). *Pseudotsuga* values decline markedly from CWHmm, whereas *Pinus* contorta values remain similar. Rosaceae show peak values at the top of the zone and in the middle. *Pyrola* peak in the beginning of the CWH/MH transition with Rosaceae, and Ericaceae display a peak at the upper boundary with the MH.

MH

As defined here, the MH is the area consisting of woodlands or parkland vegetation within the elevational limits of the MH zone (Meidinger and Pojar 1991), and where *T. mertensiana* replaces *T. heterophylla* as the dominant *Tsuga* species. It is elevationally above the CWH/MH transition and is characterised by open subalpine woodlands, discontinuous subalpine tree patches within meadow communities, and areas with discontinuous krummholz, and dwarf tree patches. On Mt. Arrowsmith the MH zone began at 1340m. *Chamaecyparis nootkatensis* is the only species of Cupressaceae, *Abies amabilis* is the only species of *Abies*, and *T. mertensiana* is the only species of *Tsuga* encountered in sample plots.

The MH is characterised by high values of *Abies* (6-31%), *T. heterophylla* (11-36%), *T. mertensiana* (5-34%), and *Alnus* (11-39%). *Pinus contorta* contributes 4-20%. With respect to trends in the pollen spectra, *Abies* and *T. mertensiana* pollen reach peak values at the lower boundary of the MH and then decline with increasing elevation. In contrast, *Pinus contorta*, *T. heterophylla* and *Alnus* values increase with increasing elevation. The trend in the percentages of these pollen types reflects changing habitat type with increased elevation observed in the field. Over a relatively short distance vegetation communities change from subalpine forest to open parkland as the exposed ridge-crest is reached. Parkland communities are more open than forest and contain only patches of *T. mertensiana* and *Abies* trees within heather and herbaceous meadow communities. Parkland areas, therefore, receive more regional pollen input from lowland *T. heterophylla* and well-dispersed *Alnus* and *Pinus* (Allen et al. 1999, Hebda and Allen 1993) accounting for the observed pattern in the pollen data.

Other arboreal components consist of low values of Cupressaceae (1-15%) relative to the previous zone, and low values of *Pseudotsuga* (<4%). The signals of Ericaceae (7%), Compositae Tubiliflorae (<2%) and Cyperaceae (7%) are notable in the non-arboreal portion of the spectra.

DWHI and THMI

DWHI values range between 0.7-0.8 in the CWHmm zone, implying a mean annual precipitation range of 2000-2500 according to Allen et al. (1999). These values are slightly higher than precipitation normals for the Alberni lowland (1910mm, Environment Canada 2003), and are consistent with the moister CWHmm classification (Meidinger and Pojar 1991) relative to the CWHxm forests surrounding Turtle Lake. THMI values for the CWHmm are near zero, owing to the absence of *T. mertensiana* in the stands.

DWHI values rise from the CWHmm to the CWH/MH transition and range from 0.8-1.0 as *Pseudotsuga* disappears from forest stands. THMI values fluctuate widely but show a general rise in values from 0.1-0.6 up-elevation. The increasing trend in THMI values reflects cooling with increasing elevation as expected. The exact relationship between THMI and temperature is not known. Using the results of Brown (2000), who calibrated THMI values to temperature based on surface samples from southern Vancouver Island, a change in THMI values of 0.1-0.6 indicates a decrease in temperature of 3° C. Accepting this value, however, and considering that the elevational boundaries of the zone lie between 1000-1234 m, a decrease of 3 °C results in an adiabatic lapse rate of 12.9 °C/1000m. Such a lapse rate is higher than the dry adiabatic lapse rate of 10 °C/1000 m, and so it is unlikely that the 0.1-0.6 rise in THMI values indicates a temperature decline of 3 °C. Using a moist adiabatic lapse rate of 6.5 °C/1000 m (Environment Canada 2003) results in a temperature decline of 1.5 °C.

DWHI values for MH range between 0.8-1.0 and reflect the absence of *Pseudotsuga* in this zone. THMI values reach peak values of 0.7 in the woodland areas of the MH but then decline to between 0.1and 0.4 up-elevation in parkland areas. This is a reflection of discontinuous tree cover and the greater regional input of *T. heterophylla* relative to *T. mertensiana* input from local patches and dwarfed individuals.

Discussion

The CWH, CWH/MH, MH zones are distinguishable from each other based on the relative abundance of arboreal taxa, including *Abies*, *T. heterophylla*, *T. mertensiana*, *Pseudotsuga*, and Cupressaceae. Specifically, *T. mertensiana*, *Abies* and Cupressaceae increase with increasing elevation until parkland habitat is reached at which point their values decline. Cupressaceae showed the most notable decline in the parkland environments, consistent with its absence in sample plots in these areas. In contrast, relative values of *T. heterophylla* pollen decline gradually from the CWH through the CWH/MH and into the MH where they rise again in the parkland. Unlike *T. heterophylla*, *Pseudotsuga* pollen declines when the tree disappears from the forest (e.g., in CWH/MH transition) and is continuously low with increasing elevation even into parkland settings.

Less diagnostic in distinguishing CWH, CWH/MH, and MH from the Mt. Arrowsmith samples is the overall non-arboreal pollen signal. Rosaceae pollen is notable in the CWH and CWH/MH and Ericaceae pollen notable near the boundary of the CWH/MH transition and MH. Ericaceae and Cyperaceae are notable components of MH.

DWHI values are moderate in the lowland forests, and increased up-slope when trees of *Pseudotsuga* begin to disappear from forest stands. Precipitation increases with increasing elevation on Vancouver Island and so this result is expected.

THMI values accurately depict declining temperatures up-slope, as expected, until the parkland is reached. At the transition to the parkland THMI values decline and give a false impression of increasing temperatures. The inversion of THMI values within parkland settings limits their value at these sites, and should be taken into consideration when attempting to calibrate temperature and THMI values for reconstruction of paleotemperature (e.g., Brown 2000).

Conclusion

Surface samples are useful in interpreting fossil assemblages on Vancouver Island, particularly at high elevation sites where few surface samples have been collected (Allen et al. 1999, Brown 2000). These samples provide pollen signatures from modern, known vegetation types and serve as analogues for interpreting fossil pollen assemblages (Birks and Birks 1980, Hebda and Allen 1993, Allen et al. 1999). Surface samples from this study contribute to a growing database (Allen et al. 1999, Brown 2000) and aid in calibrating DWHI and THMI values to modern precipitation and temperatures for the reconstruction of paleoprecipitation and paleotemperatures from fossil pollen spectra.

Chapter 6

Turtle Lake Results

Introduction

This chapter describes the results and interpretation of pollen and spore, macrofossil and charcoal analysis from the core of sediments taken from Turtle Lake. The results begin with a description of the core stratigraphy and radiocarbon chronology. Pollen and spore, macrofossil and charcoal results follow. Each zone defined within the core is first described and then interpreted.

Stratigraphy, Chronology and Sedimentation Rates

The record for Turtle Lake was derived from lake sediments and constructed by overlapping two core sequences. The combined continuous record extends to a depth of 530 cm. The base of the record, from 530-500 cm, consists of grey, silty-clay with lenses of sand and pebbles. The remaining 500 cm of the core consists mainly of dark brown to olive brown gyttja with the exception of a grey, fine grained mineral layer from 365-367 cm. The upper and lower contact to this fine-grained layer is gradational into the encasing gyttja.

Four radiocarbon dates were obtained for Turtle Lake (Table 6-1). Three of these dates were determined by Beta Analytical Inc, Miami, Florida, and one was determined by IsoTrace laboratories at the University of Toronto. All material sent for dating consisted of bulk sediment sub-samples extracted from selected horizons within the record. Calibration of radiocarbon ages to calendar years was performed using CALIB 4.3 (Stuiver and Reimer 1993), which uses the standard INTCAL98 Database for calibration (Stuiver et al. 1998). The calibrated value reported represents the median value of calendar ages output by the program for the corresponding radiocarbon date, rounded to the nearest tenth year as recommended in the program user guide if standard deviation is more than 50 years.

An age-depth model (fig. 6-1), constructed from the radiocarbon chronology, shows how sedimentation rate (the slope of each line) has changed trough time. Sedimentation rates and reported ages in this study will be from conventional radiocarbon dates, for ease of comparison to other studies. The sedimentation rate for the bottom-most silty-clay sediments from 500-530cm could not be determined because of lack of datable material. Silty-clay sediments at the base of the core may be aeolian in nature, deposited as the landscape deflated under a cold dry climate of the early post-glacial. The accumulation rate and depositional process of such sediments is different from that of gyttja and as such cannot be extrapolated from gyttja-based sedimentation rates. Furthermore, without adequate dating, it is difficult to determine whether depositional hiatuses are present within the bottom-most sediments.

The beginning of organic deposition at 500 cm is characterised by a low sedimentation rate of 0.02 cm/yr, and may be less than that of overlying sedimentation rates because of compaction. Above this interval the sedimentation rate changes to approximately 0.05 cm/yr between 455 cm (9670 ±110 ^{14}C ybp) and 265 cm (5750±90 ^{14}C ybp), as well as for samples between 265 cm (5750±90 ^{14}C ybp) and 130 cm (3050±100 ^{14}C ybp). Sedimentation rate changes to 0.04 cm/yr between 130 cm (3050±100 ybp) and 0 cm (0 ybp).

Table 6-1. Turtle Lake radiocarbon dates

Laboratory Number	**Depth (cm)**	**Sample Type**	**Conventional ^{14}C Age (years BP)**	***Calendar Age (Cal years BP)**
Beta-160793	125-130	limnic peat	3050±100	3300
Beta-160792	260-265	limnic peat	5750±90	6520
Beta-160791	450-455	limnic peat	9670±110	11140
TO-9918	499-499.5	limnic peat	11980±80	13900

*Calibration to Calendar years using CALIB 4.3 (Stuiver and Reimer 1993, 4.1) using INTCAL98 dataset (Stuiver et al 1998). Calendar age is rounded to nearest tenth.

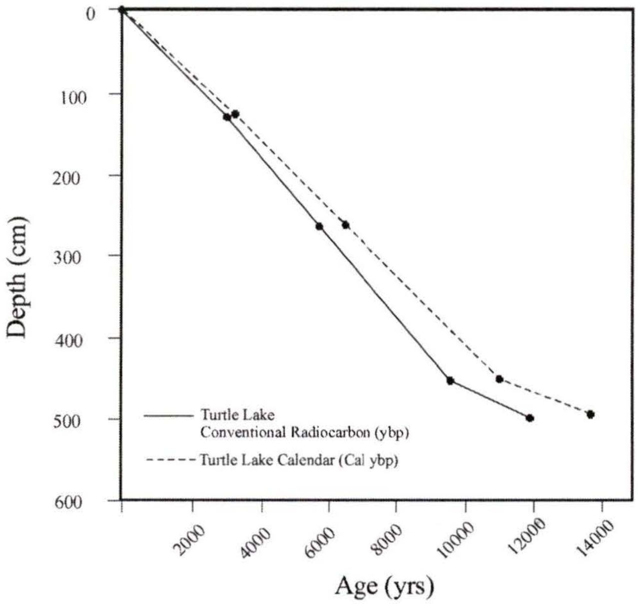

Fig. 6-1. Turtle Lake age-depth relationship

Pollen Zones

Zone boundaries were established by visual inspection and are strictly based on major changes in arboreal and non-arboreal pollen patterns in the record (fig. 6-2). Zone boundaries were drawn to ease discussion and were not based on any interpretation. Dominant arboreal taxa used to draw zone boundaries were *Pinus contorta, Abies, T. heterophylla, T. mertensiana, Pseudotsuga,* Cupressaceae, *Alnus, and Taxus brevifolia* Nutt. (hereafter *Taxus*). Although often not dominant, pollen of *Salix*, and non-arboreal pollen of *Myrica,* Rosaceae, *Epilobium,* Poaceae, Compositae Tubiliflorae, *Artemisia, Valeriana, Lysichitum,* and Cyperaceae, and spores of *Selaginella,* and *Pteridium aquilinum* (hereafter *Pteridium*) were also used to establish zone boundaries. Non-arboreal pollen is often under-represented in the region (Hebda and Allen 1993) and may reflect local vegetation, especially if taxa are insect pollinated (Gavin and Brubaker 1999). Information about local changes (e.g., bog development, edaphic conditions, microclimate) are important for a more complete reconstruction of vegetation around the site, as well as for inferring larger scale change (e.g., climate), that influence local communities.

Pollen and spore percentages, as well as charcoal influx and DWHI and THMI (Allen et al. 1999, Brown 2000) ratios are presented (fig. 6-2). Influx values (pollen/cm^2/year) for selected pollen types are summarized (fig.6-3). Macrofossil data, consisting of absolute abundance of identified fragments recovered are presented in table 6-2.

Zones 5 and 6 are separated into subzones (a) and (b) because of changes in non-dominant taxa that occur within a larger chronozone as defined by the dominant pollen types.

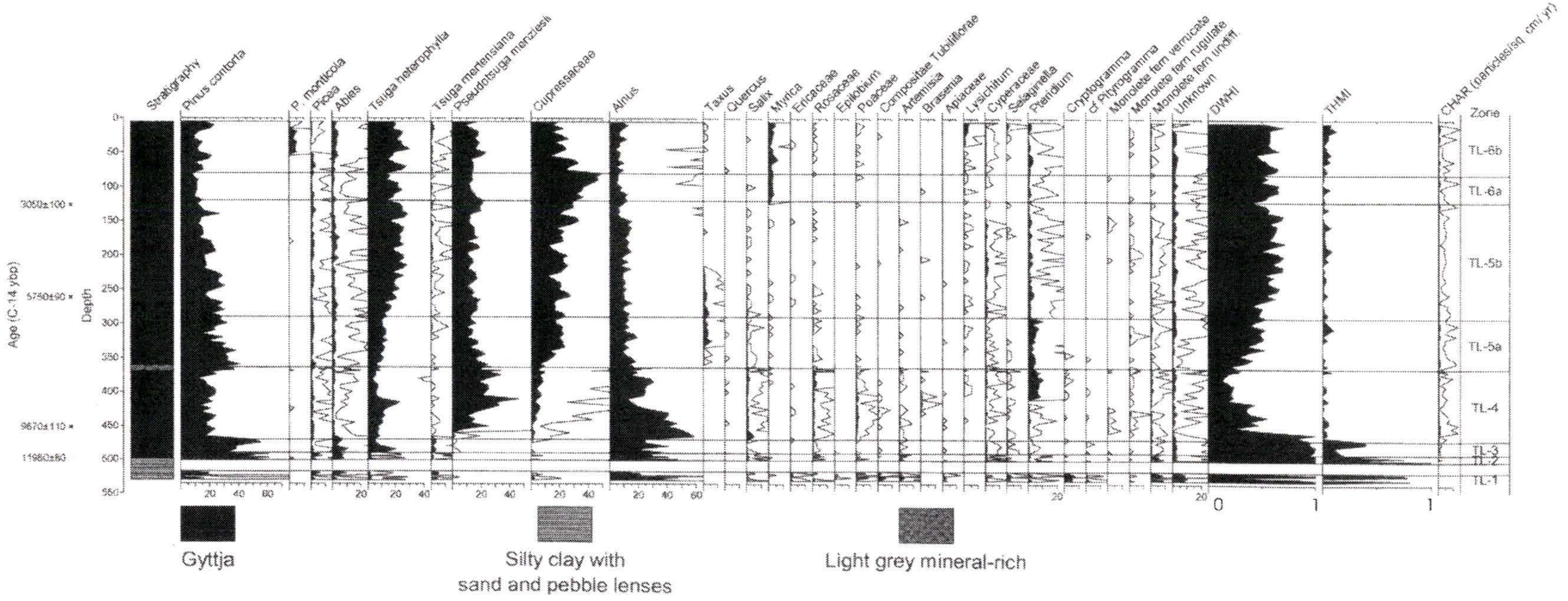

Fig. 6-2. Turtle Lake pollen and spore percentages, DWHI, THMI, and charcoal accumulation (CHAR). Unshaded curve x10

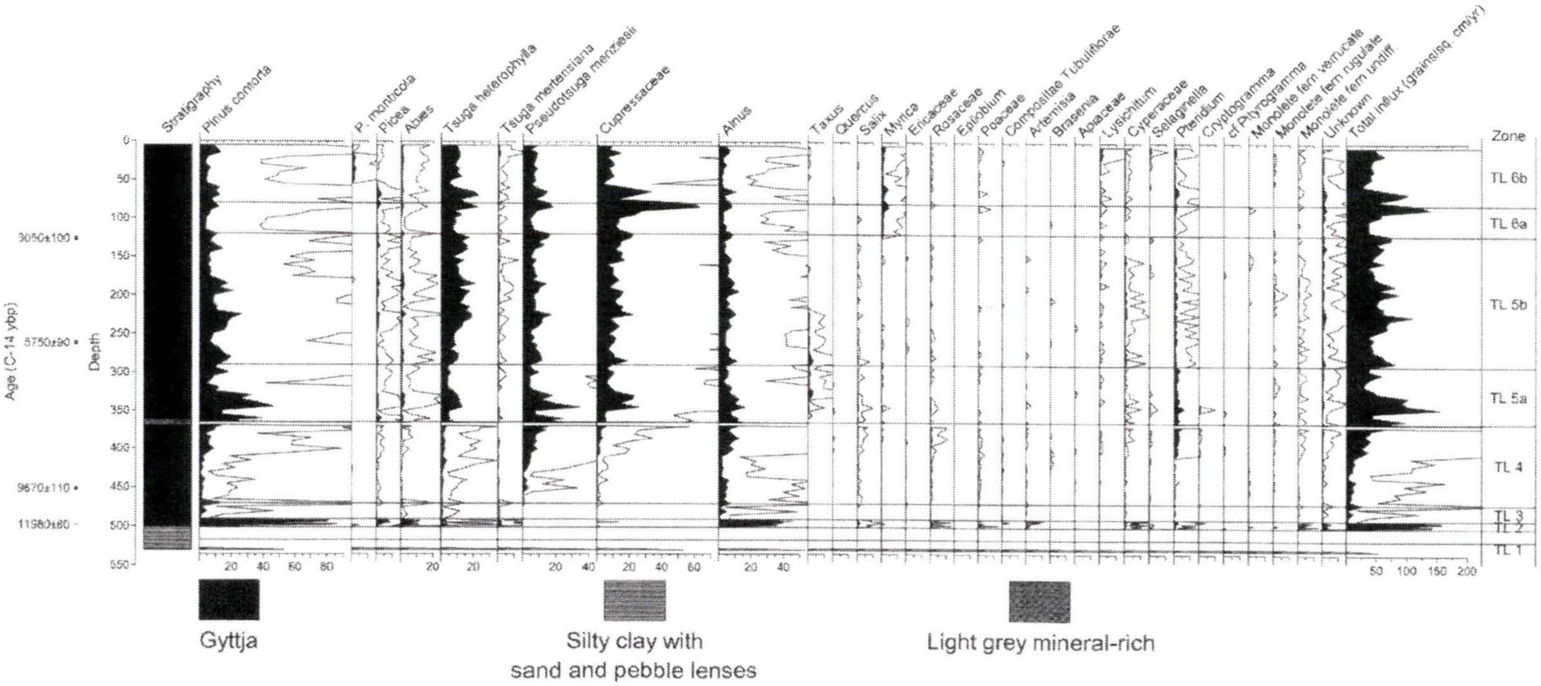

Fig. 6-3. Turtle Lake pollen and spore influx (pollen and spores/cm^2 /yr) (x100). Unshaded curve x10

Table 6-2. Turtle Lake macrofossils. *Indet=indeterminate

Samples containing macrofossils	***Volume of Sediment Processed***	***Pseudotsuga***		***T.heterophylla***		***Abies lasiocarpa***	***Abies sp. Indet****	***P. contorta***	***Chara oospore***	***Other***
Depth (cm)	(cc)	*fragment*	*whole*	*fragment*	*whole*	*fragment*	*fragment*	*fragment*		
10-15	10	-	-	-	-	-	-	-	-	
15-20	10	1	-	-	-	-	-	-	-	
25-30	20	-	-	-	-	-	-	-	-	sedge seed
35-40	20	-	-	-	1	-	-	-	-	
70-75	15	-	-	-	-	-	-	-	-	sedge seed
75-80	20	-	-	-	-	-	-	-	-	sedge seed
100-105	10	-	1	-	-	-	1	-	-	
105-110	15	-	-	-	1	-	-	-	-	*Myrica gale* -seed
110-115	20	-	-	-	-	-	-	-	2	sedge seed
115-120	20	-	-	-	-	-	-	-	1	*Myrica gale* -seed
120-125	20	-	-	-	-	-	-	-	-	sedge-seed, Nuphar-seed
135-140	20	-	-	-	-	-	-	-	-	sedge-seed
155-160	20	-	-	-	-	-	-	-	-	sedge seed
175-180	25	-	1	-	-	-	-	-	-	
180-185	25	-	-	-	-	-	-	-	-	*Polygonum* -seed
185-190	20	1	-	-	-	-	-	-	-	
210-215	20	-	-	-	-	-	-	-	-	*Polygonum* -seed
220-225	20	-	-	-	-	-	-	-	-	*Polygonum* -seed (2)
230-235	25	2	-	-	-	-	-	-	-	
235-240	20	-	-	-	-	-	-	-	-	sedge-seed
245-250	25	-	-	-	-	-	-	2	-	
265-270	25	-	-	-	1	-	-	-	-	
270-275	25	-	-	-	-	-	-	-	-	*Polygonum* -seed
275-280	25	-	-	-	-	-	-	4	-	sedge seed (2)
290-295	20	-	-	-	-	-	-	-	-	
295-300	20	-	1	-	-	-	-	-	1	
300-305	25	-	1	-	-	-	-	-	-	
305-310	15	-	-	-	-	-	-	-	-	*Lycopus* -seed
310-315	25	1	-	-	-	-	-	-	-	
315-320	20	-	-	-	-	-	-	-	4	sedge-seed
345-350	25	4	-	-	-	-	-	3	-	
355-360	25	-	-	-	-	-	-	-	2	
360-362	15	-	-	-	-	-	-	-	29	Apiaceae-seed
362-364	10	-	-	-	-	-	-	-	72	
364-365	5	-	-	-	-	-	-	-	13	
365-366	5	-	-	-	-	-	-	-	1	
372-375	15	1	-	-	-	-	-	-	-	sedge seed
455-460	25	-	-	-	-	-	-	1	-	
465-470	25	-	-	2	-	-	-	-	-	
485-490	25	-	-	-	-	1	-	-	-	staminate cone-*Pinus contorta*
490-495	25	-	-	-	-	-	-	-	1	

TL-1, 517-530 cm, >12,000 ybp, NAP

This narrow zone is characterised by non-arboreal pollen types. Dominant taxa in the assemblage include monolete fern spores (ca. 6-8%), pollen of Poaceae (ca. 1-8%), *Cryptogramma* (ca. 5-8%), Compositae Tubiliflorae type (ca. 2-5%), *Artemisia* (ca. <4%), *Pityrogramma*-type (labeled cf. *Pityrogramma*; ca. 1-3%), and spores of *Selaginella* (ca. <3%), and *Pteridium* spores (ca. <3%).

The arboreal component of this zone is dominated by pollen of *Pinus* (3-20%) and *Alnus* (20-50%). Other trees represented in the percentage profile include *Picea* (ca. 2-6%), *Abies* (ca. 3-9%), *T. heterophylla* (ca. <3%), *T. mertensiana* (ca. <5%), and Cupressaceae (ca. <2%). Pollen and spore concentration data suggests that the influx of pollen at this time was low, with total concentration ranging from 284 grains/cm^3 to 522 grains/cm^3. Charcoal is absent in this zone, and no macrofossils were recovered.

Interpretation TL-1

The relative abundance of Compositae Tubiliflorae, *Artemisia*, *Valeriana*, Poaceae, *Selaginella*, and *Cryptogramma* coupled with the low concentration of pollen and spores suggests an open landscape of low productivity. Low concentration values are consistent with under-representation of non-arboreal taxa in modern surface samples, even when non-arboreal cover is high (Hebda and Allen 1993, Brown 2000). Low influx values (implying low concentration values if sedimentation rates were low) have been observed from 30,000-14,000 ybp in Eastern Beringia and interpreted as evidence for a tundra landscape at this time (Cwynar and Ritchie 1980). In addition, low pollen and spore concentrations are consistent with low influx values from modern and fossil tundra vegetation from North America and Europe reported by Davis et al. (1973). Concentration data from a non-arboreal assemblage at Porphyry Lake is approximately 63,000 grains/cm^3 (Brown 2000), much higher than the concentration observed here. One possible explanation is that pollen and spore concentration is lower in Turtle Lake because it is a larger lake than Porphyry Lake. Larger lakes typically have low pollen and spore concentrations due to the predominance of input from regional sources (Prentice 1985).

The low input of arboreal pollen suggests that tree cover was low during the interval. The relatively high percentages of *Alnus* and *Pinus* suggest that these taxa grew in the area during TL-1. However, *Pinus* and *Alnus* are commonly over-represented in surface sample pollen spectra ranging from 10-45% and 10-80 % respectively, even when plants are locally absent (Brown 2000, Allen et al. 1999, Hebda and Allen 1993). In TL-1 high *Pinus* and *Alnus* values likely result from regional input and relatively low influx of other pollen types. *Alnus* values may represent shrub type *Alnus* (*Alnus sinuata* (Reg.) Rydb.) growing on frequently disturbed areas such as hillslopes, stream edges, or around the lake margin. *Alnus sinuata* is a nitrogen-fixing plant (Barbour et al 1999, Klinka et al. 1989) that readily colonizes disturbed sites, making it an excellent pioneer species. The presence of *Picea*, *Abies* and *T. mertensiana* indicates that scattered coniferous trees likely grew in favourable sites nearby. Modern surface sample studies suggest that *Picea, Abies* and *T. mertensiana* may be under-represented (relative to cover) in pollen spectra (Hebda and Allen 1993, Allen et al. 1999). *Picea sitchensis* perhaps grew along the marine shoreline of Alberni Inlet (provided it existed) as it can form pure stands in sites influenced by brackish water (Klinka et al. 1989). On the other hand, *Picea* pollen may have been derived from trees of *Picea engelmannii* Parry. ex Engelm., a taxon that is characteristic of more continental subalpine environments such as the east slope of the Coast Mountains and at high elevations in the Rocky Mountains (Klinka et al. 1989, Alexander and Sheppard 1990). *Abies lasiocarpa* may have grown on well-drained south-facing slopes along with *T. mertensiana* where warmer temperatures were possibly somewhat more favourable for their survival. Heinrichs et al. (2002) show that *Abies lasiocarpa* was probably more widespread in the area during the late-glacial relative to today. In alpine areas, timberline may be elevated on southern exposures (in the northern hemisphere) relative to cooler north facing sites. Perhaps a similar mechanism allowed for the growth of *Abies* and *T. mertensiana* in an otherwise relatively open landscape.

The presence of a diverse non-arboreal assemblage, low concentration values, as well as the presence of the arboreal pollen of *T. mertensiana*, and *Abies*, suggests that climate was cold, with abundant snow cover, as *T. mertensiana* relies on snowpack to inhibit ground freezing (Mathewes 1993).

The lack of charcoal reveals that fire activity was either low or that charcoal was not preserved in the sedimentary record perhaps through mechanical breakdown associated mineral sedimentation. Low fire activity and charcoal production is consistent with an interpretation of open, cold conditions with sparse vegetation cover. Similarly, lack of macrofossils indicates that either macrofossils were not abundantly preserved because of low production or because of some other factor that did not favour preservation.

TL-2, 500.5-490cm, 12, 000 ^{14}C ybp- 11, 500 ^{14}C ybp, Pinus-Alnus

This zone includes the beginning of organic deposition and is separated from TL-1 by silty clay sediments with coarse sand and pebble lenses spanning 517-500.5cm, from which no pollen was recovered. *Pinus* and *Alnus* dominate the zone. *Pinus* percentages reach their highest values in the core fluctuating between ca. 40% to 60%. *Alnus* percentages range from ca. 25% to 47% and vary considerably. *Picea* percentages increase toward the top of the zone from a low of ca. 1% to a peak of ca. 8%. *Abies* percentages maintain relatively constant values throughout the zone (3% to 8%). *T. heterophylla* occurs at low percentages (<3%). *T. mertensiana* percentages are ca. <2%.

Non-arboreal components consist of *Salix*, Rosaceae, *Artemisia,* Cyperaceae, *Pteridium* and monolete fern spores, all of which are <2%. Total influx ranges from 366 grains/cm^2/yr to 6509 grains/cm^2/yr.

DWHI values of 1 reflect the input of *T. heterophylla* pollen and the absence of *Pseudotsuga* pollen. THMI values for this zone range from 0.1 to 1 and are among the highest in the record.

A staminate cone of *Pinus contorta* was recovered from 485-490cm, at the boundary with the following zone. Charcoal accumulation for TL-2 is low.

Interpretation TL-2

High percentages of *Pinus* and the recovery of a *Pinus contorta* staminate cone indicate that forests were dominated by *Pinus contorta*. *Pinus contorta* is a successful pioneer species that grows well in open sites (Lotan and Critchfield 1990). Apparently, *Pinus contorta* invaded the landscape, colonizing exposed mineral sediments left by the dry and cold climate of full glacial conditions as climate warmed. Relatively low percentages of *Pteridium*, *Artemisia*, and Rosaceae suggest that forests were open. Despite the indication of open conditions, the onset of organic deposition suggests that the landscape had become well vegetated.

Similar to the previous zone, high *Alnus* values may have been from *Alnus sinuata* thickets growing on disturbed sites and/or riparian habitats. The low amounts of *T. heterophylla* pollen may represent regional input, perhaps from areas south or west of the ice sheet (Heusser 1964, Walker 2001). The presence of *Abies*, *Picea*, and *T. mertensiana* pollen may imply that all three trees grew on the landscape, scattered among *Pinus* trees or concentrated in specific areas such as moister sites, north-facing slopes or, in the case of *Picea,* along the marine shoreline of the Alberni Inlet. The occurrence of a needle segment from *Abies lasiocarpa* in the sample above this zone suggests that this same species grew near the site in zone TL-2

The presence of *Salix* and Cyperaceae pollen suggests that these taxa grew around the lake margin.

The presence of *Abies lasiocarpa* on the landscape indicates that conditions were cool and more continental than today as this tree is found more commonly on eastward slopes of the coast ranges in continental subalpine areas (Heinrichs et al. 2002, Franklin and Dyrness 1973).

The abundance of *Pinus* has been previously suggested as an indication of cool, dry conditions at Bear Cove Bog, northern Vancouver Island (Hebda 1983). The presence of *T. mertensiana* indicates, however, that though the climate was cool, it was sufficiently moist for a snowpack to form, as *T. mertensiana* relies on the insulation of winter snowpack to inhibit freezing of roots (Mathewes 1993). Therefore, climate of TL-2 is interpreted as cool to cold and somewhat moist (enough to produce snowpack) but perhaps more continental than today.

Low charcoal accumulation suggests that fire activity was limited during this time, or that charcoal fragments were not preserved. The accumulation of organic sediment reflects humus development in the soil profile and indicates that fuel was available on the landscape. Therefore, lack of fuel is rejected as a reason for low charcoal accumulation.

TL-3, 490-470 cm, 11, 500-10, 200, Pinus, Abies, T. heterophylla, T. mertensiana and Alnus

Pinus, *Abies*, *T. heterophylla*, *T. mertensiana* and *Alnus* dominate this zone. *Pinus* percentages decline in the first half of the zone to values of ca. 30%, but then rise rapidly again in the second half to values similar to those of TL-2 of ca. 50%. *Abies* percentages peak in the beginning of the zone reaching 11%, then show a smaller peak again near the end of the zone of ca. 8%. *T. heterophylla* percentages show a large increase in the beginning of the zone reaching 20% followed by a decline to values of ca. 5%. *T. mertensiana* percentages increase from the previous zone and reach values of ca. <4%. *Alnus* percentages are slightly lower than in the previous zone and fluctuate between ca. 18 to 40%.

Low percentages (ca. <1%) of Rosaceae, *Artemisia*, Cyperaceae, and *Nuphar* pollen, and spores of *Selaginella*, *Pteridium* and monolete ferns also occur in this zone. Total influx declines from the previous zone, ranging from 136 grains/cm^2/yr to 990 grains/cm^2/yr.

DWHI values for this zone are 1.0 indicating the dominance of *T. heterophylla* pollen over *Pseudotsuga* pollen. THMI values average 0.25 and reflect more *T. heterophylla* pollen relative to *T. mertensiana* pollen.

Macrofossils consist of a fragment of an *Abies lasiocarpa* needle and two fragments of *T. heterophylla* needles. Charcoal accumulation values are low in this zone.

Interpretation TL-3

Increased percentages of *Abies*, *T. heterophylla*, and *T. mertensiana* compared to TL-2, and fluctuating *Pinus* percentages indicate that *Pinus* forest started to be replaced by other conifers and the canopy began to close. However, later in the zone (470-475 cm) *Pinus* abundance increased again, perhaps indicating the returning dominance of this taxon.

The recovery of *T. heterophylla* needle fragments provides strong evidence that this tree grew at the site and that conditions had become more favourable for its growth. At the same time, *Alnus* cover also decreased, although the *Alnus* percentages may actually be derived from regional signal and thus show decreased expression in the pollen spectra because of increased cover of other conifer taxa near Turtle Lake (Allen et al. 1999).

The inferred increases in *Abies* (*Abies lasiocarpa* based on the recovery of needle at 485-490cm), *T. mertensiana,* and *T. heterophylla* cover suggest that climate was slightly warmer and moister than the previous zone, but was still cooler than today. The persistence of *Pinus* and increased *Abies lasiocarpa* suggests that the area continued to experience a more continental climate than today (Klinka et al. 1989).

A return to increased *Pinus* percentages combined with relatively high *T. mertensiana* percentages in the upper part of this zone suggests that climate may have reverted to a cooler state relative to the lower part of the zone, and may be a response to Younger Dryas cooling (Mathewes 1993). The upper part of the zone spans from 10, 700-10,200 ^{14}C ybp, placing it in the inferred Younger Dryas chronozone in the Pacific Northwest (Mathewes 1993). In addition, THMI ratios decline at the beginning of the zone (indicating some warming), but rise near the end of the zone (indicating cooling). Continued presence of non-arboreal taxa during this zone is consistent with expectations for Younger Dryas cooling based on other studies from Europe and the Pacific Northwest (Mathewes 1993).

Equal or higher values of *T. mertensiana* percentages in mid-to late-Holocene compared to TL-3 (fig. 6-2) might be used to argue that temperatures during TL-3 were no cooler than those experienced today. High percentages of taxa such as *Pseudotsuga* and *T. heterophylla,* in modern spectra relative to TL-3, however, suggest that temperatures were clearly warmer in the mid-to late-Holocene compared to TL-3. The comparable percentage of *T. mertensiana* (to TL-3) might be explained by the greater abundance of this taxon at higher altitudes surrounding the Alberni valley in the mid- to late-Holocene compared with TL-3. Hebda and Allen (1993), report considerable downslope transport of *T. mertensiana* pollen into lowland areas near Bella Coola, British Columbia. Upland source areas would have also existed during the time that TL-3 sediments were deposited. However, under cooler-than-present conditions these areas may have been covered by alpine vegetation with thin forest. In contrast, in the late Holocene the habitat area for *T. mertensiana* increased, leading to greater cover of this tree.

Low charcoal accumulation suggests that fires were absent in the forests during this time, or for some reason charcoal was not preserved.

In summary, *Pinus* woodlands were initially invaded by other conifer species, but then may have regained dominance in the upper part of the zone. These changes combined with the behaviour of the THMI curve values suggests that climate was initially warmer and moister relative to the previous zone, but then reverted to cooler conditions, possibly in association with Younger Dryas cooling.

TL- 4, 470-364 cm, 10, 200-7800 ^{14}C ybp, Pseudotsuga-Alnus-Pteridium

This zone is characterized by peak percentages of *Pseudotsuga*, *Alnus*, and *Pteridium*. *Pseudotsuga* appears consistently for the first time in this zone and percentages rise to 46% near the middle of the zone. *Alnus* percentages reach ca. 58% at the beginning of the zone, the highest values in the sequence. *Alnus* percentages then decrease markedly toward the middle of the zone to a low of ca. 12%, after which point they rise again to ca. 26%. *Pteridium* percentages are initially low (ca. <1%) as in the previous zone, but rise to 3-10% in the upper half of the zone.

Pinus percentages decrease from the previous zone, maintaining relatively consistent levels of approximately 20%. *Tsuga heterophylla* values increase steadily from approximately 8% to a peak of 23% toward the middle of the zone, declining abruptly to an average of ca. 7% for the remainder of the zone. Cupressaceae percentages continue to increase from the previous zone to a high of ca. 9% toward the top of TL-4. The non-arboreal component consists mainly of low percentages (ca. <2%) of *Salix* (except for a peak of 5% in beginning of zone), Rosaceae and Poaceae.

Total influx rises toward the top of the zone to a high of 3689 grains/cm^2/yr at the boundary with TL-5a. Influx of all taxa increases toward the top of the zone and is likely the result of changes internal to the basin, such as changing primary productivity, or decreased slope wash, and not to changes in forest productivity.

DWHI values decline to approximately 0.2 throughout the zone. THMI values are generally 0, reflecting the near absence of *T. mertensiana* pollen.

Macrofossils include needle fragments of *Pseudotsuga* and *Pinus*, a sedge seed and *Chara* oospores.

Charcoal accumulation increases relative to the previous zone, showing a peak at the beginning of the zone, declining and then rising again near the top.

Interpretation TL-4

Vegetation in this zone is notably different from the previous zone and is characterised by *Pseudotsuga* forest with disturbed sites occupied by *Alnus rubra* or open areas filled by *Alnus sinuata* thickets, *Pteridium*, Rosaceae, and Poaceae. The relative abundance of non-arboreal taxa such as Rosaceae, Poaceae and *Pteridium* suggest that forests were open.

Percentages of Cupressaceae pollen, probably from *Thuja plicata*, a common tree species growing near the site today, indicate that this tree may have been growing nearby. Allen et al. (1999) recorded Cupressaceae percentages of 10% in surface samples from moist areas in the CDFmm where the tree grows today. *T. heterophylla* percentages indicate that this tree probably grew in moist areas, such as north-facing slopes, near the site. The values may also partly be a consequence of regional input from the western portions Vancouver Island. Hebda and Allen (1993) suggest that *T. heterophylla* can contribute a regional signal of 1-2%, but that when 5-10% of *T. heterophylla* pollen is recorded the trees are a component of the forest. Brown (2000), also recognizes a regional input of *T. heterophylla* pollen input, but suggests that this species becomes gradually under-represented as its cover increases. Both studies conclude, however, that the relationship between *T. heterophylla* cover and pollen percentage is not well defined and contains considerable scatter in the points. In contrast, Minckley and Whitlock (2000), studied surface samples from Oregon and southern Washington, USA, and found that *T. heterophylla* pollen was potentially well distributed west of the Cascade range, reaching values of 19% even where the tree was locally absent. Taking this latter study into consideration, the increase in *T. heterophylla* pollen toward the middle of the zone may be partially due to regional input from areas west of the study site as climate warmed (Brown and Hebda 2002a, Walker 2001). Increasing *T. heterophylla* percentages on the northeast coast (Hebda 1983) and west coast (Brown and Hebda 2002a, Walker 2001) of Vancouver Island, within this time have been attributed to increasing temperatures as *T. heterophylla* replaced *T. mertensiana*. Under the assumption that *T. heterophylla* pollen was partly derived from regional input, comparison of pollen spectra from this zone with surface samples (Allen et al. 1999) suggests that forest may have been analogous to CDFmm, or possibly CWHxm1 forests (Meidinger and Pojar 1991).

High *Pseudotsuga* values and relatively abundant Poaceae and Rosaceae indicate that climate was warmer and drier than the present (Hebda 1995). Depressed values of DWHI compared to average values for CWHxm (0.4) reported from surface samples (Allen et al. 1999), also indicate less effective moisture than today.

Charcoal peaks at the beginning and end of the zone suggests that fires probably helped to maintain open forests. The increase in *Pteridium* near the end of the zone indicates an increase in open areas or greater spore production, possibly initiated by fire (Brown and Hebda 2002a, Crane 1990). However, the timing of the increase in *Pteridium* is somewhat unexpected if fires had already begun to burn at the beginning of the zone.

TL-5, 354-120cm, 7800-3000 ^{14}C ybp

This zone is characterised by increasing percentages of *T. heterophylla*, and Cupressaceae, with an associated decline in *Pinus, Pseudotsuga, and Alnus* relative to the previous zone. The zone is divided in to two parts, TL-5a and TL-5b, based on changes in the curves of *T. heterophylla*, and *Pseudotsuga*, and *Pteridium*. In TL-5a *T. heterophylla* percentages rise but remain less than *Pseudotsuga*. Also, *Pteridium* percentages decrease at the boundary of TL-5a/b. In TL-5b *T. heterophylla* percentage rises above *Pseudotsuga.*

TL-5a, 364-290cm, 7800-6300 ybp, Pinus-T. heterophylla-Pseudotsuga-Cupressaceae-Pteridium

This subzone is characterised by *Pinus*, *Tsuga heterophylla*, *Pseudotsuga*, Cupressaceae pollen, and *Pteridium* spores. *Pinus* percentages peak in the first half of the subzone, increasing from ca. 25% to 40%, decline briefly, and then rise again to ca. 25% near the end of the zone. *T. heterophylla* percentages rise in the beginning of the zone, from ca. 7% to ca. 12%. *Pseudotsuga* percentages decline slightly through the subzone (ca. 20% to ca. 15%). Cupressaceae percentages increase in this subzone toward the top, rising from 7% to 24%. *Pteridium* percentages remain high relative to the rest of the record and fluctuate between 2% and 10%.

Alnus percentages decline from the previous zone to values between 9% to 19%. *Taxus* appears for the first time in this subzone, and attains a maximum value in the upper half of the subzone of 6%. This pollen type is distinguished from that of *Thuja plicata* by a thicker wall and denser orbicule ornamentation (Owens and Simpson 1986). Although *Chamaecyparis nootkatensis* pollen is easily confused with *Taxus* (Owens and Simpson 1986), *C. nootkatensis* is more common in subalpine settings (Klinka et al 1989) and therefore the *Taxus*-like pollen more likely originated from *Taxus*. With the exception of *Pteridium,* the non arboreal component of this zone is sparse. Total influx for this subzone fluctuates between 2873 grains/cm^2/yr to 15,336 grains/cm^2/yr.

DWHI values for the subzone rise steadily toward the top from a low of 0.2 to a high of 0.5. THMI values do not exceed 0.1.

Macrofossils consist of *Chara* oospores, whole needles and needle fragments of *Pseudotsuga*, as well as *Pinus contorta* needle fragments near the beginning of the zone. Charcoal accumulation increases to its highest value in this subzone, and ranges between 0.6 particles/cm^2/yr to 2.7 particles/cm^2/yr.

Interpretation TL-5a

Increasing *T. heterophylla* and Cupressaceae, coupled with declining *Pseudotsuga* and *Alnus* suggest a transition from forests dominated by *Pseudotsuga* toward increased cover of *T. heterophylla* and Cupressaceae. Declining non-arboreal abundance reveals that forests were closing as *T. heterophylla* and Cupressaceae increased in abundance. Though *Pseudotsuga* loses its dominance from the previous zone it appears to remain co-dominant with *T. heterophylla*, and Cupressaceae. The rise in *Taxus* percentages (*Taxus brevifolia*) in the middle of subzone 5a, indicates an increase in presence of this species within the forest, possibly scattered in moist areas within the forest canopy (Klinka et al. 1989, Hicock et al. 1982). *Taxus* has to this point not been regularly observed in Pacific Northwest profiles, although needles have been recovered from 19,000 ybp sediments in the Fraser Lowland (Hicock et al. 1982). *Alnus* was likely a minor component of the forest, in disturbed sites. The decline in *Alnus* relative to the previous zone suggests either decreased disturbance or that closing forests caused dilution of its pollen by other taxa as suggested by an increase in influx of all conifers.

Comparison of *T. heterophylla*, *Pseudotsuga*, and Cupressaceae values in the record to surface samples from southern Vancouver Island (Allen et al. 1999) indicates that the forest may have been similar to modern CDF-type, or dry CWH-type forests, typical of the dry southeastern portion of Vancouver Island and the Port Alberni area today. It is probable that this interval represents a time of transition from early Holocene CDF-type forests to CWH-type forest.

Increasing amounts of *T. heterophylla* and Cupressaceae pollen and increasing DWHI values suggest that climate was moister than in the preceding zone. Relatively high values of *Pseudotsuga,* however, indicate that conditions were probably still warmer and drier than present. Raised *Taxus* pollen percentages in the middle of the zone also support an interpretation of increased moisture because *Taxus* is common in moist forest sites (Klinka et al. 1989). The trend toward the top of the zone appears to be one of increasing wetness and/or decreasing temperature (increasing effective moisture) relative to the warm and dry conditions of the previous zone.

The persistence of *Pteridium* throughout this subzone, in addition to persistent charcoal influx suggests that fire was common disturbance on the landscape. Peaks in

Pinus at the beginning and end of the zone coincide with the increases in charcoal accumulation suggesting that *Pinus* was responding positively to burning, perhaps invading recently burned areas. *Alnus* values suggest that the abundance of this taxon on the landscape was lower than in the previous zone. Perhaps fires at this time did not disturb and expose mineral soils in such a way that favoured invasion by *Alnus*.

The stratigraphy and influx data present a few problems for the estimated timing of TL-5a. Using the sedimentation rate derived from the dates at 455cm and 265 cm, the mineral horizon lies at a date of approximately 7800 ^{14}C ybp. If the fine-grained layer at 362-369 is assumed to be Mazama ash, a widely recognized ash layer in many lake sediments throughout the Pacific northwest (Hebda 1995), it forces the date of this horizon to be approximately 6800 ^{14}C ybp (Bacon 1983, Zdanowicz et al. 1999). Using the 6,800 ybp date to calculate sedimentation rates results in a rate that rises from .04 cm/yr below the mineral horizon, to 0.1 cm/yr above the above the mineral horizon. Increased sedimentation rates should decrease pollen and spore concentration. Examination of the pollen and spore concentration data, however, reveals that concentration actually increases above the mineral layer (fig. 6-4). The explanation for this rise in concentration and sedimentation rate remains unclear.

If on the other hand, the mineral layer is rejected as Mazama ash we are still left with the problem of identifying the origin of the layer and resolving why pollen and spore concentration increase above the horizon. The origin of the mineral layer at present remains unresolved.

Because the mineral layer was not directly dated, a Mazama ash date of 6,800 ybp is not included in the chronology of the sequence. Scanning electron microscopy (SEM) and major element determination by microanalysis (such as energy dispersive X-ray analysis) would reveal if the mineral layer is Mazama Ash as the 6,800 ybp Mt. Mazama eruption is the only likely source (Sarna-Wojcicki et al. 1983). There was insufficient time to carry out this analysis.

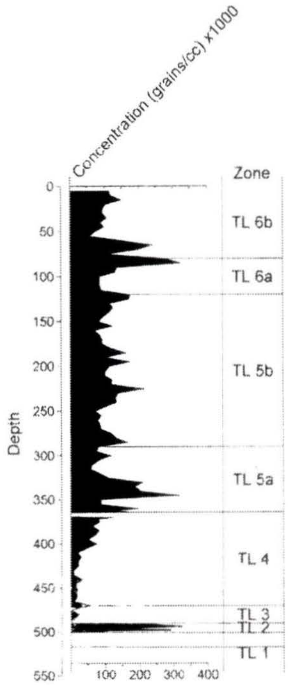

Fig. 6-4. Turtle Lake total concentration of pollen and spores (x1000)

TL-5b, 290-120cm, 6300-3000 ^{14}C ybp, T. heterophylla- Pseudotsuga-Cupressaceae zone

This subzone is characterised by higher percentages of *T. heterophylla*, and Cupressaceae, and equivalent values of *Pseudotsuga* relative to subzone TL-5a. *T. heterophylla* percentages increase from ca. 15% at the beginning of the subzone and level out to ca. 25%, toward the end of the subzone. *Pseudotsuga* percentages increase slightly from the end of the previous subzone, and fluctuate between 9% and 18% throughout TL-5b. Cupressaceae percentages maintain values similar to the end of the previous zone, but fluctuate from 12 % to 25 %.

Taxus pollen disappears toward the middle of the zone. *Pinus* percentages decline slightly toward the end of the zone decreasing from ca. 25% to ca. 15%. *Alnus* percentages are similar to the previous zone, fluctuating between 7% and 15%.

Non-arboreal types show only isolated occurrences at low values. Exceptions are an increase in Cyperaceae percentages to ca. <2%. Total influx in this subzone ranges from a low of 3595 grains/cm^2/yr to a high of 10,802 grains/cm^2/yr.

DWHI values for the subzone are initially approximately 0.5 but quickly rise and maintain values between 0.6-0.7. THMI values continue to be low, at values consistently <0.1.

Charcoal accumulation is low in this subzone. Values for charcoal influx fluctuate between a low of 0.1 particles/cm^2/yr to a high of 0.8 particles/cm^2/yr.

Macrofossils include *Pinus* needle fragments, a *T. heterophylla* needle, and a whole needle and needle fragments of *Pseudotsuga*. Also appearing in this zone are seeds of *Polygonum* sp. and sedges.

Interpretation TL-5b

Increased percentages of *T. heterophylla,* and relatively high values of *Pseudotsuga* and Cupressaceae suggest that forests closed further and were dominated by *T. heterophylla*, *Pseudotsuga*, and *Thuja plicata*, perhaps similar to modern vegetation at the site today.

Comparison to surface sample spectra from Allen et al. (1999) suggests that vegetation at this time may have resembled forests of the CWHxm1 variant, which is the variant under which the area is classified today (Meidinger and Pojar 1991), although pollen spectra of TL-5b contains more Cupressaceae pollen. Surface sample studies in Oregon and southern Washington, and at various other sites in coastal British Columbia also support an interpretation of CWH type forests, based on relatively high percentage values of *Tsuga heterophylla*, and particularly being greater than *Pseudotsuga* (Pellatt et al. 1997, Minckley and Whitlock 2000).

Taxus probably continued to occupy moist sites in the forest, but pollen evidence for its presence disappeared later in the subzone. Perhaps competition with other conifers, such as *Tsuga heterophylla* and *Thuja plicata*, reduced pollen production from *Taxus*.

Increasing Cyperaceae values probably reflect the expansion of the frequent flooding of areas at the lake margin.

Decreasing percentages of *Pinus* and relatively low *Alnus* values suggest that these taxa became less important in the forest, a possible consequence of less fire disturbance. Despite this, the recovery of *Pinus contorta* needle fragments reveals that this tree was present near the site at this time. Macrofossils of T*suga heterophylla* and *Pseudotsuga* reinforce inferences from percentage data that these trees were growing around the lake.

Based on relatively high values of *T. heterophylla* and Cupressaceae, climate is interpreted as becoming moister and possibly cooler than the previous subzone. Climate during this zone may have been similar to today.

Fires were less common on the landscape at this time than previously, which is consistent with an interpretation of relatively cool and moist climate.

TL-6, 120-0cm, 3000 ^{14}C ybp-Present

This zone is characterised by changes in Cupressaceae percentages, as well as an increase in wetland indicators *Myrica* and *Lysichitum,* compared to zone 5. The zone is divided in to two parts, TL-6a and TL-6b, based on the curve of Cupressaceae. In TL-6a Cupressaceae percentages rise above any other component. In TL-6b Cupressaceae percentages decline and take on values similar to those of *T. heterophylla* and *Pseudotsuga.*

TL-6a, 120-80 cm, 3000-1900 ybp, Cupressaceae-T. heterophylla-Pseudotsuga

This subzone is characterised by high percentages of Cupressaceae, *T. heterophylla* and *Pseudotsuga*. Cupressaceae values increase from the beginning of the zone toward the end rising from ca. 25% to values of ca. 45%. *T. heterophylla* percentages show more variation than in the previous zone, ranging from ca. 15% to ca. 25%. *Pseudotsuga* percentage values remain relatively unchanged from the previous zone and range between ca. 12%-20%. *Pinus* percentages remain relatively low, ranging from ca. 10% to 14%. *Alnus* percentages decrease from the previous subzone, dropping to a low of ca. 5%.

Myrica shows a notable rise to ca 3% toward the top of the subzone. Cyperaceae percentages decline in this subzone and show isolated occurrences of ca. <1%. Total influx for this zone declines from the previous zone with the exception of a sharp peak at the end of the zone. The total influx values for this zone range from a low of 3556 grains/cm^2/yr to the peak value of 13,741 grains/cm^2/yr.

DWHI values fluctuate slightly in this subzone, but average at 0.6. THMI values are consistently <0.1.

Macrofossils consist of a needle of *Pseudotsuga* and *T. heterophylla,* a needle fragment of *Abies*, as well as *Chara* oospores and seeds of sedges, *Nuphar*, and *Myrica gale*.

Charcoal accumulation is higher than the previous zone and exhibits two peaks in the middle and toward the end of the zone.

Interpretation TL-6a

Increased Cupressaceae and the persistence of *T. heterophylla* and *Pseudotsuga*, suggests that *Thuja plicata* took a more dominant role in forest at this time. Based on surface sample studies of modern environments (Allen et al. 1999) relatively high percentages of Cupressaceae with relatively high percentages of *T. heterophylla* and *Pseudotsuga* suggest that forests may have resembled moist, maritime CWH forests (CWHmm). *Pseudotsuga* was an important forest element, suggesting that the forest was not a wet subzone of the CWH (such as CWHvm) where *Pseudotsuga* is much rarer than in the drier CWH forests (Allen et al 1999).

An increase in *Myrica* pollen and recovery of *Myrica* seed macrofossils likely reflects the development of boggy areas around the lake, as this species grows in the lake-marginal bog today (Appendix A). The lack of other non-arboreal pollen types suggests that understory vegetation was sparse or that pollen from these plants was not efficiently dispersed and therefore not well represented. At the same time, *Myrica* thickets at the lake edge may have acted as a filter, preventing slope wash processes from delivering non-arboreal pollen into the deeper portions of the lake.

Increased Cupressaceae and persistent levels of *T. heterophylla* and *Pseudotsuga* suggest that climate was cool and moist, but sufficiently dry or disturbed by fire to allow for the persistence of *Pseudotsuga.* Higher Cupressaceae values relative to TL-5b suggest that TL-6a was moister than TL-5b. Perhaps swampy areas developed around the lake in topographic depressions that supported *Thuja plicata* (Minore 1990). DHWI values, further indicate that regional climate was relatively moist, but dry enough in areas to sustain populations of *Pseudotsuga*. Decreases in Cyperaceae values suggest that sedge or rush communities at the lake's margin became flooded and converted to a bog, consistent with the presence of *Myrica* pollen and seeds.

Peaks in charcoal accumulation indicate a rise in fire activity or at least two periods of notable charcoal production. An increase in fire activity is somewhat counter-intuitive if an interpretation of increased moisture is accepted. On the other hand, *Pseudotsuga* abundance indicates that at least parts of the surrounding area were still relatively dry, and favourable for fire. However, then the low in fire activity in the previous subzone (TL-5b) is surprising. Like TL-6a, the zone TL-5 contained comparable abundances of *Pseudotsuga* and to be consistent with the interpretation of TL-6a we might expect fires to have burned during TL-5b. The low fire activity in TL-5b, therefore may have been the result of some other phenomenon such as decreased ignition sources, or decreased transport of charcoal into the basin. Decreased transport is not likely as climate is interpreted to be relatively moist presumably with sufficient surface wash. However, vegetation at the lake margin may have filtered out some charcoal and prevented it from being transported into the deeper portions of the lake. As an alternative, perhaps the increase in charcoal in TL-6a was not related to climatic phenomenon at all but was the result of some other influence. First Nations burning practices, to clear forest areas, has been noted by Turner (1999), as has also been suggested for the latest Holocene (ca. 2000 ^{14}C ybp) (Brown and Hebda 2002b). As previously mentioned, the recovery of native artifacts from the Stamp River provides evidence that native populations existed near Turtle Lake (McMillan 1986) and therefore may have altered natural fire regimes.

TL-6b, 80-0cm, 1900-Present, Cupressaceae-Pseudotsuga-T. heterophylla

This subzone is characterised by Cupressaceae, *Pseudotsuga,* and *T. heterophylla* pollen similar to the previous zone but with changes in relative dominance of these taxa. Cupressaceae percentage decreases from the previous zone falling from ca. 30% to ca. 20%. *Pseudotsuga* percentages maintain similar values to those of the previous subzone ranging from ca. 10% to 20%. Percentages of *T. heterophylla* increase slightly from the previous zone and range from ca. 20% to 30%, declining again slightly at the end of the zone.

Pinus contorta percentage values rise from the previous zone (ca. 10-20%). *Pinus monticola* appears consistently for the first time within the record in this zone. Values for this species rise in the lower half of the zone to ca. <5% and then decline again near the top. *Alnus* shows a slight increase in percentage toward the top of the zone with values ranging between ca. 4 to 13%.

Myrica continues in the record with percentages (ca.<5%) like those of TL 6a. *Lysichitum* appears consistently for the first time in the upper half of the zone attaining percentages of ca. <5%. A peak in *Selaginella* occurs near the top of the subzone, attaining a value of 2%.

DWHI values show a slight increase toward the end of the zone and average 0.6. THMI values are, for the most part, <0.1 with an average value of 0.05.

Macrofossils consist of a fragment of *Pseudotsuga* needle, and an intact *T. heterophylla* needle. Two sedge seeds were also recovered.

The charcoal accumulation curve has an isolated peak at the beginning of the zone and then two more, larger peaks, toward the end of the zone. The top-most peak in charcoal accumulation in this subzone is the highest in the record.

Interpretation TL-6b

Percentage values of *T. heterophylla*, *Pseudotsuga* and Cupressaceae (*Thuja plicata*) indicate modern dry CWHxm forests developed in this subzone (Allen et al. 1999, Pellatt et al. 1997, Minckley and Whitlock 2000). *Thuja plicata* became less important in the forest compared with the previous subzone. Forests remained closed and resembled undisturbed CWH forests growing near the site today. Percentages of *T. heterophylla*, *Pseudotsuga* and Cupressaceae in this subzone resemble those of subzone TL –5b, suggesting that the forest in these two subzones may have been similar. Under this assumption, modern forests developed around 6300 ^{14}C ybp, were slightly modified from 3800-1900 ^{14}C ybp (subzone TL-6a) by an increase in *Thuja plicata*, and then returned to their previous form in the last 1900 years.

The peak in *Selaginella* at the very top of the subzone may reflect disturbance associated with European settlement, such as forest clearing. *Selaginella* is a shade intolerant plant that is common on open rock outcrops with shallow moisture deficient soils (Klinka et al 1989). The presence of *Selaginella* spores within the spectra is a strong indication that these types of environments existed in area surrounding the sampling site (Allen et al. 1999).

The continued presence of *Myrica* and increases in *Lysichitum* attests to the persistence of bog vegetation around the lake and the continued presence of wet areas in the forest (Klinka et al.1989).

Moisture was sufficient for *T. heterophylla* and *Thuja plicata* growth, but still dry enough, or sufficiently disturbed by fire, to support a large population of *Pseudotsuga*. Climate is interpreted to be mild and moist, similar to today, but drier than the previous subzone.

Fire continued to burn throughout the subzone to the present. Accepting an interpretation of cool and moist climate, increased fire activity may have been a result of other processes. First Nations burning is one possibility (Turner 1999, Brown and Hebda

2002b). The peak in charcoal accumulation values in the top-most samples within TL-6b may be associated with European settlement, and land management.

Summary

The Turtle Lake record begins with an undated NAP dominated assemblage that represents parkland vegetation under a climate that was cooler than today. Following this, from 12,000-11,500 ybp *Pinus contorta* and *Alnus* colonised exposed mineral soils and formed woodlands of *Pinus* and *Alnus* with scattered *Picea*, *T. mertensiana* and *Abies lasiocarpa*. Climate from 12,000-11,500 ybp was likely cooler, somewhat drier and more continental than today. From 11,500-10, 200 ybp, *Pinus* forest was initially replaced by mixed conifer forests of *Abies lasiocarpa*, *T. heterophylla*, and *T. mertensiana*, regaining dominance from 10,700-10,200 ybp. Climate initially started to warm and moisten (relative to the previous zone) and allowed mixed conifer forests to expand. Later in the zone, however, Younger Dryas cooling allowed *Pinus* to regain dominance. Climate in the mixed conifer zone was warmer than the previous *Pinus contorta* and *Alnus* zone, but was cooler than today. Open forests of *Pseudotsuga* and *Alnus* with *Pteridium* became established 10,200-7,800 ybp and reflect a climate that was warmer and drier than today. *Pteridium* increased late in this zone and its expansion may have been associated with First Nations burning. From 7,800-6,300 ybp *T. heterophylla* and Cupressaceae expanded and forest stands began to close. Climate moistened but probably remained warmer than today. From 6,300-3,000 ybp *T. heterophylla* continued to expand and became more abundant than *Pseudotsuga* forming CWHxm forests similar to today. Climate was cooler and moister than the previous zone and probably resembled modern conditions. From 3,000-1,900 ybp Cupressaceae expanded in forests probably associated with increased moisture and cooling. From 1,900 to present, Cupressaceae declined and modern CWHxm forests developed. The declining role of *Thuja Plicata* may have been due to drying relative to the previous zone, but was possibly also the result of selective tree felling by native inhabitants (Brown and Hebda 2002b, Hebda and Mathewes 1984).

Chapter 7

Harris Lake Ridge Bog Results

Introduction

This chapter describes the results and interpretation of pollen and spore, macrofossil, and charcoal analyses from the samples collected from the exposed section of Harris Lake Ridge Bog. Results begin with a description of stratigraphy, chronology, and sedimentation rates. Pollen and spore, macrofossil and charcoal results follow. Each zone defined within the core is first described and then interpreted.

Stratigraphy, Chronology, and Sedimentation Rates

Data for the Harris Lake Ridge Bog (HLRB) record were derived from a 200 cm exposed bog section sampled at 5 cm intervals. From 200-190 cm sediments consist of decomposed sandstone bedrock mixed with clay that grades into grey clay with brown mottles. From 190-100cm, sediments consist mainly of black peat. From 190-165 cm grey clay with the occasional subangular cobble grades into black peat. From 165-157 cm the peat is crumbly, sandy, and contains wood fragments. From 157-100 cm, the peat becomes less sandy. Overlying the black peat, from 100-50 cm, is dense, red, sedge peat with scattered wood fragments. At 50-5 cm peat grades first into black fibrous peat with wood, and then to mossy *Sphagnum* peat with wood, from 5-0 cm.

Four radiocarbon dates were obtained for the Harris Lake Ridge Bog record (Table 7-1), from the Brock University Radiocarbon Laboratory, St. Catherines, Ontario, Canada. Calibration of radiocarbon ages to calendar years was performed with CALIB 4.3 software (Stuiver and Reimer 1993 v.4.1), using the standard INTCAL98 Database (Stuiver et al. 1998). The value reported represents the median value of calendar ages output by the program for the corresponding radiocarbon date, rounded to the nearest 10 year (as recommended in the program user guide if standard deviation is more than 50 years). No ash units were observed in the sequence.

An age-depth model (fig. 7-1), shows the change in sedimentation rate based on the chronology provided by the radiocarbon dates. The slope of each line is equal to the sedimentation rate between the dates. Recognizing that calculated sedimentation rates using radiocarbon ages and calibrated ages differ, sedimentation rates and dates reported here are from radiocarbon ages, not calibrated ages. From 195-130 cm

Table 7-1. Harris Lake Ridge Bog radiocarbon dates

Laboratory Number	**Depth (cm)**	**Sample Type**	**Conventional ^{14}C Age (years BP)**	***Calendar Age (Cal years BP)**
BGS-2388	45-50	Bulk peat	1085±50	970
BGS-2389	80-85	Bulk peat	2325±60	2350
BGS-2390	125-130	Wood	4428±125	5010
BGS-2392	190-195	Bulk peat	10273±100	12030

*Calibration to Calendar years using CALIB 4.3 (Stuiver and Reimer 1993, 4.1) using INTCAL98 dataset (Stuiver et al. 1998). Calendar age is rounded to nearest tenth.

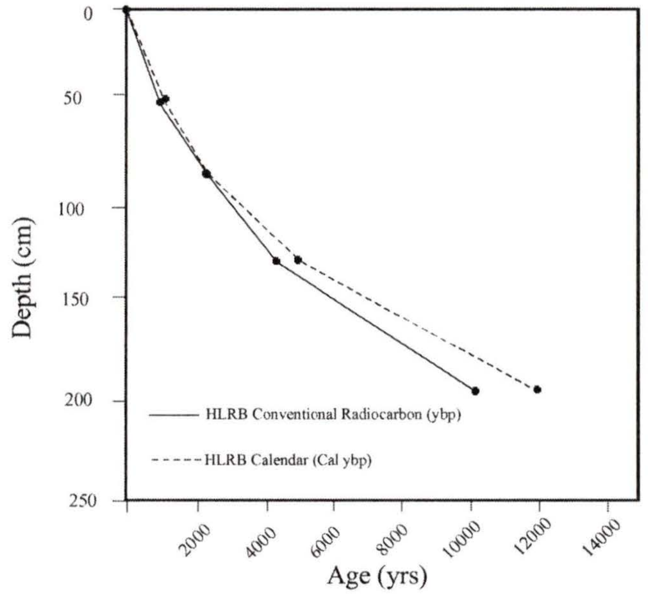

Fig. 7-1. HLRB age-depth relationship

sediment accumulation rates are the lowest in the record at 0.011 cm/yr. Above this, from 130-85cm, the sedimentation rate increases to 0.021cm/yr, then to 0.028 cm/yr from 85-50cm. The greatest sediment accumulation rate occurs from 50-0 cm and is 0.046 cm/yr. This uppermost sedimentation rate assumes that no significant erosion, or depositional hiatus has taken place.

Based on the calculated sedimentation rates, the accumulation of black peat from 190-100 cm lasted approximately from 9820 ^{14}C ybp to 3000 ^{14}C ybp. Above this, from 100-0 cm, the accumulation of the upper peat unit lasted from 3000 ^{14}C ybp to the present.

Pollen Zones

Zone boundaries were drawn by visual inspection to coincide with major changes in arboreal and non-arboreal pollen assemblages in the record (fig. 7-2). Dominant arboreal taxa used as indicators of change for this record were *Pinus*, *Abies*, *T. heterophylla, T. mertensiana*, Cupressaceae, and *Alnus*. Non-arboreal types including Ericaceae, Rosaceae, *Epilobium*, Poaceae, *Valeriana*, and Cyperaceae pollen, and *Pteridium* and monolete fern spores were also considered as important indicators of change. Non-arboreal pollen is often under-represented and may reflect local vegetation (Hebda and Allen 1993, Janssen 1973, Gavin and Brubaker 1999). Because local taxa are influenced both by site level processes and macro-scale (e.g. climatic) processes, changes in pollen percentages of local taxa may reveal details concerning small, and large-scale changes at the site. Zone HLRB 2 is divided into two subzones (HLRB 2a/2b) because of a decline in *Alnus* values and a simultaneous rise in Cupressaceae percentages within a broader zone. Similarly Zone HLRB 3 is divided into two subzones HLRB 3a and 3b based on changes in Ericaceae, Cyperaceae, and undifferentiated monolete fern spore percentages as well as a peak in *T. mertensiana* values and a decline in Cupressaceae values. The changes that delimit HLRB 3a/3b subzone boundaries take place within a visually broader interval defined by *T. heterophylla* and *T. mertensiana* pollen percentages.

Pollen and spore percentages, as well as charcoal influx and DWHI and THMI ratios are presented (fig. 7-2), and influx values for selected pollen types are summarized in (fig. 7-3). Results of macrofossil analysis are presented in table 7-2.

HLRB-1, 195-200cm, >10, 270 ^{14}C ybp, Pinus-Abies-Tsuga mertensiana-NAP

This zone is based on one sample only. *Pinus* percentages are highest in the Harris Lake Ridge Bog record at ca. 33%. *Abies* percentages (ca.15%) are similar to *T. mertensiana* percentages (ca. 16%). The remaining portion of the arboreal pollen assemblage consists of *T. heterophylla*, Cupressaceae, and *Alnus* pollen at percentages of ca. 4%, 2%, and 11% respectively.

The non-arboreal pollen spectrum consists of low percentages of *Salix*, Ericaceae, Rosaceae, *Epilobium*, Poaceae, and Cyperaceae pollen, and *Selaginella*, *Cryptogramma*, and undifferentiated monolete fern spores. Each non-arboreal pollen type contributes <2% with the exception of Cyperaceae and monolete fern spores which reach ca. 5% and 52% respectively. Total pollen influx for this zone is 238 grains/ cm^2/yr.

DWHI and THMI ratios were calculated for the zone and gave values of 1 and 0.82 respectively. A DWHI value of 1 reflects the lack of *Pseudotsuga* pollen in the spectrum, whereas a THMI value of 0.82 reflects dominance of *T. mertensiana* pollen over *T. heterophylla* pollen.

Charcoal accumulation (fragments/cm^2/year) was not calculated for this zone, as the interval was not bound by radiocarbon dates. Charcoal was recovered in this interval, however, and the concentration was 16 fragments/cm^3.

No macrofossils were recovered.

Interpretation HLRB-1

This zone represents the end of a regionally recognized open mixed conifer forest containing *Pinus*, *Abies* and *T. mertensiana*. *Abies* and *T. mertensiana* pollen are often under-represented with respect to cover (Hebda and Allen 1993, Brown 2000, Heinrichs

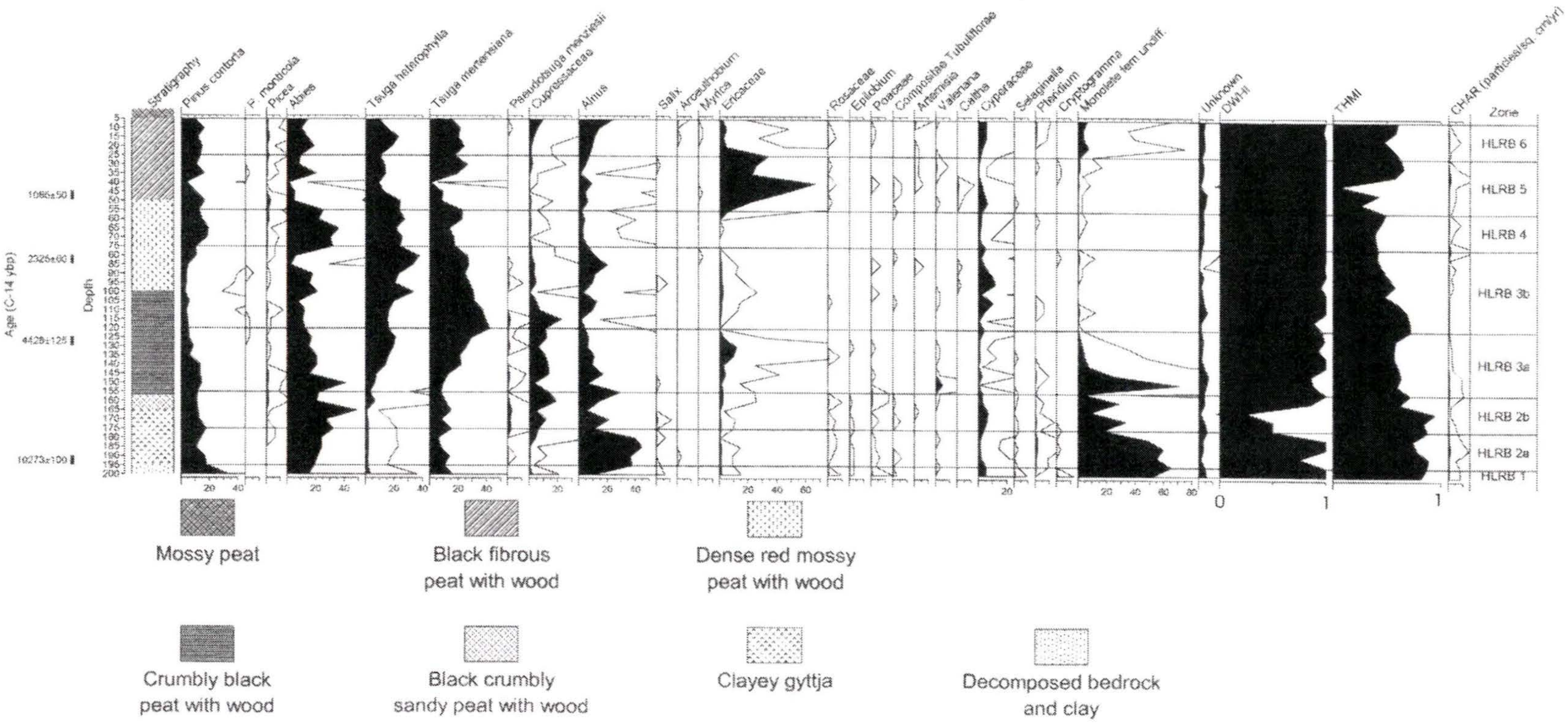

Fig. 7-2. Harris Lake Ridge Bog pollen and spore percentages, DWHI, THMI, and charcoal accumulation (CHAR). Unshaded curve X10

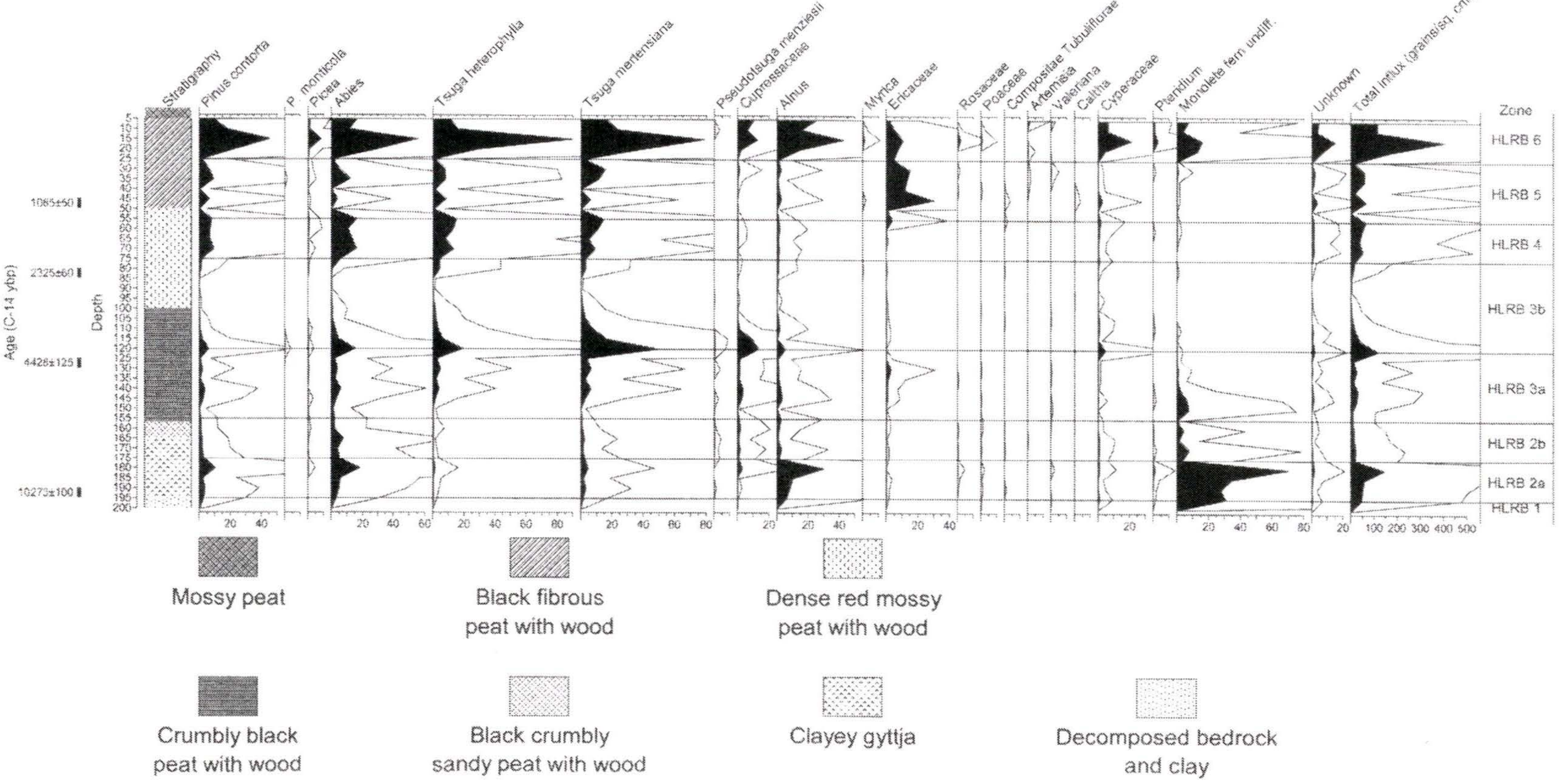

Fig. 7-3. Harris Lake Ridge Bog (HLRB) pollen and spore influx (pollen and spores/cm^2/yr) (x100). Unshaded curve x10

Table 7-2. Harris Lake Ridge Bog macrofossils. *indet=indeterminate

Samples	***Vol. of sediment processed***	***Tsuga mertensiana***			***Abies amabilis/grandis.***			***Taxus***	***Phyllodoce empetriformis***			***C. nootkensensis***	Other
Depth	(cc)	base	tip	whole	base	tip	whole	tip	base	tip	whole	branchlets	
0-5	5	2	2	3	-	-	-	-	-	1	2	-	Sedge seed (10)
5-10	5	1	9	1	1	-	-	-	2	1	2	-	Sedge seed (1)
10-15	5	1	2	4	-	-	-	-	5	4	6	1	-
15-20	5	1	7	3	-	-	-	-	13	14	11	-	-
20-25	5	1	5	-	-	-	-	-	3	3	6	-	-
25-30	5	-	-	-	-	-	-	-	-	-	1	-	-
30-35	5	-	-	-	-	-	-	-	-	-	-	-	-
35-40	5	-	-	-	-	-	-	-	-	-	-	-	-
40-45	5	-	2	-	-	-	-	-	-	3	1	-	-
45-50	5	-	-	-	-	-	-	-	1	-	3	-	-
50-55	5	1	-	-	-	-	-	-	-	-	-	-	-
60-65	5	-	14	-	-	2	-	-	-	-	-	-	*indet. needle parts
65-70	5	7	20	-	-	3	-	-	-	-	-	-	*indet. needle parts
70-75	5	11	10	3	-	-	-	-	-	-	-	-	*indet. needle parts
75-80	5	17	27	7	-	1	1	-	-	-	-	-	*indet. needle parts
80-85	5	2	9	-	-	-	-	-	-	-	-	-	*indet. needle parts
85-90	5	7	15	5	-	-	-	-	-	-	-	-	*indet. needle parts
90-95	5	14	46	1	-	3	-	-	-	-	-	-	*indet. needle parts
95-100	5	10	17	2	-	1	-	-	-	-	-	2	*indet. needle parts
100-105	5	-	-	-	-	1	-	-	-	-	-	-	*indet. needle parts
105-110	5	-	4	-	-	-	-	-	-	-	-	4	-
110-115	5	-	25	-	-	-	-	-	-	-	-	1	*indet. needle parts
115-120	5	17	86	-	1	3	-	-	-	-	-	18	*indet. needle parts
120-125	5	40	119	5	3	7	-	-	-	-	-	26	*indet. needle parts
125-130	5	13	46	-	6	9	-	-	-	-	-	10	*indet. needle parts
130-135	5	15	61	2	2	1	-	-	-	-	-	-	-
135-140	5	3	17	1	1	1	-	-	-	-	-	-	-
140-145	5	1	3	-	1	1	-	-	-	-	-	4	-
145-150	5	-	1	-	-	-	-	-	-	-	-	2	-
150-155	5	-	1	-	-	1	-	-	-	-	-	-	-
155-160	5	1	4	-	-	4	-	-	-	-	-	2	-
160-165	5	-	2	-	2	7	-	1	-	-	-	-	-
165-170	8	-	-	-	-	-	-	-	-	-	-	3	seed perigynia (2)
170-175	10	-	-	-	-	-	-	-	-	-	-	-	seed perigynia (10)
175-180	10	-	-	-	-	-	-	-	-	-	-	-	seed perigynia (2)
180-185	10	-	-	-	-	-	-	-	-	-	-	-	seed perigynia (2)

et al. 2002), and therefore it is likely that these trees grew locally. *Abies* pollen is probably from *Abies lasiocarpa*, a common subalpine species on the mainland, that may have been more widespread on Vancouver Island in the late-glacial than today (Heinrichs et al. 2002a). As previously mentioned, the recovery of an *Abies lasiocarpa* needle from Turtle Lake in late-glacial sediment is further testimony to the presence of this species on Vancouver Island at this time.

Low non-arboreal pollen percentages of Ericaceae, Rosaceae, Poaceae, Apiaceae, and *Selaginella, Cryptogramma* and monolete fern spores indicate that the forest contained openings. Small percentages of *Cryptogramma* and *Selaginella* suggest that exposed bedrock knolls existed around the site (Klinka et al. 1989, Allen 1995). Deposition of mineral sediments at this time suggests discontinuous vegetation.

Climate was cool as indicated by the presence of *T. mertensiana*. If *Abies* pollen represents *A. lasiocarpa (*Heinrichs et al. 2002a*)*, then this suggests a cooler and more continental climate than today. Unfortunately, no macrofossils were recovered in this basal zone so it is not possible to distinguish which species of *Abies* contributed to the pollen spectra. However, local presence of *Pinus* would suggest that conditions were drier and more continental than today. DWHI and THMI values suggest that climate was moist and cool.

Caution must be taken with the interpretation of vegetation and climate of this zone as it is comprised of a single sample only.

HLRB-2, 195-155cm, 10, 270-6640 ^{14}C ybp

HLRB 2 is characterised by relatively high *Pinus*, *Abies* and *T. mertensiana* pollen percentages. *Alnus* pollen values are initially high and then decline; at the same time Cupressaceae percentages rise. The pattern of *Alnus* and Cupressaceae forms the basis for separation of HLRB 2 into two subzones 2a, and 2b. HLRB 2 is also characterised by NAP spectra that include Ericaceae, Rosaceae, Poaceae, Cyperaceae, *Pteridium*, and undifferentiated monolete fern spores. A decline in monolete fern spores into subzone 2a occurs at the same time as the decline in *Alnus* percentages.

HLRB-2a, 195-175cm, 10, 270-8450 ^{14}C ybp, Abies-T. mertensiana-Alnus-NAP

Abies percentages increase toward the top of the subzone from 19% to 32%. *T. mertensiana* percentages are similar to those in the previous zone (ca. 15%). *Alnus* percentages show a large increase from the previous zone and peak at ca. 45% in the middle of the subzone. Of the other arboreal taxa present in the pollen and spore spectra, *Pinus* values decrease from the previous zone and fluctuate between 10-18%, *T. heterophylla* percentages remain low at ca. 2%, and *Pseudotsuga* appears briefly at the beginning of the zone at <1%. Cupressaceae values are initially low in the beginning of the subzone at <1% but then rise toward the top to 6%.

Non-arboreal pollen and spore spectra consist of Ericaceae, Rosaceae, *Epilobium*, Poaceae, Compositae Tubiliflorae, Cyperaceae, *Selaginella*, *Pteridium*, and monolete ferns. As in the previous zone, percentages for most non-arboreal types are <2% with the exception of Cyperaceae, and monolete fern spores whose values range from 1-5% and 17-65% respectively. In general, Cyperaceae values decrease from the previous zone. Total pollen influx ranges from 4745 grains/ cm^2/yr to 14, 590 grains/ cm^2/yr.

DWHI values fluctuate slightly in the beginning of the subzone between 1 and 0.75, but then decline at the end of the zone to 0.5. THMI values maintain high values between 0.94 and 0.74.

Charcoal accumulation sharply rises to a peak in the middle of the subzone and then declines more gradually toward the top. The peak value of charcoal accumulation in this subzone is 1.4 particles/cm^2/yr.

Few macrofossil remains were recovered in this zone with the exception of what appeared to be outer layers or perigynia of sedge seeds. Identification could not be made beyond this.

Interpretation HLRB-2a

Vegetation in this zone consisted of an *Abies* and *T. mertensiana* forest, possibly with patches of *Alnus sinuata,* a shrub that frequently occupies moist or disturbed settings in subalpine environments (Franklin and Dyrness 1973). *Alnus sinuata* communities are commonly found within the upper CWH and MH zones on Vancouver Island where they may occupy sites with deep snow accumulation and may lie adjacent to open meadow communities (Franklin and Dyrness 1973).

Low percentages of non-arboreal taxa including Ericaceae, Rosaceae, *Epilobium*, Poaceae, *Selaginella*, and *Pteridium* suggest forests were open. High percentages of undifferentiated monolete fern spores may be from *Blechnum spicant* and/or *Athyrium filix-femina* (L.) Roth. (lady fern), which suggests the existence of some open or partly open and moist areas at the site, perhaps related to seepage.

THMI values suggest that climate was cool. Low DWHI values near the end of the subzone suggests that conditions were becoming dry. The presence of open NAP indicators such as Poaceae, *Selaginella*, and *Pteridium* may reflect open patches resulting from summer moisture stress.

A peak in charcoal accumulation in this subzone may be derived from fires burning near the site and may have provided favourable openings for *Pteridium* and *Epilobium* invasion.

HLRB-2b, 175-155cm, 8450-6640^{14}C ybp, Abies-T. mertensiana-Cupressaceae-NAP

Abies percentages rise to a peak of 49 % in the middle of this subzone and then decline sharply to ca. 20% toward the top. *T. mertensiana* values are similar to the previous subzone, fluctuating between 8-15%. Cupressaceae percentages rise toward the top of the subzone to reach a peak of 19%. *Alnus* percentages, on the other hand, decrease in this zone ranging between a low of 6% and a high of 30%. From the remaining arboreal components, *Pinus* percentages maintain steady values of ca. 12%, *Picea* pollen appears more consistently, attaining values of <2%, and *T. heterophylla* percentages remain low (ca. <2%) except for rise near the top of the zone to 7%. In addition, *Pseudotsuga* percentages reach peak values for the record in this subzone attaining a maximum of 3%.

Non-arboreal components are the same as in the previous subzone (Ericaceae, Rosaceae, *Epilobium*, Poaceae, Compositae Tubiliflorae, Cyperaceae, *Selaginella*, *Pteridium*, and monolete fern spores) with percentages mostly <2%. Exceptions are

Cyperaceae percentages, which rise from the previous subzone to a peak value of 7%, and monolete fern spore values, which decline from the previous subzone to ca. 3-33%. Total pollen influx varies between 1514 - 2345 grains/ cm^2/yr.

DWHI values decline toward the middle of the zone to values of 0.3, coincident with the peak in *Pseudotsuga* pollen percentages, and then rise again toward the top to a value of 1. THMI values rise slowly toward the middle of the zone to a peak of 0.9, but then decline toward the top.

Macrofossils consist of needle fragments of *T. mertensiana* and *Abies*, and branchlets from *C. nootkatensis*. Individual Cupressaceae scales were also recovered but are not emphasized in the interpretation of this subzone because they could not confidently be identified to the species level. In addition to the *C. nootkatensis* branchlets, a needle tip from *Taxus brevifolia* was recovered. This implies that pollen identified as Cupressaceae in the record may have been derived from both *Taxus* and *C. nootkatensis* as these pollen types are morphologically similar (Owens and Simpson 1986).

Charcoal accumulation declines steadily within this subzone from 0.7 fragments/cm^2/yr at the beginning of the subzone to 0.1 fragments/cm^2/yr, rising to 1.0 fragments/cm^2/yr at the boundary with the following subzone.

Interpretation HLRB-2b

Forests of HLRB 2b began to close relative to the previous subzone. This subzone was similar to HLRB 2a with the exception that *Abies* and Cupressaceae percentages are higher, whereas *Alnus* and monolete fern percentages are lower. Macrofossil remains indicate that the species responsible for the input of Cupressaceae pollen is *Chamaecyparis nootkatensis,* a species of cedar that is common in moist, maritime subalpine environments in the Pacific Northwest (Klinka et al 1989). However, the presence of a *Taxus* needle tip also indicates that some pollen identified as Cupressaceae may be derived from *Taxus brevifolia. Taxus* favours moist forest habitats (Klinka et al. 1989) and indicates similar conditions as *C. nootkatensis*. Because of the similarity and to ease discussion, the interpretation of Cupressaceae pollen for Harris Lake Ridge Bog will assume *C. nootkatensis* was the provider of pollen identified as

Cupressaceae The increase in Cupressaceae pollen may reflect replacement of *Alnus sinuata* communities by *C. nootkatensis* as forest closed and were less disturbed. A decrease in charcoal indicates less fire disturbance in this subzone and may have been partially responsible for the replacement of *Alnus* communities by *C. nootkatensis*. Notable also in this subzone are low percentages of *Pseudotsuga* pollen. Influx of this pollen type is likely from lowland sources. Surface samples from higher elevations on Mt. Arrowsmith reveal that *Pseudotsuga* pollen is present up to several percent even when the tree is absent. Caution is needed when interpreting the *Pseudotsuga* signal from the surface samples, however, since much of the modern CWH forest has been removed and replaced by extensive stands of *Pseudotsuga* on the slopes of Mt. Arrowsmith. Despite this, extensive *Pseudotsuga* populations existed in southern lowland areas of Vancouver Island at a similar time as HLRB 2a/2b, when conditions were warmer and drier than today (Allen 1995, Brown and Hebda 2002, Heusser 1983, Hebda and Whitlock 1997). Based on these data it is suggested that *Pseudotsuga* pollen in HLRB 2b was from lowland or hillslope populations and was not at the site.

Decreases in monolete fern spores from HLRB 2a reflect declining populations of *Athyrium filix-femina,* as forest canopies closed or fire disturbance decreased. Despite closing canopies persistently low non-arboreal percentages from Poaceae, *Epilobium*, *Pteridium*, and *Selaginella* indicate that the forest still contained openings on edaphically dry sites.

Macrofossil evidence suggests that *Abies* pollen in HLRB 2 was derived from either *Abies amabilis* or *Abies grandis*. *Abies grandis* is a lowland to montane species that grows on Vancouver Island between sea level and approximately 300 m (Foiles et al. 1990). Above elevations of 460 m, *Abies grandis* is replaced by *Abies amabilis* (Foiles et al. 1990). HLRB lies at 1300 m asl, implying that under present conditions *Abies amabilis* would occupy the site. However, DWHI and THMI ratios reveal that climate was cool and dry during HLRB 2. *Abies amabilis* is relatively drought and cold intolerant (Crawford and Oliver 1990), and would be less favoured under cool and dry conditions. On the other hand, *Abies grandis* is tolerant of warm and cold conditions and is more drought-tolerant than *Abies amabilis* (Foiles et al. 1990, Crawford and Oliver 1990). Based on the evidence presented above it is suggested that the species of *Abies* during HLRB-2a/b was *A. grandis* and not *A. amabilis*. *Abies grandis-T.mertensiana* forest has no modern analogue on Vancouver Island. However similar forests may grow in the eastern Cascade Mountains of Oregon within the *Abies grandis* zone (Franklin and Dyrness 1973). The precise identity of the *Abies* pollen contributor is important to provide a more detailed interpretation of the paleovegetation and paleoclimatic conditions during HLRB 2. Further investigation of sediment for macrofossil remains of *Abies* may lead to the identification of the species of *Abies* at the site at this time.

DWHI and THMI ratios suggest that conditions at Harris Lake Ridge Bog were cool and dry, but probably warmer and drier than today. HLRB 2 falls within a time of regionally recognized warm and dry conditions in British Columbia (Hebda 1995). During this time seasonality was increased (COHMAP members 1988), leading to warm dry summers and cold winters. Climate at Harris Lake Ridge Bog was probably more continental than today with cold winters that favoured *T. mertensiana* and warm dry summers that favoured drought tolerant *Abies grandis.*

HLRB-3, 6640-1970 ^{14}C ybp

HLRB 3 is characterised by decreasing *Pinus* and *Abies* percentages and high *T. mertensiana*, and *T. heterophylla* percentages. Cupressaceae values reach their peak in the first half of the zone, whereas *Alnus* decreases toward the middle of the zone and then increases again. Another notable feature of the zone is the broad peak in Ericaceae percentages toward the middle of the zone, following an initial increase in *Valeriana* and monolete fern values in the beginning of the zone. In addition, the second half of the zone exhibits a rise in Cyperaceae values. Zone HLRB-3 is split into two subzones HLRB-3a, 3b. As previously mentioned peak values of *T. mertensiana* and Cyperaceae, and decreasing percentages of Cupressaceae, Ericaceae, and monolete fern spores form the basis for separating the zone into two subzones.

HLRB-3a, 155-120cm, 6640-3450 ^{14}C ybp, Abies- T. heterophylla-T.mertensiana-Cupressaceae-NAP

Abies percentages decline in the zone from a peak value of 41% to a low of 13% at the end of the zone. *T. heterophylla* percentages rise steadily throughout the zone reaching a maximum value of 21% near the top. *T. mertensiana* attains its maximum percentages in this zone rising steadily from a low of 10 % at the beginning of the zone to a peak value of 42% toward the top. Percentages of Cupressaceae persist at values similar to the previous subzone, fluctuating between 4% and 14%. For the remaining arboreal taxa, *Pinus* values steadily decline toward the top of the zone to 5%. *Alnus* percentages show a similar trend, declining from a peak of 17% to <2%. *Pseudotsuga* pollen grains occur sporadically.

Ericaceae percentages show a steady rise toward the middle of the zone reaching a peak of 12% and then decline sharply near the top. Notable also, is the rise in *Valeriana* percentages to 4% at the beginning of the zone. Cyperaceae percentages decline to between <1% and 4%, and *Pteridium* shows a small peak in the beginning of the zone (ca. <1%) and then disappears. As in other zones, monolete fern spores show the highest percentages of all non-arboreal types rising sharply to a maximum value in the record of 71%, followed by a steady decline toward the top. Total pollen influx for this zone ranges between 1032 grains/ cm^2/yr to 11, 923 grains/ cm^2/yr.

DHWI values vary within a narrow range, fluctuating between 0.86 and 1. THMI values fluctuate between 0.57 and 0.72 and also are similar to values reached in the last half of the previous subzone.

Abundant macrofossil material was recovered within this subzone. The highest concentration of *C. nootkatensis* branchlets, as well as whole needle and needle fragments of both *T. mertensiana* and *A. amabilis/grandis* were found. In addition, numerous needle fragments that could not be identified (due to either poor preservation or preservation of pieces which were non-diagnostic), were recovered from the upper samples (120-130cm).

Charcoal accumulation increases in the first half of the zone, and remains high before declining near the end of the subzone.

Interpretation HLRB-3a

This subzone clearly reveals both local and regional landscape changes. Increasing *T. mertensiana* and decreasing *Abies* suggests that forests were closing and that soil nutrient status was probably poorer than in HLRB 2. This is also reflected in the stratigraphy as mineral-rich gyttja sediments were replaced by the accumulation of black peat with wood. Peak percentages of *T. mertensiana* coincide with abundant macrofossils of this taxon and suggest that this tree was abundant at the site. Also, the peak in *T. mertensiana* pollen is associated with clumped *T. mertensiana* pollen in pollen slides, suggesting that the site was heavily forested. Abundant pollen and macrofossils reveal that *Abies* remained a substantial component of the vegetation despite declining percentages. The persistence of *C. nootkatensis* indicates that this tree also remained as an important component of the forest. Notable also in the subzone is the increase in *T. heterophylla* pollen toward the top. The lack of macrofossil remains for this taxon, despite the presence of macrofossil remains of *T. mertensiana* and *A. amabilis/grandis* needles, suggests that this tree was not locally present at the site and thus pollen input may be from individuals down-slope of the site. The rise in *T. heterophylla* may reflect an increase in *T. heterophylla* pollen from lowland and montane forests. Vegetation history at Turtle Lake shows a contemporaneous increase of *T. heterophylla* during this time, as do numerous other records in the region (Hebda and Whitlock 1997, Hebda 1995, Brown and Hebda 2002a, c).

Locally, rises in *Valeriana* and monolete fern spore values in the beginning of the zone suggest that moist open patches existed in the forest. An increase in Ericaceae pollen following the initial *Valeriana* rise, suggests that heath communities may have replaced the herb meadows as conditions became moister and more favourable for heather growth. A change in meadow patch communities from herb-rich (*Valeriana*) toward ericaceous (heather) supports the idea that soil nutrient status was becoming poorer. Rising *T. mertensiana* values and declining Ericaceae percentages toward the end of the zone suggest that *T. mertensiana* expanded at the expense of heath patches.

Climate in this subzone became moister relative to the previous subzone. Increasing *T. mertensiana*, and declining *Abies* suggests that the surrounding soils of the site were becoming more acidic as organic matter accumulated, probably in association with moister conditions. If *Abies grandis* populations existed previously they were probably replaced by *Abies amabilis*, because of the change to moister conditions (Crawford and Oliver 1990). The expansion of *T. heterophylla* is a further indication of increased regional moisture. Conditions may have been less continental than in HLRB 2 and as a result summer temperatures were cooler.

A rise in charcoal at the beginning of the subzone reflects increased fire activity. The increase in *Valeriana* and monolete fern is coincident with this charcoal peak suggesting that fire may have played a role in creating meadow openings within the forest.

HLRB-3b, 120-75cm, 3450-1970 ^{14}C ybp, Abies-T. heterophylla-T. mertensiana-Cyperaceae

Abies percentages fluctuate throughout from 3-32%, declining toward the end of the zone. *T. heterophylla* percentages reach highest values in the record, peaking near the end of the subzone at 38%. *T. mertensiana* values show a steady decline from the previous subzone falling from 42% at the beginning of the zone to 18% at the top. *Pinus* percentages persist at low values (ca. 4%) for much of the zone until the end where they increase slightly to 10%. Cupressaceae percentages decline from a high of 7% to 2% from the beginning of the zone toward the end.

Cyperaceae values peak in the middle of the zone to reach their highest values in the record of 12%. Values of Ericaceae pollen in HLRB 3b are lower than the previous subzone. Monolete fern spores are almost absent. Total pollen and spore influx reaches its lowest values in the record, ranging from a low of only 47 grains/cm^2/yr to 11, 920 grains/ cm^2/ yr.

For the most part, DWHI values are at the maximum values of 1.0 within this zone. This is a result of the consistent presence of *T. heterophylla* pollen versus only sporadic occurrences of *Pseudotsuga* pollen. THMI values fall from 0.7 to 0.4, reflecting the change in dominance from *T. mertensiana* to *T. heterophylla* pollen in the ratio.

Conifer macrofossils consist of branchlets of *C. nootkatensis*, as well as whole needle and needle fragments of *T. mertensiana* and *A. amabilis/grandis*, similar to the previous subzone. Samples also contain numerous needle fragments that for reasons of poor preservation or the preservation of non-diagnostic parts could not be identified. Their presence, however, suggests that conifers grew at the site at this time.

Charcoal accumulation is the lowest in this subzone, generally fluctuating between 0.1 fragments/cm^2/yr and 0.5 fragments/cm^2/yr. Accumulation reaches a minimum in the first half of the zone but then rises to a peak of 2 fragments/cm^2/yr at the boundary with the following zone.

Interpretation HLRB-3b

Closed *T. mertensiana* and *Abies* forests persisted from the previous subzone. Decreasing percentages of *Abies amabilis*, and *T. mertensiana*, combined with increases in *T. heterophylla*, *Alnus,* and Cyperaceae pollen, suggests the wet depression had increased in size, locally expanding at the expense of forest. Upon expansion, the expression of *T heterophylla* and *Alnus* pollen from lowland and hillslopes sources increased.

Increased Cyperaceae percentages suggest that a fen-like wetland expanded and that the input of other local and extra-local pollen types may have been depressed due to local input of Cyperaceae. The change in sediment accumulation from black peat to undecomposed sedge peat further suggests that sedges dominated the wet depression. Low Ericaceae values indicates that heather patches may have persisted in the forest and that either their pollen input was depressed by Cyperaceae pollen input or that areas occupied by heather became smaller.

The persistence of *T. mertensiana*, *T. heterophylla*, and *Abies* suggests that climate was moister than today, continuing the trend started in HLRB 3a. Similarly, dominance of Cyperaceae suggests that conditions continued to moisten. Finally, the deposition of undecomposed sedge peat further suggests that conditions were suitably wet to slow humification of the peat surface A decrease in THMI values seems to suggest that conditions were warmer than in HLRB 3a. However, this is likely due to increased moisture and an associated rise in *T. heterophylla* input as well as a trend to more equable (less seasonality) summer and winter temperatures. DWHI values suggest that climate was moist. The site at this time may have been comparable to the upper closed forest areas of the MH zone.

HLRB-4, 75-55cm, 1970-1260 ^{14}C ybp, Pinus-Abies-T.heterophylla-T.mertensiana

A sharp rise in *Abies* percentages characterises this zone as this taxon rises to peak values of 36%. *Pinus* percentages increase in this zone reaching a maximum value of 19%. Percentages of *T. heterophylla* decline slightly from the previous zone and average ca. 25%. *T. mertensiana* values continue to decline from the previous zone to a low of 14%, but then increase slightly toward the top to a peak of 23%. Other arboreal pollen in the zone consists of Cupressaceae, and *Alnus*. Cupressaceae percentages are <2%, and *Alnus* values are at their lowest values in the record at ca. 3%. Non-arboreal pollen is rare in this zone and consists mostly of Cyperaceae at ca. 2%. Total pollen influx ranges from 1815 grains/ cm^2/yr 5256 grains/ cm^2/yr.

DWHI values throughout the zone are 1.0. THMI values are just slightly below 0.5.

Similar to other zones, macrofossil material consisted of whole needle and needle fragments of *T. mertensiana* and *Abies*, as well as numerous unidentifiable needle fragments. No Cupressaceae branchlets or scales were recovered from samples in this zone.

A peak in charcoal accumulation was observed in the first sample of this zone. A second, smaller peak in charcoal accumulation occurs near the end of the zone.

Interpretation HLRB-4

Expansion of *Abies* and *Pinus* characterise this zone. Likely, closed forests dominated by *Abies amabilis* and *T. mertensiana* with scattered local trees of *Pinus contorta* replaced the *T. mertensiana* forests of the previous subzone. In contrast, the lack of *Pinus* macrofossils despite deposition of *A. amabilis/grandis* needles, raises the possibility that *Pinus* may not have grown locally, but existed extra-locally on open dry sites. Similarly, relatively high *T. heterophylla* percentages may be from input from lowland and montane forests. Increase in charcoal throughout the zone implies increased fire activity at this time.

A marked rise in *Abies* percentages reflects improved nutrient availability related to fire-associated soil changes and perhaps more regional input of this conifer after fire.

Soils properties such as pH and nutrient concentration (e.g., Ca, Na, Mg) can be increased by fire (Barbour et al. 1999). Perhaps recurring fire caused the soil to change from being acidic and nutrient poor, to less acidic with higher nutrient concentrations. Synchronous with the rise in *Abies,* is the rise in *Pinus*. Increased *Pinus contorta* is consistent with increased fire activity. *P. contorta* is shade-intolerant and fire-adapted. It has a large seed reserve and uses heat to release seed if cones are serotinous (Lotan and Critchfield 1990).

DWHI and THMI ratios suggest that climate was cool and moist similar to HLRB 3b.

HLRB-5, 55-25cm, 1260-520 ^{14}C ybp, Ericaceae

Ericaceae percentages rise to maximum values within this zone (ca. 66%). *Pinus* percentages maintain fairly constant values of ca. 13%, but show a depression to 4%, coincident with peak Ericaceae values. A similar effect is seen in percentage curves of *T. heterophylla*, *T. mertensiana*, and Cupressaceae. Influx trends decline for these taxa in this zone but do not show an obvious decline strictly related to the rise in Ericaceae, and thus the depression of percentage data are partially a relative decline as a result of high Ericaceae percentages (fig. 7-3). *Abies* percentages decline sharply at the beginning of the zone to a low of 1%, rise to a peak of 21% just after the middle of the zone, and then decline again to ca. 10% toward the top. Percentages of *T. heterophylla* show an overall decline from the previous zone reaching values of ca. 13% at the end of the zone.

Non-arboreal pollen other than Ericaceae is slightly more abundant than in the previous zone, showing sporadic occurrences of Rosaceae, Compositae Tubiliflorae, *Valeriana*, and *Caltha*, all at percentages of ≤1%, except for Cyperaceae and monolete fern spores. Cyperaceae values decrease from 4% to<1% from the beginning of the zone toward the end. Monolete fern spores increase slightly toward the end of the zone but are always <2%. Total pollen influx for this zone ranges between 321 grains/ cm^2/yr 6410 grains/ cm^2/yr.

DWHI values remain at 1.0, and THMI values decline to nearly zero in the first half of the zone, but then immediately rise to values above 0.5 in the upper half.

Leaves of *Phyllodoce empetriformis* are a notable component of the recovered macrofossil assemblage. This implies that high percentages of ericaceous pollen in this zone is due, at least partially, to this heather species. Other macrofossil remains consist of needle fragments from *T. mertensiana*.

Charcoal accumulation varies little in the beginning of the zone but shows an isolated peak to a value of 2 fragments/cm^2/yr near the top.

Interpretation HLRB-5

High Ericaceae percentages, and *Phyllodoce* macrofossils reveal that *Abies* and *Pinus* forests were replaced by *Phyllodoce empetriformis* communities. Increased Ericaceae cover may have resulted from repeated burning of the site such that *Abies* forests eventually gave way to heath meadow. Persistent accumulation of charcoal at values similar to the previous subzone supports an interpretation of repeated burning. Small increases and appearances of *Caltha*, Rosaceae, Poaceae, *Artemisia*, and *Valeriana*, taxa typical of open, moist vegetation, also suggests that subalpine meadow grew immediately around the site, having expanded.

The limited forest cover in HLRB 5, as evidenced by low arboreal pollen influx, consisted of *Abies* and *T. mertensiana*. The relatively high percentages of *T. heterophylla* were probably from regional and extra-local sources. Increasing arboreal percentages, combined with decreasing Ericaceae values in the upper half of the zone indicates that forest stands started to become re-established as trees invaded the heath meadows. By the end of the zone, the heather meadow had been reduced in area and the forest surrounding the site probably resembled the modern subalpine forest.

Climate at this time was probably similar to modern cool and moist conditions. Although *Phyllodoce empetriformis* communities are interpreted primarily as an indication of disturbance, their presence also suggests that climate was cool and moist. DWHI values suggest that climate was moist. The decline in THMI values are coincident with the Ericaceae pollen rise and are a result of the local removal of *T. mertensiana* trees by fire and the persistent input of *T. heterophylla* pollen from regional sources. Later in the zone THMI values increase as *T. mertensiana* returned to the local forest and indicate that conditions were cool.

HLRB-6, 25-0 cm, 520 ^{14}C ybp-Present, Abies- T. heterophylla-T. mertensiana-Cyperaceae-Monolete ferns

Abies percentages increase slightly from the previous zone and range between 11% and 19%. Percentages of *T. heterophylla* also increase, peaking in the middle of the zone at a value of 23% and then declining to ca. 10% at the top. *T. mertensiana* percentages range between ca. 15% and 24%, declining slightly to 15% near the end. *Pinus* percentages fluctuate between 9% and 16%. Cupressaceae values increase toward the end of the zone rising from 2% at the beginning to 10% at the top of the record. *Alnus* percentages continue to increase from the previous zone and rise from 9% at the beginning to 24% at the top of the record. Cyperaceae and monolete fern spores are the most prominent non-arboreal types, reaching values of 6% and 8% respectively. Ericaceae pollen is also a persistent component of non-arboreal spectra, declining from the high values that characterise the previous zone to values that range between 2% and 5%. *Pteridium* increases in this zone to ca. 1%. Total pollen and spore influx values range between 136 grains/ cm^2/yr and 4,058 grains/ cm^2/yr.

DWHI values are essentially 1.0 and THMI values average 0.6.

Abundant remains of *Phyllodoce empetriformis* leaves were recovered from sediments in this zone. Other macrofossil remains consist of whole needle and needle fragments of *T. mertensiana* and *A. amabilis/grandis*. Also, a single branchlet of *C. nootkatensis* was recovered. *Carex* spp. seeds were also recovered from the upper two samples of the record.

Charcoal accumulation values are low in the beginning of the zone (0.2 particles/cm^2/yr), and peak (0.8 particles/cm^2/yr) and then decline toward the top of the record.

Interpretation HLRB 6

Modern subalpine forests developed around the site, consisting of *T. mertensiana*, *Abies*, *C. nootkatensis*, with *Alnus* patches. Relatively high percentages of *T. mertensiana*, and *Abies* suggest that forest canopy closed relative to the previous zone. Stunted *T. mertensiana* trees were observed growing on the bog surface at the time samples were collected. Growth of these trees may have begun in the previous zone when *T. mertensiana* percentages started to rise. *C. nootkatensis* macrofossil remains suggest that this tree grew in the forest. Increasing percentages of this pollen type upward in the zone suggests that cover of *C. nootkatensis* increased up to the present. Macrofossils of *Phyllodoce empetriformis* indicate that open heath patches remained around the site.

Pinus and *T. heterophylla* pollen was probably derived from regional and extra-local sources. Lack of *T. heterophylla* and *Pinus* macrofossils despite abundant *Abies*, *T. mertensiana*, *C. nootkatensis* and *Phyllodoce empetriformis* remains suggests that *Pinus* and *T. heterophylla* did not grow immediately at the site. Increased values of *Alnus* toward the top of the zone may indicate increasing disturbance in the region and associated input of *Alnus rubra* from lower elevations. An increase in monolete fern spore values is probably a reflection of ferns growing in moist areas beneath the forest canopy or in openings.

As in the previous zone climate maintained its modern cool and moist characteristics at this time. Winters were cool with abundant snowpack, and summers were relatively short and mild with less precipitation than in winter months. The small peak in charcoal accumulation near the top of this zone may represent natural or human (European or First Nations) initiated burning near the site. Pollen percentages do not exhibit much variation associated with this small peak in charcoal, suggesting that its effect at the site may have been relatively minor or that sampling resolution did not detect an effect.

Summary

The Harris Lake Ridge Bog record has a complex history that exhibits strong local and regional influences. In the early Holocene a forest of *Abies* and *T. mertensiana* surrounded the site. The origin of the *Abies* pollen is not certain but based on available evidence it may be from *Abies grandis*. This type of forest has no modern analogue on Vancouver Island today but similar forests may occur in the eastern Cascade Mountains of Oregon. Climate in the early Holocene was cool and dry and more continental than today. In the mid- and late-Holocene forest composition changed around Harris Lake

Ridge Bog as conditions moistened, seasonality decreased, and taxa better suited to nutrient poor soils, such as *Tsuga mertensiana* and *T. heterophylla* expanded. At the same time, there is evidence to suggest that local switches between forest and *Phyllodoce empetriformis* communities were initiated by fire. Increased fire activity in the late Holocene despite inferences of a cool and moist climate from other studies (Hebda 1995) suggests that a factor other than climate may have influenced fire regimes in the area.

Chapter 8

Discussion

Introduction

The goal of this chapter is to compare the paleovegatation and paleoclimate interpretations from the Turtle Lake and Harris Lake Ridge Bog records first to each other and then to other sites in the region. Comparison of the two sites to each other is useful to gain an understanding of vegetation, climate, and disturbance histories on south central Vancouver Island. In addition, these two sites allow us to compare and contrast post-glacial vegetation change in both lowlands and subalpine areas. Furthermore, the records permit comparison of the timing of the vegetation changes at high and low elevation sites, to gain insight into the dominant influences on vegetation change at each site. Understanding dominant influences may aid in predicting vegetation change under future changes in climate and disturbance. To illustrate, suppose subalpine ecosystems responded to local disturbances more than regional climate changes. In this case ecosystem dynamics at high elevation might be best predicted by considering future local disturbance regimes resulting from macro-climatic changes.

This chapter will first compare the two records from south central Vancouver Island to each other with respect to vegetation, and climate. Vegetation history will be compared and contrasted between the lowland and high elevation site and inferences of dominant forcing mechanisms on vegetation history will be drawn. Following this, the history of fire disturbance from Turtle Lake and Harris Lake Ridge Bog will be discussed with respect to each other and to regional fire history reconstructed from other sites on Vancouver Island.

To place the records from south central Vancouver Island into a regional framework Turtle Lake and Harris Lake Ridge Bog will be compared with other lowland and high elevation sites in the region. Vegetation history at Turtle Lake will be compared with other sites on Vancouver Island, the Fraser Lowland, and western Washington State. Vegetation history at Harris Lake Ridge Bog will be compared with three other subalpine sites from south and northwest Vancouver Island. New and distinct features from the pollen records of both Turtle Lake and Harris Lake Ridge Bog will follow each regional paleovegetation comparison to highlight specific contributions made by each record to the understanding of the paleoenvironmental history of Vancouver Island and to point to areas that need more study. A summary of regional vegetation history, timing of changes, and location of records is provided in Figs. 8-1, 8-2. Comparison of regional paleoclimate reconstructions will follow the paleovegetation comparison.

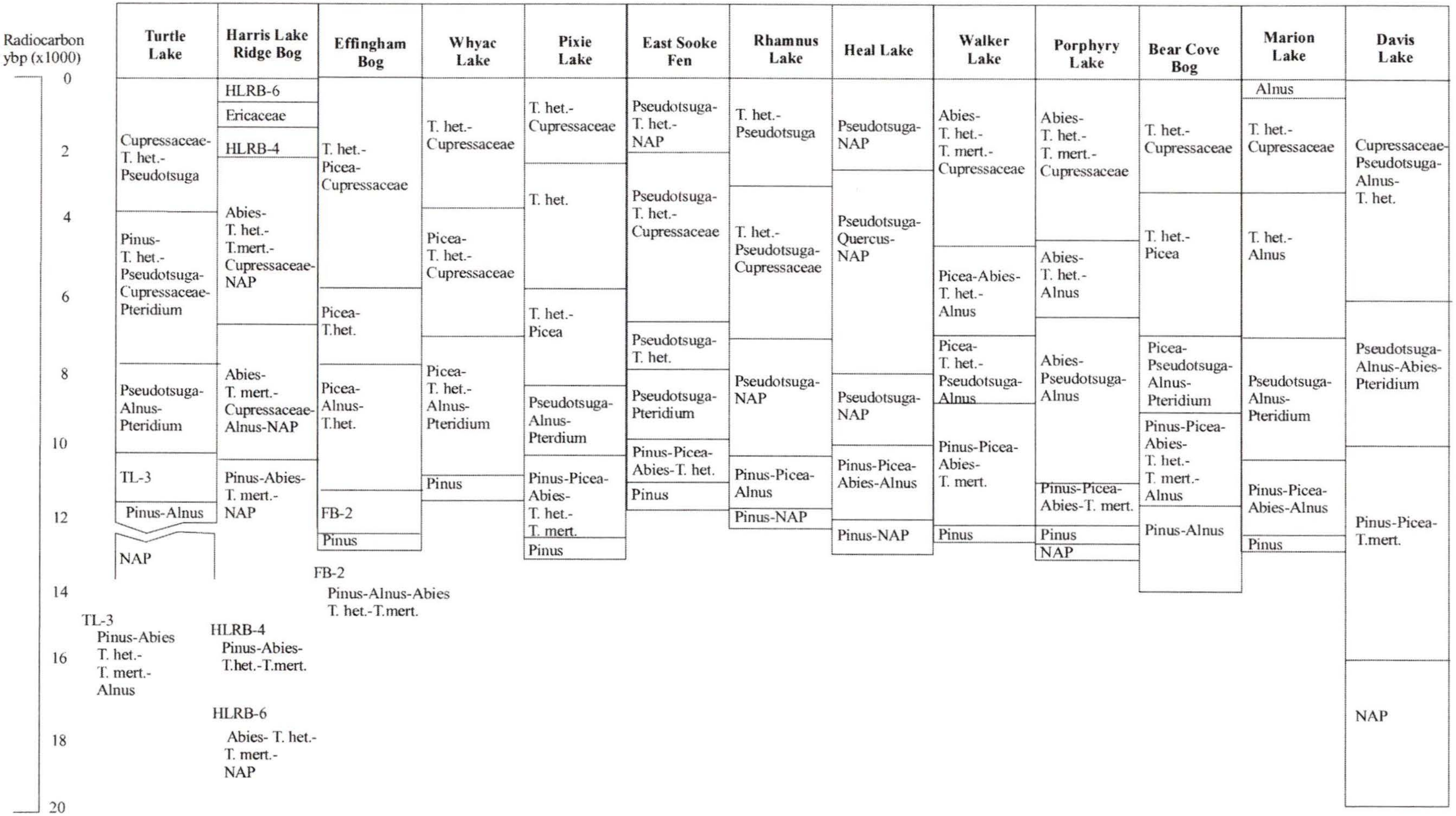

Fig. 8-1. Summary of selected pollen records from the Pacific Northwest. Pollen zones are designated according to the major taxa present. T. het.=*T. heterophylla*, T. mert.=*T. mertensiana*

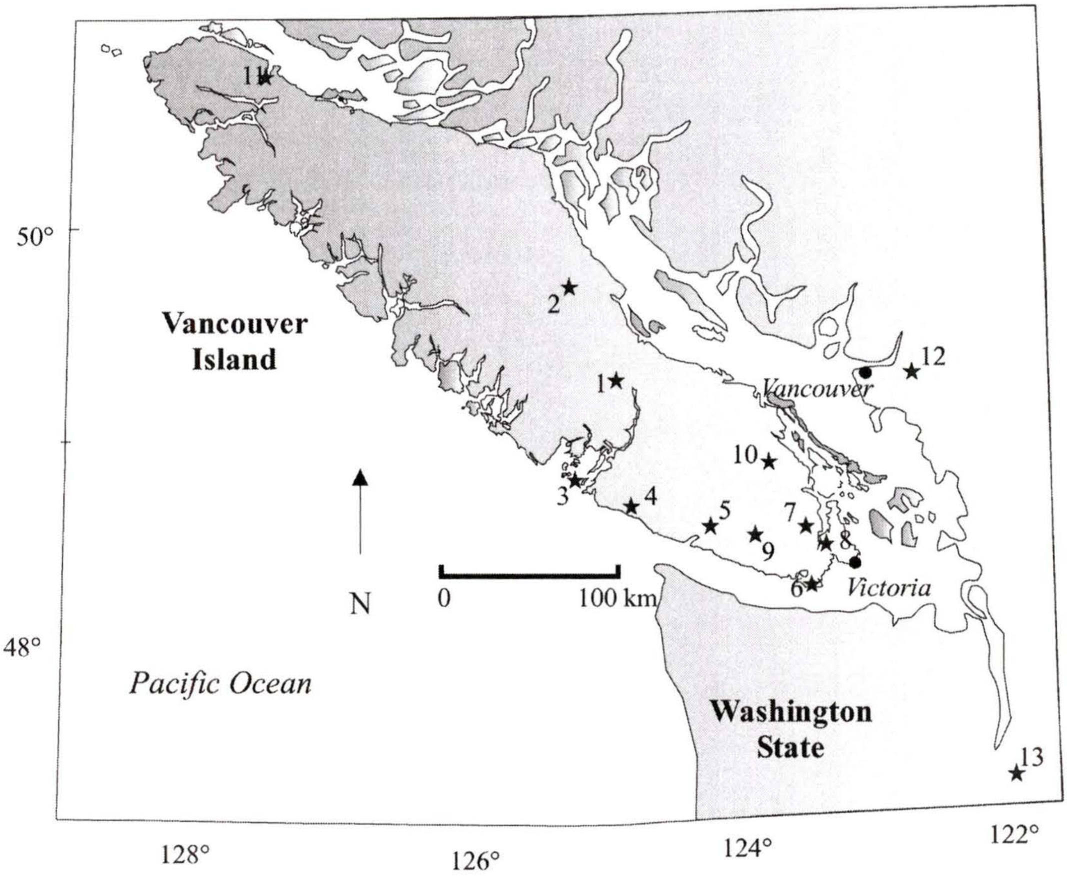

Fig. 8-2. Location of selected pollen records from the Pacific Norththwest. *1) Turtle Lake; 2) Harris Lake Ridge Bog; 3) Effingham Bog (Walker 2001); 4) Whyac Lake (Brown 2000); 5) Pixie Lake (Brown 2000); 6) East Sooke Fen (Brown 2000); 7) Rhamnus Lake (Allen 1995); 8) Heal Lake (Allen 1995); 9) Walker Lake (Brown 2000); 10) Porphyry Lake (Brown 2000); 11) Bear Cove Bog (Hebda 1983); 12) Marion Lake (Mathewes 1973); 13) Davis Lake (Barnosky 1981).*

Vegetation and Climate History of South Central Vancouver Island

Pre-Full glacial

The sequence on south central Vancouver Island begins with a NAP-dominated zone consisting of Poaceae, *Cryptogramma*, *Selaginella*, Compositae, *Artemisia*, and ferns prior to 12,000 ybp. The landscape at this time may have resembled parkland or alpine environments with low herbaceous ground cover. The NAP zone in the Turtle Lake record is separated from the organic sediments by a 16 cm unit of silt and clay with pebble to cobble sized clasts and occurs below the regionally recognized *Pinus* zone. Accordingly, there are three possible times in which the NAP zone may have been deposited.

The first possibility is that the NAP zone was deposited sometime before glaciers had reached the Alberni lowland. This implies that the basin or depression that Turtle Lake now occupies was present before the last glaciation, and was not a product of it. It is conceivable that ice proximal areas were occupied by parkland or alpine type plant communities, before they were overridden by ice. Hansen and Easterbrook (1974) used an increase in NAP types, similar to types identified in the Turtle Lake record, as an indication of cooler conditions toward the end of the Olympia non-glacial (approximately 25,000 ybp). Alley (1979) found an increase in herb pollen in a suite of sediments deposited before and during the onset of the Fraser glaciation, suggesting that these resulted from alpine vegetation as climate cooled and alpine glaciers began to flow down-valley. Although the onset of the Fraser glaciation may have began around 25-30 ka, ice was largely confined to mountain ranges until 20-25 ka (Clague 1991). Herb-dominated assemblages are common in western Washington at approximately 20,000 ybp, well before the maximum of Fraser glaciation (Heusser C. 1983). Hicock et al. 1982, used pollen and macrofossil evidence of *Abies* lasiocarpa and *Picea engelmanii* to infer that parkland grew in the Fraser lowland around 18, 000 ybp, before being overridden by advancing glaciers in the Vashon Stade. It is possible that herb dominated assemblages at Turtle Lake represent parkland or alpine meadow environments that developed as climate cooled and glacial conditions began, perhaps before 20,000 ybp.

A second option for the NAP-dominated zone is that it represents vegetation growing in the Alberni Valley during full glacial times. This implies that this site remained ice-free for some time during full glacial conditions. South of the maximum ice extent during the Fraser glaciation, non-arboreal pollen characterises full glacial deposits (Heusser C. 1983, Barnosky 1981). Brown (2000) also recovered a dominantly non-arboreal assemblage in the basal sediments of Porphyry Lake on southern Vancouver Island, and suggested that his NAP zone indicated that the site was ice-free during the Vashon Stade of the Fraser glaciation. The presence of deeply weathered porphyry in surrounding rock outcrops was used to further infer that this site had not been overridden by ice during the last glaciation. Brown (2000) suggests that the high elevation position of Porphyry Lake may have remained as an ice-free plateau that supported herb assemblages above the Fraser glaciation Cordilleran ice sheet. The NAP-dominated assemblage at Turtle Lake argues against such a suggestion if the assemblage was deposited during full glacial times, as Turtle Lake is located in the lowland of the Alberni Valley, only 80 m above sea level. Ice cover must have been much less extensive than traditionally reconstructed on Vancouver Island if a non-arboreal plant assemblage existed at Turtle Lake during the full glacial. A full glacial refugium has been suggested for ridge top sites on Brooks Peninsula on northwestern Vancouver Island and for the Queen Charlotte Islands (Hebda 1997, Warner and Mathewes 1982). Both areas are characterised by maritime climates that may have reduced ice cover. In contrast, Turtle Lake is located in a more inland setting in central Vancouver Island. Evidence for ice-free conditions on south central Vancouver Island during the Late Wisconsin has major implications regarding the geomorphologic, vegetation development and archaeological history of Vancouver Island. Discovery of ice-free conditions during the Fraser glaciation at Turtle Lake would require re-evaluation of the glacial history of coastal British Columbia.

A third possibility for the origin of the NAP-dominated zone is that it represents vegetation that colonised immature soils immediately after deglaciation, but before the regionally recognized *Pinus* zone. The lack of similar assemblages from palynological records in the area, however, suggest that a late glacial origin for the NAP assemblage is not probable. Mathewes (1973) looked at pollen assemblages from marine clays dated to 12,690 ybp, from the Fraser Lowland and found high proportions of *Pinus contorta* as well as some NAP assemblages, suggesting that the postglacial landscape was quickly colonized by *Pinus contorta*, and that it was not preceded by an NAP dominated phase. *Pinus contorta* was present as early as 13, 600 ybp at Bear Cove Bog (Hebda 1983), suggesting that *Pinus* first colonised the post-glacial landscape.

Of the three options presented for the origin of the NAP dominated zone the first option, that the zone reflects parkland or alpine tundra vegetation before ice reached the Alberni Valley, is favoured. Support for this interpretation comes from evidence for parkland conditions in the Fraser Lowland around 18,000 ybp, and from NAP dominated assemblages and inferences of parkland environments in front of advancing glaciers in Washington State around 20, 000 ybp (Heusser C. 1983, Barnosky 1981). One interesting implication is that if the NAP dominated zone in Turtle Lake does indeed pre-date the Vashon Stade, then Turtle Lake was a depositional basin before the last ice advance, and is not a Vashon glacial landform. It is possible therefore that Turtle Lake contains a record that extends even further back in time.

With respect to climate non-arboreal assemblages indicate that at the time of deposition conditions were colder than today.

Late-glacial

Beginning at 12,000 ybp organic sediment began to accumulate at Turtle Lake. Open *Pinus* and *Alnus* woodlands with scattered *Picea*, *Abies lasiocarpa* and *T. mertensiana* surrounded Turtle Lake for approximately 500 years, until 11,500 ybp.

Climate in this interval was cool to cold and drier than today, although the presence of *T. mertensiana* points to sufficient moisture to produce an insulating cover of snow in some areas (Mathewes 1993). If *Abies lasiocarpa* was present then this indicates that conditions were more continental and probably somewhat drier than today.

Late-Pleistocene

The subalpine record at Harris Lake Ridge Bog begins in the Late Pleistocene before 10, 270 ybp. From this point, vegetation and climate history from south central Vancouver Island will incorporate both records (up to this point only Turtle Lake has been discussed). At both Turtle Lake and Harris Lake Ridge Bog, vegetation is composed of mixed conifer forests (from 11,500-10,200 ybp at Turtle Lake, >10,270 ybp at Harris Lake Ridge Bog). At Turtle Lake, mixed conifer forests of *Pinus*, *Abies*, *T. heterophylla*, and *T. mertensiana* replace *Pinus* forests from the previous zone. *Alnus* thickets may have continued to occupy disturbed sites at this time. The largest difference between forest of the *Pinus* and mixed conifer zones at Turtle Lake was the increase in *T. heterophylla*. At Harris Lake Ridge Bog mixed conifer forests existed before 10,270 ybp and were composed of *Pinus*, *Abies*, and *T. mertensiana* with a non-arboreal component. Forests around Turtle Lake also contained a NAP element indicating that at both low and high elevations there were forest openings. The upper boundary of the mixed conifer zone occurs at the same time at Harris Lake Ridge Bog and Turtle Lake, indicating that forest composition changed synchronously on central Vancouver Island at both low and high elevations. This contemporaneous change suggests that macroclimate exerted the dominant influence on vegetation dynamics at the end of the Pleistocene. If vegetation change was attributed mainly to soil development, then we might expect the timing of vegetation change between the low and high elevation sites to be different since both records begin at different times

Notable in the Turtle Lake core is the registration of a Younger Dryas-like phenomenon in the latter part of the mixed conifer zone from 10,700-10,200 ybp. In this interval *Pinus* and *T. mertensiana* increased while *T. heterophylla* decreased. In contrast to Whyac Lake (Brown 2000), *Alnus* did not show peak abundance during the inferred Younger Dryas cooling at Turtle Lake, indicating that *Alnus* may not accurately record cooling and solifluction disturbance associated with Younger Dryas cooling

At Turtle Lake climate initially became moister and warmed slightly before Younger Dryas cooling. At high elevations cool and moist conditions prevailed. THMI values of 0.8 at Harris Lake Ridge Bog and 0.2 at Turtle Lake reveal that a large difference in temperature existed between the two sites. This difference was probably similar to temperature differences that exist between the two sites today because of elevation.

Early Holocene

Marked changes occur in lowland and subalpine vegetation of south central Vancouver Island at the beginning of the Holocene. In lowlands, open forests of

Pseudotsuga, *Alnus* with *Pteridium* and moist sites containing *T. heterophylla* occupied the landscape from 10,200-7800 ybp. From 7800-6300 ybp *Thuja Plicata* and *T. heterophylla* expanded. *Pteridium* grew in the understory at first but did not become abundant and/or produce abundant spores until later in the zone. The late increase in *Pteridium* may have been due to an increase in forest openings due to climatic factors or fire. Species of Poaceae and Rosaceae grew in the understory of the open forests. Lowland forests resembled CDF forests, similar to those found on southeastern Vancouver Island today.

At higher elevations, vegetation was dominated by forest stands of *Abies*, *T. mertensiana*, containing thickets of *Alnus* and non-arboreal taxa from 10,270-8450 ybp. Following this, an expansion of *Chamaecyparis nootkatensis* and replacement of *Alnus* occurred from 8450-6640 ybp. As previously discussed in the interpretation of Harris Lake Ridge Bog *Abies* pollen may be from *Abies grandis* (See Chapter 7; Zone 2a), though *Abies amabilis* remains a possibility. Because *Abies grandis* and *Abies amabilis* have different ecological characteristics (Klinka et al 1989) identification of the species at Harris Lake Ridge Bog would help to clarify the paleoenvironmenmtal conditions during the early Holocene at this site.

Based on the development of forests composed of the seral and shade intolerant taxa *Pseudotsuga*, *Alnus*, and *Pteridium* around Turtle Lake the climate of the early Holocene at low elevation on south central Vancouver Island was likely warmer and drier than today. The warm and dry period was followed by a period of warm and moist conditions. At Turtle Lake warm and dry conditions lasted from 10,200-7800 ybp. Following this, warm and moist conditions lasted from 7800-6300 ybp. Cool, dry, and continental conditions occurred at Harris Lake Ridge Bog in the early Holocene and lasted from 10,270-6640 ybp.

Mid-Holocene

Vegetation changes are roughly synchronous in the mid-Holocene between Turtle Lake and Harris Lake Ridge Bog. At Turtle Lake, forests closed and *T. heterophylla* expanded to become co-dominant with *Pseudotsuga* and *Thuja plicata* from 6300-3000 ybp. Forests may have resembled modern CWHxm forests growing in the area today. At

Harris Lake Ridge Bog forests closed and became dominated by *T. mertensiana*, *Abies*, and *Chamaecyparis nootkatensis* from 6640-3450 ybp. *T. heterophylla* expanded in extra-local and regional lowland and montane forests. Locally, moist open patches containing *Valeriana* and ferns grew in the forest around Harris Lake Ridge Bog but were later replaced by heather.

Vegetation changes at both sites indicate a transition to cooler and/or moister climate compared to earlier. Climate at Turtle Lake and Harris Lake Ridge Bog may have been similar to present-day mild/cool and relatively moist conditions.

Late-Holocene

A change in vegetation occurs in both records from approximately 3,500-1,900 ybp. At Turtle Lake, *Thuja plicata* expanded in the closed CWHxm forests from 3,000-1,900 ybp. Also, *Myrica gale* expanded in a lake-marginal wetland (possibly the modern bog). At Harris Lake Ridge Bog, closed *Abies-T. mertensiana* forests characterised the site, *T. heterophylla* expanded in regional and extra-local forests, and *Chamaecyparis nootkatensis* declined from 3,450-1,900 ybp. Cyperaceae populations increased in an expanding wet depression. Surface samples from the MH zone and the CWH/MH transition from Mt. Arrowsmith (fig. 5-1) suggest that the forest around Harris Lake Ridge Bog probably resembled the upper closed forests of the MH zone.

Both Turtle Lake and the Harris Lake Ridge Bog records indicate that climate continued to be mild/cool and moist, perhaps even cooler and moister than today. At Turtle Lake conditions were still conducive for *Pseudotsuga* to co-dominate with *T. heterophylla* in the forests but *Thuja plicata* expanded. At Harris Lake Ridge Bog the local expansion of the fen-like wetland indicates that climate was cooler and especially moister than the mid-Holocene, and possibly today.

After approximately 1900 ybp vegetation changes recorded at Turtle Lake and Harris Lake Ridge Bog are not synchronous. At Turtle Lake modern forests developed after 1900 ybp. Classified as CWHxm (Meidinger and Pojar 1991) these forests are dominated by *T. heterophylla*, Cupressaceae, and *Pseudotsuga*. In contrast, the Harris Lake Ridge Bog record reveals dramatic local changes in vegetation during the same interval. Fire disturbance seems to have exerted the dominant control over vegetation at Harris Lake Ridge Bog during the last 2,000 years.

Climate during the last 1900 years around Turtle Lake was mild and moist, similar to modern conditions in the Alberni Valley, and in similar forests on southern Vancouver Island (Brown and Hebda 2002a, Allen 1995). As stated previously, the late Holocene decline in Cupressaceae may indicate that the climate was initially cooler and/or moister than today but then warmed and/or dried. On the other hand, the development of aboriginal woodworking technology may account for the decline in cupressaceous pollen as *Thuja plicata* trees were selectively felled (Hebda and Mathewes 1984, Hebda and Brown 2002c). Resolution of this issue requires more paleoecological work focused on the last 2,000 years to gain insight into the relative importance of climatic changes and human influences.

At Harris Lake Ridge Bog, several unique changes in vegetation occurred during the last 2,000 years. The interval in characterised first by the local expansion of *Abies* and *Pinus* trees in the forest, and then by the expansion of a heath community.

From 1,970-1,260 ybp local forest stands were dominated by *Abies* and *T. mertensiana* and scattered individuals of *Pinus*. These forests may have resulted from repeated fire that opened the site and altered soil chemistry, physical properties, and nutrient availability (Barbour et al. 1999).

From 1,260-520 ybp forest at Harris Lake Ridge Bog was replaced by an open community of *Phyllodoce empetriformis*. The site resembled open subalpine or alpine communities where tree growth is limited and heather mats and *Vaccinium* spp. shrubs make up the dominant cover. This is the first time such a community has been detected. Surface samples from Ericaceae dominated communities in subalpine environments at Mt. Arrowsmith (fig. 5-3) and from Heather and Green mountains, dominated by *Vaccinium* spp. (Hebda, Unpublished results) do not produce Ericaceae pollen percentages as high as those observed at Harris Lake Ridge Bog.

Although used as an indicator of disturbance at Harris Lake Ridge Bog the dominance of heather meadow also suggests that climatically precipitation was abundant and that temperatures were cool. In the Pacific Northwest, heather communities tend to dominate in subalpine areas where snow persists into summer months and limits the growing season (Franklin and Dyrness 1973). Perhaps the lack of trees increased the albedo of the site and allowed snow to persist into the summer months. Eventually trees re-invaded the site, perhaps modifying the microclimate such that growing season lengthened (Franklin and Dyrness 1973). The pollen-based precipitation index (DWHI) indicates that climate was moist. The temperature index (THMI) was affected by the local replacement of *T. mertensiana* trees at the site by *Phyllodoce empetriformis* communities and is not reliable as an indicator of temperature during this time.

From 520 ybp to present, modern subalpine forest developed at Harris Lake Ridge Bog, consisting of *Abies amabilis*, *T. mertensiana*, and *Chamaecyparis nootkatensis*.

Summary

In summary, except for the last 2,000 years at Harris Lake Ridge Bog, vegetation change on south central Vancouver Island has been synchronous with respect to timing at low and high elevations. Synchronous vegetation change in south central Vancouver Island suggests that macroclimate exerted the dominant influence on vegetation. Although past plant communities at both sites, are for the most part, compositionally different the direction of change is similar. Discrepancies in the timing of changes at each site may be due to problems with radiocarbon date interpolation or local site factors such as soil development, aspect, surrounding physiography, microclimate and ecological effects due to elevation.

The record of local site changes at Harris Lake Ridge Bog is notable as these can be used to gain a greater understanding of subalpine dynamics in addition to providing insight into regional climate trends. Other studies from small wetlands in subalpine areas may reveal vegetation histories that are more complex than previously thought. In contrast, at Turtle Lake modern forests have existed in the area since the mid-Holocene, undergoing minor adjustments in the late Holocene when Cupressaceae increased briefly. CWHxm forests, thus, have a long history at this site.

Fire History of South Central Vancouver Island and Regional Comparison

Early glacial-late-glacial

No charcoal is recorded in the NAP zone of Turtle Lake. This suggests that fires were of little importance in this community. This result is consistent with those from a similar NAP zone at Porphyry Lake (Brown and Hebda 2002a).

Little charcoal was deposited in the first organic sediments of Turtle Lake from 12,00-11,500 ybp (Zone TL-2), indicating low fire activity in the *Pinus* woodlands that occupied the landscape. These observations also agree with other records from Vancouver Island and western Washington (Brown and Hebda 2002b, 1998, Cwynar 1987).

Low amounts of charcoal accumulated in the late Pleistocene mixed conifer forests at Turtle Lake. This indicates that fire activity was minimal at the site during this time and is inconsistent with the records from Vancouver Island (Brown and Hebda 2002b, 1998) that show the first evidence for fire in the mixed conifer zone. At high elevations, the single sample from the mixed conifer zone at Harris Lake Ridge Bog records charcoal, and it is possible that fires burned at this site. Low charcoal accumulations at Turtle Lake suggest that the fire regime at this site differed from Harris Lake Ridge Bog and from other sites.

Early Holocene

Charcoal accumulation increases at Turtle Lake from 10,200-7,800 ybp but is slightly less than during the mid-Holocene. This pattern contrasts with other lowland fire records from the Pacific Northwest that show peak fire activity in the early Holocene associated with warmer and drier conditions (Brown and Hebda 2002b, 1998, Cwynar 1987). Perhaps lower charcoal accumulation in the early Holocene at Turtle Lake, compared to the mid-Holocene, was due to limited transport of charcoal into the lake, or frequent burning in the form of ground fires that did not produce much charcoal. Low charcoal accumulation at East Sooke Fen on southern Vancouver Island in the Early Holocene was also interpreted to reflect low intensity fires or limited charcoal transport (Brown 2000, Heinrichs et al. 1999).

Early Holocene charcoal accumulation patterns at Harris Lake Ridge Bog are different from both Turtle Lake and from other subalpine fire records from 10,270-6,640 ybp (Brown and Hebda 2002b,c). At Harris Lake Ridge Bog, charcoal accumulation shows an initial peak in the early Holocene followed later by a decline. This implies a more variable fire regime at Harris Lake Ridge Bog, with no clear association with climatic trends.

Mid-late Holocene

From 7,800-5,750 ybp charcoal accumulation is at it's highest at Turtle Lake, coinciding with the expansion of *T. heterophylla* and Cupressaceae, and a decline in *Pseudotsuga* in lowland forests. Increased charcoal implies increased fire activity during this time despite a trend to moister climatic conditions. Alternatively, increased charcoal input during this time may reflect greater charcoal particle production as forests closed and crown fires replaced ground fires. Fires may not have been as frequent but perhaps more destructive during this time. A mid-Holocene rise in charcoal is similar to the record at East Sooke Fen (Brown and Hebda 2002b), another dry site. Perhaps this site also received increase charcoal input due to closing forests and more charcoal production and transport into the lake. From 5,750-3000 ybp charcoal accumulation decreased, perhaps reflecting an actual decrease in fire activity associated with moistening and cooling.

At Harris Lake Ridge Bog, the mid- late Holocene charcoal record from 6,640-1,900, is different than the record at Turtle Lake and from other subalpine sites on Vancouver Island (Brown and Hebda 2002b). In this interval, charcoal accumulation decreases to its lowest values between 6,640-1,900 ybp, perhaps reflecting climatic moistening and decreased fire activity. At other subalpine sites, Porphyry and Walker Lakes, charcoal input increases in the mid-Holocene, from 7,000-4,000 ybp, and is interpreted as a reflection of increased slope wash, as opposed to increased fire activity (Brown and Hebda 2002b). Charcoal accumulation decreases from 4,000-2,000 ybp at Porphyry and Walker lakes, possibly reflecting regional cool and moist climatic conditions (Brown and Hebda 2002b). Low charcoal input at Harris Lake Ridge Bog during the mid-late Holocene (6,640-1,900) is similar to lowland fire records from the Pacific Northwest (Brown and Hebda 2002a, 1998, Cwynar 1987).

Late Holocene

The late Holocene charcoal record at Turtle Lake, from 3,000 ybp-present is characterised by several relatively high isolated peaks. These peaks may be associated with infrequent stand destroying fires, despite increasing moisture in the area (Hebda 1995, Mathewes 1973). Similar late-Holocene trends of increased charcoal have been observed at other sites on Vancouver Island where they have been attributed to landscape burning by First Nations peoples (Brown and Hebda 2002b). Perhaps the trend to increased charcoal peaks in Turtle Lake is also an indication of First Nation burning.

Similar to Turtle Lake the last 2,000 years at Harris Lake Ridge Bog was characterised by increased fire activity that has resulted in local vegetation change. Again, increases in late-Holocene fire, despite regional moistening and cooling (Hebda 1995, Mathewes 1973), suggest that a factor other than climate influenced fire regimes.

Regional Paleovegetation Comparison

In this section vegetation history from Turtle Lake and Harris Lake Ridge Bog are compared to records from the region (figs. 8-1, 8-2). The comparisons provide insight into how vegetation history of south central Vancouver Island fits into the regional framework. This comparison is important to better understand the timing of changes, the extent of paleo-communities, and differences between sites. Several unique patterns in the pollen and spore spectra from both Turtle Lake and Harris Lake ridge are identified and discussed within a regional context.

Turtle Lake

Vegetation history at Turtle Lake is generally consistent with that of sites on southeastern Vancouver Island (East Sooke Fen (Brown and Hebda 2002a); Saanich Inlet (Pellatt et al. 2001, Heusser L. 1983); Heal and Rhamnus Lakes (Allen 1995)), and with Marion Lake in the Fraser Lowland (Mathewes 1973), and Davis Lake in the adjacent United States (Barnosky 1981) (fig. 8-1). With the exception of the basal NAP zone in

Turtle Lake, the late-glacial vegetation succession is similar at all sites. The sequence begins with colonizing *Pinus* woodlands from approximately 14,000-11,500 ybp which were later replaced by mixed conifer forests from 11,500 –10,000 ybp. On southeastern Vancouver Island the early Holocene was characterised by an increase in seral taxa such as *Pseudotsuga*, *Alnus*, and *Pteridium*, whereas the mid-late Holocene saw first the increase in *T. heterophylla*, and then Cupressaceae. Turtle Lake displays a similar history as these southeastern sites. In contrast, Turtle Lake is less similar to sites on western and northern Vancouver Island (Pixie and Whyac Lakes (Brown and Hebda 2002a); Effingham Bog (Walker 2001); Bear Cove Bog, Pyrola Lake (Hebda 1983, 1997)). Vegetation history in these areas was characterised by the expansion of *Picea* and *T. heterophylla* in the early Holocene, with increasing amounts of Cupressaceae and declining *Picea* in the mid-late Holocene. *Pseudotsuga* played a much less prominent role in the forests at these sites. Some exceptions to these general trends are outlined below.

Vegetation at Heal Lake (Allen 1995) on the Saanich Peninsula was different than Turtle Lake in the mid-Holocene. During this time *Quercus* pollen increases at Heal Lake, signifying the expansion of oak meadow. *Quercus* persisted at Heal Lake into the late Holocene when modern CDF forests were established (Allen 1995). In contrast, *Quercus* was not present at Turtle Lake, and plant communities changed from CDF-like forests in the early Holocene toward CWH forests in the mid-late Holocene. The absence of *Quercus* pollen at Turtle Lake indicates that this tree did not migrate into the area even under warmer and drier conditions of the early Holocene. *Quercus garryana* is often thought of as a xeric species (Stein 1990), its presence or expansion being an indication of warm and dry conditions (Allen 1995). The lack of *Quercus* pollen at Turtle Lake indicates that either conditions were not warm and dry enough for *Quercus* or that the migration of *Quercus* was restricted by some other factor such as soil nutrients, or competition. Stein (1990), suggests that the distribution of *Quercus* may be due to poor competition compared to seral species such as *Pseudotsuga*.

The Marion and Surprise Lake records in the Fraser Lowland (Mathewes 1973) record less *Pseudotsuga* in the Holocene than Turtle Lake. This suggests that *Pseudotsuga* was not as dominant in the Marion and Surprise Lake area as it was in the

Alberni Valley. Today, Marion Lake lies in the wet subzone of the CWH and Surprise Lake lies in the transition between wet and dry CWH subzones (Mathewes 1973). It seems that throughout much of their history, the area around both lakes was slightly wetter than the area surrounding Turtle Lake. It appears that biogeoclimatic boundaries changed position in the past, but site conditions remained the same relative to each other. This result is to be expected if vegetation change was the result of changes in macroclimate.

In Washington State, Davis Lake (Barnosky 1981) lies to the south of maximum ice extent during the Fraser glaciation. The Davis Lake sequence records open parkland vegetation from 21,000-16,000 ybp during the Evans Creek Stade when ice was close to the study site. The NAP zone in the basal sediments at Turtle Lake also record an open subalpine landscape, and perhaps is associated with vegetation communities present in the area before it was overridden by ice. Like the Davis Lake record, the NAP zone contains some quantities of *Pinus*, *Picea*, *Abies*, *T. heterophylla*, *T. mertensiana*, and *Alnus* consistent with an interpretation of parkland vegetation around Turtle Lake during this time.

In summary, comparison of the vegetation history from Turtle Lake to other sites on Vancouver Island, the Fraser Lowland and the adjacent United States indicates a history more similar to drier south and eastern sites and less similar to western and northern sites. If vegetation history in the south central portion of Vancouver Island were more similar to western and northern areas, we would expect a greater contribution from *Picea*, and less contribution from *Pseudotsuga*, and Cupressaceae during the Holocene. What we see however, is that Turtle Lake resembled a CDF-like environment in the Early Holocene and then switched to dry CWH conditions in the mid and late Holocene. This implies that the CDF-CWH transition extended into the Alberni Valley during the early Holocene and later contracted in the mid-late Holocene. Future studies west of Port Alberni, into wetter CWH zones will reveal how far west CDF boundaries extended on South Central Vancouver Island during the Early Holocene. From the vegetation reconstruction at Turtle Lake, it seems that the Alberni Valley was always a dry pocket on Vancouver Island.

Turtle Lake contains several distinct features in it's pollen and spore curves. These unique patterns are outlined below and discussed with reference to regional records.

One notable feature of zone TL 4 and zone TL 5a in the Turtle Lake record is the behaviour of *Pteridium*. Influx and percentage data for this species begin to increase at 8,670 ybp and continue to 6,300 ybp in the first quarter of zone TL 5. The early Holocene has been interpreted as a time of stable relatively warm and dry climatic conditions lasting from approximately 10,000-7000 ybp. Turtle Lake is not an exception to this; rising *Pseudotsuga* percentages and the presence of various NAP types (Poaceae, Rosaceae, *Salix* and Compositae Tubiliflorae) beginning at 10,200 ybp, reflect warm and dry conditions. *Pteridium* curves from other studies rise at the onset of early Holocene warming coincident with rises in *Pseudotsuga* (e.g., Hebda and Brown 2002a, c, Allen 1995, Mathewes 1973, Barnosky 1981). The interpretation of this trend has often been that the *Pteridium* rise was a response to increased dryness and fire activity that produced open forests (Brown 2000). The increase in *Pseudotsuga* was therefore probably a response to both warmer and drier climate as well as succession following clearance of forest cover by fire. In the Turtle Lake record, however, *Pteridium* does not rise significantly until the middle of the early Holocene, after *Pseudotsuga* begins to rise. The *Pteridium* rise at Turtle Lake seems to be delayed or offset when compared to other records.

One possible explanation for this phenomenon involves the influence of native people in the area at this time. Open conditions at the onset of the Holocene (as evidenced from the low pollen input of arboreal taxa) would be favourable for human occupation as shade intolerant herbaceous plants, such as *Camassia* spp., could be used as food and minimum tree cover could make hunting wildlife easier. As forest began to expand in the area (as evidenced by increasing *T. heterophylla* percentages from 10,000-8670 ybp) attempts were made to keep forest open by burning. The decline in fire intolerant *T. heterophylla* (Packee 1990) synchronous with the rise in *Pteridium* suggests that forest areas were being cleared of *T. heterophylla*. In contrast, *Pseudotsuga* is fire tolerant and is actually favoured by fire (Hermann and Lavender 1990). As climate became increasingly wet from 7,800 – 6300 ybp (Zone 5a) forest expansion increased necessitating continued burning of the landscape in an attempt to keep open conditions. The *Pteridium* curve declines after subzone 5a perhaps because attempts to keep the landscape open were abandoned due to population decline or the acquisition of other food sources, such as exploitation of marine resources (Hebda and Frederick 1990). *Pteridium* is known to produce more spores when not shaded, and thus is an indication of open areas (Crane 1990, Page 1976), possibly created by fire. McMillan (1996) notes the recovery of native artifacts in the Alberni Valley dating from between 9000-5000 ybp. Therefore, aboriginal people lived in the valley at this time and may have used fire as a land management strategy. The problem with this interpretation is that there is no associated increase in charcoal deposition accompanying the rise in *Pteridium*. Charcoal accumulation rises only slightly after 7,800 ybp (boundary of Zone 4/5a) rather than at 8,670 ybp when *Pteridium* first rises. However, the rise in charcoal around 7,800, after deposition of the fine-grained mineral layer at 362-365 cm might simply be an indication of greater fuel availability and associated production of more charcoal as fires consumed more biomass with increased forest cover (Brown 2000). One argument against this interpretation is the rise in *Pinus* values with rising charcoal accumulation. If increased charcoal was simply the result of more charcoal production and that substantial fire activity existed before this time, then why did *Pinus* not increase earlier? The answer to this question is not clear. Not enough evidence exists from Turtle Lake to resolve the issue of human influence on fire regimes. Although archaeological evidence indicates that the Alberni Valley was occupied by native populations, the delayed rise in *Pteridium* is not enough to make solid conclusions about whether people were responsible for the vegetation and fire patterns recorded in Turtle Lake. Despite the uncertainty future studies should recognize the possibility of human influence on vegetation and fire regimes when interpreting pollen and charcoal data.

A decline in Cupressaceae percentages during the last 2000 years is also a notable feature in the Turtle Lake record. This decline has been reported from other coastal sites, however the interpretation of the decrease is varied (e.g., Brown and Hebda 2002a, b, Mathewes and Rouse 1975, Hebda and Mathewes 1984, Hebda and Whitlock 1997, Hebda 1983, Mathewes 1973, Heusser et al. 1980). Brown and Hebda (2002b) suggest that the decrease may have been due to selective tree felling or burning, and cite an increase in *Alnus* values and charcoal on southeastern Vancouver Island sites as supporting evidence. Turtle Lake shows a slight increase in *Pteridium* toward the end of the zone accompanied by peaks in charcoal accumulation. It is possible that an increase in charcoal and *Pteridium*, despite other indications that climate was becoming moister and/or cooler, represents more fire on the landscape and was a also a consequence of human activity. Mathewes and Rouse (1975) also note a decrease in Cupressaceae pollen percentages in the late Holocene, and attribute the decline to fire disturbance. Their site however, is located on the eastern slopes of the Coast Range and thus may have experienced different ecological conditions (e.g., soil development, local climate, competing vegetation), and therefore may not be comparable to Turtle Lake. Mathewes (1973) noted maximum Cupressaceae values at approximately 1,550 BP followed by a decline toward the top of the Surprise Lake record. In contrast, the Marion Lake core from the same study did not show a synchronous decline in Cupressaceae percentages even though the lakes are located close enough that regional changes in vegetation should be reflected in both lakes. Consequently, this suggests that the Cupressaceae pollen percentage decline was a local phenomenon at Surprise Lake and therefore may have been due to factors other than climate. Mathewes (1973) offers no interpretation of the Cupressaceae decline at Surprise Lake, but concludes that the evidence at both lakes suggests wet mesothermal climatic conditions similar to those at present for the late Holocene. The pollen record of Saanich Inlet (Heusser L. 1983, Pellatt et al. 2001) also does not reveal a decline in Cupressaceae pollen after 2000 BP. Brown and Hebda (2002a) suggest that this may be due to the nature of Saanich Inlet as a large basin that records regional pollen input. Again, the implication is that the decline in Cupressaceae around some sites is a response to local changes (e.g., human initiated fire) rather than a regionally controlled response as would be expected with macroclimatic fluctuation.

Harris Lake Ridge Bog

The vegetation history from Porphyry and Walker Lakes (Brown and Hebda 2002c) on southern Vancouver Island is markedly different from that at Harris Lake Ridge Bog.

At Porphyry Lake, *Abies* and *T. mertensiana* are less abundant in the early Holocene than at Harris Lake Ridge Bog. In addition, at Porphyry Lake Cupressaceae values remain low for much of the record and rise only slightly in the late Holocene as opposed to early-mid-Holocene rise in Cupressaceae values at Harris Lake Ridge Bog.

At Walker Lake early Holocene forests of *Pseudotsuga*, *Alnus*, *Picea* and *T. heterophylla* developed later (8,800 ybp) and were markedly different from the *Abies-T. mertensiana* forests that developed around Harris Lake Ridge Bog. In addition, the Walker Lake record contains a stronger *Picea* signal.

The most striking differences between Porphyry and Walker Lakes and Harris Lake Ridge Bog vegetation occur at approximately 2,000 ybp when dramatic vegetation change occurred at Harris Lake Ridge Bog. In contrast, Porphyry and Walker Lakes saw little change in vegetation in the last 2,000 years. The paleovegetation records from Porphyry and Walker Lakes parallel those from low elevations during the post-glacial interval (Brown 2000), suggesting that these sites recorded regional vegetation patterns and were somewhat less sensitive to local dynamics. In contrast, the Harris Lake Ridge Bog record is more complicated, exhibiting strong local changes. Compared with the records derived from Porphyry and Walker lakes, the record from Harris Lake Ridge Bog, a small subalpine wetland, seems to provide a more detailed reconstruction of local in-stand vegetation dynamics than do the lake sequences.

The vegetation record at Cassiope Pond, a small subalpine pond on the Brooks Peninsula (Hebda 1997) also suggests that smaller wetland areas for more detailed reconstruction of local subalpine ecosystems than lake records. Pollen assemblages at Cassiope Pond became distinct from lowland records soon after ice retreat. At this northwest facing subalpine site, open heath and herb meadows persisted throughout the Holocene, despite major changes in the arboreal vegetation in lowland areas.

Notable in the Harris Lake Ridge Bog record is the early Holocene *Abies-T. mertensiana* forest. These forests have been discussed previously in Chapter 7. If *Abies* pollen is from *Abies grandis* then this forest has no modern analogue on Vancouver Island. This result is important in that it indicates that future climate change may lead to the development of communities that do not presently exist in the area. More macrofossil study of sediments from Harris Lake Ridge Bog is necessary to resolve which species was responsible for the *Abies* pollen.

Another distinctive feature at Harris Lake Ridge Bog is the development of extensive *Phyllodoce empetriformis* mats during the late-Holocene. Surface samples from sites dominated by heather and *Vaccinium* spp. do not produce Ericaceae pollen percentages like those seen in the Harris Lake Ridge Bog record. At Harris Lake Ridge Bog heather communities must have dominated the site and tree cover must have been low. Based on charcoal evidence it is possible that fire initiated a change that initially resulted in an increase in *Abies* and *Pinus*, and then later replacement by heather. It has been suggested elsewhere that first nations influenced fire regimes during the last 2,00 years on southern Vancouver Island (Brown and Hebda 2002b). Also, Turner (1999) notes the use of fire by native populations to promote the growth of berry producing vegetation. Perhaps the creation of Ericaceae dominated communities at Harris Lake Ridge Bog was also related to food production by native peoples. Alternatively, perhaps fire activity and expansion of heather was climatically controlled and related to some mechanism not yet recognized in paleoecological records from Vancouver Island. Further evidence is required to resolve this issue.

The relatively recent development of modern forest at Harris Lake Ridge Bog is an important observation and has implications for subalpine habitat change and the conservation of the Vancouver Island Marmot (*Marmota vancouverensis*). Invasion of open areas would be expected to negatively impact marmot populations as these animals depend on open areas with grasses and forbs for survival (Bryant 1997). It has been suggested that the rarity of the species is due to small and patchy areas of subalpine meadows on Vancouver Island (Bryant and Janz 1996). Understanding the cause for relatively recent replacement of subalpine meadow by forest may allow re-establishment of open areas (e.g., possibly through burning). The transition of forest to meadow and back to forest in the last 2000 years suggests that high elevation sites are very dynamic. That these local dynamics are recorded in the pollen and spore spectra of small wetland records suggests that future studies concerned with marmot habitat change should target these type of sites.

Regional Paleoclimate Comparison

Paleoclimatic interpretations from Turtle Lake and Harris Lake Ridge Bog are consistent in timing and direction with each other and with regional reconstructions, despite differences in vegetation assemblages (Hebda 1995, Heusser et al. 1980, Mathewes and Heusser 1981,Brown and Hebda 2002a). At Turtle Lake cold conditions are inferred from the basal NAP zone, and as previously stated may represent a time before the area was overridden by ice. Later, from 12,000-11,500 ybp climate was cool and somewhat moist but probably more continental than today. Starting at 11,500 ybp climate warmed slightly and moistened until 10,700 ybp when cooler conditions returned. The return to cooler conditions is probably the reflection of Younger Dryas cooling at this site (Mathewes 1993). The Harris Lake Ridge Bog record starts at 10,270 and records cool and continental conditions at high elevations.

Warmer and drier conditions prevailed in the Alberni Valley from 10,200-7,800 ybp, and are comparable to other records that record an early Holocene xerothermic interval (Mathewes 1973, Hebda 1995, Brown and Hebda 2002a). At high elevations around Harris Lake Ridge Bog cool, dry, and continental conditions (though warmer and drier than today) prevailed from 10,270-6640 ybp.

From 7,800-6,300 ybp climate remained warm but began to moisten in the Alberni Valley. This period represents a transition from warm and dry conditions toward mild and moist conditions of the mid- and late-Holocene. A period of transition from warm and dry to mild and moist climate is also evident from southern Vancouver Island at a similar time (Brown and Hebda 2002a, Pellatt et al. 2001).

Moistening and possibly cooling characterised the Alberni Valley from 6,300-3,000 ybp, in agreement with other records from the region (Hebda 1995, Brown and Hebda 2002a). At higher elevations, climate became moister with more equable temperatures (less seasonal difference in temperature) from 6,640 ybp to present similar to other subalpine records on Vancouver Island (Brown and Hebda 2002c).

From 3,000-1900 ybp, climate may have become moister and/or cooler than present at Turtle Lake. Other studies in the Pacific Northwest also suggest cooling and moistening during this time (Hebda 1995, Hebda and Mathewes 1984, Mathewes 1973, Heusser et al. 1980, Brown and Hebda 2002a).

Modern climate developed in the Alberni Valley at 1,900 ybp. An interpretation of mild and moist conditions during the late Holocene is consistent with other pollen studies (Hebda 1995, Brown and Hebda 2002a, Pellatt et al. 2001).

Chapter 9

Conclusion

Pollen and spore, macrofossil, and charcoal analyses from Turtle Lake and Harris Lake Ridge Bog on south central Vancouver Island have revealed post-glacial changes in vegetation, climate and fire disturbance in this area. The questions originally posed in the introduction can now be addressed.

1) What is the history of vegetation and climate at low and high elevations on South Central Vancouver Island?

The lowland paleoecological record from Turtle Lake reveals the following general sequence of vegetation and climate changes for south central Vancouver Island. Lowland areas may have been characterised by cold parkland communities possibly sometime before the Vashon Stade ice maximum. Following deglaciation cool and dry lowland areas were colonised by open *Pinus contorta* and *Alnus* forests. *Pinus* and *Alnus* forests were later replaced by more moist adapted mixed conifer forests containing *Abies lasiocarpa, T. heterophylla,* and *T. mertensiana*. Cool and dry indicators later expanded in the mixed conifer forest possibly in response to Younger Dryas cooling. *Pseudotsuga*, *Alnus* and non-arboreal types expanded in the early Holocene from 10,200-7800 ybp in response to warmer and drier climatic conditions. Moisture increased and *T. heterophylla* and *Thuja plicata* began to expand from 7800-6300 ybp, forming forests that were transitional from the warm and dry early Holocene forests to the moist and cool mid-late Holocene forests. Continued cooling and moistening lead to the development of forests co-dominated by *T. heterophylla*, *Pseudotsuga* and *Thuja plicata* similar to modern dry CWH forests from 6000-3000 ybp. At 3,000 ybp *Thuja plicata* expanded in the late Holocene and dominated the forest canopy. At 2,000 ybp *Thuja plicata* declined possibly in response to non-climatic factors. Climate was mild and moist.

The high elevation paleoecological record from Harris Lake Ridge Bog revealed the following post-glacial vegetation and climate sequence. The early Holocene was characterised by forests of *Abies* and *T. mertensiana* from 10, 270-6640 ybp when climate was cool, dry and more continental but probably warmer and drier than today. Increasing moisture and cooling, in the mid-late Holocene from 6640-1970 ybp allowed *T. mertensiana* to expand in local forests and *T. heterophylla* to expand in lowland and montane areas. At the same time, local meadows changed from herb-rich communities, indicative of moist, nutrient-rich soil to Ericaceae communities, indicative of wet, nutrient-poor soils. Marked vegetation change occurred in the late Holocene, in the last 2000 ybp, as *Abies* and *Pinus* individuals expanded initially and then were replaced by extensive *Phyllodoce empetriformis* communities with little tree cover. The dramatic vegetation changes were likely induced predominantly by fire, and secondarily by changes in climate.

2) Are vegetation and climatic inferences similar to other adjacent sites?

Comparison of Turtle Lake and Harris Lake Ridge Bog with other paleoecological records in the area reveals some similarities with respect to vegetation communities and timing of change. However, each record is also unique and contains important differences from other sites. The lowland record from Turtle Lake is similar to southeastern sites on Vancouver Island and to Marion and Surprise Lakes in the Fraser Lowland and Davis Lake in western Washington State. In contrast, south central Vancouver Island is less similar to western and northern sites on Vancouver Island.

At Harris Lake Ridge Bog, the timing of vegetation changes is similar to other records from the region, but the sequence of plant communities is unique compared to other subalpine sites on Vancouver Island. Unlike the southern Vancouver Island records of Porphyry and Walker lakes (Brown and Hebda 2002c), Harris Lake Ridge Bog strongly records changes in local vegetation through time. Vegetation changes do not closely parallel those in lowland sites. Also, the marked vegetation changes that occurred at Harris Lake Ridge Bog during in the last 2000 years stand out from other subalpine records in the region.

The vegetation and climatic reconstruction from Turtle Lake and Harris Lake Ridge Bog indicate that south central Vancouver Island has always been a relatively dry window.

3) How does fire history compare with other fire records from the region and what relationship does fire activity have with climatic inferences?

The fire records from Turtle Lake and HLRB are not clearly related to the inferred climatic patterns from this study, or from other studies in the regional Pacific Northwest (Hebda 1995, Heusser et al. 1980, Mathewes and Heusser 1981). Although climate probably had a broad influence in determining fire regimes, the apparent inconsistencies between fire reconstruction and climatic interpretations suggests that fire activity at Turtle Lake and Harris Lake Ridge Bog were not strictly controlled by climate. It seems that a factor other than climate may have played a large role in determining fire records at Turtle Lake and Harris Lake Ridge Bog. One possibility is that First Nations burning influenced fire records.

4) Did Garry Oak ecosystems expand into the central Vancouver Island during post-glacial time?

There is no evidence to suggest that Garry Oak ecosystems expanded into the vicinity of Turtle Lake during post-glacial times. Although *Quercus garryana* pollen has been shown to be under-represented in surface samples (Allen et al. 1999), the absence of the this pollen type from the Turtle Lake record suggests that Garry oak did not expand in the area.

Applications and Contributions

Paleoecological studies are important in helping us to understand long-term vegetation dynamics and to help us to predict possible vegetation and disturbance response that may occur with future climatic change. Results from paleoecological analyses have a wide range of applications in resource management, biodiversity concerns and process-related questions such as the role of fire disturbance in coastal forests and its relationship to climate. General Circulation Models suggest that climate change may be relatively rapid, and substantial changes in temperature and precipitation will occur before the end of the next century (Houghton et al. 1990, 2001). Wconsidering these scenarios, vegetation change is not some far-distant future possibility but a reality that must be faced today.

The fate of the Vancouver Island marmot (*Marmota vancouverensis* Swarth) provides a striking example of the importance of understanding the relationship of vegetation, climate, and disturbance. Changes to the species habitat may result in its extinction (Hebda 1997a). Knowledge of how habitat may change in the future allows us to predict possible risk and develop strategies to cope with change (Rizzo and Wiken 1992, Hebda 1998).

This study suggests that fire may play an important role in maintaining or creating open subalpine areas. Consequently, fire may be a useful tool in creating suitable habitat for marmot re-introduction. Future study of local vegetation change in subalpine habitats where marmots currently live will shed more light on the role of fire in these communities and add to an understanding of the relationship between marmots, vegetation, climate, and disturbance.

In addition to addressing the original objectives, the results of the study also raised additional questions. These include: 1) How, if at all, did First Nations influence fire regimes in the Holocene? 2) What was the timing of the non-arboreal zone at Turtle Lake and what does this tell us about the environmental conditions of pre- and full-glacial conditions on Vancouver Island? 3) Is there significance to the decline in Cupressaceae in the late Holocene in the Alberni Valley?

Finally, the study also provided insight into processes outside of its original design. Perhaps most importantly, we have seen that subalpine ecosystems are very dynamic and that studies from small high elevation wetlands have the potential to provide a more detailed picture of local vegetation change than do larger lakes.

As we prepare for the changes that will occur in the future the insights that we gain from paleoecological studies will become increasingly valuable. Studies such as the one presented here can act as guides to help us understand the dynamic nature of our surroundings and the ecological processes by which change may occur.

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Appendix A. Vegetation cover estimates from surface sample plots. *indicates taxon growing nearby

Sample #	sample ID	Trees	%	Shrubs	%	Bryophytes	%	Herbs	%
1	S01-1			Myrica gale	10	Sphagnum	90	Drosera rotundifolia	2
				Ledum groenlandicum	2			Rhynchospora alba	20
				Kalmia microphylla	+			Carex	+
				Vaccinium oxycoccos	10				
2	S01-2	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
				Myrica gale	10	Sphagnum	30	Drosera rotundifolia	10
				Kalmia microphylla	2			Rhynchospora alba	15
				Vaccinium oxycoccos	1			Drosera anglica	10
3	S01-3	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
				Myrica gale	50	sphagnum	100	Drosera rotundifolia	1
				Kalmia microphylla	5			Rhynchospora alba	2
				Spirea douglasii	5			Carex sp.	1
				Ledum groenlandicum	5			Vaccinium	+
								Trientalis	2
								Hypericum	+
4	S01-4	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
				Myrica gale	15	Sphagnum	+	Drosera anglica	1
								Carex	1
								Nuphar lutea	2
								Rhynchospora alba	5
								Brasenia shreberi	30
								Dulichium	+
5	S01-5	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
				Myrica gale	15	Sphagnum	+	Drosera anglica	1
								Carex	1
								Nuphar lutea	2
								Rhynchospora alba	5
								Brasenia shreberi	30
								Dulichium	+
6	S01-6	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Pseudotsuga menzesii	50	Gaultheria shallon	50	Dicranum	20	Cornus canadensis	10
		Ramnus purshiana	5	Berberis nervosa	2	Hylocomium	20	Linnea	5
		Tsuga heterophylla	10	Vaccinium parvifolium	10			Pteridium	+
7	S01-7	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Pseudotsuga menzesii	50	Gaultheria shallon	30			Lonicera	1
		Tsuga heterophylla	20	Berberis nervosa	5			Linnea	5
				Vaccinium parvifolium	20			Achyls triphylla	+
								Pteridium	2
8	S01-8	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Pseudotsuga menzesii	30	Berberis nervosa		Hylocolium	100	Linnea	5
		Tsuga heterophylla	25	Gaultheria shallon	30			Rubus ursinus	+
		Picea sitchensis	10	Vaccinium parvifolium	30			Achyls triphylla	+
								Pteridium	10
9	S01-20	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Pseudotsuga menzesii	10	Gaultheria shallon	10			Polypodium	2
		Abies amabilis	10	Vaccinium spp	10			Linnea	10
		Tsuga heterophylla	10					Lathyrus	+
		Thuja plicata	+					Pyrola secunda	*
10	S01-21	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Pseudotsuga menzesii	30	Berberis nervosa	5				
		Tsuga heterophylla	20						
		Abies amabilis	+						
11	S01-18	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga heterophylla	70	Gaultheria shallon	10			Goodyera oblongifolia	
		Pseudotsuga menzesii	40	Chimaphylla	1				2
		Thuja plicata	5						
		Chamaecyparis nootkatensis	5						

12	**S01-19**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Pseudotsuga menzesii	40	Rosa gymnocarpa	2			Linnaea	10
		Tsuga heterophylla	15	Alnus	5			Clintonia uniflora	+
		Chamaecyparis nootkatensis	10	Chamaecyparis nootkatensis	5				
		Thuja plicata	5						
13	**S01-17**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga heterophylla	30					Linnea	30
		Pseudotsuga menzesii	10					Pyrola secunda	10
		Chamaecyparis nootkatensis	20					Lupinus	5
		Tsuga mertensiana	5						
14	**S01-16**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Abies amabilis	10					Luzula	10
		Tsuga heterophylla	20					Tiarella	10
		Tsuga mertensiana	5					Pyrola secunda	2
15	**S01-15**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga heterophylla	20	Vaccinium spp	20				
		Chamaecyparis nootkatensis	20						
		Abies amabilis	20						
		Tsuga mertensiana	30						
16	**S01-14**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga heterophylla	40	Vaccinium spp	10			Pyrola secunda	+
		Pseudotsuga menzesii	20						
		Tsuga mertensiana	10						
		Chamaecyparis nootkatensis	10						
		Abies amabilis	5						
17	**S01-A**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Chamaecyparis nootkatensis	30	Vaccinium spp	5	**overall**	60	**overall**	1
		Tsuga heterophylla	15						
		Abies amabilis	5						
18	**S01-B**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Chamaecyparis nootkatensis	15	**overall**	5	**overall**	30	**overall**	2
		Abies amabilis	20						
		Tsuga heterophylla	5						
19	**S01-9**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
						overall	30		
		Chamaecyparis nootkatensis	30	Vaccinium spp	10			Tiarella trifoliata	2
		Abies amabilis	30	Rhodendron	+			Listera	2
		Tsuga heterophylla	15					Streptopus	+
		Tsuga mertensiana	15						
20	**S01-10**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Chamaecyparis nootkatensis	30	Vaccinium spp	2	**overall**	30	**overall**	0
		Abies amabilis	20						
		Tsuga heterophylla	30						
21	**S01-11**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Chamaecyparis nootkatensis	10	**overall**	0	**overall**	10	Apiaceae	10
		Abies amabilis	2					Tofieldia glutinosa	2
		Tsuga mertensiana	20					Eriophorum	60
								Leptarrhena	+
22	**S01-12**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga mertensiana	20	Vaccinium spp	10			**overall**	0
		Abies amabilis	5	Phyllodoce empetriformis	10				
		Chamaecyparis nootkatensis	2						
23	**S01-13**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga mertensiana	20	Vaccinium spp	30	**overall**	30	**overall**	0
		Abies amabilis	5	Phyllodoce empetriformis	30				
		Pinus contorta	*	Rhododendron	5				
24	**S01-C**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Chamaecyparis nootkatensis	20	Vaccinium spp	15	moss	30	Viola ?orbiculata	<1
		Tsuga mertensiana	5					Pyrola secunda	3
		Abies amabilis	25					fern	+
		Tsuga heterophylla	1						
25	**S01-D**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Chamaecyparis nootkatensis	5	Vaccinium spp	15	**overall**	30	Pyrola secunda	3
		Abies amabilis	25					Viola sp.	<1
		Tsuga mertensiana	+						
		Tsuga heterophylla	10						

26	**S01-E**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Abies amabilis	15	Vaccinium	40	**overall**	80	**overall**	10
		Tsuga mertensiana	20						
		Chamaecyparis nootkatensis	10						
27	**S01-F**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Chamaecyparis nootkatensis	5	Vaccinium	10	**overall**	70	**overall**	<5
		Abies amabilis	15						
		Tsuga mertensiana	20						
28	**S01-K**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga mertensiana	10	Phyllodoce empetriformis	1	**overall**	20	Lupin	30
		Abies amabilis	+					Pyrola sp	15
		Abies lasiocarpa	20					Lutkea pectinata	3
								Pedicularis	5
29	**S01-I**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga mertensiana	25	Phyllodoce empetriformis	40	**overall**	20	Luetkea pectinata	10
		Abies amabilis	10	Cassiope sp	5				
				Vaccinium	30				
30	**S01-J**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga mertensiana	15	Phyllodoce empetriformis	40	**overall**	20		
		Abies amabilis	20	Cassiope sp	5				
				Vaccinium	30				
31	**S01-G**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga mertensiana	65	Vaccinium	10	**overall**	40		
		Chamaecyparis nootkatensis	2						
		Abies lasiocarpa	10						
32	**S01-H**	**Trees**	**%**	**Shrubs**	**%**	**Bryo.**	**%**	**Herbs**	**%**
		Tsuga mertensiana	50	Luetkea pectinata	10	**overall**	20		
		Abies lasiocarpa	1	Cassiope sp	5				
				Vaccinium	20				
				Phyllodoce empetriformis	40				

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Publications

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