Vegetation and Climate History of Southeast Vancouver Island, British Columbia.

by

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We accept this thesis as conforming
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ABSTRACT

The vegetation and climate history of southeast Vancouver Island was reconstructed by palynologically analyzing 50 modern surface sample analogues and 2 lake sediment cores (Rhamnus and Heal Lakes). Results indicate that a series of vegetation and climatic changes have occurred in this region from the close of the Fraser Glaciation to the present. An initial phase of cool to cold and dry climate was present on southeast Vancouver Island approximately 13,000 BP to 11,800 BP. The vegetation consisted of mainly P. contorta in the lowlands and mixed forests of lodgepole pine and alder with significant subalpine vegetation in the highlands. From 11,800 BP to 10,000 BP coniferous species such as spruce, true fir and western hemlock invaded the region under a moist and cool climate. The forest structure closed decreasing non-arboreal species. The start of the Holocene (10,000 BP) was marked by the appearance of Douglas-fir in the regional forest. Decreased precipitation and increased temperatures during an initial xerothermic interval (10,000 - 7,000 years BP) caused Douglas-fir to expand into the region and lake levels to fall. Both highland and lowland forests took on modern Coastal Douglas-Fir like characteristics. An increase in precipitation and/or a modest decrease in temperature, 7,000 - 8,000 years BP, caused an increase in western hemlock and western redcedar in upland communities, whereas Douglas-fir forests with significant stands of Garry oak (a sensitive xerothermic indicator) occupied the coastal lowlands. The highland Rhamnus Lake region took on more Coastal Western Hemlock like characteristics while the lowland Heal Lake remained similar to the CDF. A moderate climate, approaching modern values, began to develop after 3,000 BP. Modern dry CWH and CDF conditions began to develop at both the Rhamnus and Heal Lake sites respectively at this time. Comparison with previous reconstruction's from Vancouver Island and coastal British Columbia reveals a good correspondence between pollen zones and timing of climatic and vegetation events. Applications of these results include forest management of potentially sensitive areas to future climate changes.

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DEDICATION

This thesis is dedicated to the memory of my father

Jack Leroy Allen
(1931 - 1993)

Chapter 1: INTRODUCTION

Palynological studies of south Vancouver Island are relatively few. However, those studies that have been done provide valuable insight into past geological, sedimentological and biological processes operating in this area since the last glaciers melted 13,000 years ago. With the advent of the personal computer, and its ability to manipulate and compare large, diverse data bases, palynological and other paleoecological data can now be interpreted to a degree unrealized two decades ago.

The potential uses of these palynological data are many, ranging from scholarly studies of forest history to applied forest management. In conjunction with other paleoecological data (e.g. dendrochronology, charcoal and macrofossil analysis, isotope data), palynological data can be used to infer past climatic conditions to gain an insight into the character and impact of future climatic alterations such as those anticipated as a result of global warming (Mathewes, 1985; Hebda, 1995). Other potential uses of these paleoecological results are studies of plant species migration and distribution (biogeography) and the character and rate of ecological processes operating at the species and ecosystem level (Hansen; 1947; Hebda, 1977; Whitlock, 1992). Palynology can also provide an environmental (climatic and ecological) framework for archaeologists studying the human component of ancient ecosystems (Hebda and Rouse, 1979; Cawker, 1983; Cwynar, 1987; Hebda and Mathewes, 1984; Birks et al., 1988; Fedje, 1993).

The effect of future climatic change on the forest structure in particular and plant associations of a region can be studied because of the close relationship that exists between climate and vegetation (Faegri and Iversen, 1975; Birks and Birks, 1980; Whitlock, 1992). These data and interpretations can potentially be applied to forest management and agriculture. Comparison of past climate and forest interaction to modern circumstances brought about by forest harvesting, agricultural and urban development may provide insight helpful to establishing policies concerning how specific regions should be managed in the future, especially in the context of future climatic changes.

Specific applications of paleoecological studies on southeast Vancouver Island include studying the climatic sensitivity of the region, particularly because of it's location in the rainshadow of the Vancouver Island and the Olympic Mountain ranges. The region includes the northern-most extension of the range of Quercus garryana Dougl. (Garry oak), the only native oak in British Columbia and presumed to be a sensitive climatic indicator (Zirul, 1967; Roemer, 1972; L. Heusser, 1983; Hebda, 1993).

Notably, there have been few recent comprehensive studies done on south Vancouver Island of a paleoecological nature. There have, however, been a number of significant studies completed for adjacent regions: north Vancouver Island (Hebda, 1983, 1984, in press), the Queen Charlotte Islands (Warner, 1984; Quickfall, 1987; Mathewes, 1989) and coastal mainland British Columbia and the Fraser Valley (Hansen, 1947; C. Heusser, 1960, 1985; Mathewes, 1973, 1993; Mathewes and Rouse, 1975; Hebda, 1977; Hebda and Mathewes, 1984; C. Heusser et al., 1980; Ryder, 1987; Williams and Hebda, 1991).

The purpose of this study is to reconstruct, in detail, the postglacial vegetation and climatic history of the Coastal Douglas-Fir (CDF) biogeoclimatic zone and the transition zone that exists between the CDF and the Coastal Western Hemlock (CWH) biogeoclimatic zones on southeast Vancouver Island. The study describes and uses new modern surface sample pollen spectra, collected from previously unsampled areas, to improve our interpretation of the fossil spectra. Two sediment cores were obtained from shallow lakes in this region and analyzed for pollen spectra. The results form the basis for vegetation and climatic reconstructions of these sensitive regional ecosystems. One core was taken from well within the CDF zone (Heal Lake), whereas the other core was obtained from the transition zone between the CDF and the CWH ("Rhamnus" Lake, named by R. Hebda). The Rhamnus Lake core also provides information about the movements of this ecotone as a result of climatic forcing in the past. Specific xerophytic taxa, such as Garry oak (Quercus garryana) and its associated herbaceous meadow species, are emphasized in the study as indicators of warm, dry conditions. As such, they may be used as components of an analogue in assessing the potential impact of proposed future climatic change and its subsequent ramifications to regional vegetation.

Percent pollen and spore spectra diagrams, pollen accumulation rates and an index of precipitation (DWHIP - Douglas-fir/Western hemlock Index of Precipitation) were calculated for all sites. Also, data from the modern surface sample portion of this study were subjected to multivariate statistics (UPGMA single linkage hierarchical cluster analysis) to elucidate any trends that may be occurring within the data that are obscured by "background noise" or over-representation of specific pollen types (Hebda and Allen, 1993). Finally, a regional synthesis of these results coupled with the results of previous studies is presented to provide an overview of the regional vegetation and climatic history of south Vancouver Island.

Chapter 2: THE SETTING - SOUTH VANCOUVER ISLAND

Introduction

Vancouver Island, located on the north-west coast of North America (Fig. 1), is the largest island of the north Pacific. Approximately 300 km long and 80 km wide (at its widest point), the island exhibits a remarkable diversity in both its geology and biology. For the past 40,000 years, Vancouver Island has undergone repeated, intense glacial activity which has created a high relief topography (Armstrong et al., 1965; Armstrong, 1981; Clague et al., 1980, 1981; Clague, 1981; Hickock et al., 1982). Coastal lowlands of the south pass through u-shaped, glacially scoured valleys into the rugged, alpine interior of the Vancouver Island Mountains. Deep, steep-walled fjords dissect the west coast of the island, reminders of the Cordilleran ice sheet that once ground its way over the region.

Geologically, Vancouver Island is composed of volcanic and sedimentary lithologic units, part of a broad Mesozoic-Cenozoic forearc complex which has grown by terrane accretion during the middle Cretaceous (Wrangellia Terrane) and the Paleogene (Pacific Rim and Crescent Terranes (England and Calon, 1991 and references therein). Between accretionary episodes, the region to the east (today known as the Strait of Georgia) subsided, becoming the extensive Georgia Basin (England and Calon, 1991).

The Quaternary Period, encompassing approximately the last two million years of geologic time, has seen multiple episodes of glacial and non-glacial deposition and erosion occurring throughout the Pacific north-west (Clague, 1991). Two distinct episodes of glaciation are believed to have occurred in the last 100,000 years; one during the early

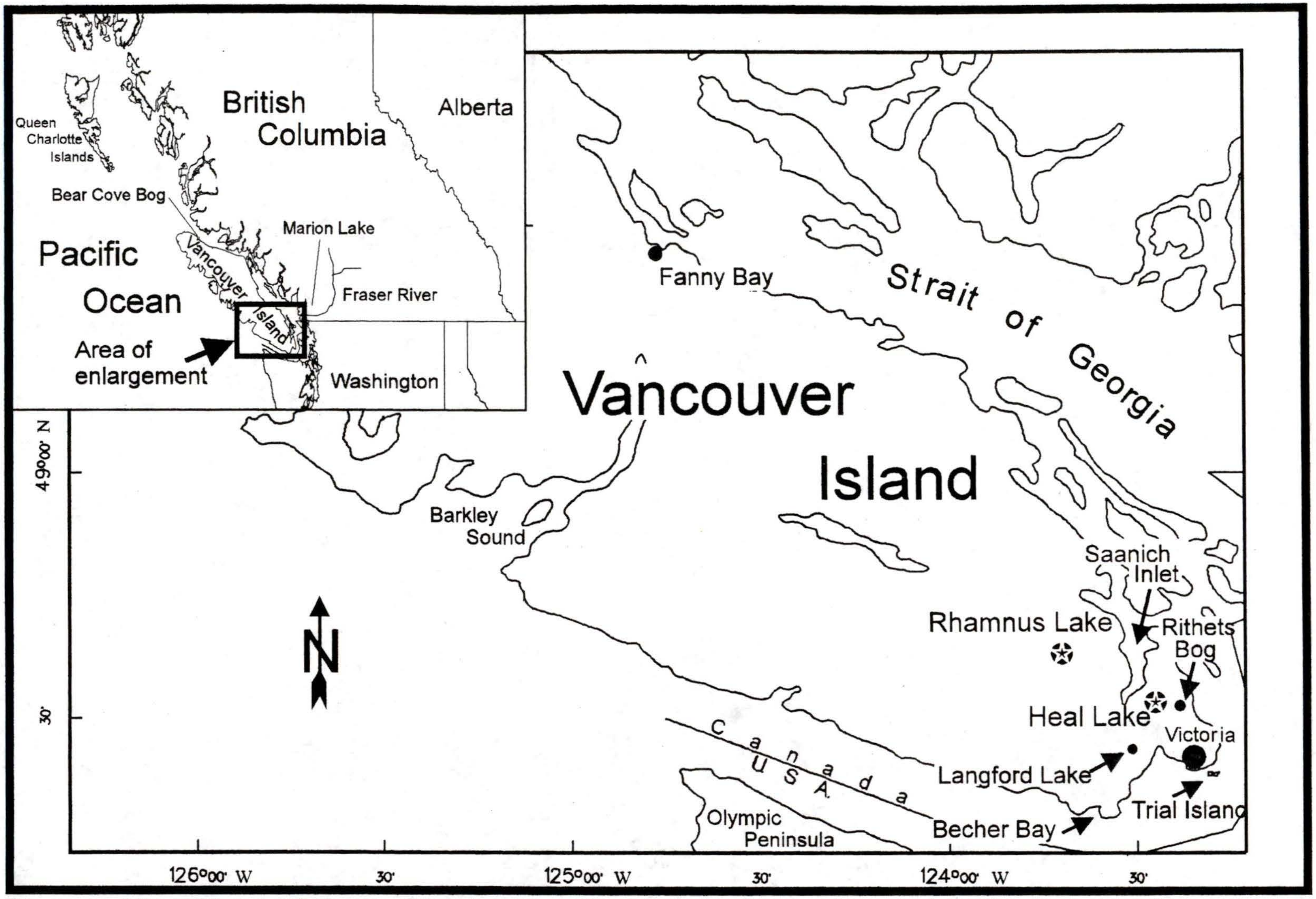

Figure 1. Map of South Vancouver Island and location of sites refered to in text. ✪ Indicates coring sites.

Wisconsinan (before 59,000 years BP) and the other during the late Wisconsinan (Fulton, 1971). Radiocarbon dates and paleoecological studies indicate that climatic deterioration and Cordilleran ice sheet growth for the late Wisconsinan episode began about 25-30 ka BP (Clague, 1980, 1981) attaining its maximum extent around 14-14.5 ka BP. Glacial decay began shortly after 14 ka BP. Parts of the coastal lowlands of southwestern British Columbia were ice free by 13 ka BP with the remainder of the ice sheet and satellite glaciers completely gone by 10,000 years BP (Armstrong et al., 1965; Fulton, 1971; Clague, 1980, 1981). Crandell et al. (1958) have established a sequence of four glacial episodes separated by non-glacial intervals that occurred in southwest B.C. during the late-Pleistocene. These episodes are (in order of occurrence): Orting Glaciation, Alderton Interglaciation, Stuck Glaciation, Puyallup Interglaciation, Salmon Springs Glaciation (>37,000 BP - 37,000 BP), Olympia Interglaciation or non-glacial (37,000 BP - 20,000 BP) and the Fraser Glaciation (20,000 BP - 10,000 BP) (Armstrong et al.,1965; Clague et al., 1981). The Fraser glaciation can be further broken into the Evans Creek and Vashon stades (20,000 BP - 14,000 BP), the Everson interstade (14,000 BP - 11,000 BP) and the Sumas stade (11,000 BP - 10,000 BP). These repeated glacial episodes have modified the Pacific Northwest landscape extensively, scouring steep sided u-shaped valleys and fjords and depositing deep and extensive layers of glacial till.

South Vancouver Island shows evidence of all Fraser glacial episodes, but the southern-most region (Saanich Peninsula) also shows evidence of having undergone extensive marine inundation due to isostatic and eustatic alterations in sea levels (Clague, 1991). Glacio-marine deposits of blue clay and fine, sorted sands are commonly found mantling the much older (Mesozoic) volcanic basement rock occupying these lowlands (Fyles, 1963).

Situated within the Coast Mountains and Islands physiographic unit of Holland (1976), the climate of south Vancouver Island is considered mesothermal with steep precipitation gradients from west to east and south to north. These gradients occur as a result of the rain shadow effect of the interior Vancouver Island mountains which block moist oceanic air masses moving eastward from the Pacific Ocean.

The moderating effect of the Pacific Ocean on the regional climate allows for the longest effective frost free growth period for plants in Canada. Because of this and the large number of different habitats due to topography and microclimate, Vancouver Island has a very diverse flora and fauna, and supports a portion of the largest remaining temperate rain forest in the world (B.C. Ministry of Forests, 1991).

Biogeoclimatic Zones and Regional Vegetation

Various classification systems have been devised to interpret and categorize modern ecosystems from the national (Ecoregions Working Group, 1989) to the regional and site specific scales (B.C. Ministry of Forests, 1991). A classification system adopted by the British Columbia Ministry of Forests in 1975, the Biogeoclimatic Ecosystem Classification (BEC) system, has been accepted as a standard classification scheme with respect to plant community structure in B.C. (B.C. Ministry of Forests, 1991).

The BEC system was initially proposed by V.J. Krajina and his students at the University of British Columbia, Department of Botany (Krajina, 1965,1969). This hierarchical classification scheme has three levels of integration: regional, local and chronological (successional). In combination with the integration levels, the BEC combines three levels of classification: zonal (or climatic), vegetation and site specific (B.C. Ministry of Forests, 1991).

At the regional level of integration, called the biogeoclimatic zone, regional climate is inferred from broad vegetation and pedological characteristics of the zonal ecosystem. These characteristics define the biogeoclimatic zone as a whole, grouping ecosystems under the influence of the same regional climate into the same units. The names of zones are usually derived from a characteristic combination of species, e.g. Coastal Douglas-Fir zone (CDF). At the local level of integration (the biogeoclimatic subzone; the basic working unit) on Vancouver Island, zones are separated along gradients of continentality (decreasing maritime influence) and precipitation. A further division of subzones into site groups (the biogeoclimatic variant), is based on variations in soil type and microclimate due to aspect, pedology and other site specific parameters (B.C. Ministry of Forests, 1991). Vegetation is emphasized in all levels of integration because it is believed to be the best integrator of the combined influence of climate and pedogenic processes, and is readily available for study and quantitative assessment.

The south Vancouver Island region is divided into three biogeoclimatic zones: the CDF zone, the Coastal Western Hemlock (CWH) zone and the Mountain Hemlock (MH) zone (B.C. Ministry of Forests, 1991; Fig 2). The CDF, located in the rain shadow of the leeward side of Vancouver Island and on islands in the Strait of Georgia, has warm, dry summers and mild wet winters. The mean annual temperature and precipitation range from

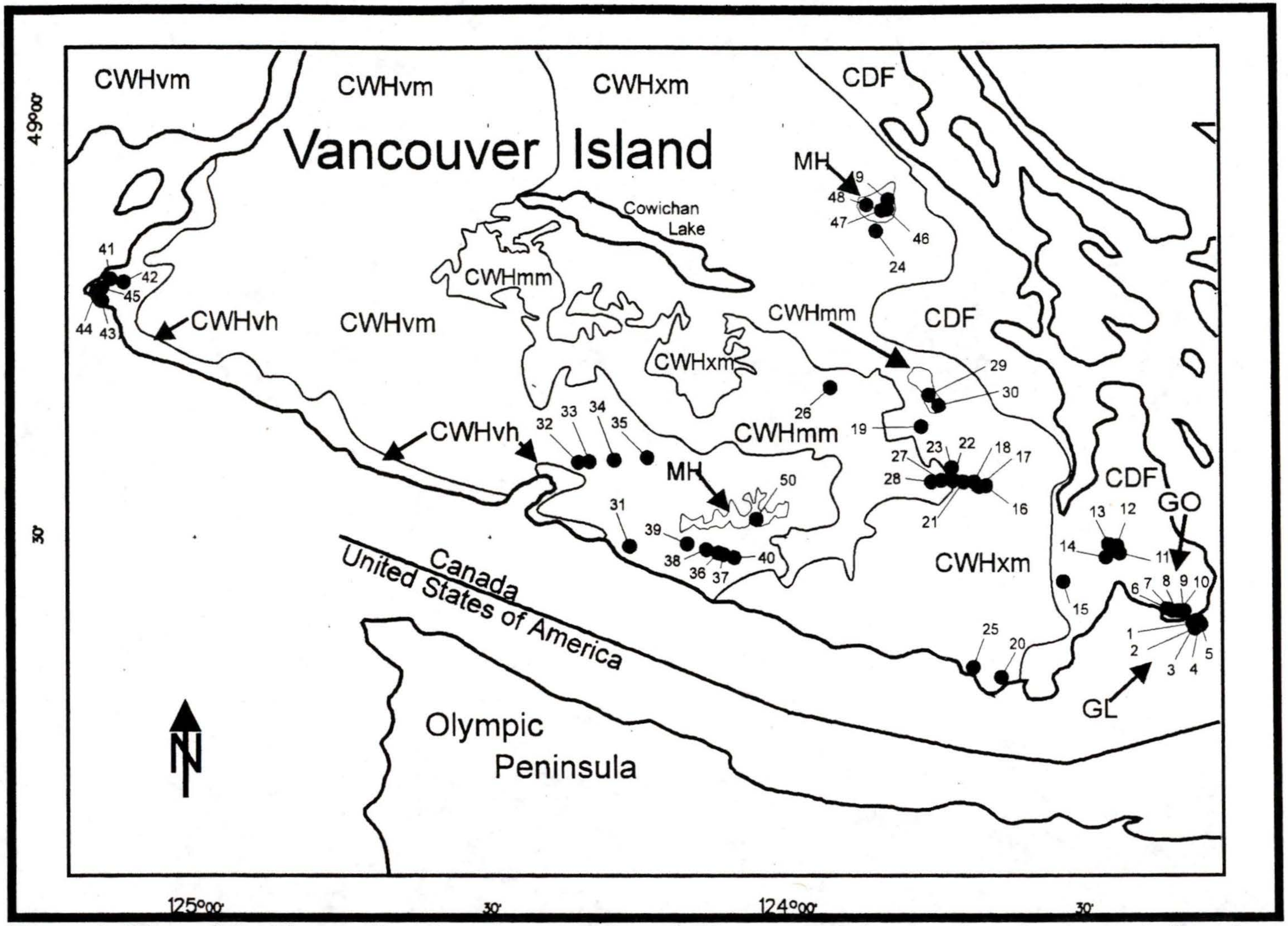

Figure 2. Map of the biogeoclimatic subzones of south Vancouver Island and surface sample locations GL=Grassland; GO=Garry Oak; CDF=Coastal Douglas-Fir; CWHxm=Coastal Western Hemlock very dry maritime; CWHmm=CWH moist maritime; CWHvm=CWH very wet maritime; CWHvh=CWH very wet hypermaritime; MH=Mountain Hemlock.

9.2 to 10.5°C, and between 647 and 1263 mm respectively (Table 1). Very little precipitation falls as snow. The CDF occurs at low elevations and extends from the coast just above sea level (10 metres on the east coast of the island) into the foothills of the Vancouver Island Mountains to an altitude of about 225 metres. Other climatic parameters may be found in Table 1.

Located within the CDF are two xeric site associations: a grassland (GRASS) association and a Garry oak (GO) association. These associations, although floristically unique, are apparently not considered large enough or distinct enough to be assigned to separate BEC subzones or variants, and as such, the CDF consists of a single subzonal ecosystem - the CDFmm (moist maritime).

Vegetation of the CDF, for the most part, has regenerated following logging at the turn of the century. There is limited mature CDF available for study, and what is left, has been impacted to a greater or lesser extent by urban development and timber harvesting. The coastal variety of Douglas-fir (Pseudotsuga menziesii var. menziesii (Mirbel) Franco) is the most common tree species of upland CDF forests. Depending on site moisture and nutrient regime, other arboreal species commonly accompany P. menziesii including: western red cedar (Thuja plicata Donn.), grand fir (Abies grandis (Dougl.) Forbes), red alder (Alnus rubra Bong.), arbutus (Arbutus menziesii Prush.) and Garry oak (Quercus garryana Dougl.) are often found growing in various proportions with Douglas-fir in differing microclimates and edaphic circumstances. Other less common conifers of the CDF include: western yew (Taxus brevifolia Nutt.), Rocky Mountain juniper (Juniperus

Table 1. Enviromental parameters for the Coastal Douglas-fir (CDF), Coastal Western Hemlock (CWH) and Mountain Hemlock (MH) biogeoclimatic zones and variants.

Climatic characteristic		CDF	CWH	CWHxm*	CWHmm*	CWHvm*	CWHvh*	MH*
Elevation (m)	Min	8.0	0.0					930.0
	Max	223.0	671.0					
Mean annual ppt. (mm)	Min	647.2	990.2	1505.0	2349.0	2787.0	2951.0	2954.3
	Max	1262.6	4386.8					
Mean July ppt. (mm)	Min	13.4	16.8	39.0	45.0	75.0	96.0	106.9
	Max	38.6	151.0					
Mean December ppt. (mm)	Min	119.2	145.7	251.0	400.0	436.0	431.0	434.8
	Max	232.9	625.4					
Mean annual temp. (°C)	Min	9.2	5.2	9.3	5.7	8.2	8.2	5.0
	Max	10.5	10.5					
Mean temp. coldest month (°C)	Min	1.8	-6.6	1.8	-2.2	0.3	3.0	-2.3
	Max	4.1	4.7					
Mean temp. warmest month (°C)	Min	15.4	13.1	17.0	14.1	16.0	13.9	13.2
	Max	18.0	18.7					

* Single parameters given. See B.C. Ministry of Forests (1991) for details. CWHxm=CWH very dry maritime; CWHmm=CWH moist maritime; CWHvm=CWH very wet maritime; CWHvh=CWH very wet hypermaritime.

scopulorum Sarg.), lodgepole pine (Pinus contorta Dougl.), western hemlock (Tsuga heterophylla (Raf.) Sarg.), and Sitka spruce (Picea sitchensis (Bong.) Carr). Big leaf maple (Acer macrophyllum Prush), and black cottonwood (Populus trichocarpa T. & G.) can form almost pure stands along streamways and in other moist to wet environments in the CDF.

Shrub and herbaceous strata are well developed in the CDF, and include about 50 rare species (Straley et al., 1985), many of which only occur within the xeric Garry oak (Roemer, 1972) and Grassland site associations of this zone. The Garry oak association is of particular interest, as it contains the only native oak to British Columbia and is mainly restricted to the drier portions of the CDF. Roemer (1972) divides the Garry oak association into two distinct floristic communities; the Quercus - Erythronium and the Quercus - Geranium. The Quercus - Erythronium association can be positively identified by the Erythronium species group, consisting of Erythronium oreganum Applegate (white fawn lily), Arenaria macrophylla Hook. (bigleaf sandwort) and Mahonia (Berberis) aquifolium Pursh (tall Oregon grape). Mean annual precipitation for this association is greater than 800 mm (Roemer, 1972). The Quercus - Geranium association does not have a distinctive flora, and is recognized by the absence of the previously mentioned Erythronium species group. This community's only positive distinction is through a loose assemblage of mostly non-native annuals, the Geranium group. Mean annual precipitation for this community is less than 800 mm.

To the west, along the windward slopes and into the interior of the Vancouver Island Mountains, the Coastal Western Hemlock zone covers much of the study area.

Occurring at low to mid elevations (mostly west of the coastal mountains in British Columbia), the CWH is, on average, the wettest biogeoclimatic zone in British Columbia with mean annual precipitation ranging from 1,000 to 4,400 mm (Table 1). Mean annual temperature is, on average, slightly lower (1° to 2°C) than the CDF, ranging from 5.2° to 10.5°C. Occupying elevations from sea level to 670 metres on windward slopes of the south (1,050 metres on leeward slopes), the CWH is usually found above the CDF and below the Mountain Hemlock zones (B.C. Ministry of Forests, 1991).

The CWH has been divided into five subzones (CWHxm, CWHmm, CWHvm, CWHdm, and CWHvh), separated along gradients of continentality (maritime to hypermaritime) and precipitation (very dry to very wet). Of these five subzones, four have distinctive enough microclimates (because of aspect or latitude) within them to warrant separation into variants: CHWvh1, CWHvm1 and 2, CWHmm1 and 2, and CWHxm1 and 2. See Table 1 for explanation of BEC coding.

Western hemlock is the most prominent tree species of the CWH, and along with a sparse herb layer and several moss species, especially Hylocomium splendens (Hedw.) B.S.G. (step moss) and Rhytidiadelphus loreus (Hedw.) Warnst. (lanky moss) it characterizes the zonal vegetation. Western redcedar, Douglas-fir, grand fir, western white pine (Pinus monticola Dougl.) and big leaf maple are commonly found mixed with T. heterophylla in the southern dry subzones. Amabilis fir (Abies amabalis (Dougl.) Forbes) and yellow-cedar (Chamaecyparis nootkatensis (D. Don) Spach) occur commonly only in wet subzones. Sitka spruce (Picea sitchensis), although wide-spread in the northern CWH zone, is restricted in the south to flood plains (along with black cottonwood) and exposed beaches. Red alder groves develop in logged-over or otherwise disturbed areas whereas lodgepole (shore) pine is common in very dry or very wet (boggy) sites throughout the zone.

A well developed shrub layer exists in hypermaritime and maritime subzones, with a preponderance of ericaceous species such as Alaskan blueberry (Vaccinium alaskaense Howell), red huckleberry (V. parvifolium Smith), and salal (Gaultheria shallon Pursh). A poorly developed herbaceous layer consisting mainly of deer fern (Blechnum spicant (L.) Roth) with a very well developed moss layer composed mainly of lanky moss, step moss and Oregon beaked moss (Kindbergia oregana (Sull.) Ochyra) characterize these subzones.

The driest subzones of the CWH support a poor to moderately well developed shrub layer. Red huckleberry, salal and Oregon-grape typify these associations. The herb and moss layers of the driest subzones are moderately well developed, and often contain species more typical of interior or continental areas.

The ecotone that exists between the CDF and the CWH extends from approximately Becher Bay on the south tip of Vancouver Island, north, along the west shore of Saanich Inlet. The CDF/CWH transition then follows the east coast lowlands to Fanny Bay, about 170 km north of the City of Victoria (Figs. 1 and 2). The boundary between the CDF and the CWH has come under scrutiny recently, and the demarcation is still open to interpretation. The original CDF/CWH border was located approximately 10 km to the west of its present location (B.C. Ministry of Forests, 1979). What today is known as the CWHxm subzone was originally considered to be a subzone of the CDF; the wetter maritime CDF (CDFb; B.C. Ministry of Forests, 1979).

The MH zone, which occurs above the CWH zone, occupies subalpine elevations of 900 to 1800 metres. Located primarily on the Coast Mountains of the mainland and the Insular Mountains of Vancouver Island, the MH is characterized by cool summers, and long, cool to cold, wet winters with heavy snow cover. The MH zone has the most severe conditions of all zones on the south island. Mean annual temperatures range from just 0° to 5°C. Mean annual precipitation, 20% to 70% of which falls as snow, ranges from 1,700 to 5,000 mm per year (B.C. Ministry of Forests, 1991).

Mountain hemlock (Tsuga mertensiana (Bong.) Carr.), yellow-cedar and amabilis fir tend to be the most common tree species in this zone. Western redcedar and western hemlock occur frequently at lower elevations to the south, whereas Sitka spruce co-dominates in the north. Lodgepole pine can occur on very dry or very wet, boggy sites. With increasing elevation, tree growth becomes progressively retarded to the point where the highest elevations (the subalpine ecotone) is composed of stunted forest parkland and a mosaic of subalpine heath, meadow and fen vegetation.

Previous Studies

To date, only three detailed studies (C. Heusser, 1960; Zirul, 1967; L.Heusser, 1983) and one summary paper (Hebda, 1995) of the late Quaternary paleoecology of south Vancouver Island have been conducted, with one long term, on going study (Heal Lake) underway. C. Heusser (1960) completed an early summary of 7 sites from

Vancouver Island and adjacent islands of the Georgia Basin. Although chronological control was not very precise, Mazama ash had been dated (now considered 6,800 BP; Bacon 1983), and can be used as a reference point. Heusser determined a regional floristic sequence that begins with a Pinus contorta dominated forest with significant Alnus sp. before 13,000 BP, under a cool to cold, dry climate. He recognized a warming trend beginning at the start of the Holocene (10,000 BP) with the introduction of Pseudotsuga menziesii, which expanded throughout the region. A trend to increasing moisture and possible cooling began in the mid-Holocene (6800 BP; Mazama ash), indicated by increased Tsuga heterophylla and Thuja plicata pollen values. Lysichitum americanum Hulten & St. John (skunk cabbage) was more abundant during this time, and may have been characteristic of mid-Holocene peatlands. It was later replaced by Sphagnum spp. and heath. Modern forest composition developed approximately 3,000 - 2,000 BP with increasing moisture and cooler temperatures relative to the previous "Hypsithermal" (xerothermic) interval. In a later summary of his work, C. Heusser (1985) considers that warm, dry summers may have persisted in this area until 3,000 BP as indicated by high Quercus garryana pollen values, and that summer climate deteriorated after this interval.

L. Heusser (1983) studied the palynology and macrofossils found in the annually laminated marine sediments of Saanich Inlet (Fig. 1), a deep (230 metre) anoxic fjord that separates the southern coastal plain of the Saanich Peninsula from the mountainous interior of the south island. L. Heusser (1983) determined that the regional vegetation sequence of the area surrounding Saanich Inlet, agreed for the most part with previous findings. Late-glacial environments were cool to cold, and possibly dry, and supported a

P. contorta / Alnus sp. dominated landscape. The early Holocene (10,000 BP - 8,000 BP) is defined by high Pinus, Alnus, Poaceae and Pseudotsuga pollen values, which are indicative of a warmer, perhaps moister environment than the post-glacial. The arrival of Quercus pollen at around 8,000 BP indicates the drying nature of this hypsithermal interval. Heusser (1983) found that high oak percentages persisted until about 3,000 BP, corroborating C. Heusser's (1960) conclusions of a warmer than present climate. Increases in Cupressaceae and Tsuga heterophylla pollen values after 2,000 BP indicates establishment of a more humid and cooler climate extending to the present.

Zirul (1967), in an unpublished undergraduate honors thesis, interpreted the paleovegetation of the Saanich Peninsula from an 8 metre sediment core obtained from Rithet's Bog (Fig. 1). Although this study provides limited insight into the vegetation history of the area due to limited chrono-stratigraphic control (a Mazama ash tephra is the only "date") and the exclusion of some major pollen types (Cupressaceae and all non-arboreal pollen) from the analysis, general trends can still be observed. Early vegetation consisted of a Pinus - Abies forest with significant amounts of alder. The initial climate during this time was probably cool to cold and dry. Quercus and Pseudotsuga pollen occurred after this phase, suggesting warming temperatures. Quercus becomes significant (15% - 20%) at around the time of Mazama ash (6,800 BP; Bacon, 1983) deposition. At this time, oak pollen is the second most abundant pollen type after alder, being even more abundant than Pseudotsuga pollen (10%).This combination may indicate a climate warmer and drier than present. From 6,800 BP to approximately 3,500 BP, oak pollen decreased to between 2% and 5% while Douglas-fir and western hemlock pollen values increased to

30% and 15% respectively. These trends suggest either increased moisture or slightly cooler temperatures or both. From 3,500 BP to present, increasing Picea and Abies values and establishment of other modern taxa indicate the development of a modern climate.

Hebda (1995) has composed a summary paper focused on the mid-Holocene (approximately 6,000 BP), in which he synthesizes all available palynological data for British Columbia. He divides the province into regions, summarizing each as to the climatic change that has occurred, and the evidence presented for these interpretations. Hebda (1995) finds general agreement between studies as to the direction and magnitude of climatic change since deglaciation. Although exact details may not match across Vancouver Island, a general pattern does occur. The post-glacial environment (13,000 - 10,000 BP) was cool to cold and probably drier than present, dominated by Pinus contorta and Alnus. The early Holocene (10,000 BP - 8,500 BP) was warmer and possibly drier than present, indicated by an increase in Pseudotsuga pollen values. A trend to increased moisture (perhaps attaining near modern values) occurs from 8,500 BP to about 4,000 BP, while temperature remains warm. This interval supports a large Quercus garryana population. From 4,000 BP to 2,000 BP, increasing T. heterophylla and Cupressaceae values suggest increasing precipitation while temperatures decrease. Modern climate and forest composition develops around 2,000 BP.

Chapter 3: MODERN POLLEN SPECTRA OF SOUTH VANCOUVER ISLAND

Introduction

The use of modern surface pollen spectra as potential analogues of past spectra and for the interpretation of past forest composition is a well established practice (Moore and Webb, 1978; C.Heusser, 1978a, 1978b; Birks and Birks, 1980; Heide and Bradshaw, 1982; Prentice, 1983; Lamb, 1984; Liu and Lam, 1985; Delcourt and Pittillo, 1986; Fall, 1992; Hebda and Allen, 1993). Under the assumption that modern plant communities respond to environmental forcing in the same manner as ancient systems (Faegri and Iversen, 1975), the direct comparison of modern spectra (usually expressed as percent pollen and spores) to an ancient spectrum allows for the characterization of the ancient ecosystem in terms of its modern analogue. From this information, transfer functions can be determined which can be used to interpret late Quaternary climates (Heusser et al., 1980; Mathewes and Heusser, 1981). As well, other statistical techniques such as *R*-values (Parsons and Prentice, 1981), cluster analysis (Prentice, 1986) or principal components analysis (ter Braak, 1983) can be used to generate detailed reconstructions of past plant communities.

The Study Area

The surface spectrum study area was chosen to include that part of Vancouver Island south of the 49° N parallel (Fig. 2). This region was selected to represent vegetation types potentially present in the cores under study (see Chapter 2 for a description of modern vegetation associations and their ecological characteristics), and covers the major plant communities found on south Vancouver Island.

Initial stages of sampling involved locating areas within the study area that still supported historic ("old-growth") vegetation cover, and had been minimally impacted by agriculture or forestry. Finding such stands was rarely possible as much of the study area has been disturbed. The introduction over the years of many adventive weed species to the area has also complicated obtaining uncontaminated pollen signals. Provincial parks, watersheds and other "protected" regions are the only areas in which potentially "uncontaminated" pollen signatures could be found, and these were utilized whenever possible. When no protected areas were available for study, open crown land, usually a Tree Farm License (TFL), was used. Ease of access was also a consideration as sampling occurred over a three year period, and repeat visits to the sites were sometimes required.

Methods - Field

Surface samples were obtained from all three of the biogeoclimatic zones present on south Vancouver Island (B.C. Ministry of Forests, 1991, 1993; Fig. 2), including all major subzones and most variants of the region (Fig. 2; Table 2). The CWHdm subzone was not sampled due to its very restricted area (Lyall Point) in Barkley Sound, whereas Coastal Western Hemlock moist maritime/submontane (CWHmm1) variant was not sampled due to the extreme scarcity of mature stands. Two restricted ecosystems (Garry oak and grassland) of the Coastal Douglas-Fir moist maritime variant were sampled to include xeric associations as part of the analyses. The Garry oak (Quercus garryana)

Table 2. Surface sample collection sites and zone designations.

Map Label	Sample	Biogeoclimatic Zone	Latitude	Longitude	Elevation (m)	NTS Map
1	S93-A	Grassland	48° 24.1'	123° 18.2'	10	92 B/6
2	S93-B	Grassland	48° 24.1'	123° 18.2'	10	92 B/6
3	S93-C	Grassland	48° 24.1'	123° 18.2'	10	92 B/6
4	S93-D	Grassland	48° 24.1'	123° 18.2'	10	92 B/6
5	S93-E	Grassland	48° 24.1'	123° 18.2'	10	92 B/6
6	S93-28	Garry oak	48° 24.9'	123° 20.7'	20	92 B/6
7	S93-29	Garry oak	48° 24.9'	123° 20.7'	20	92 B/6
8	S93-30	Garry oak	48° 24.9'	123° 20.7'	20	92 B/6
9	S93-31	Garry oak	48° 24.9'	123° 20.7'	20	92 B/6
10	S93-32	Garry oak	48° 24.9'	123° 20.7'	20	92 B/6
11	S94-1	CDFmm1	48° 29.2'	123° 27.0'	80	92 B/6
12	S94-2	CDFmm1	48° 29.1'	123° 26.7'	90	92 B/6
13	S94-3	CDFmm1	48° 29.0'	123° 26.5'	90	92 B/6
14	S94-4	CDFmm1	48° 29.0'	123° 27.0'	60	92 B/6
15	LL 0-20	CDFmm1	48° 26.8'	123° 31.8'	60	92 B/5
16	S93-1	CWHxm1	48° 34.0'	123° 42.8'	230	92 B/12
17	S93-2	CWHxm1	48° 34.0'	123° 43.0'	330	92 B/12
18	S93-3	CWHxm1	48° 34.0'	123° 43.2'	370	92 B/12
19	S93-14	CWHxm1	48° 37.8'	123° 47.8'	170	92 B/12
20	S93-40	CWHxm1	48° 19.3'	123° 38.8'	120	92 B/5
21	S93-4	CWHxm2	48° 34.0'	123° 43.3'	430	92 B/12
22	S93-5	CWHxm2	48° 34.0'	123° 43.5'	540	92 B/12
23	S93-8	CWHxm2	48° 35.2'	123° 43.8'	380	92 B/12
24	S93-9	CWHxm2	48° 52.4'	123° 50.3'	800	92 B/12
25	S93-36	CWHxm2	48° 20.5'	123° 41.0'	100	92 B/5
26	S83-16	CWHmm2	48° 40.9'	123° 55.2'	1030	92 B/12
27	S93-6	CWHmm2	48° 34.0'	123° 43.7'	620	92 B/12
28	S93-7	CWHmm2	48° 34.0'	123° 43.8'	740	92 B/12
29	R7	CWHmm2	48° 39.3'	123° 44.1'	400	92 B/12
30	R8	CWHmm2	48° 39.2'	123° 44.0'	280	92 B/12
31	S91-2	CWHvm1	48° 29.3'	124° 15.8'	210	92 C/8
32	S91-3	CWHvm1	48° 35.3'	124° 20.8'	20	92 C/9
33	S91-4	CWHvm1	48° 35.3'	124° 20.8'	20	92 C/9
34	S91-5	CWHvm1	48° 35.6'	124° 17.3'	20	92 C/9
35	S91-6	CWHvm1	48° 35.7'	124° 14.0'	40	92 C/9
36	S83-54	CWHvm2	48° 28.6'	124° 06.5'	700	92 C/8
37	S83-55	CWHvm2	48° 28.6'	124° 06.5'	700	92 C/8
38	S83-56	CWHvm2	48° 28.8'	124° 06.8'	690	92 C/8
39	S83-57	CWHvm2	48° 29.2'	124° 06.9'	670	92 C/8
40	S83-58	CWHvm2	48° 28.5'	124° 06.4'	680	92 C/8
41	S91-9	CWHvh1	48° 48.8'	125° 08.8'	40	92 C/14
42	S91-10	CWHvh1	48° 48.6'	125° 07.3'	50	92 C/14
43	S83-50	CWHvh1	48° 47.2'	125° 09.7	10	92 C/14
44	S83-51	CWHvh1	48° 47.8'	125° 10.2'	20	92 C/14
45	S83-52	CWHvh1	48° 47.9'	125° 10.0'	20	92 C/14
46	S93-10	MHmm1	48° 53.8'	123° 50.1'	1060	92 B/13
47	S93-11	MHmm1	48° 53.8'	123° 50.2'	1080	92 B/13
48	S93-12	MHmm1	48° 54.0'	123° 51.9'	1200	92 B/13
49	S93-13	MHmm1	48° 54.5'	123° 49.7'	1120	92 B/13
50	S93-25	MHmm1	48° 41.1'	123° 56.0'	1060	92 B/12

ecosystem was sampled from well developed oak parkland found within the municipal boundaries of the City of Victoria (Government House) and grassland samples were obtained from Trial Island in Gonzales Bay off the southern tip of Vancouver Island (Fig. 2). This site allowed the characterization of pollen and spore rain where there were no conifers or alder (all prolific pollen producers) to complicate the signal.

In total, one hundred and twenty five surface samples, representing 50 sites, were either collected directly or obtained from previously collected samples located at the Royal British Columbia Museum. Sampling consisted of recording the percent cover of all arboreal and non-arboreal species present at the site using a simplified relévé method (Mueller-Dombois and Ellenberg, 1974). Arboreal crown cover (percent) was estimated by visual inspection of a roughly 10 metres X 10 metres quadrate. Non-arboreal cover (percent) was estimated by visual inspection of a 1 metre X 1 metre quadrate, located at the center of the larger sampling site (Walmsley et al., 1980). About 30 cm^3 of moss or forest floor litter was taken and immediately bagged on site. When possible, five surface samples were taken to investigate the variability of the pollen signal within the larger quadrat and to ensure that the pollen signature included rarer understorey species that may not appear in a single sample. The methods used at these replicate sites consisted of estimating arboreal and non-arboreal cover as for the single sample sites, but also obtaining four more non-arboreal cover estimates and samples 5m north, south, east and west from the center of the quadrate.

Methods - Lab

Samples were catalogued and processed at the Royal British Columbia Museum's paleoecology laboratory. Chemical treatment of samples followed standard procedures as outlined by Faegri and Iversen (1975). Approximately 20 cm^3 of sample was prepared by initial boiling in 10% potassium hydroxide (KOH) for ten minutes to soften ligneous and remove humic material. The samples were then screened through a coarse filter (0.5 cm mesh) to remove larger plant fragments and sticks, and then centrifuged. The resulting pellet of reduced sample consisted mainly of fine fragments of moss, sticks and leaves as well as pollen and spores. The sample pellet was then subjected to conventional acid treatments (Fageri and Iversen, 1975) to remove carbonates (cold concentrated hydrochloric acid) and silicates (cold concentrated hydrofluoric acid). Remaining plant detritus was removed by standard acetolysis (9:1 acetic acid anhydride to sulfuric acid in a boiling water bath) for five minutes (Faegri and Iversen, 1975). The resultant pellet of residue is composed of almost pure pollen and spores.

Slides of the concentrated pollen residue were prepared according to standard techniques (Faegri and Iversen, 1975; Birks and Birks, 1980; Moore et al., 1989). Pollen was permanently mounted on microscope slides using glycerin gel as the mounting medium. Counts of a minimum of 300 pollen grains per slide (single sample site) were obtained using a Nikon Biophont microscope at 200X-1000X (oil immersion) power. Replicate samples were counted to a minimum of 200 grains per slide because the five pseudo-replicates were combined to give an overall total of at least 1000 grains per replicated site. Identification of pollen and spores was accomplished using available identification keys (Kapp, 1969; Moore and Webb, 1978; Moore et al., 1989; McAndrews et al., 1973) and the pollen and spore reference collection located at the Royal British Columbia Museum.

Methods - Statistical

The modern surface sample pollen diagram (Fig. 3) was produced by the graphics/statistics computer package SYGRAPH (Wilkinson, 1990). Each taxon within the data set was converted to a percentage of the total number of grains counted per sample (including spores and aquatics) prior to statistical manipulation. Zones, sub-zones and xeric habitats have been arranged according to their Mean Annual Precipitation values (Table 1) as given by the British Columbia Ministry of Forests (B.C. Ministry of Forests, 1991).

An index of precipitation (DWHIP) was calculated for each site (Fig. 4; Table 3) using the proportions of a more xerophytic species of conifer to a more mesic species of conifer. P. menziesii (the xerophyte) and T. heterophylla raw pollen values were used. The proportion of P. menziesii to T. heterophylla appears to be a good indicator of the effective precipitation found at a sample site, with high proportions of western hemlock found in moister sites, and high proportions of Douglas-fir found in drier sites. Western hemlock and Douglas-fir proportions were calculated from the combined total of the two pollen types. The index is calculated by the equation:

$$1.00-\left(\frac{P.menziesii}{P.menziesii+T.heterophylla}\right)$$

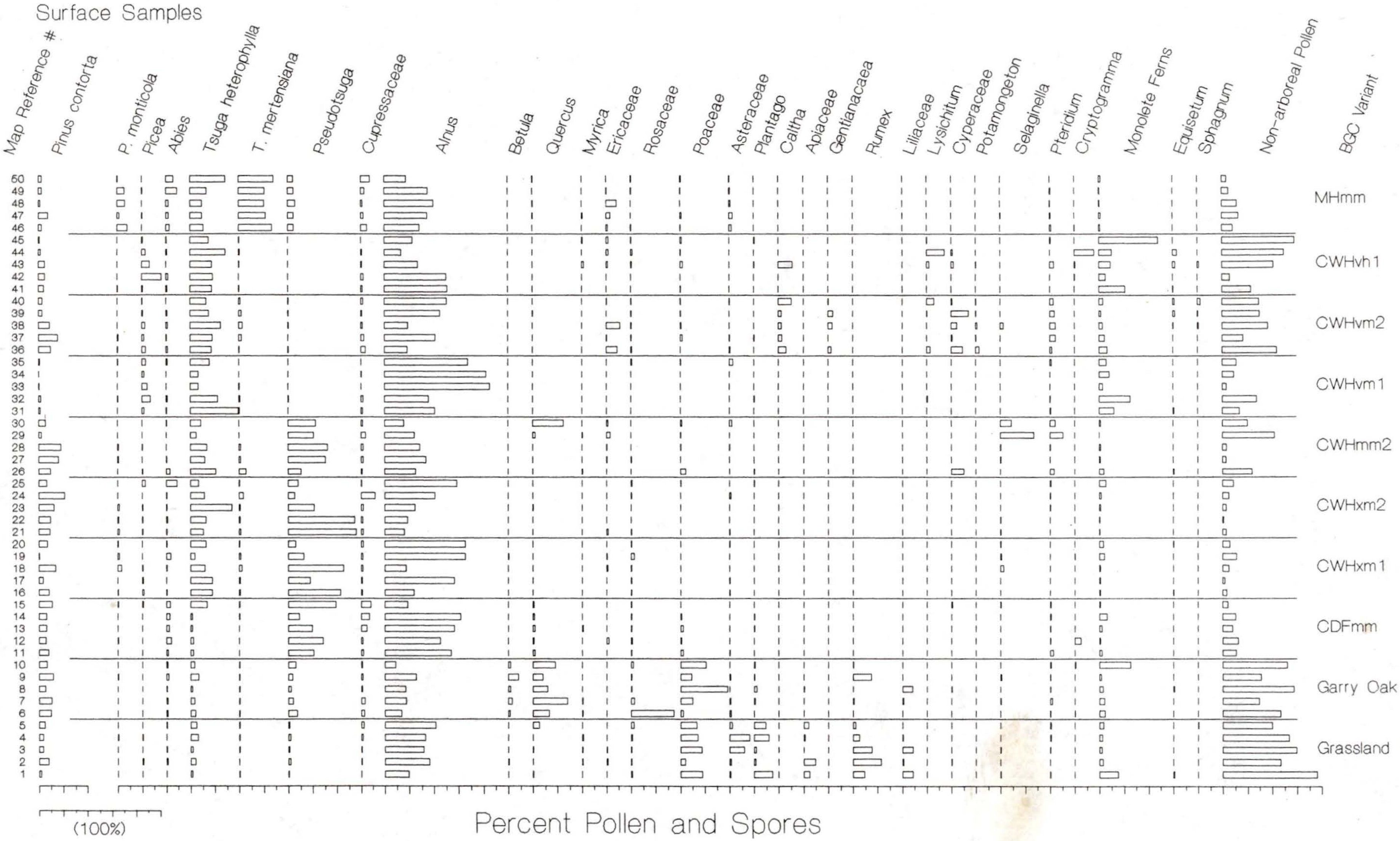

Figure 3. Pollen and spore spectra of the biogeoclimatic variants and site associations of South Vancouver Island.

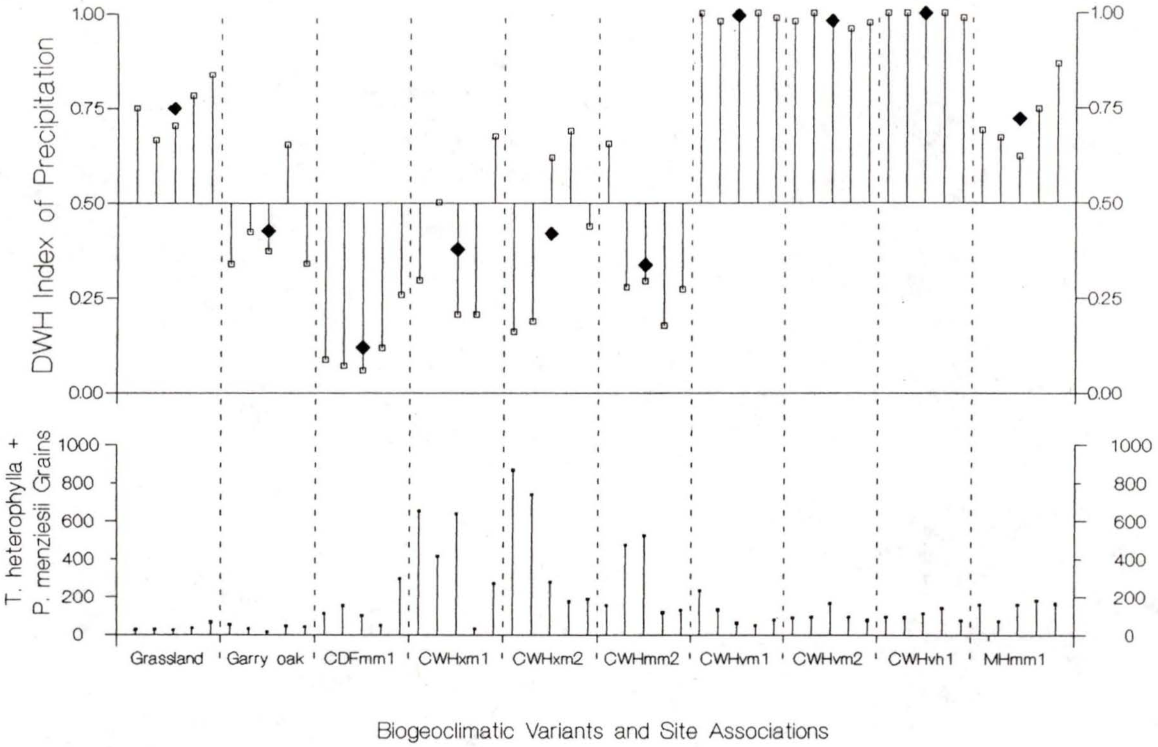

Figure 4. DWHIP values and averages for the biogeoclimatic zones and site associations of South Vancouver Island, B.C.

Table 3. DWH Index of Precipitation values and averages for modern surface sample sites.

Biogeoclimatic Zone	Map Label	T. heterophylla	P. menziesii	Total Pollen	DWHIP	Average DWHIP
Grassland	1	21	7	28	0.75	0.75
Grassland	2	20	10	30	0.67	
Grassland	3	19	8	27	0.70	
Grassland	4	29	8	37	0.78	
Grassland	5	57	11	68	0.84	
Garry oak	6	19	37	56	0.34	0.43
Garry oak	7	14	19	33	0.42	
Garry oak	8	6	10	16	0.38	
Garry oak	9	32	17	49	0.65	
Garry oak	10	15	29	44	0.34	
CDFmm1	11	10	104	114	0.09	0.12
CDFmm1	12	11	143	154	0.07	
CDFmm1	13	6	97	103	0.06	
CDFmm1	14	6	45	51	0.12	
CDFmm1	15	77	220	297	0.26	
CWHxm1	16	194	460	654	0.30	0.38
CWHxm1	17	209	207	416	0.50	
CWHxm1	18	132	507	639	0.21	
CWHxm1	19	7	27	34	0.21	
CWHxm1	20	183	88	271	0.68	
CWHxm2	21	140	728	868	0.16	0.42
CWHxm2	22	140	601	741	0.19	
CWHxm2	23	172	106	278	0.62	
CWHxm2	24	122	55	177	0.69	
CWHxm2	25	83	106	189	0.44	
CWHmm2	26	103	54	157	0.66	0.34
CWHmm2	27	132	342	474	0.28	
CWHmm2	28	155	370	525	0.30	
CWHmm2	29	21	97	118	0.18	
CWHmm2	30	36	96	132	0.27	
CWFvm1	31	235	0	235	1.00	0.99
CWFvm1	32	130	3	133	0.98	
CWFvm1	33	65	0	65	1.00	
CWFvm1	34	51	0	51	1.00	
CWFvm1	35	79	1	80	0.99	
CWHvm2	36	90	2	92	0.98	0.98
CWHvm2	37	96	0	96	1.00	
CWHvm2	38	164	3	167	0.98	
CWHvm2	39	91	4	95	0.96	
CWHvm2	40	77	2	79	0.97	
CWHvh1	41	96	0	96	1.00	1.00
CWHvh1	42	93	0	93	1.00	
CWHvh1	43	112	0	112	1.00	
CWHvh1	44	143	0	143	1.00	
CWHvh1	45	76	1	77	0.99	
MHmm1	46	110	49	159	0.69	0.72
MHmm1	47	49	24	73	0.67	
MHmm1	48	99	60	159	0.62	
MHmm1	49	136	46	182	0.75	
MHmm1	50	143	22	165	0.87	

Low DWHIP values indicate low effective precipitation (low proportion of T. heterophylla) where as high values indicate high precipitation (low proportion of P. menziesii). The DWHIP values were graphed according to the biogeoclimatic subzone from which the samples came (Fig. 4). Average value lines were calculated using the Distance Weighted Least Squares (McLain, 1974) smoothing algorithm with tension set to 0.0 (Wilkinson, 1990).

An unweighted paired group mean average (UPGMA) cluster analysis (Fig. 5) was performed on a square-root transformed data set of the percent pollen values using the computer program MVSP-2 (Multivariate Statistics Package Version 2) developed by W.L. Kovach (1990), at the Institute of Earth Sciences, University College of Wales. This program, composed of various multivariate statistical techniques and data manipulation procedures, was designed specifically for use with paleoecological and biostratigraphic data.

Square-root transformation of the percent data was deemed necessary because of the large variation in values both within, and between, sample sites. Transformations, if used wisely, can effectively lower the variance within a data set and allow patterns within the data to emerge (Prentice, 1983; Myers, 1986). The similarity matrix calculated prior to clustering was accomplished using Pearson's Product Moment Correlation Coefficient (Kovach, 1990; Wilkinson, 1990). This correlation measure was selected because of its property of measuring similarity in patterns across profiles regardless of overall magnitude of the data. That is, the Pearson coefficient is not, in general, affected by some sample sites having larger average values or variation in their pollen types. Clustering of the

Figure 5. UPGMA cluster analysis of square-root transformed surface sample data set.

similarity matrix was done using unweighted pair group mean average (UPGMA) linkage rules. The selection of pollen types to be included in the analysis was based on two criteria, the magnitude of the signal and the frequency of the signal (Heide and Bradshaw, 1981; Liu and Lam, 1985). Only those pollen types that appear in 10% or more of the samples in the data set or had a single occurrence of greater than 5% were included for analysis. Using this method, 41 pollen types were included: Pinus contorta, Pinus monticola, Picea, Abies, Tsuga heterophylla, Tsuga mertensiana, Pseudotsuga menziesii, Cupressaceae, Alnus, Populus, Salix, Acer, Betula, Quercus garryana, Myrica, Corylus, Ericaceae, Rosaceae, Caprifoliaceae, Poaceae, Shepherdia canadensis, Arceuthobium, Asteraceae, Chenopodiaceae, Plantago, Caltha, Apiaceae, Plectritis congesta, Gentianaceae, Rumex, Liliaceae, Lysichitum, Cyperaceae, Potomageton, Selaginella, Pteridium aquilinum, Cryptogramma crispa, monolete ferns, Equisetum and Sphagnum.

Results

The modern surface sample percent pollen diagram (Fig. 3) shows clear differences between the pollen spectra of sampling units. The Grassland (GL) and GO associations show very low levels of conifer (gymnosperm) pollen and high levels of angiosperm pollen types; consistent with the open grassland and meadow characteristics of these units. The forested biogeoclimatic subzones and variants exhibit the opposite gymnosperm/angiosperm pollen signature of the GL and GO.

The CDFmm, the CWHxm and CWHmm subzones all support high levels of Pseudotsuga pollen coupled with moderate levels of Tsuga heterophylla pollen. Except for the CWHmm2, which shows a moderate NAP signature. The very moist CWHvm and CWHvh subzones exhibit moderate to high levels of T. heterophylla and little to no Pseudotsuga pollen. The NAP signature of these areas indicates a well developed understorey. The MHmm sub-zone is interesting in that Pseudotsuga pollen is present at low levels, similar to those found in the GO samples, along with moderate T. heterophylla levels. This occurs because the MH zone is adjacent to the lower elevation CDF and CWH zones. For the first time, Tsuga mertensiana pollen is detected in consistently significant amounts. Alder and pine pollen appear in every surface sample of the study, with Alnus being the dominant pollen type found throughout the study area.

The driest variants (CDFmm1, CWHxm1, CWHxm2 and CWHmm2) and the Garry oak site association all have low average DWHIP values (Fig. 4;, Table 3) ranging from 0.12 to 0.43. This reflects the high proportion of Douglas-fir pollen in their spectra. The CDFmm1 variant exhibits over a 3 to 1 ratio of P. menziesii to T. heterophylla pollen (average DWHIP = 0.12). Increasing effective moisture in the drier CWH variants (CWHxm1, CWHmx2, CWHmm2) causes an increase in average DWHIP values (0.38, 0.42 and 0.34 respectively) until a "cross-over" results and western hemlock becomes the dominant conifer in the wetter variants. The Garry oak site association's average DWHIP value (0.43) is slightly higher than those found for the dry variants, but is still indicative of a dominance of P. menziesii in the pollen signature. The wet CWH variants (CWHvm1, CWHvm2 and CWHvh1) exhibit very high average DWHIP values, averaging 1.00 in the CWHvh1 and 0.99 and 0.98 in the CWHvm1 and CWHvm2 variants respectively. The MHmm1 and Grassland site association have moderately high average DWHIP's of 0.72

and 0.75. The results from both site associations and the MHmm1 variant indicate that the influx of pollen from local and regional sources is important to these spectra (Hebda and Allen, 1993).

The cluster analysis (Fig. 5) of the Pearson correlation's shows obvious differences in how the modern surface pollen spectra from each sampling unit cluster with each other. For the most part, sites sampled in the same subzone, variants or associations, tend to cluster with samples taken from the same units. The analysis can be divided into 2 distinct clusters; Cluster A, composed of the xeric association samples and Cluster B, composed of the forested biogeoclimatic subzones and variants. These two clusters remain separate from each other until final linkage occurs at a similarity of 0.466 (Appendix 1).

For the most part, distinct groupings of samples form within both clusters and include samples taken from the same unit (Fig. 5). The GL and GO associations form exclusive groups (C and D) within Cluster A. Even though the similarity between samples within these groups is not high relative to other groups, they remain separate from each other, and Cluster B, until late in the analysis (linkage 46, Similarity=0.562; Appendix 1). Group B is composed of four groups of clustered samples, E, F, G and H as well as two outlier samples, group I. Group E, is composed of all the CDFmm and all but one the CWHxm samples as well as two CWHmm2 samples. Group F is composed exclusively of the five MHmm1 samples, and remains distinct from Group E until late in the analysis (linkage 43; Similarity=0.687; Appendix 1). Group G is composed of the remaining CWHvm1, CWHvm2 and CWHvh1 variants as well as two CWHmm2 and a single CWHxm2 sample. This group shows less similarity within the cluster, than do Groups E or F, but still exhibits distinct clustering. An outlier cluster (Group H) and two samples (Group I) account for the remaining samples of Cluster B. These outliers remain separate until late in the analysis (linkage 47, 48, and 49; Similarity=0.540, 0.495 and 0.485 respectively; Appendix 1).

GRASSLAND (GL) SYSTEM

This grassland site association (Trial Island; Figs. 1 and 2) is typified by a high (40% - 80%) NAP component and a very low arboreal component. Composed mainly of grasses (Poaceae), Asteraceae, Plantago, Apiaceae, Rumex, Liliaceae and Cryptogramma spores, the GL pollen signature typifies an open native herbaceous community with adventive weeds. Quercus garryana pollen is observed at low levels (<5%) from a single sample located adjacent to a stunted, sprawling oak shrub. Very low values (<3%) of Pseudotsuga, Cupressaceae, Abies and Picea occur in all samples. Pinus contorta pollen (ranging from 2%-10%) occurs in all samples. Although Alnus pollen values (20%-40%) are the second lowest of any of the sampling units, alder still dominates the AP signal. Only the GO association has lower alder percentages. As the grassland sampling area contained only two arboreal taxa, Salix and Quercus, and even these were restricted in their distribution within the sampling area, the high AP clearly represents regional background values as the nearest conifers and alder are approximately 1.5 km to the north, in the City of Victoria.

GARRY OAK (GO) SYSTEM

The GO system, like the GL system, is typified by a high NAP/low AP pollen signature. Garry oak pollen values are the highest of any unit sampled, ranging from a low of 10% to a high of nearly 30%. However, unlike the NAP component of the GL association, the NAP of the GO is composed mainly of grasses and monolete fern spores. Other non-arboreal pollen types consistently found within this unit include Rosaceae, Asteraceae, Pteridium and Plantago, but their values are either very low (less than 1% or 2%), or when present in greater amounts, are found only at isolated localities (e.g. Rosaceae at station 6; Figs. 2 and 3) underneath shrubs such as Holodiscus. Alnus values (10% - 30%) are the lowest of any of the sampling units. Betula pollen appears in all samples of this system with values ranging from a low of 1% to a high of 8% and are probably produced by horticultural specimens within the city. Pollen values of other arboreal species are all low (5% or less) and are mostly a reflection of background pollen rain. Pseudotsuga, T. plicata and Pinus grow near to the sample site but T. heterophylla does not and its signal must indicate long range transport of pollen from regional forests.

CDFmm SUBZONE

(Coastal Douglas-fir moist maritime)

The CDFmm has a markedly higher AP signal compared to the GL or GO systems. Douglas-fir, the dominant conifer pollen type in this subzone, has values ranging from about 15% to nearly 40%. High Alnus values (20%-60%) probably reflect the disturbed nature of the this unit because of logging and other human encroachment. Cupressaceous pollen (T. plicata) occurs at about 2% in the xeric sample areas to almost 10% in mesic sites. There is a slight, yet consistent presence of Abies pollen at 1%-5%. Regional background levels of Pinus contorta (10%-15%) and T. heterophylla (<5%) appear in the pollen signature. Quercus garryana pollen values are drastically reduced (less than 1%) compared to samples from the GO site. Non-arboreal pollen and spore values are relatively low in this subzone, ranging from 10% - 20% overall. The NAP is composed of mainly monolete fern spores and grasses, with a slight (less than 1%) Pteridium signal across the subzone.

CWH Biogeoclimatic Zone

The CWH zone, in general, exhibits high AP to NAP pollen signatures across the variants sampled. The subzones that exhibit low to moderate mean annual precipitation values, CWHxm (1505.0 mm) and the CWHmm (2349.0 mm; Fig. 2, Table 1), have relatively high Pseudotsuga pollen values (average 26%) combined with a moderate T. heterophylla pollen signal (average 13%). The wetter CWH variants (CWHvm1, CWHvm2, CWHvh1) have slightly higher T. heterophylla pollen values (averaging around 18%) than the drier variants. However, the near absence of Pseudotsuga pollen across these moister variants is conspicuous. Douglas-fir pollen values never attain 1% and grains were observed in only 7 of the 15 samples that comprise these variants. Picea pollen values follow the reverse of the Pseudotsuga signature, being more abundant in the wetter variants (averaging almost 4%) and almost non-existent in the drier (averaging less than 0.7%).

Other arboreal pollen types that appear, to a greater or lesser degree, in all variants of the CWH include: Pinus contorta type pollen, Abies, Cupressaceae and Alnus. Although differences between variants do occur, these are slight and difficult to interpret as to whether they contribute to the identification of the community or not. Pinus monticola type pollen appears sporadically throughout higher elevation CWH subzones.

Non-arboreal pollen values also appear to vary along this "gradient of precipitation", but not as clearly as the arboreal types. The two driest CWH variants (CWHxm1 and CWHxm2) have the lowest NAP values of all the units sampled. The NAP is composed almost entirely of monolete fern spores. The moister variants have markedly higher NAP values (average 40% - 50%); in some instances attaining levels nearly as high as those found in the GL and GO systems. The NAP component of the wetter variants exhibit a higher degree of diversity than the drier environments of the CWH, and includes Ericaceae, Asteraceae, Caltha, Gentianaceae, Lysichitum and Cyperaceae.

CWHxm1 VARIANT

(Coastal Western hemlock very dry maritime/eastern)

The spectra of this variant exhibit higher values of T. heterophylla (from about 6% to 20%) compared to the CDF subzone. Pseudotsuga values are moderately high, ranging from about 10% to over 40%. Cupressaceae pollen occurs consistently at about 1%-2% for all samples. High values of Alnus occur across the variant, ranging from a low of 10% to a high of about 80%. T. mertensiana pollen registers for the first time at very low percentages (less than 2%). Consistent background levels of Pinus pollen occur at around

10%-15%. Abies, and Picea values are low. NAP values are consistent with those seen in the CDFmm subzone (less than 10% overall), and are composed mainly of monolete fern spores with small amounts (less than 1%) of Ericaceae and Rosaceae. Selaginella, an indicator of specific open sites, is also found in small amounts.

CWHxm2 VARIANT

(Coastal Western hemlock Very Dry Maritime/Western)

Alnus pollen values are high as are those of Pseudotsuga, and T. heterophylla (averaging about 40%, 40%, and 20% respectively). Cupressaceous pollen occurs consistently in moderate to high amounts, ranging from a low of 2% to a high of 12%. Picea and Abies pollen values are relatively low (usually less than 1%), but do attain significant levels (approximately 3% and 12% respectively) in isolated samples. Relatively high levels of Pinus contorta pollen (10% - 25%) and T. mertensiana pollen (less than 1% to 3%) occur in this variant.

The NAP pollen signature, as with the CWHxm1, is reduced compared to other sampling units. The spectra are composed mainly of monolete fern (less than 1% to almost 6%) and some Pteridium spores (less than 1%). Other pollen types found in this variant include those from the Asteraceae and Ericaceae, but not in any significant amounts and in isolated samples only.

CWHmm2 VARIANT

(Coastal Western hemlock Moist Maritime/Montane)

The arboreal pollen spectra of the CWHmm2 variant resemble those of the CWHxm subzone, but differ in their NAP signature. High Pseudotsuga and T. heterophylla pollen values (averaging 23% and 12% respectively) occur in all samples. T. mertensiana, Abies and Picea pollen values remain low at less than 5%. Cupressaceae pollen is consistently present at low values, ranging between 1% and 4%. In the majority of samples, Pinus values remain similar to those of the CWHxm variants (greater than 10%). However, two isolated stations (29 and 30; Fig. 2) from a xeric site with Garry oak, exhibit values less than 5%. Quercus pollen occurs at both sites 29 (about 2%) and 30 (almost 25%) and represents a very localized signal.

The NAP spectra of the CWHmm2 exhibit an apparent increase in species diversity. Cyperaceae, Selaginella, and Pteridium are all present in significant amounts in individual samples. Selaginella and Pteridium have their greatest values in samples 29 and 30, which represent the xeric oak environment. Ericaceae, Poaceae and Asteraceae pollen appear in small amounts, averaging 1%, 1.5% and 0.5% respectively.

It is important to note that the xeric oak community is expressed in surface sample spectra only as a local phenomenon, and that its signal is quickly lost in the adjacent forest due to over shadowing by more prolific conifers and alder.

CWHvm1

(Coastal Western hemlock Very Wet Maritime/Submontane)

T. heterophylla becomes the dominant conifer pollen type in this variant, with values ranging from 6% to almost 40%. Pseudotsuga pollen nearly disappears from the spectrum. Picea pollen values increase moderately compared to the drier CDF and CWH subzones, from an average of less than 1% to almost 4%. Alnus pollen values increase drastically over the adjacent variant, more than doubling from an average of 25% to an average of 62%. Cupressaceae, Abies and T. mertensiana percentages remain low (2% or less). Pinus contorta type pollen is at its lowest values, never attaining more than 2% in any sample of the variant. The NAP pollen signature of the CWHvm1 variant is made up almost entirely of monolete fern spores, ranging from a low of 3% to a high of over 25%.

CWHvm2

(Coastal Western hemlock Very Moist Maritime/Montane)

The CWHvm2 variant exhibits a very similar arboreal pollen signature to that of the CWHvm1 with high T. heterophylla (averaging almost 18%) and low Pseudotsuga (averaging less than 0.5%) pollen values. Picea values decrease moderately from the previous CWHvm1 variant, ranging from a low of 0.5% to a high of almost 3%. Pinus contorta, T. mertensiana, and Cupressaceae pollen all increase slightly from the previous variant. Abies maintains a consistent presence at around 1%. Overall Alnus values are slightly less (average 35%) from the previous (CWHvm1) variant. although still maintaining a dominant role in the spectrum.

The NAP signal of the CWHvm2 is high in comparison to other CWH variants due to the many bogs and wet areas supported by the increasingly moist climate. Ericaceae, Caltha type, Gentianaceae, Lysichitum and Cyperaceae pollen all occur in significant amounts of 5% or greater. Pteridium and monolete fern spores (averaging 2% to 6% respectively), occur in all samples. Rosaceae, Poaceae, Asteraceae and Equisetum appear in small amounts (less than 1%) consistently throughout the variant.

CWHvh1

(Coastal Western hemlock Very Wet Hypermaritime/Southern)

T. heterophylla values are high, ranging from a low of 15% to a high of nearly 30%. Pseudotsuga disappears nearly completely from the record, whereas Pinus pollen values average less than 4%. There is a slight increase in average Picea values (greater than 5%) compared to the CWHvm subzone. Abies, T. mertensiana, and Cupressaceae all maintain low pollen values, averaging less than 1% each.

Total NAP values are similar to those found in the CWHvm2 variant. High monolete fern values dominate the spectrum, ranging from 9% to almost 50%. Caltha and Lysichitum pollen as well as Pteridium spores are evident in moderate to high amounts in isolated samples of this variant. Other non-arboreal pollen types found in the spectrum at low levels (less than 3%) include: Myrica, Ericaceae, Rosaceae, Caprifoliaceae, Cyperaceae and Equisetum.

MHmm1

(Mountain hemlock Moist Maritime/Windward)

The MHmm1 variant exhibits the highest levels of Tsuga mertensiana pollen values of any of the sampling units, ranging from 20% to almost 30%. T. heterophylla maintains similar values to those found in the CWH variants, averaging around 15%. Abies, Pseudotsuga and Cupressaceae pollen are consistently present in low amounts (about 5%) across the variant. Alnus percentages maintain their characteristic high values (greater than 20%, but ranging to nearly 40%). Pinus contorta type pollen values remain similar to those of the previous variant (CWHvh1) , whereas P. monticola type pollen becomes much more evident in the spectrum, averaging over 4%. There is little Picea pollen in the spectra.

A modest NAP signal is evident with an average value across the variant of less than 9%. The pollen and spore types that comprise the NAP signature include Myrica, Ericaceae, Rosaceae, Poaceae, Asteraceae, Pteridium and monolete ferns. All of these pollen and spores maintain low values (less than 1%) except for isolated samples where Ericaceae, Poaceae and Asteraceae attain values approaching 10% of the total pollen sum.

Interpretation

Pollen percentages distinctly vary among sampling units. Both of the xeric associations, most of the biogeoclimatic subzones and some variants can be distinguished by their pollen spectra (Fig. 3) and the manner in which their samples cluster (Fig. 5). A clear separation can be seen between non-forested/parkland samples (the GL and GO systems) and those obtained from forested sites (CDF, CWH and MH samples). Also, separation of forested sites along gradients of precipitation and/or elevation appears possible through the use of the DWHIP (Fig. 4) or the use of other arboreal indicators such as the high altitude T. mertensiana in the case of the MHmm1 variant (Fig. 3).

The CDFmm subzone and the drier CWHxm variants share similar pollen spectra as do the three wetter CWH variants (CWHvm1, CWHvm2 and CWHvh1). The CWHmm2 appears to have a pollen signature transitional between the dry and wet CWH variants. The MHmm1 variant is characterized by a unique combination of arboreal types, clearly separating it from the other samples.

The grassland (GL) system, characterized by its high NAP and low AP percentages, is easily discernible from all the biogeoclimatic units and the GO association. The isolated nature of the sampling area (Trial Island, 1 km south of Vancouver Island; Figs. 1 and 2), and the lack of arboreal species present there, explain this distinctiveness. The strong herbaceous signal of species from such families as the Poaceae and Asteraceae is distinctive when not diluted by arboreal pollen. The distinctive Plantago and Rumex pollen has two sources. Native Plantago spp. (plantain), are common on banks, cliffs, rocky places and salt marshes along the coast. Native Rumex sp. (dock) is locally common on sand dunes and wet, sandy beaches. Hebda and Rouse (1979) have previously noted Plantago in Vancouver Island pollen spectra. However, today Trial Island meadow vegetation contains several adventive species, among them Plantago lanceolata and Rumex acetosella.

The shrub layer pollen signal, composed of a small amount of rosaceaous pollen, is interesting in that it seems to indicate that this stratum is poorly developed palynologically compared to the herbaceous stratum. However, the distribution of shrubs is patchy and as they are insect pollinated, it is not surprising that the signal is weak.

The low AP signature is consistent with values that could be expected as background pollen influx (Hebda and Allen, 1993). Only Salix, Quercus garryana and Populus tremuloides inhabit the island, occurring as small, isolated stands or as in the case of Quercus garryana, as a single, ground hugging patch. The Alnus pollen, found at 20% to 50% in the GL pollen spectra, is obviously related to regional (background) pollen rain, as there are no individuals found on the island or within 1.5 to 2 kilometres of the sampling site. Clearly, relatively high (20% - 40%) and predominating Alnus values can occur in a spectrum where alder is not even part of the nearby vegetation. Other AP types also found in the spectrum must also be part of this regional influx.

The Garry oak system is distinct from the grassland and other associations because of significant values of Quercus garryana pollen and lower NAP values than the GL. The higher Garry oak percentages are not surprising since oak is the dominant tree species in the sample stands. Though the average Alnus pollen percentage for this system is the lowest of any sampling unit it is still nearly as abundant as oak even though there are few alders present in this urban area, further evidence of alder as a regionally over-represented pollen type.

Low Pseudotsuga values encountered in the GL are not necessarily a consequence of decreased abundance of the species in the vegetation, but rather are a result of under-representation of the species in the pollen rain. Douglas-fir is the primary conifer species in the oak parkland, yet its average value for the samples (about 4%) is less than half that of oak (9%). Hebda and Allen (1993) found that Pseudotsuga pollen can be expected to occur at 0% - 3% in surface samples obtained from areas with no standing Douglas-fir. But, where Pseudotsuga constitutes more than 25% of the species cover, 10% to over 50% pollen should be expected. The paucity of Douglas-fir pollen at this locale can probably be attributed to the nature and location of the surface samples themselves. The moss pollsters used in this analysis were generally obtained from within oak/shrub/herbaceous complexes with significant rosaceae and grasses. Pollen input from these well stratified communites probably over-shadows the local Douglas-fir pollen signal.

The well developed signal for the shrub layer, consisting mainly of rosaceaous pollen types, may also be used to separate the GL from the Garry oak parkland. Even though the same problems of under-representation of entomophilous pollen may occur here as in other sites, the shrub cover is more continuous, especially under the oaks, and a clearer signal is obtained. Many of the grasses and other herbaceous elements are weedy, adventive species growing between the shrub thickets, and their application to reconstruction's of past vegetation are not useful (Hebda, 1982).

High Pseudotsuga and Alnus pollen, coupled with the consistent presence of Cupressaceae and Abies, delineate the Coastal Douglas-Fir (CDF) zone. The low NAP component indicates the closed nature of the forest canopy, low light levels, and reduced herbaceous cover. High Alnus values are linked to the high level of disturbance in the area from forestry, agriculture and urban development. The notable Cupressaceae pollen values come from T. plicata which is a significant element of moist forest stands in the CDF.

Coastal Western hemlock subzones are not as easily separated from each other by their pollen signatures as are the dry associations and the CDFmm. But, there are distinct differences between the wet and dry variants. The most obvious distinguishing feature is the presence or absence of Pseudotsuga pollen in the spectra, and its proportional relationship with western hemlock pollen as indicated by the DWHIP values. The wet CWH variants (vm1, vm2 and vh1) exhibit higher DWHIP values (Fig. 4) than do the drier variants (xm1, xm2 and mm2) which show the reverse. This occurs because the drier CWH stands support more Douglas-fir trees.

The two CWHxm variants cannot be distinguished from each other, but can be distinguished from the other moister variants (mm2, vm1, vm2, vh1). A distinctive feature of these two variants is their low average DWHIP values (0.38 and 0.42 respectively). These values indicate a high proportion of Douglas-fir in the spectra , as might be expected from the dry nature of these subzones. A slight increase in the average Pinus pollen values may potentially be used to separate the two variants of this subzone. However, as both average values fall below those considered as regional (8% and 12% respectively), its use as a diagnostic feature may be limited.

The CWHmm2 variant exhibits a pollen spectrum transitional between the dry and wet CWH variants. A moderately well developed NAP signature coupled with a high AP signal of Pinus, T. heterophylla and Pseudotsuga pollen characterizes this unit. The high non-arboreal and oak pollen values from samples 29 and 30 separate them from the CWHxm subzone and reflect the intentional sampling of the margins of a south facing open, rocky meadow area within the CWHmm2 variant that supported the western most known stand of Quercus trees. These samples show that such openings are only recorded by local spectra and are not apparent from samples in typical forest stands. The presence of Selaginella spores in these samples probably reflect the dry nature of these openings, characteristic of this vegetation.

The wettest CWH variants (CWHvm1, CWHvm2 and CWHvh1) can be distinguished from the other sampling units by the near absence of Douglas-fir pollen and high T. heterophylla pollen values. The driest of these wet variants, the CWHvm1, exhibits two characteristics that may separate it from the other two; a relatively low Pinus component and a low NAP component. Pinus values are the lowest of any unit, whereas the NAP spectrum consists almost entirely of monolete fern spores. The CWHvm2 and the CWHvh1 support higher Pinus values and a more diverse NAP spectrum due to the many bogs that develop under the high precipitation found in this variant (B.C. Ministry of Forests, 1991). However, differentiation between these wetter variants does not appear possible through the pollen signatures. The three wettest variants all exhibit high average DWHIP values, nearing 100% (DWHIP=1.00) dominance of western hemlock.

The MHmm1, is distinguished by very high values of Tsuga mertensiana, Abies and Pinus monticola pollen. In the area sampled adjacent to the CDF, spectra have low, yet consistent values of Pseudotsuga menziesii pollen. The Pseudotsuga signature of this variant is not nearly as high as those found in the drier CWH or CDF zones, averaging around 5%, but resembles that found in the GO sites. This similarity may indicate the influence of Pseudotsuga on the extra-local (within 1 to 2 km) sources found at these sites (Alley, 1976,1979; Hebda and Allen, 1993). Other than these three features, the overall pollen spectra resemble that of the drier CWH variants. A slight increase in NAP percentages may be due to increased "patchiness" of the forest cover at high elevation, and open herbaceous areas and shrubs in the understory.

Comparison to previous studies

Several studies have described the modern pollen spectra from the Pacific Northwest (PNW). Alley (1979) utilized 18 surface samples from sites located in the CDF, CWH and MH zones of south Vancouver Island. Although his sample size was very small, he found that the three zones could be distinguished on the basis of their respective arboreal and non-arboreal pollen signatures. The two lower elevation zones (CDF and CWH) could be separated from the MH zone by their arboreal dominated spectra. Although he notes that P. menziesii is generally under-represented in the region, its presence identifies the CDF and drier CWH zones. Also, the presence of T. heterophylla and Thuja plicata as important elements of the CWH zone was recognized. The MH zone is usually marked by a considerable influx of anemophilous arboreal pollen from lower zones, and exhibits a well developed NAP signature; especially with respect to wetland species. He concludes that because of considerable variations in the modern spectra brought about by logging, agriculture and local edaphic conditions, the modern surface sample data may be valuable for gross comparative purposes and for drawing general conclusions about paleoenvironments, but they should not be regarded as a precise representation of those paleocommunities.

C. Heusser (1969, 1973, 1978a, 1978b), in a series of papers describing the modern pollen rain associated with the Pacific slope of Washington and Oregon, utilized surface samples taken from a transect of communities on the Olympic Peninsula, in the Puget Lowland and western Oregon, extending from sea level to alpine tundra, to determine if their respective ecosystems were definable by their pollen signatures. He found that the modern surface sample pollen signatures, in general, reflected the vegetation of the area from which the pollen originated. Although the modern pollen signal can be obscured by over or under representation of species because of differential pollen production and/or dispersal mechanisms, zonal vegetation types can still be distinguished if these potential problems are recognized and accounted for. For example, as on Vancouver Island Alnus is consistently over-represented throughout the PNW, especially in areas of recent disturbance. Its presence in a spectrum has limited utility, other than to note that the genus is growing in the region. Conversely, Pseudotsuga menziesii, the dominant tree of the Puget Lowland, is heavily under-represented in the modern pollen spectra from this area. Although its modern pollen values may not be indicative of the basal area of standing trees, its presence does indicate its importance in the regional forest community, most particularly in the drier habitats. The wetter west coast forests of the Olympic Peninsula exhibit modern spectra with a prominence of T. heterophylla. NAP spectra can be useful in combination with arboreal data to define specific microhabitats, but their use as a defining characteristic is limited.

Hebda and Allen's (1993) study of a transect from the cool, moist west central coast of British Columbia (Bella Coola) to the cold, dry interior plateau of the Cariboo region, attempted to define zonal vegetation through the use of modern surface pollen spectra. Sixty-four surface samples were analyzed from 5 different biogeoclimatic zones for their modern pollen signatures. The zones could be identified by their respective spectra. Two of the zones studied are of particular relevance, the CWH and the IDF (Interior Douglas-fir), the latter being very similar in floristic composition to the CDF of the south coast. The CWH was characterized by high percentages of western hemlock, Sitka spruce, Cupressaceae and alder. The NAP, as a whole, is important, consisting mainly of skunk cabbage and ferns. The IDF/CWH transition can be characterized by increasing prominence of Douglas-fir pollen in the spectra. Although the representation of western hemlock and spruce remain similar to that of the true CWH, it is the high P. menziesii values that identify the transition. The true IDF can be identified by the dominance of P. menziesii and the decreasing importance of more mesic spruce and hemlock. NAP values are very low and not considered very useful for diagnostic purposes.

Conclusions

The use of modern pollen spectra for comparative purposes in the reconstruction of paleoenvironments is considered a valuable technique in paleoecology (Birks and Birks, 1980; Faegri and Iversen, 1975). However, a relationship must be shown to exist between the sites floristic composition and vegetation and the modern pollen signature obtained from surface samples before any type of climatic or vegetative history can be deduced. On south Vancouver Island, the three biogeoclimatic zones, CDF, CWH and MH can all be identified by prominent occurrences of specific pollen types and the proportions in which those pollen types are found. Distinguishing characteristics of the zones include:

1) The dry CDFmm subzone (Figs. 4 and 5) is distinguished by high proportions of Douglas-fir pollen (low average DWHIP values) and the low importance of more mesic species such as western hemlock and Sitka spruce.

2) Specific site associations within the CDF can be identified by the presence or absence of specific species such as Quercus garryana, or the proportion of arboreal to non-arboreal pollen such as in the case of the grassland (GL) ecosystem (Fig. 4).

3) The CWH zone is easily distinguished by a high proportion of mesic arboreal species, particularly western hemlock which becomes the dominant tree and pollen type of the forest. The subzones and variants of the CWH can more or less be separated into drier and wetter variants. The dry subzones (CWHxm and CWHmm) can be seen as transitional from the CDF to the wet CWH. Although Douglas-fir pollen is found in relatively high amounts in the CWHxm variants, its influence decreases with distance from the CDF, until in the CWHmm variant, where western hemlock becomes more abundant. The moist CWH variants (CWHvh and CWHvm) found on the west coast of the island, are not easily separated from each other.

4) The MHmm subzone can be identified by the prominence of T. mertensiana, Abies and Pinus monticola. NAP spectra indicative of open, wetland environments can also be useful in defining this ecosystem.

Chapter 4: RHAMNUS LAKE HISTORY

Site Description

Rhamnus Lake (123° 43' W long., 48° 38' N lat.) is a small, upland eutrophic lake in the Shawnigan Lake Research Forest of the Canadian Forest Service (Fig. 1). The lake is located on the south slope (north-east aspect) of the Koksilah River valley at an elevation of approximately 350 metres asl. The Koksilah River valley is a u-shaped, glacially formed valley, trending east north-east by west south-west across south Vancouver Island. The site is situated in the transitional CWHxm subzone located between the Coastal Douglas-Fir (CDFmm) and the wetter Coastal Western Hemlock (CWH) biogeoclimatic variants (B.C. Ministry of Forests, 1991). This area was selected because of its advantageous position in this transition zone and the logistic support of the Canadian Forest Service.

The lake is approximately 400 metres long and 200 metres wide, with a surface area of approximately 8 hectares. There is no inlet stream to Rhamnus Lake; recharge of the basin is controlled by springs and surface run-off from the steeply sloping hills adjacent to the site. A small exit stream, located in a boggy area to the east, appears to be a seasonal outlet, becoming dry during periods of decreased precipitation. To the north, east and west are steep, well drained forested slopes, characteristic of the mountainous interior of Vancouver Island. The prevalent winds generally blow from the east or west and are constrained by the topography of the Koksilah River Valley. This wind would carry pollen grains primarily from the extra local and regional components of the pollen rain (Prentice, 1983, Webb, 1974). The localized herbaceous component found along the lake margins and within the surrounding forests, will be under-represented in the pollen rain because of its entomophilous nature and the size and weight of the grains (Faegri and Iversen, 1975; Prentice, 1983).

Vegetation

The regional vegetation surrounding the study site consists mainly of managed Douglas-fir (Pseudotsuga menziesii) stands and scattered white and shore pine (Pinus monticola and P. contorta) forest with an understorey of salal (Gaultheria shallon) and Oregon grape (Mahonia nervosa). Other shrub layer species include Rosa gymnocarpa Nutt. and R. nutkana Presl. (the bald hip and Nootka rose respectively). Bracken fern (Pteridium aquilinum) can be found scattered in the more open areas of the forest. Adjacent to the lake, a well developed shrub layer, composed mainly of Ledum groenlandicum Oeder (Labrador tea), exists. Herbaceous flora is mainly restricted to boggy areas located at the east and west ends of the lake. Grasses (Poaceae), rushes (Scirpus spp.), sedges (Carex spp.) and other hygric acidophiles dominate these areas.

North of Rhamnus Lake, approximately 4-5 km across the Koksilah River valley, scattered patches of Douglas-fir/Garry oak/Arbutus association occupy the steep, well drained, south facing slope. These patches are scattered among partially closed Douglas-fir/Gaultheria shallon forests, and in some instances achieve open meadow-like characteristics. According to Roemer's (1972) classification scheme, a

Quercus/Erythronium association occurs on such shallow, rocky, poorly developed subsoils with a thin layer of organic detritus.

Methods

Rhamnus Lake was sampled with a modified Livingston corer. One metre long sections of sediment were removed and divided into 10 cm intervals. The sections were scraped clean of potential contaminants and bagged on site. Stratigraphy of the core was recorded prior to sample removal. Bagged samples were taken to the Royal British Columbia Museum for analysis. Four samples, roughly 1.5 metres apart, were taken for radiocarbon dating purposes and sent to Beta Analytic Inc., University Branch, P.O. Box 248113, Coral Gables, Florida, U.S.A., for processing.

Sediment analysis followed standard techniques as outlined in chapter 2 (Faegri and Iversen, 1975; Birks and Birks, 1980). Two (2) cm^3 of subsample were removed from the core segments and placed in individual 30 ml polyethylene centrifuge tubes. A single tablet of exotic spore marker (Lycopodium spores, Batch # 201890; 11,267±370 grains/tablet) was added to approximately every second sample for the calculation of pollen accumulation rates (Birks and Birks, 1980; White, 1988). A minimum of 300 pollen grains per sample were counted at 200X - 1000X (oil emersion) power. In many cases, 400-500 pollen grains per sample was deemed necessary to allow enumeration of rare herbaceous pollen types. Micrographs of select individual Rosaceae pollen grains were taken using a J.E.O.L. - JSM 35c scanning electron microscope, located at the Pacific Forestry Center of the Canadian Forest Service, Victoria, B.C. Raw data were converted to percent pollen and spores for each sample and pollen concentration and pollen accumulation (influx) rates (Birks and Birks, 1980) were calculated for alternating samples. Graphs were produced using SYGRAPH (Wilkinson, 1990), a graphical sub-routine of the statistics package SYSTAT (Wilkinson, 1990). A high precision AMS (Accelerator Mass Spectrometry) date of a single Abies lasiocarpa needle found at the lake gyttja/basal clay interface was done by T. Brown of the Nuclear Physics Laboratory, University of Washington, Seattle, Washington, U.S.A.

Results - Core Stratigraphy and Radiocarbon Dates

The Rhamnus Lake sediment core (Fig. 6) consists of unconsolidated to consolidated organic gyttja from 0.0 metres to a depth of 7.15 metres with increasing compaction and dryness with depth. The lowermost 10 cm sample consists of a clay/gravel mixture incorporating small amounts of organic matter. Four radiocarbon dates and an AMS date were obtained for the length of the core (Table 4). All dates fall into their correct stratigraphic sequence. Mazama ash, a volcanic ash tephra deposited as a result of the eruption of Mount Mazama (now Crater Lake) in southwestern Oregon approximately 6,800 years ago (Bacon, 1983), is obvious at 420 cm to 423 cm. Calculated sedimentation rates between radiocarbon dates indicate a relatively constant rate of around 0.06 cm/year has occurred in the Rhamnus Lake basin for the past 8,500 years. Previous to this period, sediment accumulated at a slightly reduced rate of approximately 0.05 cm/year. This means that on average, each 10 cm sample spans between 170 and 200 years.

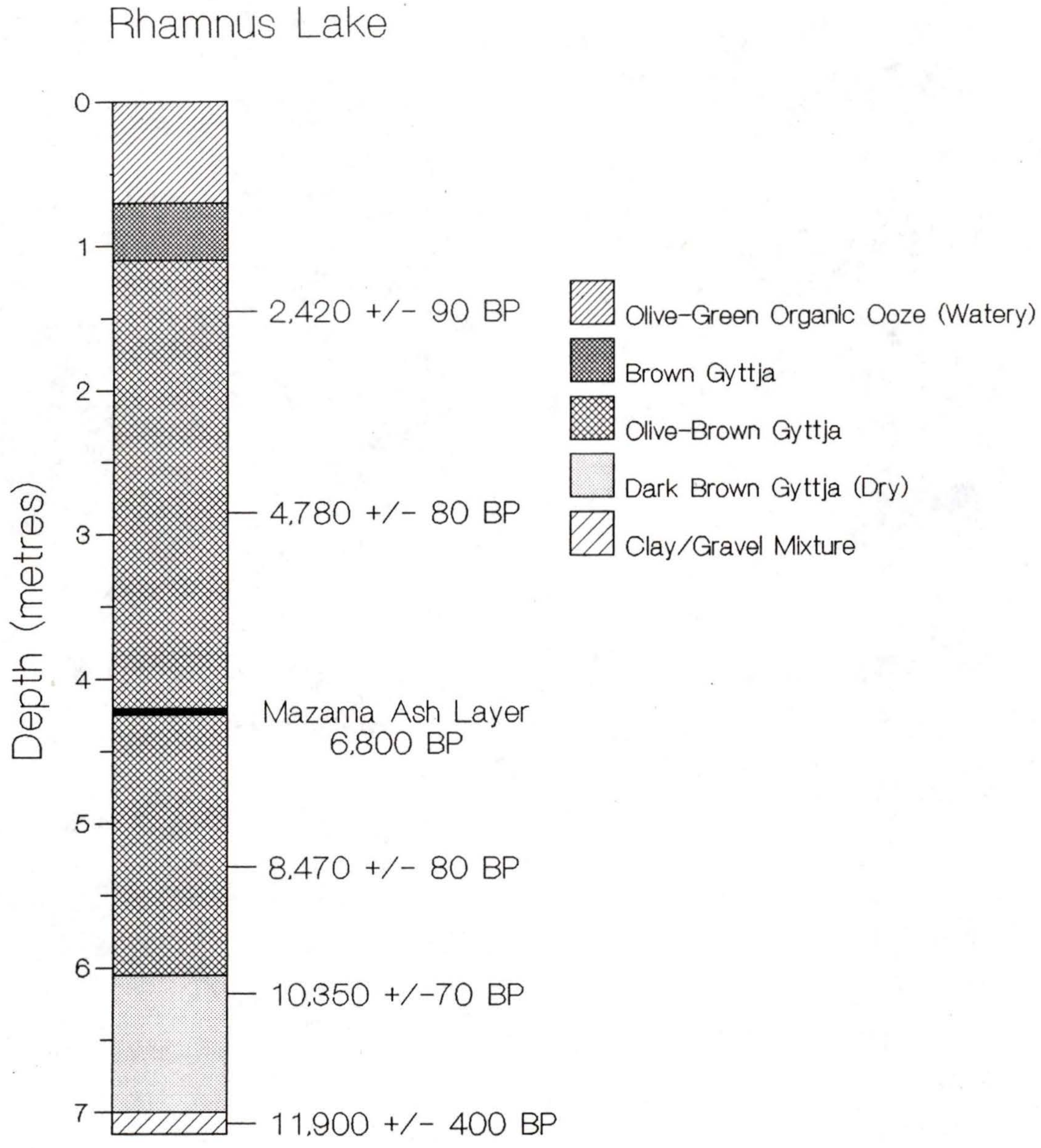

Figure 6. Rhamnus Lake sediment core stratigraphy and radiocarbon dates.

Table 4. Radiocarbon dates from Rhamnus Lake core.

Sequence	Depth (cm)	Lab Number	Type	14C age	13C adjusted age
RL-1	140-150	Beta-65197	Gyttja	2,240 ± 90 BP	2,240 ± 90 BP
	280-290	Beta-65198	Gyttja	4,780 ± 80 BP	4,710 ± 80 BP
	520-530	Beta-50821	Gyttja	8,470 ± 80 BP	8,440 ± 80 BP
RL-4	670-680	Beta-50822	Gyttja	10,350 ± 70 BP	10,270 ± 70 BP
	760-765	TABRH002	A. lasiocarpa needle	N/A	11,900 ± 400 BP

Results - Pollen Zones

Results for Rhamnus Lake are summarized and presented in a percent pollen diagram (Fig. 7), a pollen accumulation rate (influx) diagram (Fig. 8) and a DWHIP diagram (Fig. 9). All pollen and spore percentages were calculated using the sum total of palynomorphs, including aquatics. Most taxa used in the diagrams are self-explanatory. Undifferentiated cupressaceous pollen may contain Thuja, Chamaecyparis and/or Juniperus pollen types, depending on the paleoenvironment. Chenopodiaceae type pollen may also include some members of the Amaranthaceae. Monolete fern spores include the sum of three spore types: undifferentiated, verrucate and rugulate. NAP includes all pollen and spores from non-arboreal taxa.

Pollen concentrations are very high throughout the record, averaging almost 200,000 grains/cm^3, ranging from a low of about 26,000 to a high of over 3,000,000 grains/cm^3. Pollen accumulation rates (Fig. 8) average almost 13,000 grains/cm^2/year, ranging from a low of 1,600 to a high of almost 60,000 grains/cm^2/year. Initial influx rates are moderately high at about 20,000 grains/cm^2/year, decreasing rapidly to less than 10,000 grains/cm^2/year approximately 11,800 BP. From 11,400 BP to the beginning of the Holocene, influx rates increase dramatically, averaging approximately 50,000 grains/cm^2/year at the Pleistocene/Holocene boundary. At approximately 10,000 BP, influx rates decrease to between 5,000 and 10,000 grains/cm^2/year, maintaining these levels for the next 9,500 years. The last 500 years of the record exhibits a continued decrease in PAR's to their minimum of less that 2,000 grains/cm^2/year.

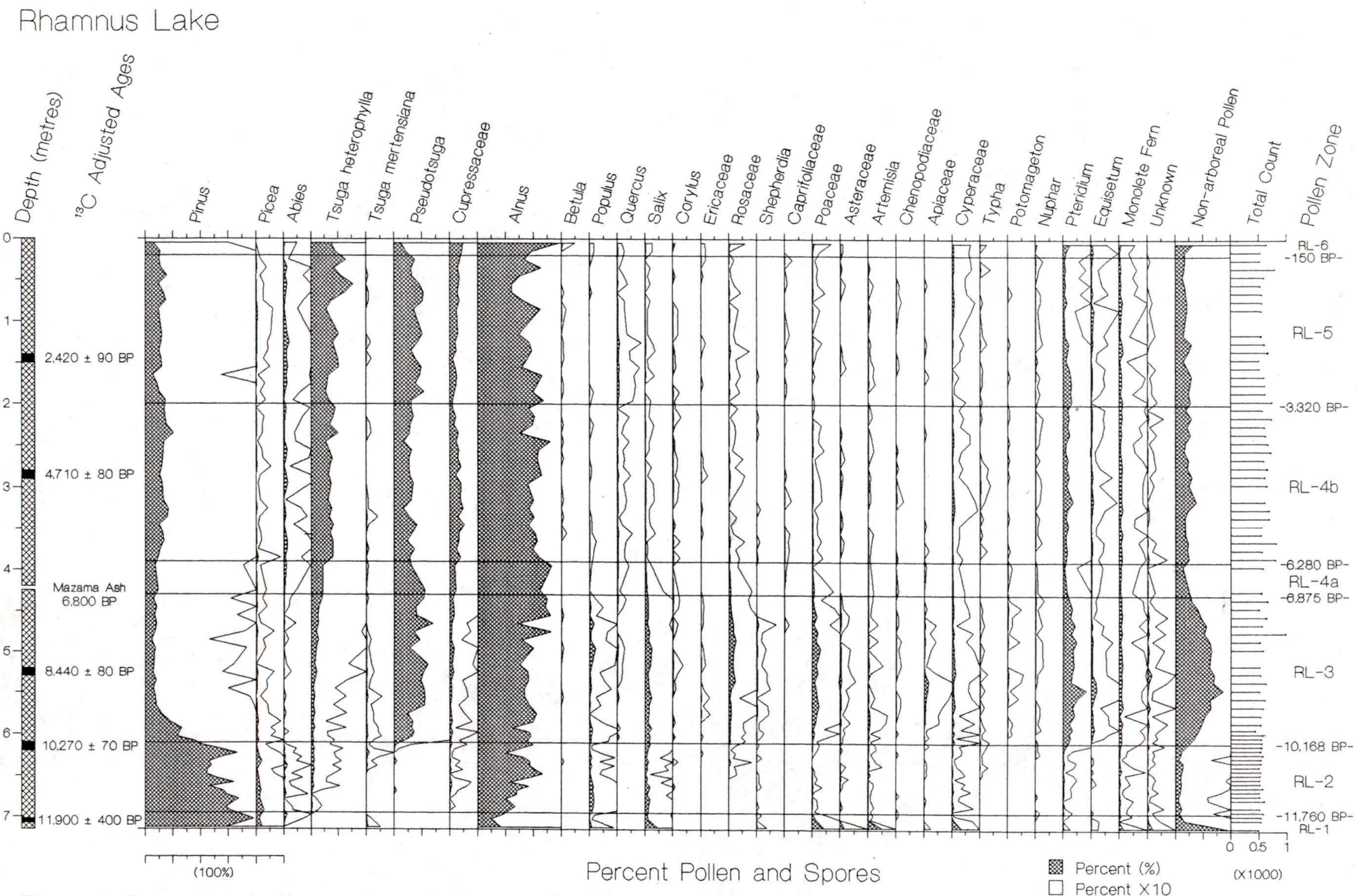

Figure 7. Percentage pollen and spore diagram for Rhamnus Lake.

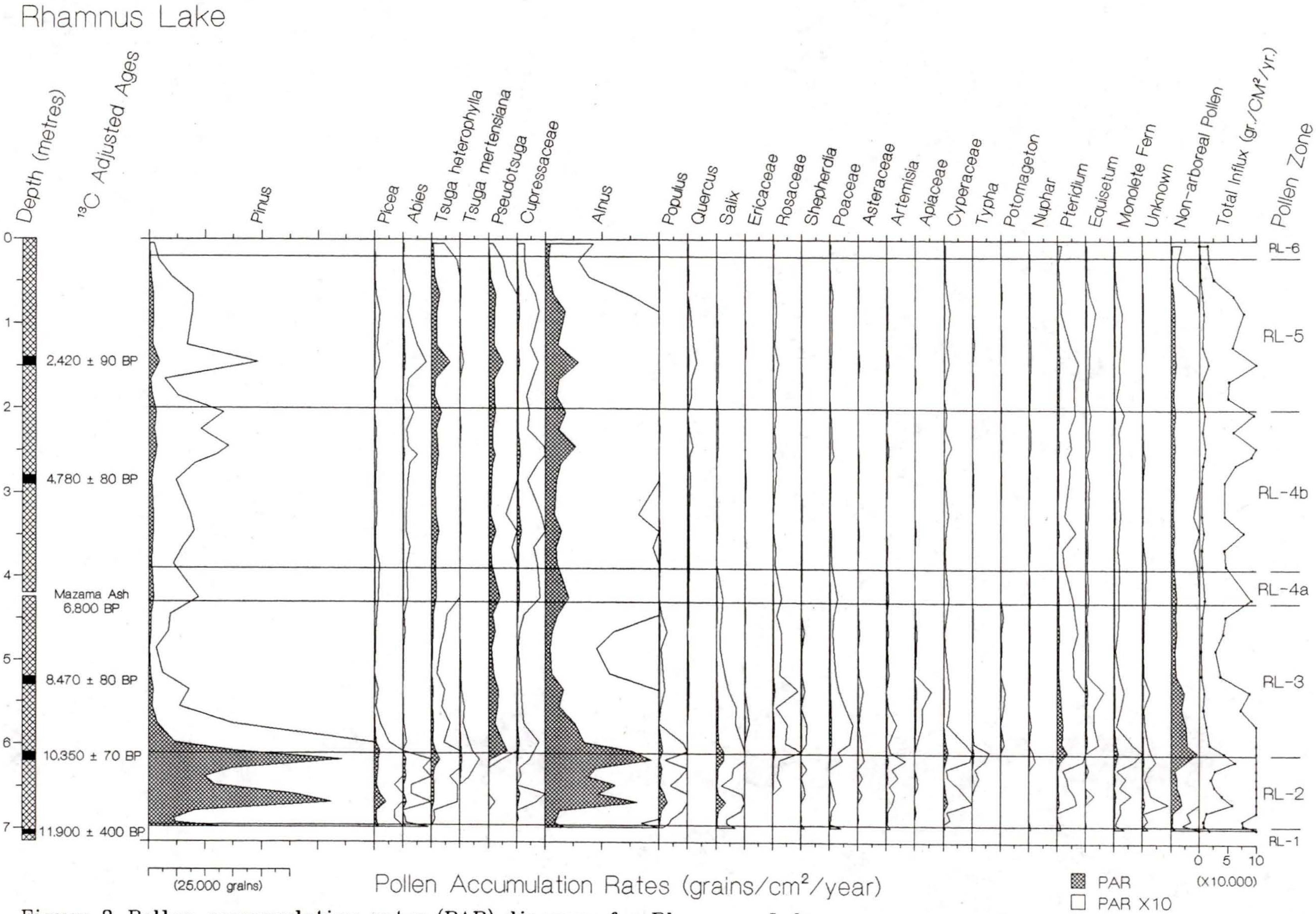

Figure 8. Pollen accumulation rates (PAR) diagram for Rhamnus Lake

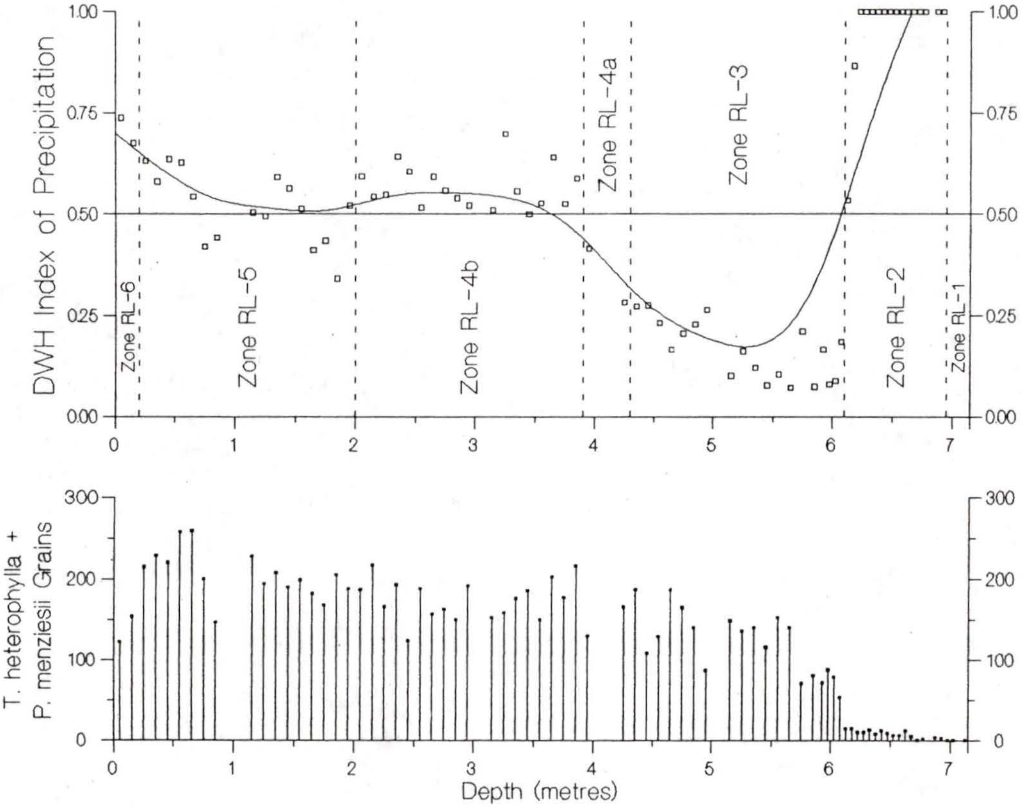

Figure 9. DWHIP values for Rhamnus Lake sequence.

Compared to the concentrations and influx rates calculated by L. Heusser (1983) from her work in Saanich Inlet, Rhamnus Lake pollen concentrations and influx are substantially higher. In Saanich Inlet, 15 km west of Rhamnus Lake, pollen concentrations average 5,000 grains/cm^3/year over the same time period, 40 times lower than Rhamnus Lake. Influx values are also considerably lower in Saanich Inlet, although the general trend of very high influx during the initial post-glacial phase of the record, decreasing at the Pleistocene/Holocene boundary to minimum values and staying low for the rest of the sequence is similar.

The percent pollen diagram was divided into 6 zones by inspection; RL-1 to RL-6. One zone, RL-4, was divided into two sub-zones (RL-4a and RL-4b). Zone boundaries were defined by observation of patterns of species associations and their ecological characteristics. The zones can be viewed as significant intervals of similar vegetation. Subzones were defined when a zone displayed a change in a few pollen types.

ZONE RL-1: Pinus-NAP zone

(7.15 m - 6.95 m; 12,100 BP - 11,800 BP)

Pinus dominates this zone with percentages ranging from 60% to almost 80%. Alnus pollen values fluctuate between 10% and 20%, and appear to negatively mirror the Pinus trend. Salix values are high in the basal sample (ca. 10%), decreasing to around 2%. Picea and Abies percentages attain highs of about 4% and 2.5% respectively. The NAP signature declines rapidly from a high of 40% in the earliest part of the zone to a low of about 3% in the latter part. Poaceae, Artemisia and Cyperaceae type pollen dominate NAP spectra with values in excess of 10% in the oldest part of the record. All NAP pollen and spore values drop to near zero at the RL-1/RL-2 boundary.

Influx in the zone (single sample) is moderately high at about 18,000 grains/cm^2/year. As in the percent pollen diagram, Pinus pollen dominates the influx spectrum of this zone, with approximately 13,000 grains/cm^2/year. Alnus pollen influx is 3,400 grains/cm^2/year. Total NAP influx does not exceed 800 grains/cm^2/year.

ZONE RL-2: Pinus-Alnus zone

(6.95 m - 6.10 m; 11,800 BP - 10,200 BP)

Pinus values decrease from about 70% at the base of RL-2 to 45% at the RL-2/RL-3 boundary. Alnus increases from a low of 20% at the base of the zone to a high of about 50% near the middle portion of the zone, decreasing to 40% at the top. Picea pollen values decrease from a high of 6% to a low of about 1%. Tsuga heterophylla is present for the first time in this zone. A small peak of T. mertensiana (ca. 2%) occurs just prior to the RL-2/RL-3 division. Both Populus and Salix maintain values throughout the zone of approximately 2%-3% each. A trace of Pseudotsuga pollen occurs just prior to the RL-2/RL-3 boundary. Non-arboreal pollen values are the lowest of any zone, averaging around 5% and never attaining values greater than 7%.

RL-2 exhibits the greatest pollen and spore accumulation rate of all the zones, averaging around 25,600 grains/cm^2/year. Although pollen and spore influx in RL-2 is initially quite low (around 7,500 grains/cm^2/year), this value increases to over 50,000 grains/cm^2/year near the middle of the sequence, and attains nearly 60,000 grains/cm^2/year in the youngest samples of the zone. As in RL-1, Pinus and Alnus contribute the majority of grains to the total count, averaging around 16,000 and 8,800 grains/cm²/year respectively. Picea, Abies and T. heterophylla contribute minor amounts to the total arboreal signal. NAP influx in this zone is very low in comparison to total arboreal influx, ranging from a low of only 180 grains/cm²/year to a high of 1,800 grains/cm²/year.

The DWHIP diagram (Fig. 9) shows a near 100% dominance of Tsuga pollen over Pseudotsuga pollen (average DWHIP=0.96) from 11,800 BP to approximately 10,400 BP, at which time, the introduction of Pseudotsuga pollen to the record cause the DWHIP values to drop rapidly to around 0.50 at 10,200 BP, the boundary between zones RL-2 and RL-3.

ZONE RL-3: Pseudotsuga-NAP zone

(6.10 m - 4.30 m; 10,200 BP - 6,900 BP)

Pseudotsuga pollen initially appears near the RL-2/RL-3 boundary, increasing rapidly to between 20% and 30%. Tsuga heterophylla pollen increases from a low of about 2% in basal samples, to a high of nearly 8% in upper samples. Pinus pollen decreases markedly from nearly 40% at the start of the zone to 10%. Alnus maintains high values throughout, averaging around 40%. NAP percentages, at 30%, attain their highest average values of the sequence. Two rosaceous pollen types, cf. Potentilla and Spiraea douglasii (Fig. 10) along with members of the Poaceae predominate, averaging around 5% each, while Pteridium, the dominant fern, ranges from 4% to 16%, averaging around 8%.

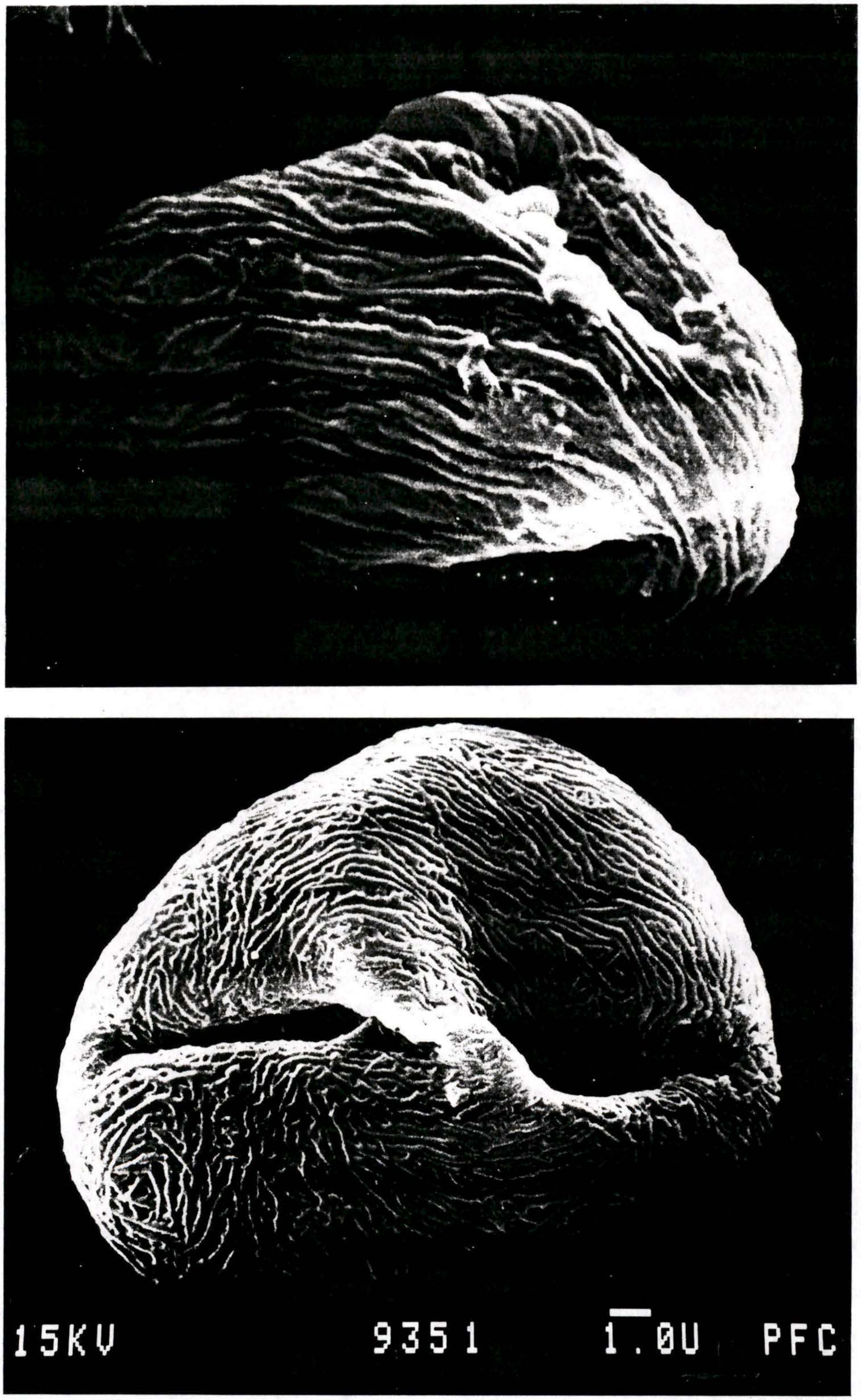

Figure 10. SEM photos of cf. Potentilla (top) and Spiraea douglasii (bottom) from Rhamnus Lake.

Quercus garryana pollen appears for the first time, attaining values of less than 1% in isolated samples.

Average pollen influx decreases from the previous zone. High influx is observed at the RL-2/RL-3 boundary (41,000 grains/cm^2/year), dropping rapidly to less than 10,000 grains/cm^2/year midway through the zone, and to less than 5,000 grains/cm^2/year near the RL-3/RL-4 boundary. Pinus and Alnus influx values decrease to minimum levels (less than 2,000 grains/cm^2/year) around 9,000 BP. NAP influx is significant for the first half of zone RL-3 (10,200 BP to about 8,400 BP), averaging 2,500 grains/cm^2/year. From the mid-point of RL-3 to the RL-3/RL-4 boundary, NAP influx decreases to less than 1,000 grains/cm^2/year.

Zone RL-3 has the lowest indices of precipitation (Fig. 9; Appendix 2) of all the pollen zones, ranging from 0.08 to 0.28. Pseudotsuga comprises approximately 75% to 90% of the sum of the two pollen types during this period (10,200 BP to 6,900 BP). DWHIP values are generally lowest in the deepest samples, increasing up the core.

ZONE RL-4: Tsuga heterophylla - Pseudotsuga menziesii - Cupressaceae zone

(4.30 m - 2.00 m; 6,900 BP - 3,300 BP)

This zone is typified by increasing Tsuga heterophylla and Cupressaceae coupled with decreasing Pseudotsuga. Alder increases slightly, to around 40% while pine remains low to between 10% and 15%. True fir (Abies) becomes a consistent contributor to the spectra at approximately 2%. NAP values decrease from the previous zone, to between

10% and 15% on average. The zone can be divided into two subzones, a short transition subzone, RL-4a, and a longer more homogenous subzone, RL-4b.

Zone RL-4a

(4.30 m - 3.90 m; 6,900 BP - 6,300 BP)

This short pollen subzone, encompassing only about 600 years, exhibits decreasing Pseudotsuga values (from about 20% to 13%) coupled with increased T. heterophylla pollen percentages over the previous zone (averaging around 10%). A slight increase in Cupressaceae type pollen values parallels the T. heterophylla trend. Alnus maintains high levels of around 40%-50%. Total NAP pollen and spore values decrease compared to the previous RL-3 zone. Pteridium spore values drop to between 1% and 3%. Rosaceae pollen types and Poaceae pollen also decrease from the previous zone to minimum values (less than 2%). Quercus pollen occurs in small amounts (less than 1%) and increases up the subzone.

Pollen accumulation rates increase slightly from the previous zone. Alnus and Pseudotsuga start with relatively high values (approximately 4,100 and 2,000 grains/cm^2/year respectively), then decrease significantly at the RL-4a/RL-4b boundary. NAP influx values remain similar to those found in the latter half of zone RL-3.

The DWHIPs indicate a transitional phase occurs starting at 6,900 BP and continuing to 6,300 BP when western hemlock pollen increase with respect to Douglas-fir pollen with a DWHIP value of around 0.50.

Zone RL-4b

(3.90 m - 2.00 m; 6,300 - 3,300 BP)

T. heterophylla and Cupressaceae values almost double from zone RL-4a, averaging around 15% and 7% respectively. Pseudotsuga pollen percentages decrease from the previous zone to around 10%. A gradual increase in Pinus values from 10% to around 25% occurs, while Abies maintains low, yet consistent values of between 1% and 3%. Quercus pollen is present in low, consistent, amounts of about 1%. Populus and Salix pollen occur in only intermittent samples, and never in values greater than 1%. Non-arboreal pollen and spore values increase marginally compared to zone RL-4a, ranging from a low of around 5% to a high of approximately 13%, composed mainly of Pteridium and Cyperaceae. Poaceae and Rosaceae pollen values are significantly lower than in the previous zone.

Total PAR's remain consistent with those found in zone RL-4a, averaging around 6,500 grains/cm^2/year. Arboreal pollen types exhibit a slight increase in influx from the oldest samples to the youngest. Alnus is by far the dominant pollen type present in zone RL-4b (averaging 2,900 grains/cm^2/year), followed by T. heterophylla (1,000 grains/cm^2/year), Pseudotsuga (750 grains/cm^2/year) and Cupressaceae (400 grains/cm^2/year). Pinus maintains values similar to those of the previous zone. Abies and Quercus contribute a small, yet significant proportion to the total. NAP values remain consistent with those found in zone RL-4a, composed mainly of Pteridium and monolete ferns. Rosaceae, Poaceae and Cyperaceae are the dominant herbs.

A slight predominance of western hemlock pollen can be observed in the DWHIP diagram (Fig. 9). The indices of precipitation (Appendix 3) only rarely drop below 0.50, indicating that the proportion of Tsuga heterophylla is for the most part, greater than that of Pseudotsuga for the duration of the zone.

ZONE RL-5: Tsuga heterophylla - Pseudotsuga menziesii - Cupressaceae zone
(2.00 m - 0.20 m; 3,300 BP - 150 BP)

Abundant Tsuga heterophylla and Pseudotsuga pollen values define this zone. Western hemlock values range from 13% to 30% across the zone and Pseudotsuga averages around 17%. Abies attains highest levels of any zone, averaging around 2%. A slight increase in Cupressaceae pollen values occurs during the zone, from a low of 2% at the RL-4b/RL-5 boundary to a high of nearly 8% at the RL-5/RL-6 transition. Quercus pollen attains its highest values (around 2%) in the earliest samples of RL-5, declining to a low of 0.5% in the youngest samples. Alnus maintains values similar to those found in the previous zone. NAP percentages remain similar to those of RL-4, averaging about 5%. Pteridium, the most dominant NAP type, originally exhibits relatively high values (5%-6%), but decreases to minimum values (approximately 1%) halfway through the zone, at about 1,500 BP. Rosaceae, Poaceae, Cyperaceae and monolete fern pollen and spores comprise the majority of NAP palynomorphs.

All arboreal pollen types exhibit values similar to those seen in zone RL-4a. Alnus, Pinus, Pseudotsuga and Tsuga heterophylla are the dominant pollen types. A five fold increase in the PAR's of all arboreal pollen types present occurs at around 2,500 BP.

Subsequent to this peak, pollen values return to previous levels, decreasing drastically approximately 900 BP, to very low levels of less than 600 grains/cm^2/year each. At the RL-5/RL-6 transition, all pollen influx values are at a minimum.

The DWHIP values indicate that this time period alternates between a western hemlock-dominated and Douglas-fir-dominated spectrum. The earliest samples of RL-5 exhibit low DWHIP values (Pseudotsuga dominated spectrum) for about 500 years. These values increase about 2,800 BP, at which time T. heterophylla dominates the spectrum for the next 500 years. This cycle is repeated during the remaining 1000 year period of zone RL-5.

ZONE RL-6: Alnus - Cupressaceae - NAP zone

(0.20 m - 0.00 m; 150 BP - 0 BP)

Zone RL-6 encompasses the last ca. 150 years of record, and is recognized by an increase in alder pollen, which attains a high of nearly 55%. Tsuga heterophylla, Pseudotsuga and Pinus values all decrease sharply during the last 150 years, attaining values significantly lower than the previous zone. NAP values increase substantially, almost doubling from 6% to 10%. Ericaceae, Rosaceae, Poaceae, Cyperaceae and Pteridium all increase significantly.

Total pollen accumulation rates are the lowest of any zone at about 1,500 grains/cm^2/year. Alnus is the only arboreal pollen that exhibits a significant influx increase. All other arboreal pollen types either decrease or remain constant (Cupressaceae).

Zone RL-6 exhibits a higher abundance of western hemlock to Douglas-fir pollen (average DWHIP=0.71).

Interpretation and Discussion

The palynologic record of Rhamnus Lake is consistent with other pollen records of the region (C. Heusser, 1960; 1985; L. Heusser, 1983; Zirul, 1967), and indicates that a series of vegetation and climatic changes have occurred over the past 13,000 years. However, before an interpretation of the vegetation and climate can be completed, careful inspection of the results are needed, especially with respect to over representation of certain pollen types, namely Pinus and Alnus. Although the percent diagram (Fig. 7) indicates that alder and pine were the dominant arboreal species found during the late Pleistocene and that Alnus continued to hold dominance during the Holocene, examination of the pollen accumulation rates suggests otherwise.

Initially both Alnus and Pinus dominate the arboreal vegetation, and the high PAR's testify to this. However, after the beginning of the Holocene, both pine and alder influx rates drop drastically, indicating the actual number of trees present decreases also. The high percentage values are an artifact of over-representation. Both pine and alder are prolific pollen producers, and their pollen can be transported long distances on air currents. Surface sample studies done in the central interior of British Columbia (Hebda and Allen, 1993) showed that even when Pinus or Alnus were not present in the local vegetation, their background pollen levels were relatively high at between 15% and 20%.

The remaining arboreal species used in the study do not suffer from this same problem, but may be under-represented.

Zone RL-1, encompasses a time of deglaciated, unstable, terrain around the lake basin. Initially, the landscape supported a lodgepole pine and alder parkland with open grassy areas. The preponderance of pine and alder pollen in both the percent and PAR diagrams suggests that the area was quickly colonized by these seral species. Small, yet significant amounts of spruce, mountain hemlock and subalpine fir suggest that these conifers also grew in the forest/parkland. The presence of Abies lasiocarpa in the forest surrounding Rhamnus Lake is confirmed by the presence of a needle in the basal sediments (clay/gyttja interface) of the core. Although A. lasiocarpa occurs today on only a few high peaks of the Vancouver Island mountains, in the late-Pleistocene it may have been more widely distributed. Also, these conifers may have come as migrants from the Puget Trough area to the south, as it supported a rich parkland community of both arboreal and non-arboreal taxa during glacial times (Heusser, 1978b). Relatively high values of taxa such as Artemisia and Poaceae not only indicate the openness of the forest, but also suggest a precipitation regime much drier than present. This early, post-glacial pioneering stage lasted for approximately 500 years. There is no modern equivalent to this vegetation community. The climate was probably cool to cold and dry (Hebda, 1995).

Openings become restricted or disappear in zone RL-2, as arboreal taxa such as spruce, western hemlock and alder, expand from about 11,800 BP to approximately 10,200 BP. Although Pinus and Alnus still dominated the landscape, the increase in Picea along with the introduction of other shade tolerant species such as T. heterophylla, suggest a closing of the canopy and the maturation of the forest and soils. Populus trees, although not identifiable to species from the pollen record, probably grew on immature mineral soils in semi-open to open areas (Mott, 1976) in the vicinity of Rhamnus Lake. Salix, a more hygric genus, probably grew along the lake margins, in areas exposed to both high light (shade intolerant) and a relatively high soil moisture content. The incorporation of these species in the forest mosaic suggest that effective moisture increases from that of the previous zone. A peak of Tsuga mertensiana at approximately 10,500 BP, may signal rapid cooling, the equivalent of the Younger Dryas miniglaciation of Europe (Mathewes, 1993). As with zone RL-1, there does not appear to be a modern equivalent to the forest composition of this zone. The closest modern community may be the MH zone, but key elements are missing such as higher T. mertensiana values. The climate was initially cool to cold, with increasing effective precipitation to the start of the Holocene (Hebda, 1995).

The assemblages of zone RL-3 indicate that Douglas-fir forests replaced the seral lodgepole pine and mixed conifer stands. For approximately the next 3,300 years (10,200 BP to 6,900 BP), this forest of predominantly Douglas-fir persisted. Based on comparison to the surface sample data (see chapter 3), western hemlock was probably a minor constituent of the forest, growing only in moist sites, its presence in the spectrum a result of long distant transport (possibly from the west) rather than dominance in the vegetation. A cupressaceous taxon (probably Juniperus) occurred in the area, but without any macrofossil remains for verification, it is difficult to be certain of the source of the pollen. However, regional records clearly indicate that neither western red cedar nor yellow

(Alaskan) cedar were elements of the vegetation during this warm, dry period (Hebda and Mathewes, 1984). Consequently, it can be assumed that any cupressaceous pollen probably came from Juniperus spp., possibly Juniperus scopulorum. Hebda (1995) suggests that this xerophyte was an important element of early Holocene vegetation in other parts of southern British Columbia.

The forest canopy appears to have been relatively open because of the large amounts of bracken fern, grasses and other herbaceous taxa. This suggests that effective moisture was much less than present, consistent with regional climatic histories (Hebda, 1995). The decrease in effective moisture appears to have been sufficient to have caused Rhamnus Lake to nearly dry out. The presence of high concentrations of Potentilla and Spiraea pollen (Fig. 10), both mainly insect pollinated, in the sediments of this zone indicates that the lake was either very shallow or converted to a wetland. This recently exposed lake basin allowed their proliferation in the area. Both of these taxa favour moist to wet areas such as lake margins, marshes and damp meadows (Hitchcock and Cronquist, 1973; Pojar and MacKinnon, 1994).

Quercus becomes evident for the first time in the arboreal component at approximately 9,000 BP. The first sign of oak is significant because oak has relatively low pollen production and limited dispersal, and therefore the pollen is rarely observed at any distance from the parent plant (see chapter 3). This suggests that Quercus may have been growing near Rhamnus Lake between 8,000 and 9,000 years ago. Plectritis congesta, (sea blush), which is a recognized component of the Garry oak ecosystem (Roemer, 1972;

1993), is also found occasionally within this period; further evidence of the close proximity of the oak association to the lake.

The NAP signature during this interval suggests an open forest community with significant grass/herb dominated areas. High pollen and spore values for Pteridium, Poaceae, Rosaceae and other shade intolerant species indicate the openness of the forest canopy and inter-trunk space. The modern CDF biogeoclimatic zone is perhaps the closest approximation to this ancient community. The high P. menziesii values coupled with a very diverse NAP component, is similar to that found in the modern CDFmm subzone (Fig. 3). The climate during this time was warm and dry; Hebda (1995) termed this the "xerothermic interval".

Gradual infilling of the canopy occurred around 6,900 BP, at the start of zone RL-4. Since then, decreases in all non-arboreal taxa have occurred. Zone RL-4 can be divided into two subzones. Zone RL-4a, lasting about 600 years, is characterized predominantly by a Douglas-fir forest, with notable western hemlock, and can be viewed as transitional from RL-3 to RL-4b. Zone RL-4b, lasting for 3,000 years from about 6,300 BP to 3,300 BP, was a period in which shade tolerant western hemlock seedlings were freely regenerating under a closed, climax community. Palynologically, this period resembles parts of the modern CWH zone, with relatively high T. heterophylla and P. menziesii pollen values coupled with a low NAP signature composed mainly of monolete ferns and Pteridium. The pollen spectrum of the initial period, RL-4a, is similar to that of the dry CWH subzones, such as CWHxm and CWHmm, whereas the remainder of the zone, RL-4b, resembles that of the wet CWH subzones, CWHvm and CWHvh. Zone RL-4 is important in that it shows clearly the alteration of the forest community from an ecosystem similar to the modern CDF to that of the CWH; evidence of increasing moisture and perhaps decreasing temperatures.

The expansion of Cupressaceae in the forests at this time is further evidence of increasing moisture. Abies (perhaps A. grandis), a more mesic taxon, is also present in significant amounts during this phase. The consistent Garry oak signal throughout the zone, indicates that this tree still grew in the region.

From 6,300 BP to 3,300 BP, zone RL-4b, the spectra indicates a forest composed of an admixture of Pseudotsuga and T. heterophylla with possibly Thuja plicata in moister areas such as along stream banks and on flood plains. Picea and Abies probably inhabited moist lowlands and valley bottoms. Pteridium appears to be the main NAP taxon in openings, (though much less abundant than in previous zones), followed by monolete ferns. The low NAP indicates a nearly closed Douglas-fir/Western hemlock forest; perhaps similar to the CWHxm found in the region today. The climate was warmer than or perhaps similar to modern with increased available moisture.

Zone RL-5 (3,300 BP to 150 BP), sees the persistence of Douglas-fir/western hemlock forests in the region. However, spruce, true fir and oak increase slightly, remaining relatively high throughout the zone (Fig. 7). Quercus garryana attains maximum values (2% to 3%) during the initial phase of this zone, decreasing prior to the RL-5/RL-6 boundary at around 2,000 BP. Except for the peculiar oak signal, modern CWH-like characteristics become established during this phase. The high proportions of western hemlock and cupressaceous pollen coupled with significant Douglas-fir resemble the pollen spectra of the CWHxm or perhaps even the moister CWHmm subzone.

Like oak, Pteridium appears to be slightly more abundant than in the previous zone. Increases in the relative abundance of bracken fern and oak may be the result of two factors, either a slight warming and drying trend as compared to zone RL-4, or other environmental factors such as increased fire frequency (Cwynar, 1987), which allowed for the growth and expansion of the oak community. This warmer period was followed by cooling about 1,000 BP.

From 150 BP to present, zone RL-6 exhibits a relative increase in alder coupled with a decrease in western hemlock, Douglas-fir, spruce and pine, reflecting historic logging and agricultural land clearing. The alder signal is not as strong as that found at other south British Columbia sites (Mathewes, 1973; Mathewes and Rouse, 1975; Mathewes and King, 1989), suggesting less extensive human impact. Decreased forest cover, is further indicated by an increase in herbaceous types such as Poaceae.

Conclusions

Figure 11 summarizes the vegetation and climate history for the Rhamnus Lake core. An initial post-glacial zone, RL-1, supports an open lodgepole pine community under a cool to cold and dry climate. Increasing moisture allows for the expansion of alder and coniferous species in RL-2, closing the canopy and reducing light levels. Temperatures were still cool, but effective precipitation increased. Decreasing moisture and increasing temperatures at the beginning of zone RL-3 are suggested by the

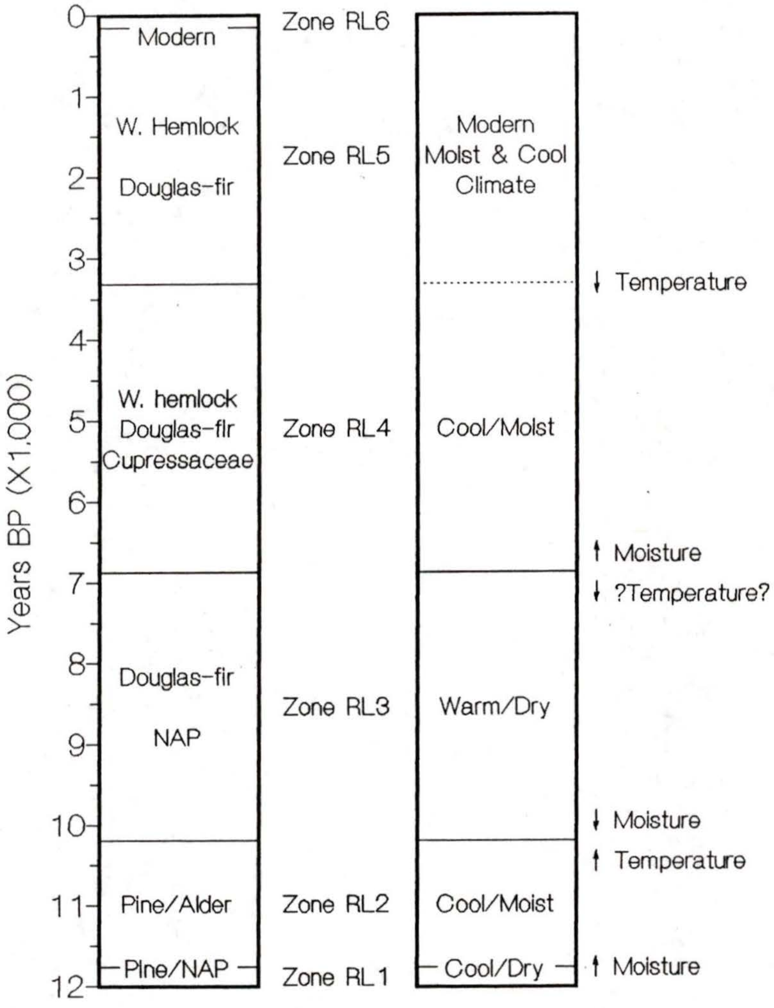

Figure 11. Vegetation and climatic history of Rhamnus Lake.

introduction and expansion of the more xerophytic Douglas-fir and an increase of grass and herbaceous communities. This phase of the sequence is recognized as the classic xerothermic interval. RL-4 reflects a rise in effective precipitation while temperatures remain similar to, or slightly less than, the previous interval. Western hemlock, Douglas-fir and Cupressaceae dominate the arboreal component. The extent of open herbaceous communities decreases during this period, an indication of the closure of the forest community. In zone RL-5, an initial warming and/or drying period is followed by decreasing temperatures and the establishment of the modern moist and cool climate. Closed forests composed of western hemlock, with significant Douglas-fir, typified the vegetation. Garry oak stands occurred in the region, and probably grew in warmer, drier microhabitats similar to those found in the region today. The final zone, RL-6, is a regionally recognized period of disturbance and expansion of alder.

Chapter 5: HEAL LAKE HISTORY

Site Description

In the fall of 1991, Heal Lake (123° 28' W Long., 48° 32' N Lat.), located at the Hartland Road Landfill, on the Saanich Peninsula (Fig. 1), was drained to provide additional space for the disposal of municipal wastes. This site is situated within the dry CDFmm subzone, at 126 metres asl. The lake was small (approximately 4 ha), approximately 9 metres in depth at the deepest point, and was confined on the eastern side by a large rock bluff and on the western side by the slopes of Mt. Work. The long axis of the lake trended north-west by south-east, and was about 150 metres wide and over 300 metres in length. In the summer of 1992, excavation of the lake sediments was begun and samples obtained.

Vegetation

Vegetation surrounding the lake includes Pseudotsuga menziesii (Douglas fir), Arbutus menziesii (Pacific Madrone), Thuja plicata (Western red cedar) and Alnus rubra (red alder) on the rocky slopes of Mt. Work, whereas abundant Acer macrophyllum occupies the moister, unstable stream margins. Shrubs of the area include: Rubus spectabilis, Gaultheria shallon, Mahonia nervosa, Polystichum munitum, Vaccinium sp. ("huckleberries") and abundant Cystisus scoparius (Scotch broom) on dry, disturbed sites. Various grasses, ferns and other small herbs are also present, including Pteridium aquilinum and Plectritis congesta (sea blush). Ericaceous species, such as Labrador tea (Ledum groenlandicum) grew around the lake margins at the time of draining.

Methods

Multiple columns of lake margin peat and gyttja as well as two (gyttja) cores were taken from the Heal Lake basin. A combined column/core sediment suite was used to analyze the pollen record of this site. Column samples were obtained from excavated faces of the lake sediments by first vertically facing the sediment bank and removing large bulk samples of peat. Samples were obtained in 10 cm intervals and comprised approximately 4000 cm^3 (20 cm X 20 cm X 10 cm). In many cases, sample material was screened on site to remove macrofossils and wood debris for radiocarbon dating and analysis and identification of plant remains. Core samples were obtained in 10 cm intervals using a modified Livingston corer. Because of the poor resolution provided by a 10 cm sampling interval at the base of the core, a series of six samples from a finely sampled column (2.5 cm intervals), obtained about 5m from the core site, was used in place of the basal most 15 cm of the core (810 cm - 825 cm). Sampling techniques followed standard procedures as outlined above and in chapter 4. Both core and column samples were cleaned of potential contaminated material and bagged on site. Samples were taken to the Royal British Columbia Museum, Victoria, B.C., for processing and analysis.

Laboratory procedures followed the standards as given by Faegri and Iversen (1975), and outlined in chapter 4. Because of the fibrous nature of the column sediments (sedge peat), techniques similar to those outlined in chapter 3 were used. Samples for radiocarbon dating were taken from selected levels and sent to Beta Analytic Inc. for analysis.

Results - Core and Column Stratigraphy and Radiocarbon Dates

There is substantial overlap in the chronology of the upper column section and the core as seen by the Mazama tephra (6,800 BP; Bacon, 1983), located at a depth of 300-302 cm in the column and a depth of 445-447 cm in the core (Fig. 12). Because the sequence is composed of three different sections, the usual practice of the sample number being equivalent to sample depth in the sequence was not used. Instead, the sedge peat column and sediment core were aligned at the Mazama ash tephra. The ash layer in the lake core was re-calculated to 300 cm and the final 15 cm of the long core was replaced by the short core. This gives an overall length to the sequence of 690 cm.

A total of seven radiocarbon dates were obtained for the column/core sequence; three from the column sequence and four from the long core (Table 5). The lowermost core section was not dated. However, a basal date of 12,840 +/- 80 BP was obtained from the clay/gyttja interface from a sediment column (HL 921130-1) 2 metres to the west.

The uppermost column samples (HL1a 920617-1A; Fig. 12) are composed mainly of sedge peat and detrital plant remains, with a significant amount of gyttja starting at the 210 cm mark and extending below Mazama ash. The column extends from the sediment surface (0 cm) to a depth of approximately 340 cm. The stratigraphy is as follows: red-brown fibrous sedge peat (0 cm - 80 cm); black-brown crumbly sedge peat (80 cm - 150

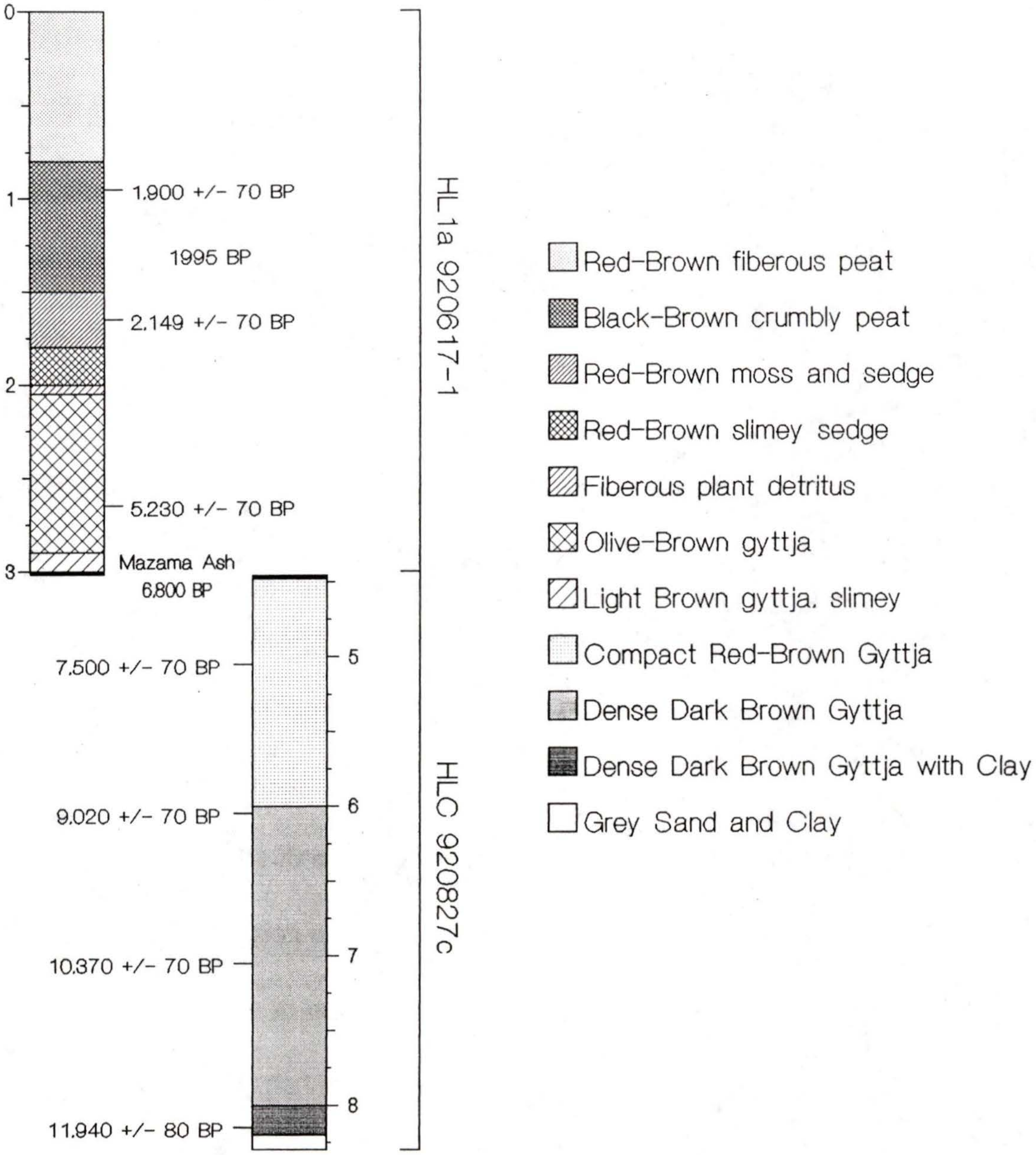

Figure 12. Heal Lake column and core stratigraphy and radiocarbon dates.

cm); red-brown moss and sedge peat (150 cm - 180 cm); red-brown slimy sedge peat (180 cm - 200 cm); fibrous plant detritus consisting of leaves, sticks and cones intermixed with sedge peat (200 cm - 205 cm); olive-brown gyttja (205 cm - 290 cm); light brown slimy gyttja (290 cm - 300 cm); Mazama ash tephra (300 cm - 302 cm); olive-brown gyttja (302 cm - 340 cm).

Radiocarbon dates from the column samples (Table 5) were obtained from wood fragments taken from three depths and are given as C13 adjusted ages. The following chrono-sequence was observed: 90 cm - 100 cm (1,890 +/- 70 BP); 160 cm - 170 cm (2,100 +/- 70 BP) and 260 cm - 270 cm (5,190 +/- 70 BP). All radiocarbon dates appear to fall into their correct stratigraphic order.

It should be noted, that the two youngest radiocarbon dates (1,890 BP and 2,100 BP) were both taken from large wood fragments removed from the column section. The slight differences in ages (only 210 years) coupled with their stratigraphic separation of 70 cm (90-100 cm and 160-170 cm respectively), may be due to transport of the wood from its original site of deposition to its current location. A fossil beaver dam was observed in column sections 2 metres to the south of the sampling location, and these pieces of wood may have been originally part of that structure. Since the radiocarbon dates suggest that these wood samples may be contemporaneous, an average date of 1,995 years BP at a stratigraphic level of 130 cm will be used (Fig. 12).

The section of sediment core (HLC 920827-C; Fig. 12) was analyzed from the 445 cm level (Mazama ash) to the basal clay/diamicton layer at 830cm. The core consists entirely of lake gyttja, with clay and diamicton occurring at the base. The stratigraphy of

Table 5. Radiocarbon dates from Heal Lake sequence.

Sequence	Depth (cm)	Lab Number	Type	14C age	13C adjusted age
HL1a 920617-1	90-100	Beta-71375	Wood	1,900 ± 70 BP	1,890 ± 70 BP
	160-170	Beta-71376	Wood	2,140 ± 70 BP	2,100 ± 70 BP
	260-270	Beta-71377	Wood	5,230 ± 70 BP	5,190 ± 70 BP
HLC 920827c	500-510	Beta-71379	Gyttja	7,500 ± 70 BP	7,420 ± 70 BP
	600-610	Beta-71380	Gyttja	9,020 ± 70 BP	8,980 ± 70 BP
	700-710	Beta-71381	Gyttja	10,370 ± 70 BP	10,270 ± 70 BP
	810-820	Beta-71382	Gytjja	11,940 ± 100 BP	11,820 ±100 BP
HL 921130-1	0-5	Beta-60553	Gyttja	12,840 ± 80 BP	

the core is as follows: Mazama ash tephra (445 cm - 447 cm); compact red-brown gyttja (447 cm - 600 cm); dense, dark brown gyttja (600 cm - 800 cm); dense dark brown gyttja with clay lenses (800 cm - 820 cm); diamicton (820 cm - 830 cm).

Radiocarbon dates from the core (Table 5) were obtained from gyttja samples extracted from selected intervals and are given as C13 adjusted ages. The following chrono-sequence was observed: 500 cm - 510 cm (7,420 +/- 70 BP); 600 cm - 610 cm (8,980 +/- 70 BP); 700 cm - 710 cm (10,270 +/- 70 BP) and 810 cm - 820 cm (11,820 +/- 100 BP). All radiocarbon dates fall into their correct stratigraphic order. The lowermost samples are taken from a short core (HL 920928-1) that extends from the 820 cm level into the blue-clay and sand layer at 835cm.

Because of the different sediment types found in the columns and core, differing sediment accumulation rates (SARs) are seen between the column samples and core samples. The column samples, being composed of sedge peat, accumulate at a slower rate than the lake gyttjas found in the core. Column HL1a 920617-1 averages 0.043 cm/year whereas the core (HLC 920827-C), has a slightly higher SAR, averaging 0.078 cm/year. No sediment accumulation rates were calculated for the lowermost column section (HL 920928-1).

Pollen Zones

Results for Heal Lake are summarized and presented in a percent pollen diagram (Fig. 13), a pollen accumulation rate diagram (Fig. 14) and a DWHIP diagram (Fig. 15). All statistical techniques follow those outlined in Chapters 3 and 4.

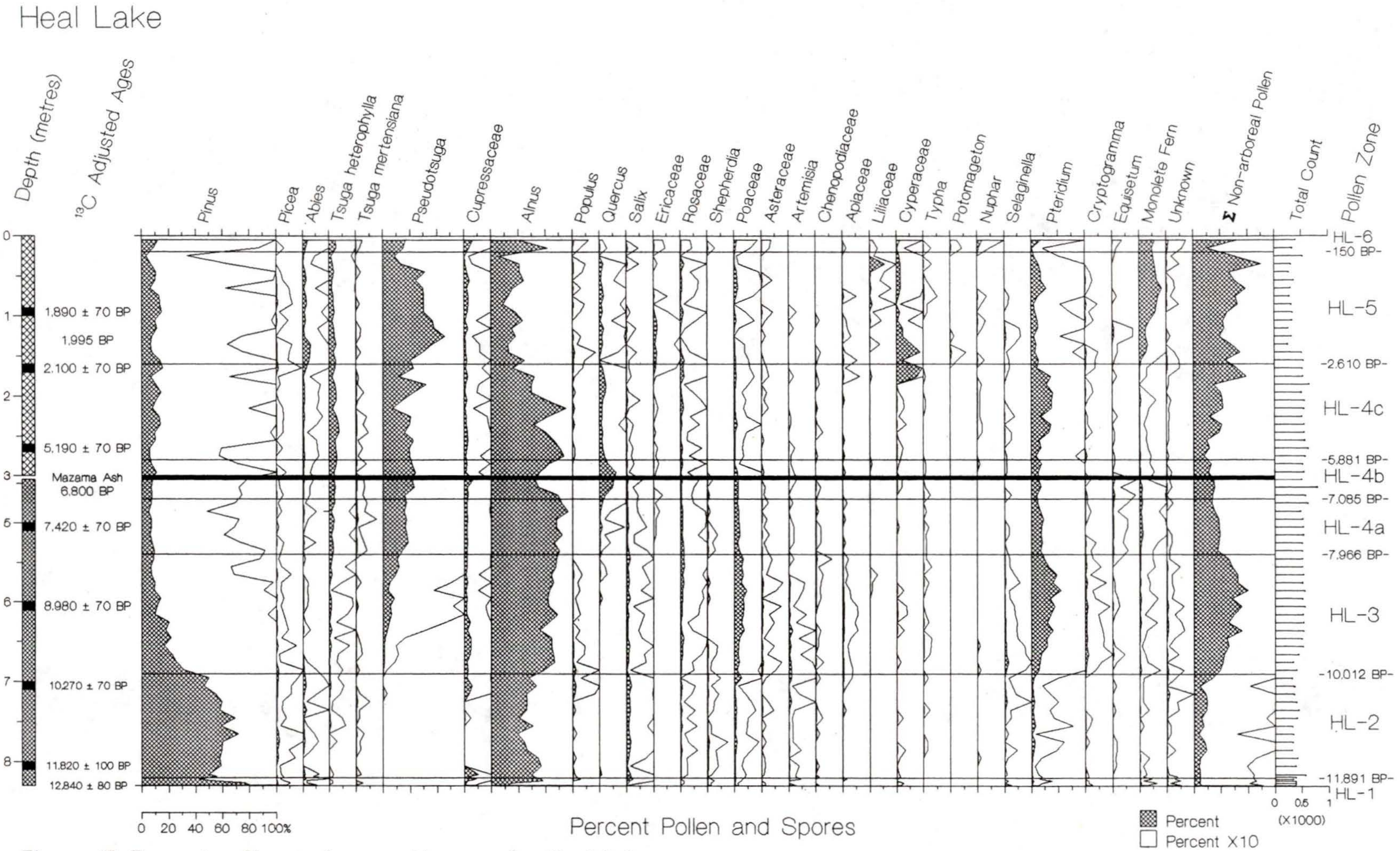

Figure 13. Percent pollen and spore diagram for Heal Lake.

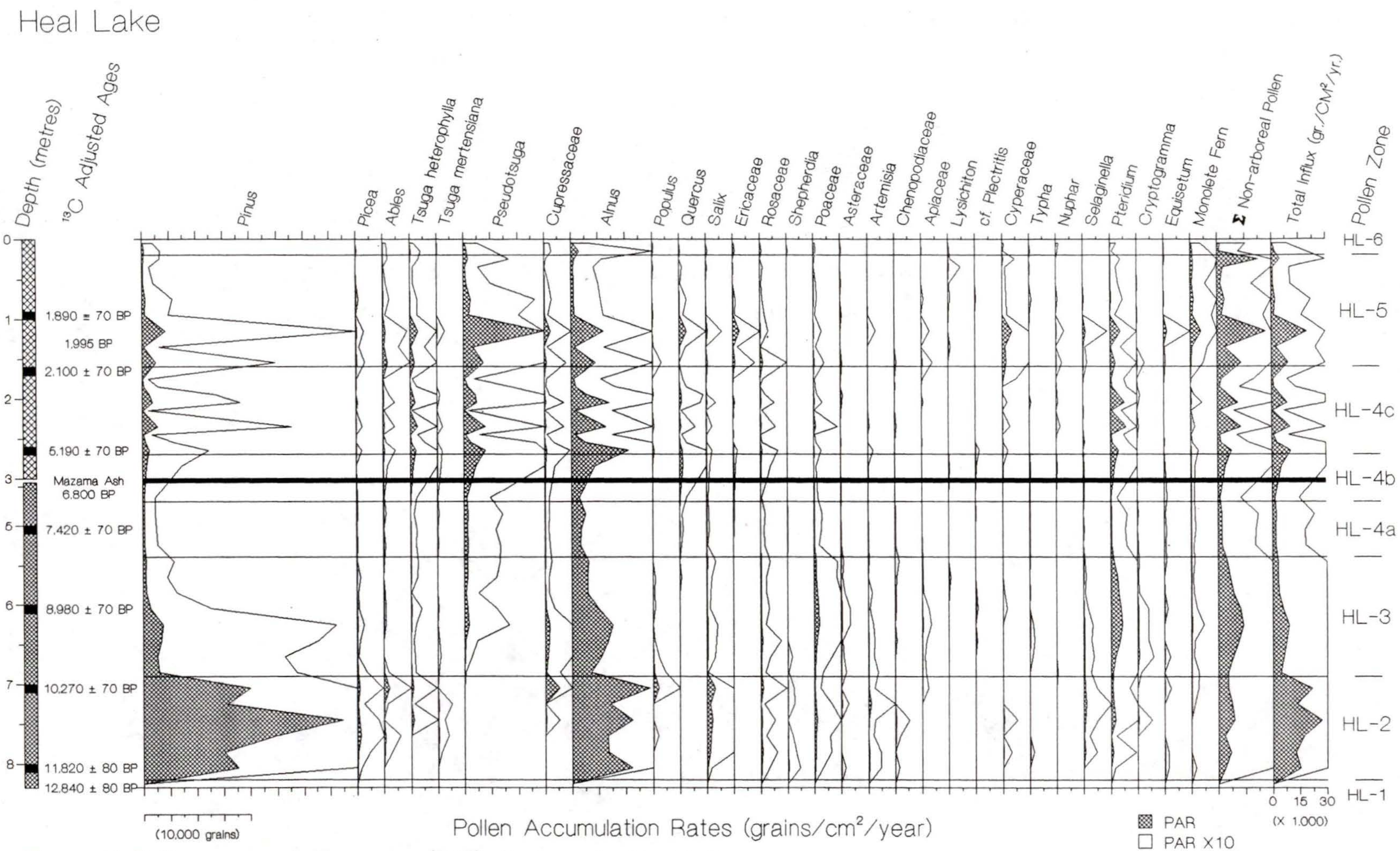

Figure 14. Pollen accumulation rates (PAR) diagram for Heal Lake.

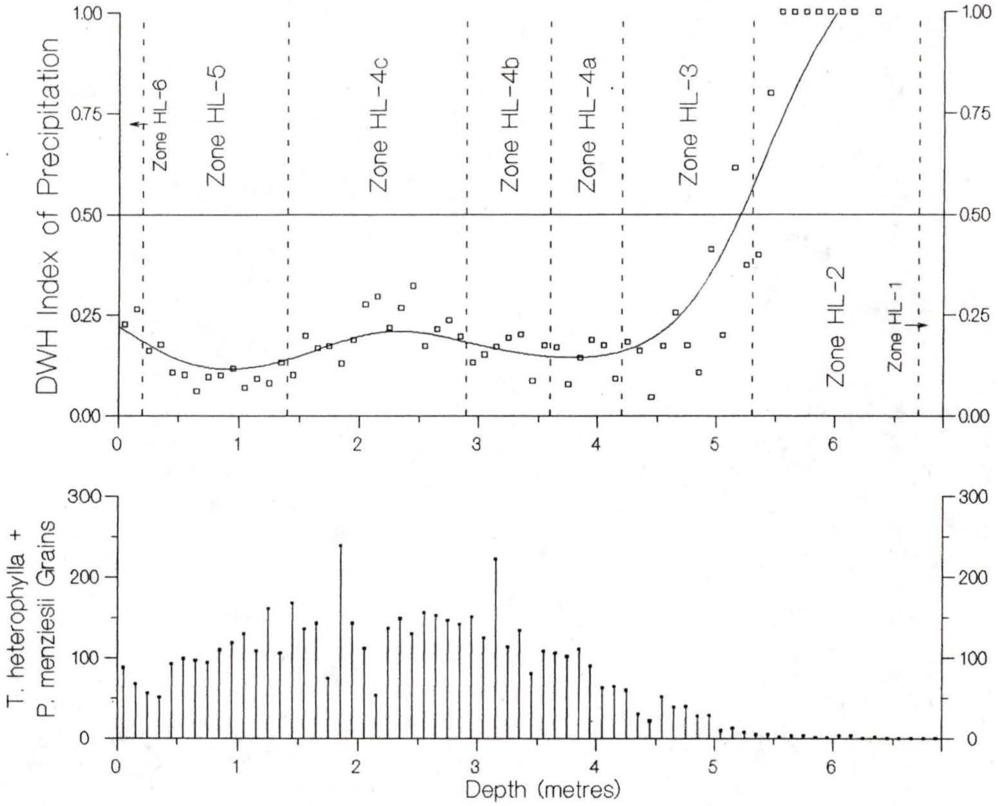

Figure 15. DWHIP values for Heal Lake column and core sequence.

Pollen concentrations fluctuate dramatically throughout the column/core sequence. The lowest concentrations are found midway through the peat column (8,400 grains/cm^3) while the highest values are found in the basal-most column samples (2,202,700 grains/cm^3). The average concentrations for the upper column, the core and the lower column are around 87,000 grains/cm^3, 126,000 grains/cm^3 and 789,000 grains/cm^3 respectively. Pollen accumulation rates also differ significantly. Overall, the average PAR for the sequence is 23,500 grains/cm^2/year, ranging from a low of 780 grains/cm^2/year to a high of 157,400 grains/cm^2/year. Initial influx is very high, averaging 56,400 grains/cm^2/year from the basal column sequence (12,000 BP - 11,800 BP). The average pollen accumulation rate of the core decreases to around 9,300 grains/cm^2/year, with a significant shift occurring around the Pleistocene/Holocene boundary (10,300 BP), where influx drops from over 22,500 grains/cm^2/year to less than 5,000 grains/cm^2/year. The upper column has the lowest average PARs at about 4,700 grains/cm^2/year, ranging from a high of over 22,300 grains/cm^2/year to less than 800 grains/cm^2/year. Overall, the pollen concentrations and accumulation rates are an order of magnitude greater than those found by L. Heusser (1983) in Saanich Inlet. Heusser found concentrations ranging from 1,000 to 5,000 grains/cm^3 with accumulation rates of 1,000 to 2,000 grains/cm^2/year.

The percent pollen diagram (Fig. 13), was divided into 6 pollen zones (HL-1 to HL-6) by visual inspection, in the same manner as the Rhamnus Lake diagram. Subzones were defined when a zone displayed a change in a few pollen types rather than several major taxa.

ZONE HL-1: Pinus - NAP zone

(6.90 m - 6.80 m; 12,840 BP - 11,900 BP)

Pinus dominates this zone with percentages ranging from 40% to 80%, averaging 63%. Alnus values average around 25%, ranging from a low of 12% to a high of 38%. NAP contributes about 5%, composed mainly of monolete ferns, Pteridium, Shepherdia and Poaceae grains. Other pollen types that contribute significantly to the record include Cupressaceae (probably Juniperus sp.) at 3.5% and Salix at 2%.

Pollen accumulation rates for the zone are high at about 63,500 grains/cm^2/year. Pinus dominates the zone with values ranging from 11,500 to over 80,000 grains/cm^2/year. Alnus pollen influx ranges from 5,000 to almost 60,000 grains/cm^2/year, averaging around 20,000 grains/cm^2/year. Total NAP influx never exceeds 7,500 grains/cm^2/year, mainly confined to 1,000 to 2,000 grains/cm^2/year.

ZONE HL-2: Pinus - Alnus zone

(6.80 m - 5.50 m; 11,900 BP - 10,000 BP)

Pinus and Alnus dominate this zone, averaging around 60% and 30% respectively. NAP increases from a low of about 3% in the oldest samples of the zone to a high of around 14% at the HL-2/HL-3 boundary. The NAP component is composed of mainly Pteridium, Selaginella, Rosaceae, Shepherdia, Poaceae, Asteraceae and Artemisia. Other arboreal flora that contribute significantly to the pollen signature include: Salix (about 3%); Populus (<1%); Picea (1% - 2%) and Abies (1% - 2%). Tsuga heterophylla and T. mertensiana occur at very low values and in isolated samples. Juniperus type pollen

(Cupressaceae) occurs abundantly at the beginning (10%) and end (5%-10%) of the zone, but is non-existent in the intervening samples.

Pollen accumulation rates (Fig. 14) decrease from the previous zone, averaging 25,000 grains/cm^2/year through HL-2. Although pollen and spore influx is initially high (50,000 grains/cm^2/year) in the oldest samples, these values drop to between 15,000 and 30,000 grains/cm^2/year at the HL-2/HL-3 boundary.

The DWHIP values (Fig. 15; Appendix 3) shows a nearly 100% dominance (average DWHIP=0.97) of western hemlock to Douglas-fir for the majority of the zone. However, western hemlock pollen values occur at very low levels. At approximately 10,000 BP (the HL-2/HL-3 boundary and the start of the Holocene), the first appearance of Douglas-fir pollen occurs and the dominance of western hemlock decreases rapidly.

ZONE HL-3: NAP - Pseudotsuga zone

(5.50 m - 4.00 m; 10,000 BP - 8,000 BP)

Pinus decreases from 40% at the start of the zone to 10% mid-way through; maintaining 10% to 15% for the remainder of the sequence. Alnus pollen values are consistent at between 40% and 50%. Pseudotsuga increases from less than 1% at the HL-2/HL-3 boundary to greater than 10% at the HL-3/HL-4 boundary. Cupressaceous type and Salix pollen maintain consistent values of between 2% and 5%. NAP percentages increase from a low of around 20% to highs of over 40%, decreasing near the HL-3/HL-4 boundary to 25%. The majority of the NAP is contributed by Pteridium spores and Poaceae and Rosaceae pollen.

Total pollen accumulation rates decrease for the first time to less than 10,000 grains/cm²/year, averaging only 5,500 grains/cm^2/year for the zone. Pinus and Alnus still contribute the majority of arboreal grains to the PAR total, averaging 1,000 and 2,400 grains/cm^2/year respectively. Pseudotsuga and Cupressaceous pollen types contribute about 200 grains/cm^2/year each. It is interesting to note the inverse relationship of these two pollen types; Douglas-fir has it's lowest input at the start of the zone, whereas Cupressaceae has its highest. This trend reverses up-sequence. NAP pollen influx averages 1,500 grains/cm²/year.

The diagram of the DWHIP values (Fig. 15) shows the increasing dominance of Pseudotsuga. At the beginning of HL-3, the DWHIP's are approximately 0.50 (50% Douglas-fir, 50% western hemlock), however, near the HL-4 boundary, Pseudotsuga pollen grains become more prevalent, and index values drop to less than 0.30 (70% Pseudotsuga to 30% Tsuga).

ZONE HL-4: Pseudotsuga - Quercus - NAP zone

(4.00 m - 1.60 m; 8,000 BP - 2,600 BP)

Pseudotsuga and Tsuga heterophylla both increase over the previous zone. Douglas-fir attains values ranging from a low of 15% to a high of 30% whereas western hemlock attains values of between 2% and 8%. Alnus maintains values of between 30% to over 50%. NAP percentages decrease slightly over the previous zone, dropping to 15% to 20%. Quercus garryana appears for the first time in significant quantities, attaining a maximum of over 10% (HL-4b), but generally maintaining values between 1% and 5%.

Total pollen accumulation rates fluctuate over the zone, ranging from a low of less than 1,000 grains/cm²/year to a high of over 10,000 grains/cm²/year in isolated samples.

The DWH indices of precipitation for the entire HL-4 zone average less than 0.20, indicating the dominance of Douglas-fir over western hemlock pollen.

Three sub-zones have been delineated due to changes in the spectra of specific pollen types.

Subzone HL-4a

(4.00 m - 3.30 m; 8,000 BP - 7,100 BP)

Pseudotsuga values increase to 20% while Tsuga heterophylla percentages average around 3%. Alnus attains its highest values of the sequence, averaging 50%. Quercus garryana pollen is observed for the first time in consistent quantities, fluctuating around 1%. NAP values range from 15% to 20%, and are composed of mainly Pteridium (5% - 9%) and Poaceae (2% - 4%) pollen types. Rosaceae, monolete ferns and Equisetum occur at 1% - 2%.

Pollen and spore accumulation rates average around 2,000 grains/cm²/year through the sub-zone. Both Pseudotsuga and the NAP (chiefly Rosaceae, Poaceae, Pteridium and monolete ferns) each contribute about 350 grains/cm²/year. The DWHIP's for zone HL-4a show a higher proportion of P. menziesii pollen than T. heterophylla pollen, indicating that, on average, Douglas-fir pollen dominates western hemlock pollen by about 4 to 1.

Subzone HL-4b

(3.30 m - 2.70 m; 7,100 BP - 5,900 BP)

This subzone, which includes the Mazama ash tephra shows a substantial increase in Douglas-fir and Garry oak pollen values. P. menziesii maintains percentages of 15% to 25% while Q. garryana attains its highest values of the sequence at 5% to 13%. T. heterophylla values increase slightly from the previous subzone to 4% - 5%. NAP values show a decreasing trend through the sub-zone, averaging 13% - 14%, the result of lower Poaceae and monolete fern values. Pteridium percentages remain essentially the same as for sub-zone HL-4a, averaging 6%.

The total PAR for the sub-zone is around 3,300 grains/cm^2/year. Pseudotsuga, T. heterophylla, Cupressaceae, Quercus, Alnus, Pinus and the NAP all show substantial increases in accumulation rates. Douglas-fir and alder are the dominant pollen types, with 680 and 1,500 grains/cm^2/year respectively. The DWHIP's for HL-4b show an increase in western hemlock pollen. However, Douglas-fir pollen is still the dominate type, with ratios in excess of 4:1 (DWHIP=0.20).

Subzone HL-4c

(2.70 m - 1.60 m; 5,900 BP - 2,600 BP)

Pseudotsuga percentages show a slight decrease from the previous subzone to 19%. T. heterophylla increases slightly to over 5%. Alder decreases from a high of 53% at the HL-4b/HL-4c boundary to 30% at the HL-4b/HL-5 boundary. Quercus decreases substantially from the previous subzone to 3% - 4%. The NAP shows a steady increase, from a low of less than 10% at the HL-4b/HL-4c boundary to almost 40% at the HL-4c/HL-5 boundary. Pteridium is the most dominant NAP type, averaging around 11%. Cyperaceae, Rosaceae and Ericaceae pollen values increase at the HL-4c/HL-5 boundary, with Cyperaceae showing the greatest overall change.

Pollen accumulation rates for this subzone are almost double those of the previous subzone, and fluctuate dramatically. Average PAR is about 4,500 grains/cm^2/year. Douglas-fir, alder and bracken fern are the dominant pollen and spore types present with 860, 1,800 and 560 grains/cm^2/year respectively. Total NAP influx averages 820 grains/cm^2/year. Moderately low DWHIP values (0.20 to 0.30) indicates a slight increase in Tsuga heterophylla over the previous zone. However, this slight increase in western hemlock does not cause an overall decrease in the dominance of Pseudotsuga, which maintains around 4:1 pollen ratios, the same as in HL-4b.

ZONE HL-5, Pseudotsuga - NAP zone

(1.60 m - 0.20 m; 2,600 BP - ca. 150 BP)

Douglas-fir pollen percentages rise substantially across this zone, averaging almost 30%. Alder values decrease to less than 17%. Tsuga heterophylla, Cupressaceae and Quercus maintain values similar to the previous zone at 3.5%, 2% and 2% respectively. Abies attains significant levels of between 1% and 6%. Total NAP values are high, averaging over 33%, composed mainly of monolete ferns (15%), Pteridium (5%) and Cyperaceae (6%). Rosaceae, Poaceae and Ericaceae are also present in small, yet significant amounts.

Total pollen accumulation rates for zone HL-5, average around 6,000 grains/cm^2/year. The pollen accumulation rates for Douglas-fir, alder and western hemlock are similar to those found in zone HL-4c. Significant increases over the previous zone occur in Abies (150 grains/cm^2/year), the Ericaceae (150 grains/cm^2/year), the Cyperaceae (280 grains/cm^2/year), and the monolete ferns (325 grains/cm^2/year). The DWHIP values are low, averaging 0.11 and indicate this to be the driest pollen zone. Douglas-fir shows a return to very high values, ranging from a mere low of 80% to a high of 94%.

ZONE HL-6, Alnus - NAP zone

(0.20 m - 0.00 m; 150 BP - present)

Zone HL-6, consisting of only two samples, is recognized by an increase in Alnus and NAP pollen and spore values, attaining 40% and 30% respectively. T. heterophylla, Pseudotsuga and Cupressaceae pollen types all show modest increases over the final samples of the previous zone (HL-5). Quercus pollen, although present, is much reduced in abundance from that found in HL-5 (>0.5%). The NAP is dominated, as in HL-5, by monolete fern spores (10%), with lesser amounts of Pteridium (4%), Nuphar (2%),Cyperaceae (1.5%) and grasses (1.5%).

Pollen influx rates average 1,300 grains/cm^2/year, significantly lower than that seen in zone HL-5. Slight increases over the latter samples of the previous zone are seen in Alnus and the NAP signal, with values averaging 460 and 220 grains/cm^2/year respectively. Douglas-fir and western hemlock values decrease. The final sample (0 cm -

10 cm) shows a decrease in all pollen types except NAP. The DWHIP values for HL-6 average 0.24, which is a slight increase over the previous zone.

Interpretation and Discussion

As with the Rhamnus Lake pollen record, the Heal Lake sequence is, in general, consistent with the findings of previous authors (C. Heusser 1960, 1985; L. Heusser 1983; Zirul 1967). The vegetation changes that have occurred in the area over the last 13,000 years suggest a climate that has altered from cool and dry, to warm and dry, to warm and moist, to moderate and moist.

Zone HL-1 can be interpreted as a pioneering, open lodgepole pine forest or parkland. The openings supported alder and possibly juniper (Cupressaceae) from 12,840 BP to 11,900 BP. However, significant alder pollen could also come from trees growing around the lake margin or along stream or creek banks. The landscape was possibly prone to erosion, and had a poorly developed mineral soil (glacial) that supported the nitrogen fixing Alnus. The lack of a high NAP signal indicates the restricted nature of openings in the forest canopy. The climate was probably cool to cold, and dry (Hebda 1995). Compared to the biogeoclimatic zones of today (chapter 3), there is no modern zonal equivalent in the region to the vegetation of HL-1.

Pinus and Alnus continue to dominate the landscape in zone HL-2 (11,900 BP to 10,000 BP). Pollen accumulation rates suggest high numbers of individuals in the vegetation for both species. However, the presence of spruce, true fir (perhaps Abies lasiocarpa, as indicated by the Rhamnus Lake results) and western hemlock suggests an increase in available moisture, from that of the previous zone, as these species prefer moist habitats (Krajina et al., 1982). The inclusion of these elements into the lodgepole pine alder forest is supported by the influx rates of these species. Although long distance transport from distant sites is a possibility, their presence in such high absolute numbers suggest they are part of the local vegetation. Another indication of the greater availability of moisture is increased Salix, probably occupying areas around the lake margins. Increased openings in the pine forest canopy in the latter stages of the zone can be inferred from the high percentages and influx rates of Cupressaceae and Populus. As well, Selaginella, a clubmoss, prefers open to only partially shaded environments (Pojar and MacKinnon, 1994). Tsuga mertensiana pollen, although found in small amounts, combined with a notable Artemisia signal suggest that temperatures may still have been cool. It should be noted, that although Artemisia is considered a classic steppe genus, one species also grows along beach fronts of northwestern North America. In the Heal Lake sequence, it appears in association with other cold adapted species, so it is assumed that temperatures were cool. In general, the climate of zone HL-2 was initially cool to cold and dry almost 11,900 years ago, with increasing moisture beginning shortly after. There is no close modern biogeoclimatic equivalent to the vegetation assemblage of HL-2, but the high pine values combined with Abies and Picea suggest an ESSF (Engelmann Spruce - Subalpine Fir) or MS (Montane Spruce) like vegetation community, similar to those found in the interior of British Columbia (Ministry of Forests, 1991; Hebda and Allen, 1993).

A rapid decrease in Pinus and Alnus pollen, coupled with increasing Pseudotsuga and NAP types and very low PAR's, attests to further opening of the forest canopy in zone HL-3 (10,000 BP to 8,000 BP). Douglas-fir, a shade intolerant, xerophytic species that can not regenerate freely under closed forest canopies (Tsukada, 1982; Krajina et al., 1982), becomes established in the ecosystem. The major increases in Poaceae and Pteridium further suggest increased, or enlarged, canopy openings. The introduction of Douglas-fir, probably indicates warming temperatures and decreased moisture, with warm temperatures lasting for the remainder of the sequence. In this zone, for the first time Douglas-fir pollen becomes more dominant than western hemlock pollen, emphasizing the shift in the climatic regime from a moist environment to a relatively dry one. Overall, this zone exhibits decreasing moisture with increasing temperatures. The vegetation pattern of zone HL-3 is similar to that of the modern CDFmm subzone.

Zone HL-4 (8,000 BP to 2,600 BP) is typified by increasing values of Douglas-fir, continued presence of NAP and the addition of the xerophytic species Quercus garryana. A decrease in openings and eventual canopy closure can be seen in the decrease in NAP and PAR's, and increased T. heterophylla. Although initial influx rates for Douglas-fir are low (HL-4a), they rise rapidly (HL-4b) and then maintain high values (HL-4c), indicating increased cover. Quercus follows a similar trend for subzones HL-4a and HL-4b as Douglas-fir, but decreases significantly in subzone HL-4c. Plectritis, a known component of Garry oak meadow ecosystems (Roemer, 1972) is found at the HL-4b/HL-4c boundary. These trends indicate that Garry oak becomes established in the region approximately 8,000 years ago, expanding about 1,500 years later to establish open oak parkland with meadows. This vegetation lasted for only 1,000 years, before infilling of the canopy and a decrease in openings occurs. The climate of this zone was initially warm and dry (HL-4a), becoming moister and perhaps cooler in HL-4b, culminating with increasing moisture in HL-4c. Modern CDFmm parameters probably apply to this zone. The DWHIP diagram indicates that after the initial post-glacial period of cool to cold temperature (HL-1 and HL-2), the establishment of a vegetation community similar to the modern CDF occurs, and is maintained for the duration of the sequence.

Zone HL-5 (2,600 BP to 150 BP) is marked by increases in Abies (probably A. grandis), Picea and Pseudotsuga. The increase in true-fir and spruce values are probably a reflection of extra-local pollen rain, suggesting that the region may have experienced increased moisture. Increasing PAR's suggests continued forest closure. Ericaceae taxa, such as G. shallon or Vaccinium sp., along with Pteridium occur in the forest understorey. Other ericaceous species (e.g. Ledum groenlandicum) along with Cyperaceae, sedges and Lysichitum grew in abundance in newly developing bogs, fens and marshes around the lake margins. Oak remains in the ecosystem but is not nearly as abundant as in HL-4. Decreased oak values indicate the restricted nature of the oaks, however, significant parkland does still occur around the lake as shown by the presence of a diverse NAP including Rosaceae, grasses and monolete ferns.

The climate is cooler than the previous zone (HL-4) and may be moister, based on the significant increases in taxa such as Abies and Picea. However, even though Garry oak, an assumed xeric indicator (Heusser, 1960) declines in this zone, this does not necessarily mean that overall precipitation increases. In some cases, direct competition from Douglas-fir may cause a decrease in the oak population, or a restriction of its habitat (Stein, 1990). The increase in Pseudotsuga values support this. Overall, the climate of this zone approaches modern values with parameters similar to those of the CDFmm in which it is situated today.

The final zone, HL-6 (150 BP to present) reflects historic logging and land clearing. The increase in alder and NAP, coupled with a relative decline in western hemlock and Douglas-fir clearly indicates the changing nature of the landscape (Mathewes, 1973; Mathewes and Rouse, 1975). The changes in the arboreal signals, though not as strong as other south British Columbia sites (L. Heusser 1983), suggest that alteration of the forests was less extensive than in other areas.

It should be pointed out, that the low DWHIP values, except for zones HL-1 and HL-2, consistently show Pseudotsuga pollen dominates Tsuga heterophylla in the lowlands since 10,000 BP. This suggests that the CDF biogeoclimatic zone became established very early in the history of this site and has remained since the start of the Holocene.

Conclusions

Figure 16 shows the vegetation and climatic history of the Heal Lake area which begins with a lodgepole pine/alder forest (12,840 BP to 11,900 BP) on an unstable landscape under a cool to cold, dry climate. Moisture increases during HL-2, from 11,900 BP to 10,000 BP, while temperatures remain cool. The environment supported lodgepole pine and alder with significant shrub and herbaceous elements. Zone HL-3 (10,000 BP to 8,000 BP) reflects increasing temperature and decreasing moisture as pine and alder

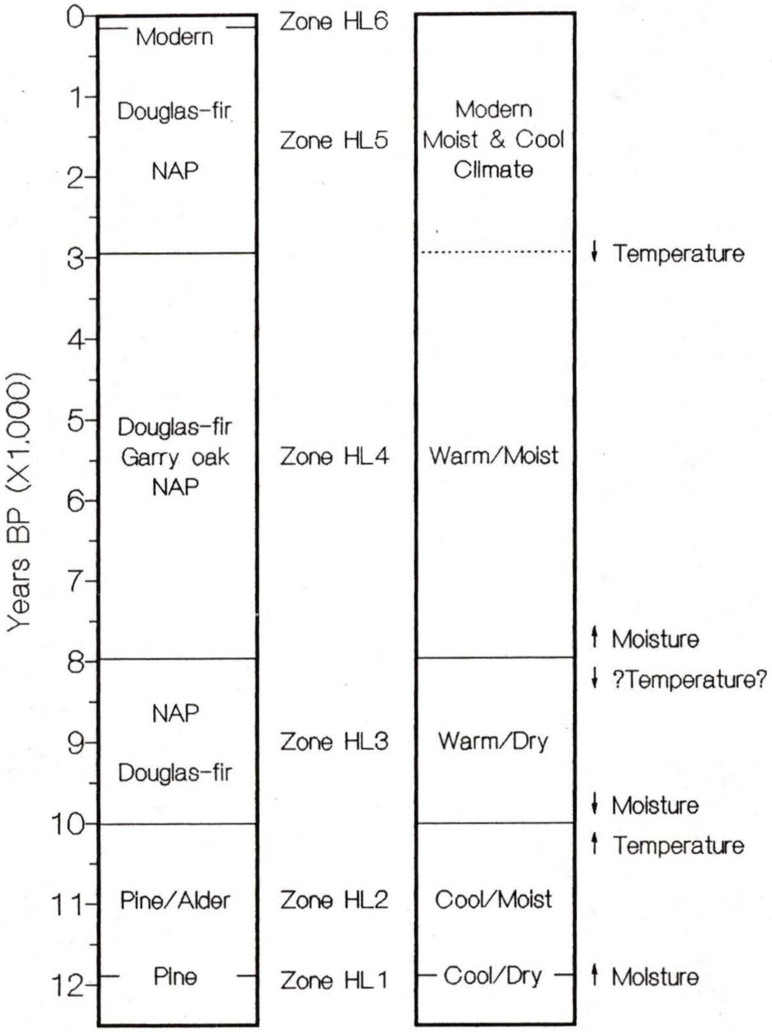

Figure 16. Vegetation and climatic history of Heal Lake

decrease and Douglas-fir increases. Meadows or grasslands expand during this interval. Zone HL-4 (8,000 BP to 2,600 BP), initially warm and dry, culminates with increasing moisture. A closing forest of mainly Douglas-fir occupies the landscape. Garry oak parkland and meadows expand initially during this interval, decrease in the latter part of the zone. The establishment of modern vegetation and climate occurs in zone HL-5. The forest is composed of mainly Douglas-fir with significant amounts of T. heterophylla and Cupressaceae (Thuja plicata). Herbaceous wetland and meadow species occur frequently as wetland communities develop at the edge of the lake. Change in forest composition due to agriculture and forestry practices has caused an increase in seral species such as alder and a real decrease in other coniferous species in the last 150 years.

Chapter 6: VEGETATION AND CLIMATIC HISTORY OF SOUTH VANCOUVER ISLAND AND THE ADJACENT REGION

Vegetation and Climate History

The vegetation and climate histories of Rhamnus and Heal Lakes on southeast Vancouver Island show a high degree of similarity (Fig. 17). Significant differences that do occur are related to species proportions and timing of vegetation changes between the highland interior Rhamnus Lake site and the lowland coastal Heal Lake site. In both areas, an initial phase of open lodgepole pine and alder forest occupied the landscape after the last of the glacial ice retreated from Vancouver Island 12,000 - 13,000 years ago. Unforested communities existed during this time in both the highlands and on the Saanich Peninsula. However, the Rhamnus Lake area appears to have supported more herbaceous species than the Heal Lake region. This difference is probably due to Rhamnus Lake's montane environment, where, at over 200 metres higher in elevation than Heal Lake, Rhamnus Lake was likely closer to retreating alpine glaciers during this cool (to cold) and dry period (Mathewes, 1973; Wainman and Mathewes, 1987; Hebda, 1995). High levels of both grasses and Artemisia support the subalpine nature of the highlands at this time.

Precipitation levels and perhaps temperature begin to increase around 11,800 BP at both sites. Increased moisture allowed the movement of more mesophytic species into the region. Spruce, true fir (Abies) and western hemlock expanded the diversity of the predominantly pine and alder upland, forest while the Heal Lake region supported a lodgepole pine woodland with bracken fern and alder in the understory and significant

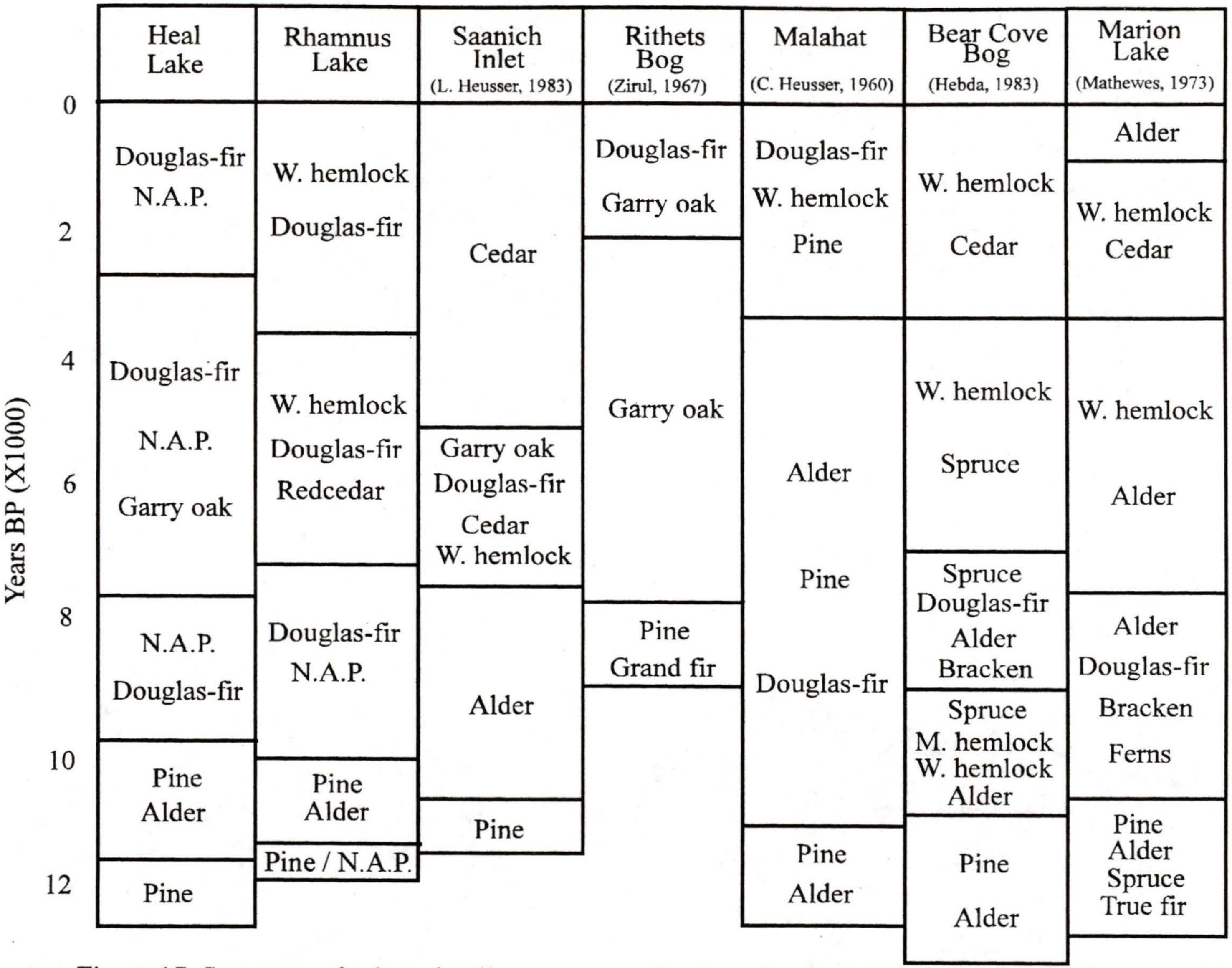

Figure 17. Summary of selected pollen sequences from southwest British Columbia. Pollen assemblages are designated by major taxa present.

grass/herb openings. The increasing number of tall conifer species at the Rhamnus Lake site may have caused the forest canopy to close, decreasing light levels needed by herbaceous species for growth. Also, increased precipitation at this time, may have caused groundwater levels to rise in the region, expanding the surface areas of both Rhamnus and Heal lakes; possibly further decreasing the lake marginal herbaceous vegetation at both sites. The climate during this period was still cool, but the increasing effective precipitation would have encouraged forest development.

A xerothermic period (Mathewes, 1973; Mathewes and Heusser, 1981), is obvious at both sites. This warm, dry interval marks the beginning of the Holocene, approximately 10,000 BP, with the introduction of Douglas-fir to the regional vegetation. This phase is typified at both sites by increased herbaceous flora, and a drying of the lake basins (decreased lake surface areas) to the point where Rhamnus Lake almost completely dries out as indicated by the presence of very high concentrations of entomophilous Rosaceae pollen (Spiraea douglasii and cf. Potentilla, see Fig. 10). This family, which produces pollen that are isopolar radially symmetric monads (Hebda et al., 1988; Hebda and Chinnappa, 1988, 1990), is not adapted for aerial transport, and therefore, such high concentrations of their pollen must indicate the presence of plants growing very near or at the site of deposition. Also, the general ecological characteristics of the genera and likely species further suggest substantial lowering of the watertable. Both Spiraea and Potentilla favour moist to wetland conditions such as meadows, swamps and lake margins (Hitchcock and Cronquist, 1973; Pojar and MacKinnon, 1994), or very shallow water, not a fully charged lake basin.

Forest structure and composition alter substantially at both the Heal and Rhamnus Lake sites. Increasing temperatures and decreasing effective precipitation during this time (Mathewes and Heusser, 1981) allow expansion of Douglas-fir into the region. At Rhamnus Lake, P. menziesii becomes the dominant conifer, probably leading to openings in the forest canopy which allowed an understory of bracken fern and grasses to develop.

The vegetation of the Heal Lake area during this time is not only indicative of a warm/dry climate, but of an open parkland type setting. Douglas-fir populations expand slowly in the lowlands compared to Rhamnus Lake. A mosaic of scattered Douglas-fir and alder groves, with an understory of bracken fern, occupied a herbaceous and grass dominated landscape including shrubs. High levels of Selaginella spores support the open nature of the vegetation as this genus characteristically grows on exposed rocky surfaces in high light (open) conditions (Hitchcock and Cronquist, 1973).

It is after the xerothermic period that Rhamnus and Heal Lake vegetation and climatic histories begin to diverge both in timing and composition. A post-xerothermic increase in western hemlock pollen suggests that temperatures began to decline and/or precipitation increased at Heal Lake approximately 8,000 years BP and at Rhamnus Lake about 7,000 years BP. It appears that these changes were more profound at the Rhamnus Lake site, as indicated by a rapid decline in Douglas-fir and a large increase in western hemlock pollen. Also, a marked increase in Cupressaceae (probably T. plicata) at Rhamnus Lake, 6,000 years ago, strongly indicates increasing moisture and decreasing temperatures in that area (Hebda and Mathewes, 1984). The herbaceous component of the highland vegetation decreased substantially as the western hemlock forest developed.

However, at Heal Lake Pseudotsuga actually increases substantially during this period, suggesting that temperatures probably remained warmer longer or precipitation did not increase to the same levels as in the highlands. The accompanying low levels of western hemlock at Heal Lake can probably be attributed to regional influx of pollen from the west, as T. heterophylla has reasonable long-range transport (Hebda and Allen, 1993). The shrub and herbaceous strata surrounding Heal Lake, although depressed, does not exhibit as severe a decline as that found at Rhamnus Lake during the same time period. This suggests that the vegetation occupying the lowlands remained open longer. These vegetation and structural differences indicate that the climate of the Saanich Peninsula was substantially different (drier and/or warmer) than that found in the highland area of Rhamnus Lake in the mid-Holocene.

A further indication of the climatic differences between the two sites can be seen in both the timing and distribution of the xeric Garry oak interval. At Rhamnus Lake, Quercus pollen is first observed at approximately 10,000 BP with a weak signal that continues throughout the Holocene. Except for a brief period at about 3,300 years BP, low oak pollen values found at Rhamnus Lake suggest that input is not locally, but regionally derived, and was perhaps similar to the distribution of oak found in the Koksilah valley today. At Heal Lake, oak pollen first becomes evident around 9,000 BP, and developed a much stronger signal, especially during the mid-Holocene. The late arrival of oak at the Heal Lake site is probably the result of competition between established xerothermic Pseudotsuga forests and the immigrating oak. Stein (1990) suggests that Q. garryana may have a restricted distribution more because of its inability to out-compete other seral species such as Pseudotsuga, rather than its xerothermic requirements. Also, as Quercus is not a very prolific pollen producer compared to other arboreal taxa, any grains that are deposited at the sites may be largely overshadowed by more prolific arboreal species such as pine and hemlock.

It is not until well beyond the xerothermic interval that oak becomes abundant at the two sites. The first indication of an increase in oak is observed in the Heal Lake core at about 7,000 BP and 3,300 BP in Rhamnus Lake sediments. At Heal Lake, oak occurs in such high concentrations that it could only have been produced from an almost pure oak biome that must have surrounded the lake. This would be a similar situation of oak parkland to that suggested by Zirul (1967) for the area surrounding Rithets Bog, 10 km to the southeast, during the same time period. The level of oak in the Rhamnus Lake area, although not as abundant as at Heal Lake, indicates its presence in the highlands, but not as a dominant element. Local climate during this period was probably too cool and/or moist to support extensive oak stands in the direct vicinity of Rhamnus Lake. However, it probably did occupy xeric sites and other suitable microhabitats , such as those found today on the south facing slopes of the Koksilah River valley, only 3 km distant.

Increasing precipitation along with moderating temperatures, approaching modern values, began to develop approximately 3,000 - 3,300 years BP. This climatic transition can be seen most clearly at the Heal lake site, where Douglas-fir reasserts itself as the dominant forest tree, and mesic to hygric non-arboreal types such as Lysichitum and Cyperaceae increase. Although Garry oak and its associated shrub and herbaceous component is still relatively abundant in the pollen record, it is substantially reduced from its previously high values. Modern forest composition develops during this period.

The establishment of today's CDF and CWH biogeoclimatic zones within modern limits of distribution occurs during this final phase. Using the DWHIP values as a proxy data to differentiate between dry (CDF) and moist (CWH) vegetation's, CDF-like conditions were present at both Heal Lake and Rhamnus Lake regions as early as 10,000 years BP. This does not mean that the structure and composition of the vegetation were the same as those found in the modern CDF, but rather the proportions of western hemlock and Douglas-fir are similar to today's values. This "proto-CDF" remained at both sites until the end of the xerothermic interval (approximately 7,000 BP), at which time, the changing climate, most pronounced in the highlands, causes the Rhamnus Lake forest composition to alter, producing more CWH-like characteristics approximately 6,000 years ago and continuing to the present. At Heal Lake, after the initial establishment of the CDF at the start of the Holocene (10,000 years BP), little alteration has occurred, and a CDF-like community has occupied the site for the duration of the Holocene.

Regional Comparison

The results of both cores agree favorably with the findings of other studies done on Vancouver Island (C. Heusser, 1960; Zirul, 1967; L. Heusser, 1983; Hebda, 1983) and coastal British Columbia (Mathewes, 1973, 1985). Figure 17 summarizes the vegetation and climatic histories developed by previous authors compared to my findings. It must be noted, that the sequence developed by Zirul (1967) has limited chronostratigraphic control, with Mazama ash (6,800 BP; Bacon, 1983) as the only date, and as such, the chronology of his sequence is comparable to the others in a general way.

Both C. Heusser (1960, 1985) and L. Heusser (1983), begin the south island regional sequence begin with a Pinus contorta dominated community under a cool to cold and dry climate approximately 12,000 years BP. The late post-glacial (ca. 11,500 BP to 10,000 BP) was a period of cool temperatures and increasing moisture and is typified by a substantial increase in Alnus and a minor increases in other coniferous taxa such as Picea, Abies, and Tsuga. It is during this period that Mathewes (1993) finds evidence of a Younger Dryas-like cooling approximately 10,500 BP.

The early Holocene warm/dry interval is recognized by all three authors (C. Heusser, 1960; Zirul, 1967; L. Heusser, 1983). The appearance of Pseudotsuga pollen is consistently found at the Pleistocene/Holocene boundary (10,400 - 10,000 BP). Increased moisture and possible cooling occurs in the mid-Holocene (approximately 8,000 BP to 4,000 BP), with the increase of T. heterophylla and later Cupressaceae (cf. Thuja plicata). A Quercus garryana maximum is recognized during this period, indicating that temperatures, although cooler than the previous phase, were probably still warmer than modern values (Hebda, 1995). After 4,000 BP, continued increasing moisture and moderation of temperatures to near modern values are indicated by the establishment of a modern forest community of primarily Douglas-fir on the Saanich Peninsula (L. Heusser, 1983; Zirul, 1967) and western hemlock in the upland areas (Malahat - C. Heusser, 1960).

The similarity of previous studies to these results indicates that the vegetation changes (and hence climatic changes) were not a localized phenomenon, but occurred over the entire south island region. Although the degree to which the forest community changed and the timing of these changes may differ slightly from locality to locality, the overall south island sequence is remarkably consistent. However, plant communities do not migrate into areas, individual species do (Hebda, 1982), and compared to areas outside of the south island region the vegetation histories may differ substantially. Therefore, the climatic trends that caused floristic and vegetation changes on south Vancouver Island ultimately resulted in changes elsewhere, albeit, in some cases with substantial differences in timing.

A study done on the north end of Vancouver Island near Port Hardy (Bear Cove Bog; Hebda, 1983) as well as a summary paper on mid-Holocene vegetation and climatic history (Hebda, 1995), shows an initial vegetation sequence consistent with those of the south island. From 14,000 BP to 11,500 BP, a Pinus contorta/Alnus woodland occupied the landscape, presumably under a cool to cold, dry climate. With increasing moisture, this community was replaced by a mixed coniferous forest (Picea, T. mertensiana and T. heterophylla) with Alnus, from the late-Pleistocene (11,500 BP) to the early Holocene (9,000 BP). Continued warming is recognized by the arrival and expansion of Pseudotsuga from 9,000 BP to 7,000 BP. This "northern" xerothermic period starts a millennium later than the xerothermic of the south, and is important in that it indicates the overall regional change to a warmer, drier climate. The vegetation of this phase was also significantly different than the Douglas-fir communities of the south island. Most notable is the lack of Garry oak (a xerophyte). It is difficult to say whether oak is absent due to the climatic conditions (too cool and moist)) or whether it did not have sufficient time to migrate so far north before the climate became too cold for its establishment by 7,000 BP. From 7,000 BP to 3,000 BP, increasing effective precipitation, and cooling temperatures caused an extensive western hemlock/spruce forest to develop. This hemlock/spruce community was significantly different from that found in the south, where Douglas-fir predominated. Modern forest composition (dominated by T. heterophylla and Thuja plicata), and climate became established after 3,000 BP.

Marion Lake, located in the University of British Columbia's research forest approximately 40 km northeast of the city of Vancouver in southwest British Columbia, is an important site with respect to studies of the climatic history of the Pacific Northwest (Mathewes, 1973,1985). Sediments from this lake have been extensively analyzed for pollen, macrofossils and chironomid larval remains. As well, a 12,000 year record of precipitation and temperature trends has been established on the basis of the pollen and the use of transfer functions (Mathewes and Heusser, 1981). The vegetation history of the Marion Lake area (Mathewes, 1973,1985), although comprising only five pollen zones, is very similar to that of south Vancouver Island. The initial pine/alder phase suggests cool, continental conditions prevailed after the ice melted. During the late-Pleistocene, a mixed forest of Abies, Picea and Tsuga mertensiana occupied the landscape under an increasingly moist environment. The early Holocene saw the introduction of Pseudotsuga and Tsuga heterophylla, with a decrease in true fir, spruce and mountain hemlock. Temperatures increased while precipitation decreased. This xerothermic phase extended from about 10,500 BP to approximately 7,500 BP. From 7,500 BP to 3,000 BP, increasing moisture and decreasing temperatures allowed for the development of a western hemlock/western redcedar forest. From 3,000 BP to present, the establishment of a modern climatic regime resulted in the increase in T. plicata to the detriment of other conifers. As with the results from Bear Cove Bog (north Vancouver Island), even though the species migrating into the region may have differed in proportion to those found on Vancouver Island, the climatic trends and states are consistent (Hebda, 1995).

In general, the quantitative climatic states and trends derived from the transfer functions, support the qualitative trend interpreted from pollen analysis. According to Mathewes and Heusser (1981) the early Holocene hypsithermal period was, on average, 2-4 C° warmer (July mean temperature) than the rest of the Holocene, with the greatest difference found in Alaska (4 C°) and the least in western Washington (1-2 C°). Precipitation was also lower during this time, with mean annual precipitation values of 900-1000 mm less in the Alaska region and 600 mm less in southwestern B.C. Both the temperature and precipitation values are consistent with the climatic trends determined from the Heal and Rhamnus lake cores.

In summary, throughout the Pacific Northwest, the timing of climatic events lag from south to north and with increasing elevation (C.Heusser, 1985; Hebda, 1995). Even though the vegetative history of the individual localities may differ, the climatic history is relatively consistent, varying slightly in magnitude and timing but never in expression. All regional records exhibit an initial cool, dry phase, supporting a pine/alder dominated community. Increasing moisture in the late-Pleistocene causes a change in community composition to mixed coniferous forest with abundant alder. A warm, dry xerothermic period is observed during the early Holocene, allowing more xerophytic species, such as

Douglas-fir, to proliferate. This period is followed by a trend of increasing moisture coupled, at least in the later stages, with decreasing temperature. More mesophytic to hygric species (e.g. western hemlock or western red cedar) comprise the forests of this time. Modern climate and forest community composition begin to appear approximately 3,000 BP, continuing to develop into the present.

Chapter 7: SUMMARY, APPLICATIONS AND CONCLUSIONS

Introduction

The results of pollen analysis of 50 modern surface sample sites and 2 lake sediment cores (Rhamnus Lake and Heal Lake) on southeast Vancouver Island shows that a series of vegetation and climatic changes have occurred in this region from the close of the Fraser Glaciation to the present. The interpretation of these changes can be aided by the use of modern surface sample analogues. The use of modern analogues does not imply that paleovegetation of a particular time and place was identical to its modern biogeoclimatic equivalent, rather, the growth conditions of the paleocommunity must have been similar to present if it supported a similar flora. The vegetation and climate history, beginning with a recently deglaciated landscape, is detailed through successive changes to our modern moderate and moist climate and vegetation communities. The history was compared to other studies done on Vancouver Island, the lower mainland and the northwest coast of Washington and Oregon. The potential applications of the study will now be discussed, and the major conclusions summarized.

Applications

The results from this investigation have a broad range of applications. The modern surface and the lake sediment data contribute to a growing data base of late Quaternary paleoenvironmental information in British Columbia (Hebda, 1995). This data base is available to archeologists to form environmental frameworks in which to view past cultures. Paleobotanists can use the data to help understand today's vegetation and species distributions in the rare ecosystems of southeast Vancouver Island. Paleoclimatologists can use these results to reveal the history of regional climate states and trends. Concerning forest management, this study clearly demonstrates that today's transitional forests have a high degree of sensitivity to potential climate change.

The modern surface sample data will provide the base to a larger study that will describe all the biogeoclimatic zones and variants of south Vancouver Island in terms of their respective pollen signatures. The modern plant communities and their signatures contribute modern analogues for future palynologic work in this area and adjacent regions. A high resolution data base of this type will be extremely valuable for use in future paleovegetation and paleoclimatic reconstructions of Pacific Northwest sites.

The Heal Lake history contributes the basic framework for a much larger, comprehensive study. Heal Lake was completely drained in the spring of 1992 and the basin was extensively sampled over a six month period. The study of its sediments will include not only the palynology of multiple sequences from the middle of the lake basin to its margins, but macrofossil, dendrochronologic, isotopic and charcoal analyses as well. This plethora of information will provide a detailed history of the formation of the lake and the surrounding regional vegetation. Coupled with paleohydrologic studies the investigations will establish Heal Lake as a comprehensive paleoecological reference study site.

Data from both the Rhamnus and Heal Lake cores, contributes to the construction of maps of potential sensitivity of regional forests to future climatic warming. Regional

CDF forests (e.g. Heal lake) may convert to parkland and thus become less productive, while regional CWH forests may shift toward a CDF type regime. The results of this study establish the eastern most terminus of an east-west transect of a series of cores that will be used to investigate the sensitivity of forests on south Vancouver Island. The history of Quercus garryana and its associated rare meadow species clearly indicates that this rare and endangered ecosystem was once much more extensive. Its past extent further identifies areas of potentially lower timber productivity resulting from climatic change.

Conclusions

The following conclusions have been reached from the analyses performed during this investigation:

1) Modern surface sample pollen spectra, obtained from vegetation communities as defined by the B.C. Ministry of Forests biogeoclimatic ecosystem classification, provide a sufficiently distinct signature to be used as analogues for past vegetation. Garry oak and grassland communities are easily separated from the arboreal dominated CDF, CWH and MH zones. The CDF and drier CWH communities of the east side of the island are palynologically distinct from the wetter west coast, while the MH is defined by mountain hemlock pollen.

2) The use of Garry oak as an indicator of xeric communities, and therefore low forest productivity, is possible. If the paleorecord contains pollen zones with spectra exhibiting high oak pollen values relative to other arboreal pollen, it is reasonable to assume that the

vegetation composition and structure would be similar to that of the modern Garry oak site association, that is, an open parkland with scattered trees and shrubs and a rich herbaceous flora.

3) A general index of gross effective precipitation can be calculated using the combined total of Pseudotsuga menziesii and Tsuga heterophylla pollen in the paleorecord. These DWH indices of precipitation reflect the dominance of xeric Douglas-fir to mesic western hemlock or vice versa. High index values indicate high proportions of western hemlock in the forest vegetation and therefore a higher effective precipitation whereas low values indicate higher proportions of Douglas-fir pollen and subsequently lower effective precipitation.

4) The vegetative histories of Rhamnus and Heal Lakes are initially very similar, diverging radically 7,000 - 8,000 years ago. Initial vegetation at both sites consisted of lodgepole pine and alder on a post-glacial landscape. Forest composition changes in the late Pleistocene exhibiting a greater diversity of coniferous species. The start of the Holocene is marked by the introduction of Douglas-fir pollen to the paleorecord. Douglas-fir dominated the partially closed upland forests, whereas the lowlands of the Saanich Peninsula supported open Douglas-fir parkland up to the mid-Holocene. Increasing western hemlock around Rhamnus Lake during the mid-Holocene suggests a change in the regional vegetation from CDF like characteristics to CWH like characteristics which continue today. From the beginning of the Holocene to present, the Heal Lake region has continued to exhibit CDF like characteristics.

5) The climatic history of southeast Vancouver Island is consistent with other studies done in the region. Although magnitude and timing of climatic events may differ slightly from site to site due to local conditions, the general trends are remarkably similar. An initial cool to cold and dry post-glacial period is followed by increasing moisture and temperatures until, at the start of the Holocene, a xerothermic interval results. This warm/dry interval lasts for approximately 2,000 - 3,000 years. Increasing moisture and/or decreasing temperatures occur during the latter part of this period to the mid-Holocene. From the mid-Holocene to the late-Holocene, temperature and effective precipitation levels stabilize to near present values and a moderate climate develops.

This study demonstrates that the development of a paleoenvironmental data base for the Vancouver Island region is useful for understanding the relationship between paleovegetation and paleoclimate. This information can be applied to modern forest management to provide an indication of potentially sensitive areas to climatic alterations, and to what extent and direction a regions vegetation will change. It is hoped that the increased understanding gained from this study will lead to both a recognition of the importance of paleoecologic work in understanding and adapting to future climate changes and the recognition of the importance of rare ecosystems, like the Garry oak community, to our region's vegetation heritage.

REFERENCES

Alley, N.F. 1976. The palynology and palaeoclimatic significance of dated core of Holocene peat, Okanagan Valley, southern British Columbia. Canadian Journal of Earth Sciences, 13:1131-1144.

Alley, N.F. 1979. Middle Wisconsin stratigraphy and climate reconstruction, southern Vancouver Island, British Columbia. Quaternary Research, 11:213-237.

Armstrong, J.E. 1981. Post-Vashon Wisconsin glaciation, Fraser Lowland, British Columbia. Geological Survey of Canada, Bulletin 322.

Armstrong, J.E., Crandell, D.R., Easterbrook, D.J., and Noble, J.B. 1965. Pleistocene stratigraphy and chronology in southwestern British Columbia and northwest Washington. Geological Society of America Bulletin, 76:321-330.

Bacon, C.R. 1983. Eruptive history of Mount Mazama and Crater Lake Caldera, Cascade Range, U.S.A. Journal of Volcanology and Geothermal Research, 18:57-115.

B.C. Ministry of Forests. 1979. Biogeoclimatic units of central and southern Vancouver Island. Research Branch, Ministry of Forests, Victoria B.C.

B.C. Ministry of Forests. 1991. Ecosystems of British Columbia. Special Report Series #6. Research Branch, Ministry of Forests, Victoria B.C.

B.C. Ministry of Forests. 1993. Biogeoclimatic units of the Vancouver forest region: Southern Vancouver Island and Sunshine Coast. Map Sheet 5 and 6, 1:250,000. Research Branch, Ministry of Forests, Victoria B.C.

Birks, H.J.B. and Birks, H.H. 1980. Quaternary Palaeoecology. Edward Arnold Publishers Ltd., London.

Birks, H.H., Birks, H.J.B., Kaland, P.E. and Moe, D. 1988. The Cultural Landscape: Past, Present and Future. Cambridge University Press.

Cawker, K.B. 1983. Fire history and grassland vegetation change: three pollen diagrams from southern British Columbia. Canadian Journal of Botany 61:1126-1139.

Clague, J.J. 1980. Late Quaternary geology and geochronology of British Columbia. Part 1: Radiocarbon dates. Geological Survey of Canada, Paper, 80-13:1-28.

Clague, J.J. 1981. Late Quaternary geology and geochronology of British Columbia. Part 2: Summary and discussion of radiocarbon-dated Quaternary history. Geological Survey of Canada Paper, 80-35:1-41.

Clague, J.J. 1991. Quaternary glaciation and sedimentation. In Geology of the Cordilleran orogen in Canada, H. Gabrielse and C.J. Yorath (eds.), Geological Survey of Canada, Geology of Canada, No. 4:419-434.

Clague, J.J., Armstrong, J.E. and Mathewes, W.H. 1980. Advance of the late Wisconsin Cordilleran ice sheet in southern British Columbia since 22,000 yr BP. Quaternary Research, 13:322-326.

Clague, J.J., Harper, J.R., Hebda, R.J. and Howes, D.E. 1981. Late Quaternary sea level and crustal movements, coastal, British Columbia. Canadian Journal of Earth Sciences, 19:597-618

Clague, J.J. and R.W. Mathewes. 1989. Early Holocene thermal maximum in western North America: New evidence from Castle Peak, British Columbia. Geology 17:277-280.

Crandell, D.R., Mullineaux, D.R. and Waldon, H.H. 1958. Pleistocene sequence in the southeastern part of the Puget Sound lowland, Washington. American Journal of Science, 256:384-397.

Cwynar, L.C. 1987. Fire and the forest history of the north Cascade Range. Ecology, 68:791-802.

Cwynar, L.C. 1988. Late Quaternary vegetation history of Kettlehole Pond, southwestern Yukon. Canadian Journal of Forest Research 18:1270-1279.

Delcourt, H.R. and Pittillo, J.D. 1986. Comparison of contemporary vegetation and pollen assemblages: an altitudinal transect in the Balsam Mountains, Blue Ridge Province, western North Carolina, U.S.A. Grana, 25:131-141.

Ecoregions Working Group. 1989. Ecoclimatic Regions of Canada, First Approximation. Ecoregions Working Group of the Canada Committee on Ecological Land Classification. Ecological Land Classification Series, No. 23, Sustainable Development Branch, Canadian Wildlife Service, Conservation and Protection, Environment Canada, Ottawa.

England, T.D.J. and Calon, T.J. 1991. The Cowichan fold thrust system, Vancouver Island, southwestern British Columbia. Geological Society of America Bulletin, 103: 336-362.

Faegri, K. and Iversen, J. 1975. Textbook of Pollen Analysis. 2nd ed. Hafner Publishing Co., New York.

Fall, P.L. 1992. Pollen accumulation in a montane region of Colorado, U.S.A.: a comparison of moss polsters, atmospheric traps, and natural basins. Review of Palaeobotany and Palynology, **72**: 169-197.

Fedje, D.W. 1993. Sea-levels and prehistory in Gwaii Haanas. M.A. Thesis, Department of Archaeology, University of Calgary, Calgary.

Fulton, R. 1971. Radiocarbon geochronology of southern British Columbia. Geological Survey of Canada, Paper, 71-37:1-28.

Fyles, J.G. 1963. Surficial geology of the Horne Lake and Parksville map-areas, Vancouver Island, British Columbia. Geological Survey of Canada Mem. 318.

Hansen, H.P. 1947. Postglacial forest succession, climate and chronology, in the Pacific Northwest. Transactions of the American Philosophical Society (N.S.) 37(1).

Hebda, R.J. 1977. The paleoecology of a raised bog and associated deltaic sediments of the Fraser River Delta. Ph.D. Thesis. University of British Columbia, Vancouver, 201 p.

Hebda, R.J. 1982. Postglacial history of grasslands of southern British Columbia and adjacent regions; In Grassland Ecology and Classification Symposium Proceedings, ed. A.C. Nicholson, A. McLean, and T.E. Baker: British Columbia Ministry of Forests, Victoria, British Columbia. p. 157-191.

Hebda, R.J. 1983. Late-glacial and postglacial vegetation history at Bear Cove Bog, northeast Vancouver Island, British Columbia. Canadian Journal of Botany, 61:3172-3192.

Hebda, R.J. 1984. Postglacial vegetation history of Brooks Peninsula, Vancouver Island, British Columbia. In Abstracts, 6th International Palynological Conference, August 26 - September 1, 1984, Calgary, Canada. p. 62.

Hebda, R.J. 1993 Climate history, Heal Lake, Vancouver Island, British Columbia. Program with Abstracts and Field Guide. Canadian Quaternary Association. Meeting, April 18-21, 1993, Victoria, B.C. p A20.

Hebda, R.J. 1995. British Columbia vegetation and climate history with focus on 6 ka BP. Géographie physique et Quaternaire. 49(1):55-79.

Hebda, R.J. (in press). Late Quaternary Paleoecology of Brooks Peninsula. Accepted for publ. In Hebda, R.J. and Haggarty J.C. eds. Brooks Peninsula: A Glacial Refugium. To be published by Royal British Columbia Museum.

Hebda, R.J. and Allen, G.B. 1993. Modern pollen spectra from west central British Columbia. Canadian Journal of Botany, 71:1486-1495.

Hebda, R.J. and Chinnappa, C.C. 1988. Studies on pollen morphology of Rosaceae in Canadian Review of Palaeobotany and Palynology, 64: 103-108.

Hebda, R.J. and Chinnappa, C.C. 1990. Pollen morphology of the Rosaceae of western Canada, III. Geum. Canadian Journal of Botany, 68:1369-1378.

Hebda, R.J., Chinnappa, C.C. and Smith, B.M. 1988. Pollen morphology of the Rosaceae of western Canada, II. Dryas, Fragaria, Holodiscus. Canadian Journal of Botany, 66:595-612.

Hebda, R.J. and Mathewes, R.W. 1984. Holocene history of cedar and Native Indian cultures of the North American Pacific Coast. Science, 225:711-713.

Hebda, R.J. and Rouse, G.E. 1979. Palynology of two Holocene cores from the Hesquiate Peninsula, Vancouver Island, British Columbia. Syesis, 12:121-129

Heide, K.M. and Bradshaw, R. 1982. The pollen-tree relationship within forests of Wisconsin and upper Michigan, U.S.A. Review of Palaeobotany and Palynology, 36:1-23.

Heusser, C.J. 1960. Late-Pleistocene environments of North Pacific North America. American Geographical Society Special Publication No. 35.

Heusser, C.J. 1969. Modern pollen spectra from the Olympic Peninsula, Washington. Bulletin of the Torrey Botanical Club, 96:407-417.

Heusser, C.J. 1973. Modern pollen spectra from Mount Rainer, Washington. Northwest Science, 47:1-8.

Heusser, C.J. 1978a. Modern pollen spectra from western Oregon. Bulletin of the Torrey Botanical Club, 105:14-17.

Heusser, C.J. 1978b. Modern pollen rain in the Puget Lowland of Washington. Bulletin of the Torrey Botanical Club, 105: 296-305.

Heusser, C.J. 1985. Quaternary pollen records from the Interior Pacific Northwest Coast: Aleutians to the Oregon-California boundary. In: V.M. Bryant and R.G. Holloway (Eds.) Pollen Records of Late-Quaternary North American Sediments. (Texas. pp. 141-165) American Association of Stratigraphic Palynologists Foundation, Dallas.

Heusser, L.E. 1983. Palynology and paleoecology of postglacial sediments in an anoxic basin, Saanich Inlet British Columbia. Canadian Journal of Earth Sciences, 20:873-885.

Heusser, C.J., Heusser, L.E. and Streeter, S.S. 1980. Quaternary temperatures and precipitation for the northwest coast of North America. Nature, 286:702-704.

Hicock, S.R., Hebda, R.J., and Armstrong, J.E. 1981. Lag of the Fraser glacial maximum in the Pacific Northwest: pollen and macrofossil evidence from western Fraser Lowland, British Columbia, 19:2288-2296.

Hitchcock, C.L. and Cronquist, A. 1973. Flora of the Pacific Northwest: An Illustrated Manual. University of Washington Press, Washington, U.S.A.

Holland, S.S. 1976. Landforms of British Columbia: a physiographic outline. 2nd ed. B.C. Department of Mines Petroleum and Energy Resources, Bulletin, No. 48. Victoria B.C.

Kapp, R.O. 1969. How to Know Pollen and Spores. Nature Key Series. Wm. C. Brown and Co. Publishers. Iowa.

Kovach, W.L. 1990. M.V.S.P. 2: A Multivariate Statistics Package. Institute of Earth Studies, University College of Wales. Wales, U.K.

Krajina, V.J. 1965. Biogeoclimatic zones and biogeocoenoses of British Columbia. Ecology of Western North America, 1:1-17.

Krajina, V.J. 1969. Ecology of forest trees in British Columbia. Ecology of Western North America, 2:146.

Krajina, V.J., Klinka, K. and Worrall, J. 1982. Distribution and ecological characteristics of trees and shrubs of British Columbia. Faculty of Forestry, University of British Columbia, Vancouver.

Lamb, H.F. 1984. Modern pollen spectra from Labrador and their use in reconstructing Holocene vegetational history. Journal of Ecology, 72:37-59.

Liu, K. and Lam, N.S. 1985. Paleovegetational reconstruction based on modern and fossil pollen: an application of discriminant analysis. Annals of the Association of American Geographers, **75**: 115-130.

Mathewes, R.W. 1973. A palynological study of postglacial vegetation changes in the University Research Forest, southwestern British Columbia. Canadian Journal of Botany 51:2085-2103.

Mathewes, R.W. 1985. Paleobotanical evidence for climatic change in southern British Columbia during Late-glacial and Holocene time. In C.R. Harington (Ed.) Climate Change in Canada 5: Critical Periods in the Quaternary Climatic History of Northwestern North America. Syllogeus 55:397-422.

Mathewes, R.W. 1989. Paleobotany of the Queen Charlotte Islands. pp 75-90. In: G.G.E. Scudder and N. Gessler (Eds.) The Outer Shores. (August 1984. 327 pp) (:) Based on the proceedings of the Queen Charlotte Islands First International Symposium, University of British Columbia, Vancouver, B.C.

Mathewes, R.W. 1993. Evidence for Younger Dryas-Age cooling on the North Pacific Coast of America. Quaternary Science Reviews, 12:321-331.

Mathewes, R.W. and Rouse, G.E. 1975. Palynology and paleoecology of early postglacial sediments from the lower Fraser River Canyon of British Columbia. Canadian Journal of Earth Sciences, 12:745-756.

Mathewes, R.W. and Heusser, L.E. 1981. A 12,000-year palynological record of temperature and precipitation trends in southwestern British Columbia. Canadian Journal of Botany, 51: 707-710.

Mathewes, R.W. and King, M. 1989. Holocene vegetation, climate, and lake-level changes in the Interior Douglas-fir Biogeoclimatic Zone, British Columbia. Canadian Journal of Earth Sciences, 26:1811-1825.

McAndrews, J.H., Berti, A.A. and Norris, G. 1973. Key to the Quaternary pollen and spores of the Great Lakes region. Life Sciences Miscellaneous Publications, Royal Ontario Museum. Ontario.

McLain, D.H. 1974. Drawing contours from arbitrary data points. The Computer Journal, 17:318-324.

Moore, P.D. and Webb, J.A. 1978. An Illustrated Guide to Pollen Analysis. Hodder and Stoughton, London

Moore, P.D., Webb, J.A. and Collinson, M.E. 1991. Pollen Analysis. Blackwell Scientific Publications, Oxford.

Mott, R.J. 1976. Populus in the late-Pleistocene pollen spectra. Canadian Journal of Botany, 56:1021-1031.

Mueller-Dambois, D. and Ellenberg, H. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York.

Myers, R.H. 1986. Classical and modern regression with applications. Prindle, Webber and Schmidt Publishers, Boston.

Parsons, R.W. and Prentice, I.C. 1981. Statistical approaches to R-values and the pollen-vegetation relationship. Review of Palaeobotany and Palynology, 32:127-152.

Pojar, J. and MacKinnon, A. (eds.). 1994. Plants of coastal British Columbia including Washington, Oregon and Alaska. B.C. Ministry of Forests. Lone Star Publishing, Vancouver B.C.

Prentice, I.C. 1983. Pollen representation, source area and basin size: Toward a unified theory of pollen analysis. Quaternary Research., 23:76-86.

Prentice, I.C. 1986. Vegetation responses to past climatic changes. Vegetatio, 67:131-141.

Quickfall, G.S. 1987. Paludification and the climate on the Queen Charlotte Islands during the past 8000 years. M.Sc. thesis, Department of Biological Sciences, Simon Fraser University, Burnaby. 99 p.

Roemer, H.L. 1972. Forest vegetation and environments on the Saanich Peninsula. Ph.D. Thesis. Department of Biology, University of Victoria, Victoria, B.C.

Roemer, H.L. 1993. Vegetation and ecology of Garry oak woodlands. In . R.J. Hebda and F. Aitkens (Eds.) Garry oak-meadow colloquium, Victoria 1993: Proceedings. Garry Oak Meadow Preservation Society. Victoria, B.C. pp 19-24.

Ryder, J.M. 1987. Neoglacial history of the Stikine-Iskut area, northern Coast Mountains, British Columbia. Canadian Journal of Earth Sciences, 24:1294-1301.

Stein, W.I. 1990. Quercus garryana Dougl. ex Hook Oregon White Oak. In Burns, R.M. and B.H.Honkala. Silvics of North America Volume 2, Hardwoods. Agriculture Handbook 654, Forest Service, United States Department of Agriculture, Washington D.C. pp.650-660.

Straley, G.B., Taylor, R.L. and Douglas, G.W. 1985. The rare vascular plants of British Columbia. National Museum of Canada, Syllogeus No. 59. Ottawa, Ont.

ter Braak, C.J.F. 1983. Principle components biplots and alpha and beta diversity. Ecology, 64:454-462.

Tsukada, M. 1982. Pseudotsuga menziesii (Mirb.) Franco: its pollen dispersal and late Quaternary history in the Pacific Northwest. Japanese Journal of Ecology, 32:159-181.

Wainman, N. and Mathewes, R.W. 1987. Forest history of the last 12,000 years based on plant macrofossil analysis of sediment from Marion Lake, southwestern British Columbia. Canadian Journal of Botany, 65:2179-2187.

Walmsley, M., Utzig, T., Vold, T., Moon, D. and van Barneveld, J. (editors). 1980. Describing ecosystems in the field. B.C. Ministry of the Environment / B.C. Ministry of Forests. RAB Technical Paper, 2 / Land Management Report No. 7. Victoria B.C.

Warner, B.G. 1984. Late Quaternary paleoecology of eastern Graham Island, Queen Charlotte Islands, British Columbia, Canada; Ph.D. thesis. Department of Biological Sciences, Simon Fraser University, Vancouver, B.C. 190 p.

Webb, T, III. 1974. Corresponding patterns of pollen and vegetation in Lower Michigan: A comparison of quantitative data. Ecology, 55:17-28.

White, J.M. 1988. Methodology of the exotic spike: Differential settling of palynomorphs during sample preparation. Pollen et Spores, 30:131-148.

Whitlock, C. 1992. Vegetation and climatic history of the Pacific Northwest during the last 20,000 years: Implications for understanding present-day biodiversity. Northwest Environmental Journal, 8:5-28.

Wilkinson, L. 1990. Sygraph: The System for Graphics. Evanston, Il: SYSTAT, Inc.

Williams, H.F.L. and Hebda, R.J. 1991. Palynology of Holocene top-set aggradational sediments of the Fraser River Delta, British Columbia. Palaeogeography, Palaeoclimatology, Palaeoecology, 86:297-311.

Zirul, D. 1967. Pollen analysis of a bog in the Garry Oak Zone of southern Vancouver Island, B.C. B.Sc. Thesis, University of Victoria, Victoria, B.C.

Appendix 1. Similarities and node clustered from UPGMA cluster analysis from surface sample data.

Node	Group 1	Group 2	Similarity	Number of Nodes in Fused Group
1	CWHMM2	CWHMM2	0.991	2
2	CWHXM2	CWHXM2	0.988	2
3	CWHVM1	CWHVM1	0.984	2
4	CWHXM1	NODE 2	0.974	3
5	CDFMM1	CDFMM1	0.972	2
6	MHMM1	MHMM1	0.969	2
7	CWHXM1	NODE 4	0.962	4
8	CWHXM1	CWHXM1	0.954	2
9	NODE 7	NODE 1	0.952	6
10	NODE 3	CWHVM1	0.951	3
11	CWHVM1	CHWVH1	0.950	2
12	NODE 5	CDFMM1	0.949	3
13	CWHVM1	NODE 11	0.943	3
14	NODE 6	MHMM1	0.941	3
15	NODE 14	MHMM1	0.935	4
16	CDFMM1	NODE 9	0.934	7
17	NODE 16	CWHXM2	0.917	8
18	NODE 8	CWHXM2	0.914	3
19	NODE 18	CWHXM1	0.905	4
20	NODE 10	CWHVH1	0.900	4
21	NODE 12	CDFMM1	0.897	4
22	CWHVM2	CWHVM2	0.887	2
23	NODE 21	NODE 19	0.884	8
24	NODE 13	NODE 20	0.881	7
25	NODE 15	MHMM1	0.881	5
26	GRASS	GRASS	0.873	2
27	CWHXM2	CWHVM2	0.873	2
28	CWHVM2	CWHVH1	0.870	2
29	CWHMM2	CWHVM2	0.833	2
30	GO	GO	0.832	2

Appendix 1. (cont.)

Node	Group 1	Group 2	Similarity	Number of Nodes in Fused Group
31	CWHMM2	CWHMM2	0.823	2
32	GRASS	NODE 26	0.819	3
33	NODE 27	NODE 24	0.800	9
34	NODE 23	NODE 17	0.792	16
35	NODE 30	GO	0.789	3
36	GRASS	NODE 32	0.786	4
37	NODE 33	NODE 28	0.781	11
38	NODE 36	GRASS	0.765	5
39	NODE 29	NODE 22	0.756	4
40	NODE 37	CWHVH1	0.727	12
41	NODE 40	NODE 39	0.712	16
42	NODE 35	GO	0.707	4
43	NODE 34	NODE 25	0.687	21
44	NODE 43	NODE 41	0.643	37
45	GO	NODE 42	0.636	5
46	NODE 38	NODE 45	0.562	10
47	NODE 44	NODE 31	0.540	39
48	NODE 47	CWHVH1	0.495	40
49	NODE 48	CWHVH1	0.485	41
50	NODE 46	NODE 49	0.466	51

Appendix 2. DWH Index of Precipitation values for Rhamnusl Lake samples.

Sample	Pollen Zone	T. heterophylla	P. menziesii	Total Pollen	DWHIP	Average DWHIP
00-10	RL-6	90	32	122	0.74	0.71
10-20	RL-6	104	50	154	0.68	
20-30	RL-5	136	79	215	0.63	
30-40	RL-5	133	96	229	0.58	
40-50	RL-5	140	80	220	0.64	
50-60	RL-5	162	96	258	0.63	
60-70	RL-5	141	118	259	0.54	
70-80	RL-5	84	116	200	0.42	
80-90	RL-5	65	82	147	0.44	
110-120	RL-5	115	113	228	0.50	
120-130	RL-5	96	98	194	0.49	0.52
130-140	RL-5	123	85	208	0.59	
140-150	RL-5	107	83	190	0.56	
150-160	RL-5	102	97	199	0.51	
160-170	RL-5	75	107	182	0.41	
170-180	RL-5	73	95	168	0.43	
180-190	RL-5	70	135	205	0.34	
190-200	RL-5	98	90	188	0.52	
200-210	RL-4	111	76	187	0.59	
210-220	RL-4	118	99	217	0.54	
220-230	RL-4	91	75	166	0.55	
230-240	RL-4	124	69	193	0.64	
240-250	RL-4	75	49	124	0.60	
250-260	RL-4	97	91	188	0.52	
260-270	RL-4	93	64	157	0.59	
270-280	RL-4	91	72	163	0.56	
280-290	RL-4	81	69	150	0.54	
290-300	RL-4	100	92	192	0.52	
310-320	RL-4	78	75	153	0.51	0.55
320-330	RL-4	111	48	159	0.70	
330-340	RL-4	98	78	176	0.56	
340-350	RL-4	93	93	186	0.50	
350-360	RL-4	79	71	150	0.53	
360-370	RL-4	130	73	203	0.64	
370-380	RL-4	93	84	177	0.53	
380-390	RL-4	127	89	216	0.59	
390-400	RL-4	54	76	130	0.42	
420-430	RL-4	47	119	166	0.28	
430-440	RL-3	51	136	187	0.27	
440-450	RL-3	30	79	109	0.28	

Appendix 2. (cont.)

Sample	Pollen Zone	T. heterophylla	P. menziesii	Total Pollen	DWHIP	Average DWHIP
450-460	RL-3	30	99	129	0.23	
460-470	RL-3	31	156	187	0.17	
470-480	RL-3	34	131	165	0.21	
480-490	RL-3	32	108	140	0.23	
490-500	RL-3	23	64	87	0.26	
510-520	RL-3	15	134	149	0.10	
520-530	RL-3	22	114	136	0.16	
530-540	RL-3	17	123	140	0.12	
540-550	RL-3	9	107	116	0.08	0.16
550-560	RL-3	16	137	153	0.10	
560-570	RL-3	10	130	140	0.07	
570-580	RL-3	15	56	71	0.21	
580-590	RL-3	6	75	81	0.07	
590-595	RL-3	12	60	72	0.17	
595-600	RL-3	7	81	88	0.08	
600-605	RL-3	7	72	79	0.09	
605-610	RL-3	10	44	54	0.19	
610-615	RL-2	8	7	15	0.53	
615-620	RL-2	13	2	15	0.87	
620-625	RL-2	10	0	10	1.00	
625-630	RL-2	10	0	10	1.00	
630-635	RL-2	12	1	13	1.00	
635-640	RL-2	8	0	8	1.00	
640-645	RL-2	12	0	12	1.00	
645-650	RL-2	9	0	9	1.00	0.96
650-655	RL-2	6	0	6	1.00	
655-660	RL-2	6	0	6	1.00	
660-665	RL-2	12	0	12	1.00	
665-670	RL-2	4	1	5	1.00	
670-675	RL-2	0	0	0		
675-680	RL-2	2	0	2	1.00	
685-690	RL-2	4	0	4	1.00	
690-695	RL-2	3	0	3	1.00	
695-700	RL-1	0	0	0		
700-705	RL-1	0	0	0		
710-715	RL-1	0	0	0		

Appendix 3. DWH Index of Precipitatioin values for Heal Lake.

Sample	Pollen Zone	T. heterophylla	P. menziesii	Total Pollen	DWHIP	Average DWHIP
00-10	HL-6	20	68	88	0.23	0.25
10-20	HL-6	18	50	68	0.26	
20-30	HL-5	9	47	56	0.16	
30-40	HL-5	9	42	51	0.18	
40-50	HL-5	10	83	93	0.11	
50-60	HL-5	10	89	99	0.10	
60-70	HL-5	6	91	97	0.06	
70-80	HL-5	9	85	94	0.10	
80-90	HL-5	11	99	110	0.10	0.11
90-100	HL-5	14	105	119	0.12	
100-110	HL-5	9	121	130	0.07	
110-120	HL-5	10	99	109	0.09	
120-130	HL-5	13	148	161	0.08	
130-140	HL-5	14	92	106	0.13	
140-150	HL-5	17	151	168	0.10	
150-160	HL-5	27	109	136	0.20	
160-170	HL-4	24	119	143	0.17	
170-180	HL-4	13	62	75	0.17	
180-190	HL-4	31	208	239	0.13	
190-200	HL-4	27	116	143	0.19	
200-210	HL-4	31	81	112	0.28	
210-220	HL-4	16	38	54	0.30	
220-230	HL-4	30	107	137	0.22	
230-240	HL-4	40	109	149	0.27	
240-250	HL-4	42	88	130	0.32	
250-260	HL-4	27	129	156	0.17	
260-270	HL-4	33	120	153	0.22	
270-280	HL-4	35	112	147	0.24	0.19
280-290	HL-4	28	114	142	0.20	
290-300	HL-4	20	131	151	0.13	
440-450	HL-4	19	106	125	0.15	
450-460	HL-4	38	184	222	0.17	
460-470	HL-4	22	92	114	0.19	
470-480	HL-4	27	107	134	0.20	
480-490	HL-4	7	74	81	0.09	
490-500	HL-4	19	90	109	0.17	
500-510	HL-4	18	88	106	0.17	
510-520	HL-4	8	94	102	0.08	
520-530	HL-4	16	95	111	0.14	
530-540	HL-4	17	73	90	0.19	

Appendix 3. (cont.)

Sample	Pollen Zone	T. heterophylla	P. menziesii	Total Pollen	DWHIP	Average DWHIP
540-550	HL-3	11	52	63	0.17	0.28
550-560	HL-3	6	59	65	0.09	
560-570	HL-3	11	49	60	0.18	
570-580	HL-3	5	26	31	0.16	
580-590	HL-3	1	21	22	0.05	
590-600	HL-3	9	43	52	0.17	
600-610	HL-3	10	29	39	0.26	
610-620	HL-3	7	33	40	0.18	
620-630	HL-3	3	25	28	0.11	
630-640	HL-3	12	17	29	0.41	
640-650	HL-3	2	8	10	0.20	
650-660	HL-3	8	5	13	0.62	
660-670	HL-3	3	5	8	0.38	
670-680	HL-3	2	3	5	0.40	
680-690	HL-3	4	1	5	0.80	
690-700	HL-2	2	0	2	1.00	0.97
700-710	HL-2	4	0	4	1.00	
710-720	HL-2	3	1	4	0.75	
720-730	HL-2	1	0	1	1.00	
730-740	HL-2	1	0	1	1.00	
740-750	HL-2	4	0	4	1.00	
750-760	HL-2	4	0	4	1.00	
760-770	HL-2	0	0	0		
770-780	HL-2	2	0	2	1.00	
780-790	HL-2	0	0	0		
790-800	HL-2	0	0	0		
800-810	HL-2	0	0	0		
140-142.5	HL-2	2	0	2	1.00	
142.5-145	HL-1	1	0	1	1.00	1.00
145-147.5	HL-1	0	0	0		
147.5-150	HL-1	1	0	1	1.00	
150-152.5	HL-1	1	0	1	1.00	
152.5-155	HL-1	0	0	0		

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