POSTGLACIAL CHANGES IN VEGETATION AND CLIMATE
NEAR TREELINE IN BRITISH COLUMBIA

Ph.D. Thesis

by

Marlow Gregory Pellatt

August, 1996

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Marlow Gregory Pellatt

B.Sc., Simon Fraser University, 1990

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POSTGLACIAL CHANGES IN VEGETATION AND

CLIMATE NEAR TREELINE IN BRITISH COLUMBIA

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Abstract

Plant macrofossils and pollen were studied in sediments from six small subalpine lakes on the Queen Charlotte Islands and in the northern Cascade Mountains of southwestern British Columbia. Two major climatic intervals are inferred from treeline shifts on the Queen Charlotte Islands, and three climatic intervals are detected from sites on Mount Stoyoma in the Cascades. The two main climatic intervals on the Queen Charlotte Islands correspond with the early Holocene xerothermic period and neoglacial cooling. The three main climatic intervals on Mount Stoyoma correspond with the early Holocene xerothermic period, the mesothermic period, and neoglacial cooling.

Paleobotanical evidence from subalpine lakes on the Queen Charlotte Islands documents the local presence of western hemlock and Sitka spruce between 9600 and 6650 radiocarbon years before present (^{14}C yr BP), indicating warmer than present conditions during the early Holocene xerothermic period. Following this warm period (after 6000 ^{14}C yr BP) the establishment of subalpine forest begins, with conditions similar to present developing by 3500 ^{14}C yr BP. This cooling corresponds with glacial advances observed in southwestern British Columbia and the Rocky Mountains.

Similar vegetation and climate changes were inferred from lake sediments on Mount Stoyoma in the northern-most Cascades, supporting the contention that regional climatic changes, rather than local site factors, were

responsible for the major observed patterns. Warm and dry conditions are indicated prior to Mazama tephra deposition (6800 ^{14}C yr BP), during the early Holocene xerothermic period. Increasing precipitation between 6800 and 3500 ^{14}C yr BP corresponds with the mesothermic period. Modern subalpine communities become established around 3500 ^{14}C yr BP.

Surficial sediment samples from forty-two lakes, distributed from sea-level to the subalpine of coastal British Columbia, were analysed for pollen and spores. Pollen analysis revealed characteristic differences among the assemblages of the Coastal Western Hemlock, Mountain Hemlock and Engelmann Spruce-Subalpine Fir biogeoclimatic zones. Cluster analysis and detrended correspondence analysis correctly group the sites according to their biogeoclimatic zones and geographic origin. Canonical correspondence analysis groups the study sites into biogeoclimatic zones in relation to annual precipitation, growing season precipitation, annual snowfall, annual temperature and growing degree days. These modern samples are useful in identifying possible analogues for Holocene fossil pollen assemblages.

Dedication

To Kelly,

Natashia and

Shavaun

Acknowledgements

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW.

The postglacial history of British Columbia is as intriguing and varied as the landscape itself. The complexity of the landscape and climate has produced unique vegetation assemblages today as well as in the past. With the possible exception of glacial refugia on the Queen Charlotte Islands, Hecate Strait, and Brooks Peninsula on Vancouver Island, British Columbia was essentially covered by ice at some time during the Wisconsinan Glaciation (Mathewes, 1989). The Cordilleran Ice Sheet carved valleys and left barren landscapes that were colonised by pioneer plants, and then developed over the millennia into the ecosystems we know today. This postglacial vegetation history is the research focus of this thesis.

Through the understanding of postglacial vegetation history, the paleoecologist can also infer past climate trends. When several forms of proxy climate evidence, such as pollen and plant macrofossils, are combined with radiometric dating, tephrachronology and multivariate statistics, the paleobotanist can begin to piece together the puzzle that is the past. This is done using the concept of uniformitarianism, the idea that "the present is the key to understanding the past". Uniformitarianism states that the physical, chemical and biological processes that are in effect today are the same ones that have existed throughout the Earth's history (Delcourt and Delcourt, 1991). Given sufficient fossil, stratigraphic and other evidence, past

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ecosystems can be reconstructed (Delcourt and Delcourt, 1991). It is this logic, as well as the analogue concept, that make up the crux of paleoecological investigations. The importance of the analogue concept is that by understanding how closely a past ecosystem resembles a present one, it becomes possible to understand the rate of ecological change through time (Delcourt and Delcourt, 1991).

Pioneering palynological studies in British Columbia were conducted by H.P. Hansen in the 1940 and 50's and C.J. Heusser in the 1960's (Hansen, 1940 & 1955; Heusser, 1960, 1969 & 1985). This early work paved the way for a greater understanding of the relationships between pollen and vegetation assemblages, as well as broad scale patterns of change during postglacial time. Three broad periods of Holocene climate change have been inferred from palynological studies. These periods are the early Holocene xerothermic period (warmer and drier climate than present), a mid-Holocene "mesothermic" period (warmer than present with equivalent moisture), and Neoglaciation (cool, moist, modern climate) (Mathewes and Heusser, 1981; Porter and Denton, 1967; Hebda, 1995). As most palynological investigations have been conducted at low to mid-elevation study sites, it is important that investigations also be undertaken at high elevations to see if the patterns of ecosystem change are similar or different. The main objectives of this study are to:

1) to reconstruct postglacial changes in treeline and vegetation communities at high elevations on the Queen Charlotte Islands and the southern interior of British Columbia,

2) to infer postglacial climate change from the paleobotanical evidence at the study sites, and

3) to determine how well pollen assemblages from lake sediments represent the plant communities they were collected in.

The rest of this chapter will review some of the ground work in which the research in this thesis was based on.

Late-Pleistocene and Holocene climate of British Columbia:

Fraser Glaciation:

The Canadian Cordillera is a magnificent collection of mountain ranges that are part of the great western mountain belt of North and South America (Clague, 1989). At present the Cordillera supports many valley glaciers and small ice caps. During major Pleistocene cold periods, glaciers advanced from the Cordilleran mountains to bury most of British Columbia, and parts of the Yukon, District of MacKenzie, and Alberta beneath as much as 2.5 km of ice (Clague, 1989). The climate period of interest in this thesis encompasses the termination of the late-Pleistocene, more specifically the end of the Fraser Glaciation, and the Holocene (last 10,000 years).

The Fraser Glaciation can be divided into three stades and one named interstade (Booth, 1987). Preceding the Fraser glaciation was the Olympia interglaciation in which non-glacial conditions occurred in the Pacific Northwest (Booth, 1987; Clague 1989). Deposits associated with this period are dated at least 40.5 ka (thousand ^{14}C years before present; Booth, 1987). As temperatures decreased at the close of the Olympia interval, mountain icecaps began to coalesce to form an ice cap. Proglacial outwash in the Georgia Depression records the initial southward expansion of ice at *ca* 28.8 ka. The first Fraser maximum stage, called the Coquitlam stade, occurred between 22 and 19 ka (Booth, 1987; Ryder and Clague, 1989; Mann and Hamilton, 1995). A temperature decrease of up to 6°C probably occurred during this stade. The Coquitlam stade was relatively short lived, and its resulting ice advances failed to reach Vancouver Island and Puget Sound (Mann and Hamilton, 1995). Following the Coquitlam advance, alpine glaciers retreated and the western part of the Fraser Lowland was ice free and forests established by 18.7 ka (Booth, 1987; Ryder and Clague, 1989). This period is called the Port Moody interstade (Mann and Hamilton, 1950.

The maximum advance of the Cordilleran ice sheet during the Fraser Glaciation occurred between 14.5 and 14 ka and is called the Vashon stade (Booth, 1987; Ryder and Clague, 1989; Mann and Hamilton, 1995). Valley and piedmont glaciers in the Strait of Georgia advanced into Juan de Fuca Strait, and at its maximum, 250 km south of the Canada - U.S.A. border

(Booth, 1987; Ryder and Clague, 1989; Mann and Hamilton, 1995). The glacial maximum had occurred on the Queen Charlotte Islands before 16 to 15.5 ka (Mann and Hamilton, 1995). The retreat of the ice was fairly rapid in the Pacific Northwest after 14 ka, but was punctuated by minor readvances such as the Sumas Stade between 11.7 and 11.1 ka (Booth, 1987; Ryder and Clague, 1989; Mann and Hamilton, 1995). Glacial retreat was somewhat slower east of the Cascade mountains than on the coast, but it is generally agreed that collapse of the Cordilleran Ice Sheet had occurred by 10 ka (Booth, 1987; Ryder and Clague, 1989; Mann and Hamilton, 1995).

Younger Dryas:

The Younger Dryas was first noted in Scandinavia as a climatic reversal in which tundra indicators, such as *Dryas octopetala*, reappeared after trees had begun to colonise the unglaciated landscape during the Allerod warming (Peteet, 1995). Many stratigraphic studies in eastern North America and Europe have provided additional evidence for the Younger Dryas event between 11,000 and 10,000 ^{14}C yr BP (Peteet, 1995). Recently, attention has turned to stratigraphic study sites in western Canada which indicate that a Younger Dryas-like cooling event occurred between 11,000 and 10,000 ^{14}C yr BP on the Queen Charlotte Islands, southern British Columbia and southeastern Alaska (Mathewes, 1993; Mathewes *et al.,* 1993; Peteet, 1995).

<u>The Holocene:</u>

Milankovitch orbital theory suggests that maximum Holocene warmth in the northern hemisphere should occur around the Pleistocene/Holocene boundary (Clague and Mathewes, 1989). As predicted, the maximum warmth for the last 10,000 years occurred in the early Holocene. There is evidence of an early Holocene warm/dry period between 10,000 and 7000 ^{14}C yr BP at sites in southwestern B.C., Vancouver Island and the Queen Charlotte Islands (Mathewes, 1973; Mathewes and Heusser, 1981; Warner, 1984; Walker, 1988; Mathewes, 1985; Clague and Mathewes, 1989; Clague *et al.,* 1992, Pellatt and Mathewes, 1994; Hebda, 1995). Transfer functions of pollen data at Marion Lake, B.C. indicate that temperature was at least 2°C warmer in the early Holocene than it is today (Mathewes and Heusser, 1981). This early/warm period in British Columbia has been called the early Holocene xerothermic period (Mathewes and Heusser, 1981). Mid-Holocene cooling and treeline shifts were underway by 5000 ^{14}C yr BP (Mathewes, 1973; Mathewes and King, 1989, Warner, 1984; Pellatt and Mathewes, 1994), in synchrony with the Garibaldi phase of Neoglaciation (Ryder and Thomson, 1986). Mid-Holocene climate in the southern interior of British Columbia is similar to that of southwestern and coastal B.C., except that early Holocene warmth appears to have extended to around 4500 ^{14}C yr BP (Hebda, 1995). Hebda (1995) has termed the mid-Holocene warm period between 7000 and 4500 ^{14}C yr BP the "mesothermic period". It appears that the mesothermic

period maintained warmer than present temperatures, with precipitation equivalent to modern conditions, but more than in the early Holocene xerothermic.

During the late-Holocene, widespread glacial advances occur and cool/moist modern climate establishes throughout southern and central British Columbia (Porter and Denton, 1967; Ryder and Thomson, 1986; Ryder, 1989a; Luckman *et al.*, 1993; Pellatt and Mathewes, 1994; Hebda, 1995; Clague and Mathewes, 1996). Notable neoglacial advances in the late-Holocene include the Tiedemann glacial advance in the Coast Mountains between 3300 to 1900 ^{14}C yr BP, and the Peyto and Robson glacial advances in the southern Canadian Rocky Mountains between 3100 and 2500 ^{14}C yr BP (Ryder and Thomson, 1986; Luckman *et al.*, 1993). In the last millennia, "Little Ice Age" glacial activity has occurred in many places throughout British Columbia (and throughout the mountain ranges of the world) in which many glaciers have reached their Holocene maximum (Porter and Denton, 1967; Ryder, 1989a). Little Ice Age glacial advances in British Columbia have been observed in the southern coast mountains, northwestern B.C., and in the Canadian Rockies (Porter and Denton, 1967; Ryder and Thomson, 1986; Ryder, 1989a; Luckman *et al.*, 1993; Clague and Mathewes, 1996).

As the 21st century approaches, humanity is faced with a new climatic challenge; glaciers are retreating, greenhouse gases (i.e., CO_2, CH_4, and

fluorocarbons) are increasing, and global temperatures are on the rise (COHMAP, 1988; Houghton and Woodwell, 1989; Graham *et al.*, 1990). This new phase of Holocene climatic change is an anthropogenically induced global warming event. The long-term effects are unknown, but what we do know is that temperature changes of between 0.5 and 2°C have significantly rearranged vegetation assemblages in the past, and thus we can expect them to be greatly altered in the future (Mathewes and Heusser, 1981; Clague and Mathewes, 1989; Graham *et al.*, 1990; Clague *et al.*, 1992; Pellatt and Mathewes, 1994).

Pollen Analysis:

Pollen analysis is a well-established research tool for the reconstruction of paleoenvironments in the Quaternary. According to MacDonald (1990), pollen analysis was utilised in approximately 25 percent of all published research papers from English and French Quaternary journals in 1986. A number of characteristics make pollen excellent microfossils for analysing the vegetational history for an area. Some of these characteristics are (MacDonald, 1990):

1) pollen and spores are produced in large numbers during the natural reproductive cycle of many plants,

2) the number of pollen and spores released in the environment depends upon the parent plants' population and therefore reflect vegetational composition in some way,

3) most pollen and spores never fulfil their reproductive potential and some of these are deposited in environments where they are preserved as fossils,

4) the grains can be extracted from sediments and can be identified to taxonomic levels ranging from family to species,

5) pollen and spores from different stratigraphic levels provide information on changing vegetation in the past, and

6) palynological data from different sites provide information on differences in vegetation at these sites.

These characteristics make palynology the cornerstone of this thesis. When pollen analysis is used in conjunction with plant macrofossil analysis, a detailed understanding of local and regional changes in vegetation can be gained.

Pollen Ratio Analysis:

During a warmer and perhaps drier period, an increase in treeline elevation is expected (Clague and Mathewes, 1989). This change should be apparent as shifts in pollen and plant macrofossil composition in the sedimentary sequences of small lakes. Research in the Canadian Rocky

Mountains and the eastern Coast Mountains of British Columbia has established the usefulness of using *Picea/Pinus* pollen ratios to infer altitudinal shifts in vegetation composition (Kearney & Luckman, 1983; Beaudoin, 1986; Luckman & Kearney, 1986; Evans, 1993). Changes in treeline location are apparent in past environments through comparison of fossil and modern pollen ratios. Modern pollen ratios are derived from pollen samples collected along elevational transects near a study site (Kearney & Luckman, 1983; Beaudoin, 1986; Luckman & Kearney, 1986; Evans, 1993). It was shown that the krummholz zone had lower ratios than the surrounding subalpine forests. Beaudoin (1986) proposed that there was a recognisable relationship between vegetation types which could be used to infer elevation above present treeline. Luckman and Kearney (1986) have come to similar conclusions from their research. Thus it seems reasonable to assume that pollen ratio analysis should be useful in separating subalpine from alpine forests in southern British Columbia.

Plant Macrofossil Analysis:

Plant macrofossils are vegetative and reproductive plant remains visible to the naked eye (Warner, 1990). The plant fossil assemblage normally represents only a fraction of the total flora that lived at the time of deposition. Thus it is important to understand the taphonomic processes that influence composition of a plant macrofossil assemblage, such as

dispersal mechanisms, seed productivity, stream and river hydrology, and winter ice (Warner, 1990).

Plant macrofossils have generally been used as a tool to supplement pollen analysis. As indicated by Birks and Birks (1980), Grosse-Brauckmann (1986) and Wainman (1986), plant macrofossils:

1) establish the local presence of plants because plant macrofossils are not usually well dispersed,

2) allow for the positive identification of local plants to the genus or species level, and

3) establish the presence of plants that are either poorly represented or absent in the pollen assemblage (e.g., insect-pollinated species and aquatics with non-preservable pollen).

As stated by Warner (1990) "The most valuable use of plant macrofossils in Quaternary geology is in the reconstruction of local environments and the history of past climates". Plant macrofossils are deposited locally, so they are an ideal tool for examining local vegetation changes in sensitive ecotones such as treeline. This characteristic becomes even more important when extra-local and regional pollen is a major component of the pollen assemblage.

Dunwiddie (1987) examined plant macrofossil and pollen assemblages along an elevational gradient in Mount Rainier National Park, Washington. He restricted his study to small, closed basins in an attempt to eliminate

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extra-local transport of plant macrofossils and pollen as well as to reduce leaf damage due to water turbulence. Dunwiddie compared the basal areas of the surrounding coniferous forest vegetation to the macrofossil and pollen assemblages present in the surface samples. He found that there was a high correlation between the coniferous needle assemblages in the surface samples and the basal area of the trees in the surrounding forest. On the otherhand, his study revealed that pollen was generally derived from extra-local sources and it greatly over-represented lowland taxa. Needles from species such as Douglas-fir (*Pseudotsuga menziesii*) and subalpine fir (*Abies lasiocarpa*) were slightly under-represented; western hemlock (*Tsuga heterophylla*), mountain hemlock (*Tsuga mertensiana*) and Pacific silver fir (*Abies amabilis*) were slightly over-represented; and yellow cedar (*Chamaecyparis nootkatensis*) was greatly under-represented. Dunwiddie (1987) also noted that ~22% of the vascular plant species at the study sites were represented in the macrofossil assemblage, with ~85% of the tree species being present. Thus in the coniferous dominated forests of the Pacific Northwest, plant macrofossil analysis is a valuable tool in determining local community structure.

Plant macrofossil analysis has been used in reconstructing subalpine plant communities by Davis *et al* (1980), Dunwiddie (1986), Jackson (1989), and Pellatt & Mathewes (1994). Davis *et al* (1980) examined pollen and plant macrofossils from six sites along an elevational gradient in the White

Mountains of New Hampshire. The authors noted changes in the elevational distribution of the four main coniferous trees in the area during the Holocene. At present, white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*) are confined to low elevations, but white pine grew 350 metres above its present limit at 9000 ^{14}C yr BP, and eastern hemlock grew 300 to 400 metres above its present limit at 7000 ^{14}C yr BP. Both of these conifers remained at higher elevations than present until the onset of the Little Ice Age a few centuries ago. Although not as clearly observed in the macrofossil record, the two high elevation conifers, balsam fir (*Abies balsamea*) and black spruce (*Picea mariana*) were present at high elevations throughout the Holocene (although black spruce was very infrequent until 2000 ^{14}C yr BP). Thus the magnitude of climatic change on the high elevation conifers is not well understood, as growth form (krummholz versus tree) cannot be ascertained from pollen or plant macrofossil data. The possibility of a non-analogous paleoenvironment also exists.

Dunwiddie (1986) reconstructed 6000 years of postglacial history of three high elevation ponds on Mount Rainier, Washington. The elevations of the sites range from 1300 to 1500 metres. Changes in species composition, fire frequency and treeline were determined from sediment cores collected from the lake basins. Successional species such as noble fir (*Abies procera*) Douglas-fir and lodgepole pine (*Pinus contorta*) were present or most abundant before 3400 ^{14}C yr BP. This seral plant macrofossil assemblage

plus relatively high charcoal values prior to 3400 ^{14}C yr BP indicate a warmer/drier climate from 6000 to 3400 ^{14}C yr BP. Neoglacial cooling appears to have begun between 3700 and 3400 ^{14}C yr BP as indicated by the prominence of typical high elevations species , such as mountain hemlock, yellow cedar and western hemlock.

Jackson (1989) examined plant macrofossils from a number of sediment cores along an elevational gradient in the Adirondack Mountains of New York. He detected a shift from a white pine, eastern hemlock, yellow birch (*Betula lutea*) dominated forest between 9000 to 5000 ^{14}C yr BP to a red spruce (*Picea rubens*) forest that reached its maximum extent around 2500 ^{14}C yr BP and remained stable until present. The vegetation history of the area indicates that climate was warmer and possibly drier between 9000 and 5000 ^{14}C yr BP than at present. Jackson also determined that during the Holocene; white pine, eastern hemlock and yellow birch grew at elevations 300, 200 and 150 metres higher (respectively) than present.

Fossil Logs and Wood as an Indicator of Treeline Shifts:

Some of the best supporting evidence of treeline shifts comes from fossil logs located above the present elevational limits of the tree species involved. Clague and Mathewes (1989) found fossil logs and wood well above the present treeline at Castle Peak in the eastern Coast Mountains of British Columbia. The fossil logs and wood were radiocarbon dated between 9100

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and 8200 14C yr BP. The trees were identified as whitebark pine (*Pinus albicaulis*) and subalpine fir. At present these tree species reach their upper limits from 60 to 130 metres below the fossil trees. Clague and Mathewes (1989) used an adiabatic lapse rate of 6.5°C/km to reconstruct temperature changes in regards to the position of past and present treelines. They determined that climate during the early Holocene was at least 0.4 to 0.8°C warmer than at present. Clague *et al* (1992) used oxygen isotope analysis of tree rings to estimate that precipitation between 9100 and 8200 14C yr BP was lower than present. This data supports the assumption of the early Holocene xerothermic period at Castle Peak.

Other researchers have also observed past treelines that are higher than present. Carrara *et al* (1991) examined fossil wood from the exposed sediments of Lake Emma, Colorado. Lake Emma was a tarn located in the San Juan Mountains which was drained in 1978. Thirty-nine radiocarbon dates were obtained on wood from Engelmann spruce (*Picea engelmannii*) and subalpine fir and produced ages of 9600 and 5400 14C yr BP. These trees presently grow around 80 to 140 m lower than the fossil wood location. Using an adiabatic lapse rate of 6.2°C per km, Carrara *et al* (1991) determined that early Holocene temperature was at least 0.5 to 0.9°C warmer than present.

Luckman *et al* (1993) used fossil wood left behind by the retreating Athabasca and Dome Glaciers; detrital logs from Peyto, Saskatchewan,

Robson and Yoho Glaciers; and *in situ* stumps at Peyto and Robson Glaciers to examine Neoglacial and Little Ice Age glacier fluctuations in the Canadian Rockies. Rooted stumps that show evidence of being killed by the glacier (e.g., shearing in a down-ice direction) indicate the growth location and limiting age for the overlying till or glacial advance that killed them (Luckman *et al.*, 1993). Detrital wood (wood found lying on or within deposits of the forefield of the glacier) gives a minimum elevation and upvalley distance for treeline at the time of growth (Luckman *et al.*, 1993). It must be considered that detrital wood may have been transported from extra-local sources (landslide or human transport) which may be older or younger than the glacial limits in question. The authors found that wood derived from the Athabasca Glacier was 7550 to 8230 ^{14}C yr BP and Dome Glacier was 6120 to 6380 ^{14}C yr BP old, indicating that treelines were higher during the early Holocene. Fossil stumps and detrital wood from Peyto, Robson, Saskatchewan and Yoho Glaciers yielded dates between 2490 and 3100 ^{14}C yr BP (with 12 dates being between 2800 and 2990 ^{14}C yr BP), indicating that forests were overridden by glaciers between 2500 and 3500 ^{14}C yr BP. This glacial episode has been designated the Peyto Advance and correlates with the Tiedemann Advance in the British Columbian Coast Mountains (Luckman *et al.*, 1993).

Radiocarbon ages from fossil wood, stumps and logs from the Coast Mountains of British Columbia, the San Juan Mountains of Colorado, and

the Canadian Rockies indicate changes in treeline during the Holocene. These sites support the concept of an early Holocene warm period (early Holocene xerothermic period or Hypsithermal), with temperature warmer by up to 0.9°C. Evidence for an early to mid-Holocene warm period is supported by many studies of low-elevation study sites in the Pacific Northwest (Barnosky, 1981; Mathewes and Heusser, 1981; Hebda, 1983; Wainman and Mathewes, 1987, Mathewes and King, 1989; Pellatt and Mathewes, 1994; Hebda, 1995; McLachlan and Brubaker, 1995). Mathewes and Heusser (1981) used transfer functions to determine that temperature in the early Holocene at Marion lake, southwestern British Columbia, was up to 2°C warmer than present. Shifts from a montane Coastal Western Hemlock zone to a Mountain Hemlock zone occurred at Louise Pond, a high elevation pond on the Queen Charlotte Islands (Pellatt and Mathewes, 1994). Thus it appears that warmer temperatures occurred in a number of biogeoclimatic zones in British Columbia during the Holocene.

CHAPTER 2: BIOGEOCLIMATIC ZONES OF THIS STUDY[1]:

Introduction:

British Columbia is a diverse geographic area divided into fourteen biogeoclimatic zones (Figure 2.1) (Meidinger and Pojar, 1991; MacKinnon *et al.*, 1992). A biogeoclimatic zone is a descriptive classification unit used by the B.C. Ministry of Forests to describe the distinct climax plant association in relation to regional climate (Pojar, 1983a; Meidinger & Pojar, 1991). They are areas of broadly homogenous climate, reflected by specific patterns of vegetation across the landscape (Pojar, 1983a; MacKinnon *et al.,* 1992). Four biogeoclimatic zones were examined during this study.

The Coastal Western Hemlock Zone (CWH):

The Coastal Western Hemlock zone is situated at low to mid elevations along the British Columbia coast, mostly west of the Coast Mountains (Pojar & Klinka, 1983a; Meidinger & Pojar, 1991). It is on average the rainiest zone in B.C. and has a cool mesothermal climate, although summer drought is common. The mean annual temperature is ~8°C (10.5 to 5.2°C) with 4 to 6 months per year warmer than 10°C. The mean temperature of the coldest month is 0.2°C (4.7 to -6.6°C) (Meidinger & Pojar, 1991). Annual

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[1] The taxonomic nomenclature used for the vegetation of the Queen Charlotte Islands follows Calder and Taylor (1968). The taxonomic nomenclature used for all other areas in this thesis follows Hitchcock and Cronquist (1973).

Figure 2.1

Map showing the 14 Biogeoclimatic Zones of British Columbia (Meidinger and Pojar, 1991).

Biogeoclimatic Zones of British Columbia

Legend:

- glaciers and icefields
- ALPINE TUNDRA
- SPRUCE – WILLOW – BIRCH
- BOREAL WHITE AND BLACK SPRUCE
- SUB-BOREAL PINE – SPRUCE
- SUB-BOREAL SPRUCE
- MOUNTAIN HEMLOCK
- ENGELMANN SPRUCE – SUBALPINE FIR
- MONTANE SPRUCE
- BUNCHGRASS
- PONDEROSA PINE
- INTERIOR DOUGLAS-FIR
- COASTAL DOUGLAS-FIR
- INTERIOR CEDAR – HEMLOCK
- COASTAL WESTERN HEMLOCK

1:7 500 000

PACIFIC OCEAN

Queen Charlotte Islands

Vancouver Island

Hecate Strait

Dixon Entrance

Strait of Georgia

precipitation averages 2228 mm (1000 to 4400 mm) with less than 15% of total precipitation occurring as snowfall in the south, but as much as 40 to 50% occurring as snowfall in northern parts of the zone (Pojar & Klinka, 1983a; Meidinger & Pojar, 1991). Western hemlock (*Tsuga heterophylla*) is the climatic climax tree in this zone, but often occurs in association with several other species. Western redcedar (*Thuja plicata*) occurs commonly south of 56°N, Douglas-fir (*Pseudotsuga menziesii*) is common south of 53°N in dry areas, Sitka spruce (*Picea sitchensis*) favours low elevations such as flood plains or exposed beaches, and red alder (*Alnus rubra*) is abundant in disturbed areas (Meidinger & Pojar, 1991).

The Coastal Western Hemlock Zone of the Queen Charlotte Islands:

The Coastal Western Hemlock zone on the Queen Charlotte Islands has been referred to as the Northern Oceanic or Queen Charlotte Island subzone (CWHg) (Banner, *et al.*, 1983), but has been reclassified as the Wet Hypermaritime subzone (CWHwh) by the British Columbia Ministry of Forests (Green & Klinka, 1994). There are currently two CWHwh variants recognised on the Queen Charlotte Islands; the Submontane Wet Hypermaritime Variant (CWHwh1), and the Montane Wet Hypermaritime Variant (CWHwh2). The main distinguishing factor between the CWHwh and other CWH subzones is the widespread occurrence of *Picea sitchensis* in

a wide range of habitats and the absence of *Abies amabilis* and *Pseudotsuga menziesii* (Banner *et al.,* 1983; Green & Klinka, 1994).

The CWHwh1 extends from sea level to around 350 metres (250 m approaching the CWHvh2 to the west) on the Queen Charlotte Lowlands, Skidegate Plateau, and the eastern edge (leeward side) of the Queen Charlotte Ranges. It has mild, wet winters with little snowfall, and cool moist summers. Occasional warm dry periods occur in the summer due to the rain shadow effect of the Queen Charlotte Ranges. Cloud and fog are frequent throughout the year (Banner *et al.,* 1983; Green & Klinka, 1994). The climatic climax species of the CWHwh1 is *Tsuga heterophylla* with *Thuja plicata* and *Picea sitchensis* being important co-dominants. Understory plant species include *Vaccinium alaskaense, Vaccinium parvifolium, Vaccinium ovalifolium, Hylocomium splendens, Rhytidiadelphus loreus,* and *Rhizomnium glabrescens* (Banner *et al.,* 1983; Green & Klinka, 1994). The herb and shrub layers are sparse with a moss understory. This is probably due to heavy deer browsing (Green & Klinka, 1994).

The CWHwh2 (approximately 305 and 600 m) occurs above the CWHwh1, throughout the eastern Skidegate Plateau and eastern Queen Charlotte Ranges. The CWHwh2 is cooler and wetter, and has greater snowfall and more persistent snowpack than the CWHwh1 below it (Banner *et al.,* 1983; Green & Klinka, 1994). Forests on zonal sites are dominated by *Tsuga heterophylla, Thuja plicata,* and *Chamaecyparis nootkatensis. Picea*

sitchensis occurs to a lesser degree than in CWHwh1. Minor amounts of *Tsuga mertensiana* may occur, but its vigour is low. Understory plant species include *Vaccinium alaskaense, Vaccinium parvifolium, Vaccinium ovalifolium, Huperzia selago, Hylocomium splendens, Rhytidiadelphus loreus, Rhizomnium glabrescens* and *Scapania bolanderi* (Banner *et al.*, 1983; Green & Klinka, 1994). As with the CWHwh1, the understory is dominated by mosses, probably due to heavy deer browsing (Green & Klinka, 1994). The principal indicators distinguishing the CWHwh1 from the CWHwh2 are increased presence of *Chamaecyparis nootkatensis, Tsuga mertensiana, Scapania bolanderi*, small twistedstalk (*Streptopus streptopoides*), Indian Hellebore (*Veratrum viride*) and *Dicranum* sp. in the CWHwh2.

On the outer coast of the Queen Charlotte Islands exists the Central Very Wet Hypermaritime Variant (CWHvh2), which was previously referred to as the Coastal Cedar - Pine - Hemlock Zone (CCPH) (Banner *et al.*, 1983; Green & Klinka, 1994). The CWHvh2 occupies the outer and exposed coastal areas on the western edge of the Skidegate Plateau and the windward side of the Queen Charlotte Ranges (except for south Moresby where it covers most of the lower elevation of the range), from sea level to around 500 metres above sea level (Banner *et al.*, 1983; Green & Klinka, 1994). The CWHvh2 has a "hyperoceanic" climate that is much wetter than the CWHwh with more than 3500 mm difference in mean annual precipitation (Banner *et al.*,

1983). Cool, wet conditions prevail throughout the year, with cloud and fog cover being the norm. There is very little snowfall in the CWHvh2 and any snowpack is ephemeral (Banner *et al., 1983*).

The climatic climax forest for the CWHvh2 consists of low productivity mixtures of *Thuja plicata*, *Tsuga heterophylla*, and variable amounts of *Chamaecyparis nootkatensis*. *Pinus contorta var. contorta*, *Picea sitchensis*, and *Tsuga mertensiana* occur in relatively minor amounts (Banner *et al.,* 1983; Green & Klinka, 1994). Much of the landscape in the CWHvh2 is covered with blanket bogs, with open bogs and bog woodlands occurring on slopes up to 60 degrees (Banner *et al.,* 1983). Major understory species include salal (*Gaultheria shallon*), Alaska blueberry (*Vaccinium alaskaense*), false azalea (*Menziesia ferruginea*), deer fern (*Blechnum spicant*), *Hylocomium splendens*, and *Rhytidiadelphus loreus*, with minor amounts of goldthread (*Coptis* sp.), skunk cabbage (*Lysichiton americanum*) and *Sphagnum girgensohnii* (Green & Klinka, 1994). The CWHvh2 is distinguished from the CWHwh and the Wet Hypermaritime Mountain Hemlock Subzone (MHwh) principally in that it supports a greater abundance of *Chamaecyparis nootkatensis* and *Tsuga mertensiana*, fern-leaved goldthread, skunk cabbage and *Sphagnum girgensohnii*, and less *Picea sitchensis* than the CWHwh. The CWHvh2 has 50% less *Tsuga mertensiana* cover than found in the MHwh. The MHwh has no *Gaultheria shallon* (Green & Klinka, 1994).

The Mountain Hemlock Zone (MH):

The Mountain Hemlock zone is the characteristic subalpine environment of coastal British Columbia, occupying elevations from 900 to 1800 m in the south, and 400 to 1000 m in the north (Meidinger & Pojar, 1991). Climate is characterised by short, cool summers and long, cool, wet winters with extensive snow cover (Brooke *et al.,* 1970; Pojar & Klinka, 1983b; Meidinger & Pojar, 1991). Mean annual temperature varies from 0 to 5°C with average monthly temperatures below 0°C for 1 to 5 months, and above 10°C for 1 to 5 months. The very deep winter snow pack lasts for a considerable period, and is a primary factor restricting tree growth (Brooke *et al.,* 1970; Meidinger & Pojar, 1991). Mountain hemlock (*Tsuga mertensiana*) is the climax tree species in this zone with Yellow cedar (*Chamaecyparis nootkatensis*) and amabilis fir (*Abies amabilis*) being common associates. Amabilis fir does not, however, occur on the Queen Charlotte Islands. There are transitions between the Mountain Hemlock Zone and each of the other biogeoclimatic zones examined in this study. At high elevations the Mountain Hemlock Zone grades into the Alpine Tundra zone; at lower elevations it grades into the Coastal Western Hemlock Zone. The MH characterises the coastal subalpine, but grades into the ESSF as one moves east into a more continental climate (Pojar & Klinka, 1983b).

The Mountain Hemlock Zone of the Queen Charlotte Islands:

The subalpine zone on the Queen Charlotte Islands usually occurs at elevations above 550m, and is best developed in the Queen Charlotte Ranges and in the highest mountains of the Skidegate Plateau (Banner *et al.,* 1983). The MH is represented as the Wet Hypermaritime Mountain subzone (MHwh), with Windward (MHwh1) and Leeward (Mhwh2) Variants. The climatic climax tree of the MH is mountain hemlock (*Tsuga mertensiana*). The Mountain Hemlock Zone is characterised by short, cool, wet summers and cold, extremely wet winters with extensive snowfall (Banner *et al.,* 1983), and can be divided into a low subalpine forested subzone and a high subalpine, parkland subzone (Brooke *et al.,* 1970). Yellow cedar (*Chamaecyparis nootkatensis*) can be a co-dominant tree in some areas of the Mountain Hemlock Zone, whereas Sitka spruce (*Picea sitchensis*) and western redcedar (*Thuja plicata*) are only minor components at the lowermost limits of the zone. Common subalpine herbs and dwarf shrubs include *Cassiope mertensiana, Senecio newcombii* and *Empetrum nigrum.* Mountain hemlock ecosystems include extensive heath and herb meadows at higher elevations (Banner *et al.,* 1983).

The Engelmann Spruce - Subalpine Fir Zone (ESSF):

The Engelmann Spruce - Subalpine Fir zone is the uppermost forested zone in the southern three-quarters of interior British Columbia (Coupe, 1983; Meidinger & Pojar, 1991). The continental climate is relatively cold, moist, and snowy, with a short growing season, and long, cold winters. The mean annual temperature is -2 to 2°C with 5 to 7 months below 0°C. Two months or less are above 10°C (Coupe, 1983; Meidinger & Pojar, 1991). Precipitation ranges from 400 mm in the drier portions to 2200 mm in the wetter areas. As much as 50 to 70 % of the precipitation falls as snow. Soils generally freeze in the winter.

Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) are the climax trees of the ESSF. Engelmann spruce is longer lived and thus often dominates the canopy of mature stands with subalpine fir in the understory. Subalpine fir becomes dominant at the higher elevations of the ESSF in wetter areas (Meidinger & Pojar, 1991). Whitebark pine (*Pinus albicaulis*) appears in drier parts of the ESSF and mountain hemlock may occur in the western portion of the ESSF near the MH zone.

Alpine Tundra Zone (AT):

Alpine Tundra occurs in the high mountains above subalpine zones throughout the province. Average temperatures are below zero for seven to

eleven months of the year   (Pojar, 1983b; Meidinger & Pojar, 1991). The

alpine zone is essentially treeless, but krummholz (stunted trees) can exist at

the lower elevational boundary.   Common krummholz species include

subalpine fir, mountain hemlock and whitebark pine. Alpine vegetation is

dominated by herbs, dwarf shrubs, lichens and bryophytes. Soil remains

frozen for most of the year, and soil development is slow (Pojar, 1983b;

Meidinger & Pojar, 1991).

CHAPTER 3: THE QUEEN CHARLOTTE ISLANDS: Biophysical setting and Study Sites.

Queen Charlotte Island Physiography:

The Queen Charlotte Islands are an archipelago of approximately 150 islands, 80 km off the central coast of British Columbia (Figure 3.1), with most of the land mass lying between 52 and 54 degrees north latitude and 131 and 133 degrees west longitude (Calder & Taylor, 1968). Skidegate Inlet and Skidegate Channel separate the two main islands, Graham and Moresby (Calder & Taylor, 1968). Other large islands are Langara, off the northwest tip of Graham Island, and Louise, Lyell, and Burnaby Islands off the east coast of Moresby Island. The islands have a land area of about 6140 square kilometres and are subdivided into three physiographic units: the Queen Charlotte Ranges, the Skidegate Plateau and the Queen Charlotte Lowlands (Calder & Taylor, 1968; Sutherland Brown, 1968).

All the lakes cored in this study are located in the Queen Charlotte Ranges which extend from Cone Head on Runnel Sound to Cape St. James (Sutherland Brown, 1968). Most of Moresby Island, but only a small portion of Graham Island fall within the Queen Charlotte Ranges with the western boundary the Pacific coastline and the eastern boundary extending along a line from Rennel Sound to Vertical Point on Louise Island (Sutherland-

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Figure 3.1

Map of the Queen Charlotte Islands showing three major physiographic subdivisions and locations of radiocarbon-dated late-Quaternary palynological study sites. Inset map shows the Queen Charlotte Islands in relation to Canada.

QUEEN CHARLOTTE ISLANDS

54°

▲ Serendipity
Bog Lake

● Masset

QUEEN CHARLOTTE
LOW LANDS

GRAHAM
ISLAND

SKIDEGATE PLATEAU

▲ Boulton Lake
▲ Cape Ball

● Tlell

HECATE STRAIT

53°

Shangri-la Bog

● Sandspit

QUEEN CHARLOTTE RANGE

Louise
Pond

MORESBY
ISLAND

N

PACIFIC OCEAN

SC-1
Pond

52°
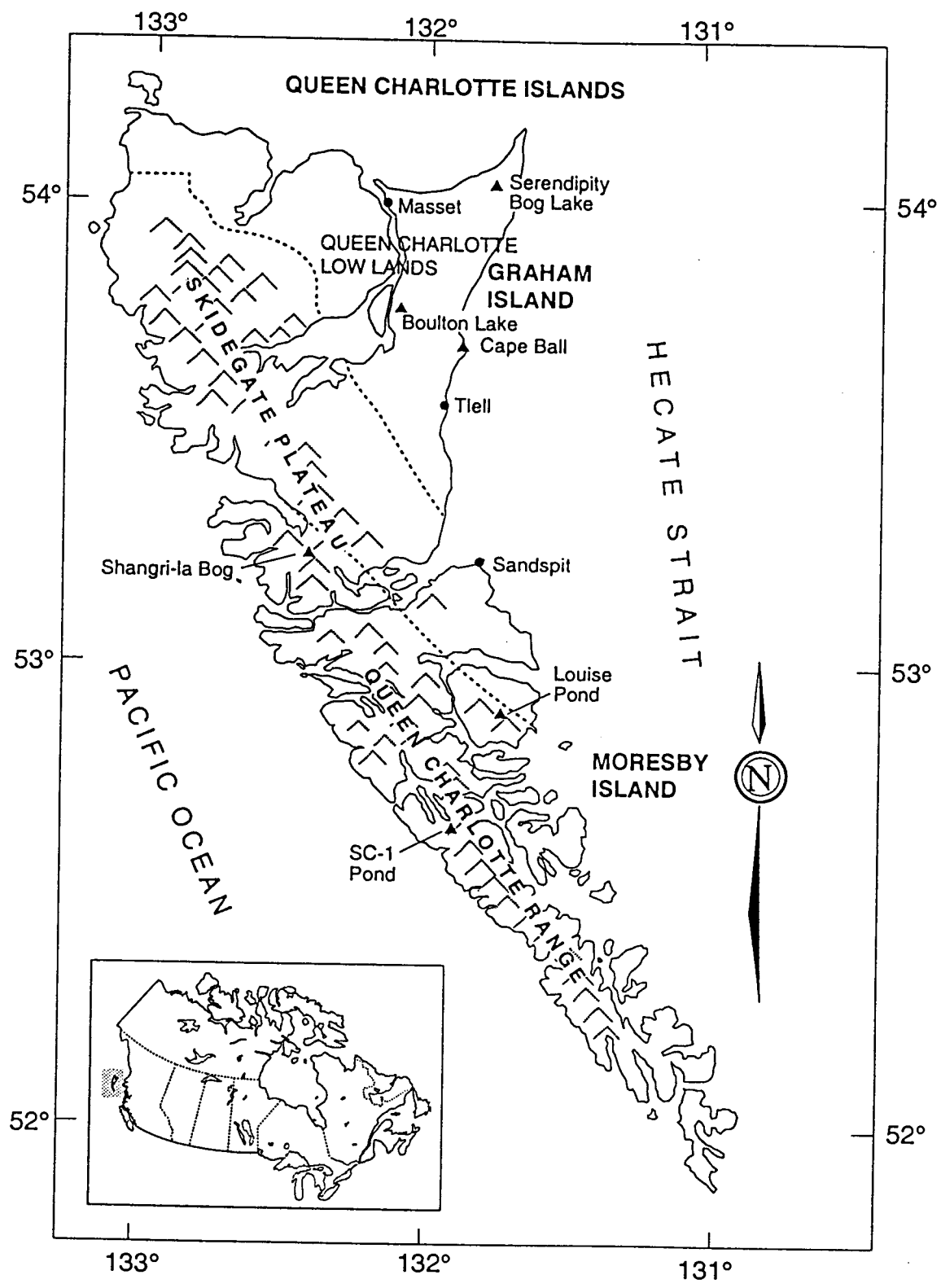
● -towns

▲ -¹⁴C-dated study site

29b

Brown, 1968). Within the Queen Charlotte Ranges there are three groups of high peaks (Figure 3.1):

1) The San Christoval Range which forms a lineal range extending from Tasu Sound to Gowgia Bay and from the Pacific Ocean to Darwin Sound (Sutherland Brown, 1968). Most of this range is underlain by granitic rocks. The study site SC-1 Pond is located in this range, 550 metres above sea level at 52°40'N and 131°54.4'W. The SC-1 Pond area is underlain by Jurassic plutons of hornblende diorite and quartz diorite (Sutherland Brown, 1968; Sutherland Brown & Yorath, 1989).

2) Another group of high mountains within the Queen Charlotte Ranges extend from Security Inlet in the north, to south of Kootenay Inlet to Vertical Point in the east (Sutherland Brown, 1968). Most of the peaks, such as Mount Moresby (1130 m) and Mount Kermode (1070 m), are formed of Triassic volcanic rocks, but some are granitic. The study site named Louise Pond is located on Louise Island at 650 metres above sea level at 53°25.0' N and 131°45.2' W. Louise Pond is underlain by Tertiary plutons of quartz monzonite, granite, granodiorite and quartz diorite (Sutherland Brown, 1968; Sutherland Brown & Yorath, 1989).

3) A third group of high mountain peaks includes Mount La Perrouse (1130 m) and Mount Stapleton (1070 m). The northern peaks are formed from granitic rocks, whereas the southern peaks are composed of slightly metamorphosed volcanic rocks (Sutherland Brown, 1968). The study site

Shangri-La Bog is located within this group of high peaks, 595 m above sea level at 53°16'N and 132°24.5'W. Shangri-La Bog is underlain by Tertiary plutons of quartz monzonite, granite, granodiorite and quartz diorite (Sutherland Brown, 1968; Sutherland Brown & Yorath, 1989).

This physiographic discription of the Queen Charlotte Islands study sites applies to the research discussed in the next two chapters.

CHAPTER 4: PALEOECOLOGY OF POSTGLACIAL TREELINE FLUCTUATIONS ON THE QUEEN CHARLOTTE ISLANDS, CANADA: LOUISE POND[2].

Introduction:

The study of postglacial vegetation changes is an important method for reconstructing paleoclimate, since the link between climate and regional vegetation zonation is well-established (COHMAP, 1988). The desire to reconstruct past climates has been a stimulus to many kinds of paleoenvironmental research, including studies to track past treelines, both in the boreal forest (Payette and Gagnon, 1979) and in the alpine-subalpine ecotone of the western Cordillera, as discussed below.

Treeline, the upper limit of tree growth (Kimmins, 1987) in mountainous areas is an ecotone defined largely by temperature during the growing season and also by precipitation and snowpack characteristics throughout the year (Brooke *et al.*, 1970; Tranquillini, 1979; Arno and Hammerly, 1984). Paleoenvironmental data from the Cordillera of western North America show that treelines have fluctuated significantly since deglaciation, strongly suggesting that postglacial climate has also changed (Kearney and Luckman, 1983; Luckman and Kearney, 1986; Clague *et al.*, 1992). These and other studies tend to focus on occurrences of fossil wood

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[2] This chapter is adapted from Pellatt and Mathewes (1994).

above present treeline, supplemented by palynological investigation of peat deposits and stable isotope analysis of wood. Few high-elevation studies have been able to secure dated sedimentary records that span the entire Holocene (last 10,000 radiocarbon years) and provide a continuous record of local vegetation and climate changes. Pollen analytical studies of high montane sites also suffer from problems caused by abundant upslope transport of pollen from low-elevation forests (Kearney and Luckman, 1983; Warner, 1984). This phenomenon limits the potential resolution of past treeline altitudes from palynological studies, although the use of indices based on abundance ratios of selected pollen types can be a useful tool for the reconstruction of past elevations (Beaudoin, 1986; Luckman and Kearney, 1986). Similarly, non-arboreal indicator pollen can be used to distinguish subalpine and alpine communities (Mathewes, 1988).

Recently, the value of plant macrofossils for vegetation reconstruction in the Pacific Northwest has been recognised, particularly since needles of the dominant coniferous trees are identifiable to species (Dunwiddie, 1985), well-preserved and abundant in sediments of some small lakes (Dunwiddie, 1987; Wainman and Mathewes, 1987). A major advantage of macrofossils from a closed lake is that they are more local in origin than pollen and spores, and thus have greater potential for treeline paleoecology. This study combines pollen and plant macrofossil analysis with radiocarbon dating of a small subalpine lake on Louise Island (Queen Charlotte Islands) in British

Columbia (Figure 3.1). At present, no published data is available concerning postglacial treeline changes in this area. The objectives of this study are to reconstruct Holocene treeline and vegetation shifts at Louise Pond, using plant macrofossil and pollen analysis, and to infer climatic changes at high elevations on the Queen Charlotte Islands.

Study Site:

Physiography:

Louise Pond is located at 650 m elevation on Louise Island (131°45.2' W and 53°25.0' N) (Figure 4.1). The surface area is ~0.3 ha and the bedrock-rimmed basin is developed in granitic rocks, suggesting good conditions for radiocarbon dating. Surface inflows are local and intermittent, and an overflow outlet drains the lake.

Climate:

The climate of the Queen Charlotte Islands is primarily dictated by the interaction of weather systems dominated by the Aleutian Low, the North Pacific High, and the rugged topography of the coastal mainland mountains to the east and the mountains on the Queen Charlotte Islands themselves (Calder and Taylor, 1968). Summer weather on the islands is mainly influenced by the North Pacific High; an extensive high pressure zone that generates cool, moderately wet conditions between mid-May and mid-

September. In winter, the Coast Mountains to the east isolate the islands from continental air masses, producing relatively mild temperatures under the influence of the Aleutian low. The Queen Charlotte Ranges force the air masses to rise, cool and produce extensive winter rainfall (Calder and Taylor, 1968). Precipitation in the mountains and on the west coast of the islands can exceed 5000 to 7500 mm per year, which produces heavy snowfalls at elevations above 600 m (Calder and Taylor, 1968). This mild, hypermaritime climate allows for the development of coniferous rainforests with large trees at low elevations, as well as extensive forest-bog complexes on poorly drained sites (Banner *et al.,* 1983).

Vegetation:

Trees growing around Louise Pond include mountain hemlock, shore pine (*Pinus contorta var. contorta*) and yellow cedar. Many trees exhibit stunted growth forms, but some large and wellformed specimens of yellow cedar grow near the lake outlet. Common shrubs and dwarf-shrubs include Sitka alder (*Alnus viridis), Vaccinium vitis-idea, Empetrum nigrum, Cassiope mertensiana and Cornus unalaschkensis.* Herbs and dwarf shrubs of wet soils, such as *Fauria crista-galli, Kalmia polifolia, Drosera rotundifolia, Pinguicula vulgaris, Geum calthifolium, Tofieldia glutinosa, Gentiana douglasiana, Leutkea pectinata, Coptis asplenifolia, Lycopodium sitchense, Huperzia selago, Blechnum spicant* and the endemic *Senecio*

newcombii also grow around the basin. Plant cover on the south-facing slopes above the lake basin grades rapidly into a belt of shrubs and krummholz and then rocky alpine vegetation. The vegetation surrounding Louise Pond is typical of the upper subalpine Mountain Hemlock Zone (Figure 4.1).

Methods:

A 390 cm sediment core was collected from the deepest basin (4.9 m) of Louise Pond, using a modified Livingstone piston corer with 5 cm core tube. The core segments were transported to Simon Fraser University (SFU), and stored at 4°C for later analysis. The sediments were subsampled and analysed for pollen at 10 cm intervals between 0 to 130 cm and at 5 cm intervals from 130 to 390 cm. Five radiocarbon dates on bulk sediments were obtained at selected depths (Table 4.1) to provide an absolute chronology. These were supplemented by two AMS (accelerator mass spectrometry) dates on conifer needles to date vegetation changes more precisely in the early Holocene. Age throughout this study is referred to as radiocarbon years before present (^{14}C yr BP), datum 1950.

Figure 4.1

Photograph of Louise Pond. Note the surrounding Mountain Hemlock zone parkland.

Figure 4.1

Table 4.1
Radiocarbon dates for high elevation paleobotanical sites
on the Queen Charlotte Islands

Site	Depth (cm)	Age (yr BP)	Laboratory Number	Material Dated
Shangri-La Bog	75 -83	7190±100	GSC-3357*	sandy gyttja
SC-1 Pond	257-264.5	7180±110	GSC-4040*	gyttja
Louise Pond	80-90	2100±100	Beta-49370	gyttja
Louise Pond	175-180	4030±100	Beta-49371	gyttja
Louise Pond	280-285	5790±130	Beta-49372	gyttja
Louise Pond	345-350	7350±120	Beta-49373	gyttja
Louise Pond	350-355	8700±150	TO-4017**	Mountain hemlock needles
Louise Pond	380-385	9870±120	TO-4018**	Mountain hemlock needles
Louise Pond	385-390	10,620±130	Beta-38886	gyttja

*   Reported errors for GSC (Geological Survey of Canada) are ± 2s; all others are ± 1s.

** AMS (Accelerator mass spectrometry) dates from Isotrace Laboratory, Toronto, Canada.

Beta = Beta Analytic, Florida, U.S.A.

Plant Macrofossil Analysis:

Subsamples of 25 ml sediment were determined by displacement in water and screened for plant macrofossils. Wet sediments were sieved through 250 mm mesh brass screens under running tap water. Plant macrofossils were picked from screened residues while viewing under a Wild dissecting microscope, and identified with the aid of dichotomous keys (Calder and Taylor, 1968; Dunwiddie, 1985) and comparisons with the SFU plant macrofossil reference collection. Totals of identifiable tips and bases of fragmented conifer needles were divided by 2 and added to the whole needle counts before plotting. Raw data were entered into TILIA v1.1 (Grimm, 1991a) and plotted as absolute concentrations per 25 ml sediment. Stratigraphically constrained cluster analysis (CONISS) was used to zone the plant macrofossil data and TILIAGRAPH v1.7 (Grimm, 1991b) was used to produce the plant macrofossil diagram (Figure 4.2).

Pollen Analysis:

Subsamples of 1 ml were removed from each sediment interval to be processed for pollen. Volumes were determined by displacement in water, using a 10 ml graduated cylinder. A known concentration of marker spores (11,300 ± 400 *Lycopodium*) was added to the 1 ml subsamples before processing. The protocols for pollen extraction are those suggested in

Figure 4.2

Plant macrofossil diagram for Louise Pond, showing bulk sediment dates (three youngest) and two AMS dates on conifer needles at the base. Zones were derived by constrained cluster analysis (CONISS).

Figure 4.2
Louise Pond, Queen Charlotte Islands
Plant Macrofossils per 25 ml Sediment
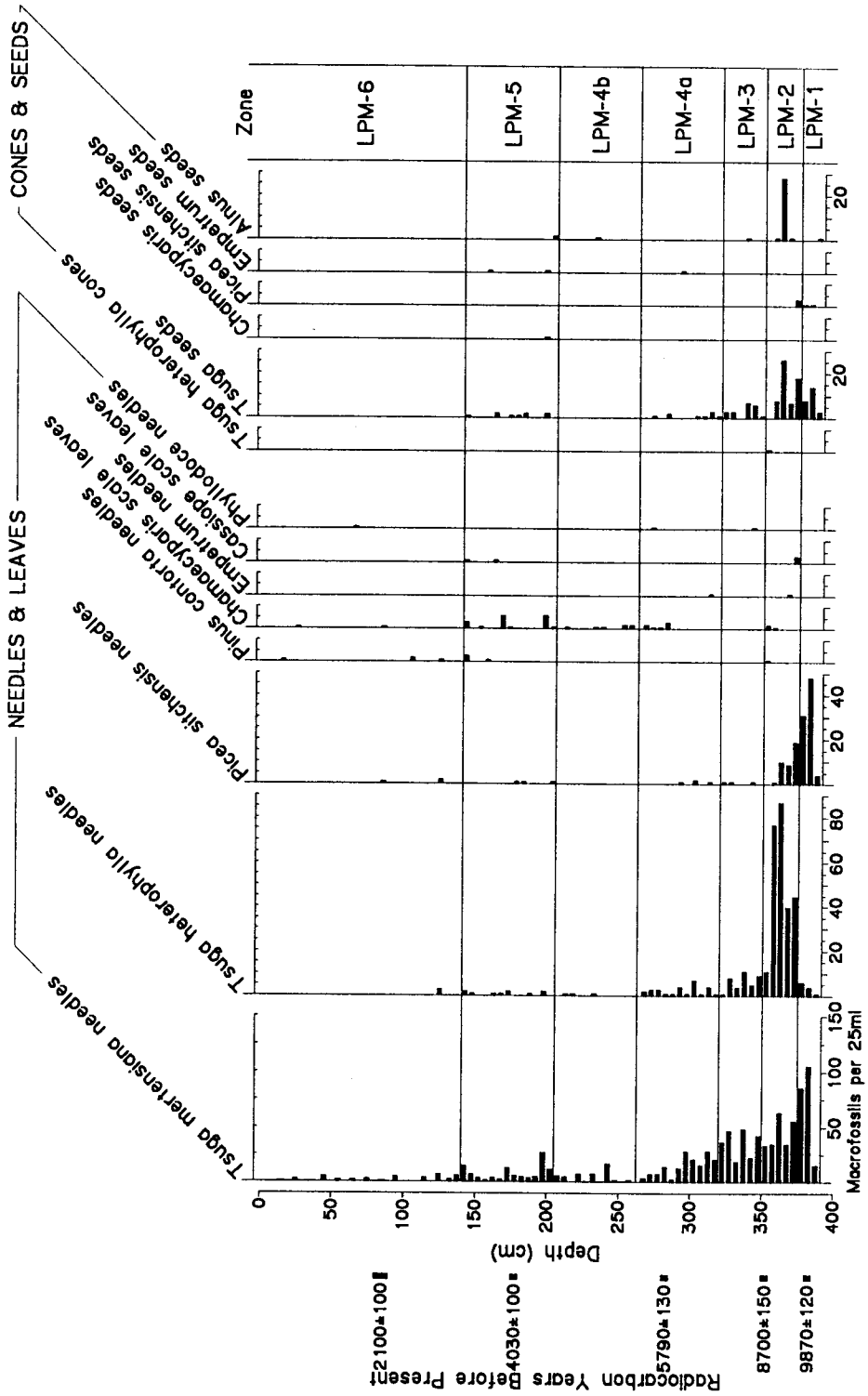
Marlow Pellatt, 1994

Berglund and Ralska-Jasiewiczowa (1986). Identifications of pollen and spores were aided by published keys (McAndrews *et al.*, 1973; Faegri and Iversen, 1989; Moore *et al.*, 1991) and the SFU modern reference collection. A Carl Zeiss binocular compound microscope was used to view palynomorphs.

Routine counting was carried out at 500X magnification and critical identifications were made under oil immersion at 1200X. Pollen and spores identified per sample ranged between 500 to 875 grains. The basic pollen sum used for percentage calculation includes all terrestrial pollen. Raw data were converted into percentages using TILIA v 1.1 (Grimm, 1991a). TILIAGRAPH v1.7 was used to generate the pollen diagram (Figure 4.3), which was subdivided into local pollen zones using CONISS. Plant taxa used to generate the zonation dendrogram are mountain hemlock, western hemlock, spruce, lodgepole pine and Cupressaceae.

Results and Discussion:

The lake sediment core consists primarily of dark brown gyttja with abundant macroscopic plant remains. Sand-silt layers occur at 362.5, 142.5 and 135 cm and the base of the core (390 cm) consists of a thin band of clay sitting on an impenetrable surface, presumed to be bedrock.

Figure 4.3

Percentage pollen diagram for Louise Pond, with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. Bulk sediment dates (three youngest) and two AMS dates on conifer needles at the base, are shown on the left. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 4.3
Louise Pond, Queen Charlotte Islands
Pollen Percentage Diagram

Marlow Pellatt, 1994

42b
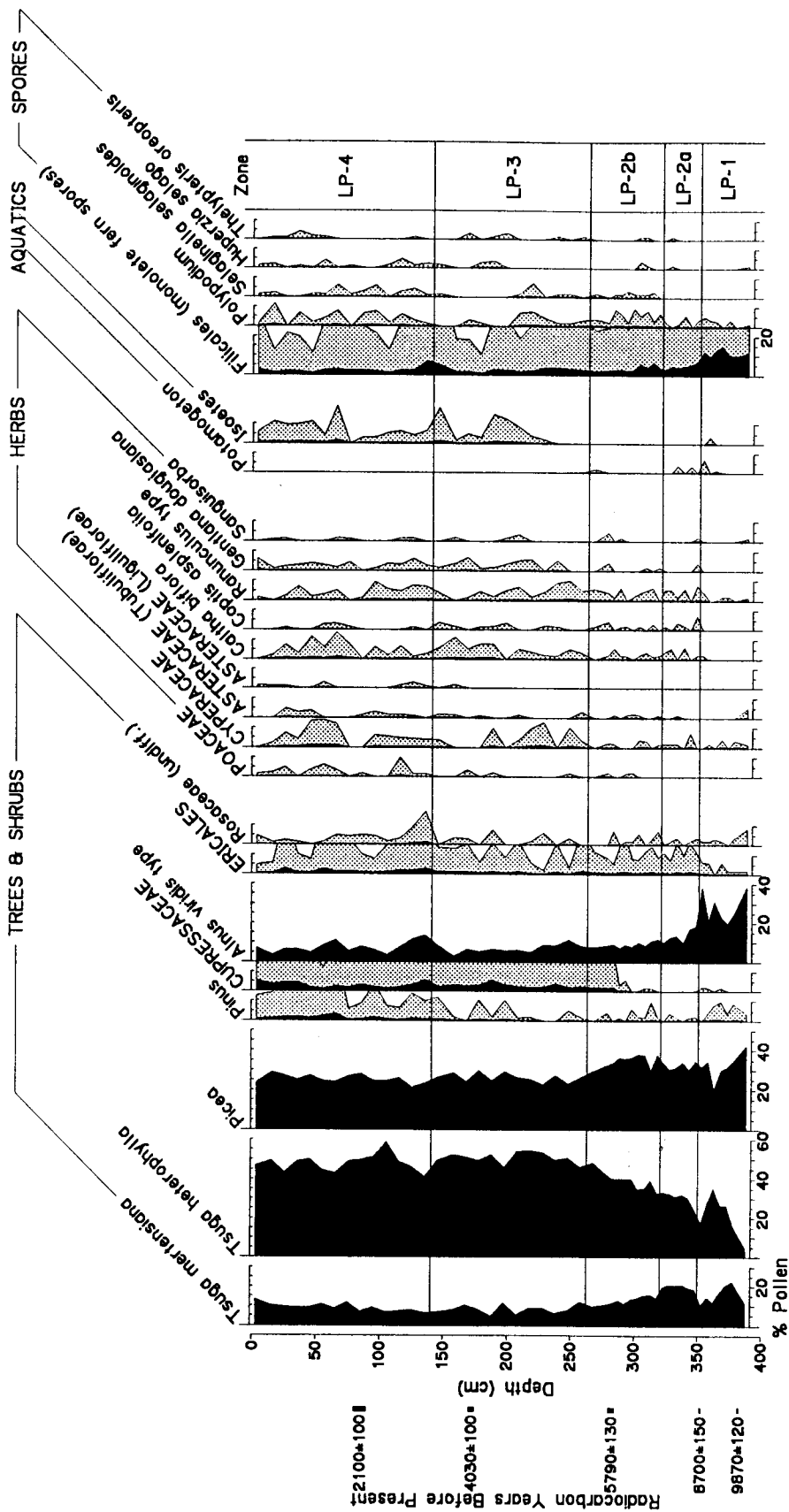
<u>Macrofossil Zonation:</u>

Figure 4.2 summarises the plant macrofossil data and radiocarbon ages for Louise Pond. Six local macrofossil assemblage zones are identified.

Zone LPM-1 (Mountain hemlock - Sitka spruce, 390 - 375 cm, 9870 ± 120 - *ca* 9600 ^{14}C yr BP):

Zone LPM-1 displays maximum abundance of mountain hemlock and Sitka spruce needles. Seeds of Sitka spruce and alder are present and hemlock seeds are abundant. All of the alder seeds that were identifiable to species throughout the core were Sitka alder *(Alnus viridis)*. The overall abundance of conifer macrofossils in the zone indicates that climate conditions were more favourable for tree growth than today at this elevation.

Mountain hemlock typically occurs in the subalpine zone of the Queen Charlotte Islands whereas Sitka spruce is adapted to the mesothermal climate of lower elevations (Calder and Taylor, 1968; Klinka *et al.*, 1989). When sedimentation began in Louise Pond around 10,000 ^{14}C yr BP, spruce probably arrived as a coloniser of immature soils, similar to its present role as a pioneer on glacial moraines in Alaska (Arno and Hammerly, 1984).

The ecological indicator value of spruce needles at this site is unclear, however, since late-glacial spruce cones at Cape Ball on eastern Graham Island (Figure 3.1) were intermediate in morphology between Sitka and white spruce *(Picea glauca)*, and may represent hybrids (Warner and

Chmielewski, 1987). This hybrid is sometimes referred to as Roche spruce (*Picea lutzii*) and is common today in the coastal Skeena River valley on the adjacent mainland (MacKinnon *et al.*, 1992). Needles of Roche spruce are flattened in cross-section, similar to Sitka spruce, and unlike the four-angled needles of white spruce. Spruce needles in the Louise Pond core are either pure Sitka or Roche spruce, but definitely not white spruce. For convenience, the flattened spruce needles are all referred to as Sitka spruce in this paper.

Zone LPM-2 (Western hemlock - Mountain hemlock - Sitka spruce, 375 - 350 cm, *ca* 9600 - 8700 ± 150 ^{14}C yr BP):

Zone LPM-2 records a dramatic change in the plant macrofossil assemblage. Western hemlock (*Tsuga heterophylla*) needles increase to maximum concentrations at the top of the zone. Mountain hemlock needles are also abundant while spruce needles decline. Hemlock and alder seeds reach maximum concentrations with a large spike in alder at 360 - 365 cm (*ca* 9100 ^{14}C yr BP). Presently, western hemlock exists as a low to mid-elevation, mesothermal tree on the Queen Charlotte Islands, and is the climax species of the Coastal Western Hemlock Zone (Calder and Taylor, 1968; Klinka *et al.*, 1989). A western hemlock seed-cone at 352.5 cm (*ca* 8700 ^{14}C yr BP) indicates that local climatic conditions were still warm enough for its local sexual reproduction.

Zone LPM-3 (Mountain hemlock - Western hemlock, 350 - 320 cm, 8700 ± 150 - *ca* 7300 ^{14}C yr BP):

Zone LPM-3 is marked by a decrease in the abundance of plant macrofossils relative to earlier zones. Needles of mountain hemlock are more abundant then western hemlock and Sitka spruce is no longer a significant element in the macrofossil assemblage. Western hemlock needles are declining, but still remain an important component of the macrofossil assemblage. This appears to be a period of gradual climatic transition from warmer to cooler conditions as western hemlock is replaced by mountain hemlock. This may be due to increasing annual snowfall, which favours mountain hemlock (Arno and Hammerly, 1977).

Zone LPM-4 (Mountain hemlock - Yellow cedar - Western hemlock, 320 - 205 cm, *ca* 7300 - 4400 ^{14}C yr BP):

Zone LPM-4 is divided into two subzones (LPM-4a and LPM-4b). Subzone LPM-4a (320 - 262.5 cm, *ca* 7300 - 5400 ^{14}C yr BP) records decreasing deposition of all plant macrofossils. Yellow cedar foliage appears in this subzone at 282.5 cm (*ca* 5900 ^{14}C yr BP) and remains a significant component throughout. Spruce needles and hemlock seeds still occur in subzone LPM-4a but not in LPM-4b. Both western hemlock and Sitka spruce prefer mesothermal climates without extensive snowfall, whereas yellow cedar and mountain hemlock are well adapted to cold and snowy

regimes (Arno and Hammerly, 1977). The vegetation of subzone LPM-4a thus implies that the climate in the watershed was cooler and wetter than in the older zones.

Subzone LPM-4b (205 - 262.5 cm, *ca* 5400 - 4400 ^{14}C yr BP) is dominated by mountain hemlock needles and lesser amounts of yellow cedar foliage. Western hemlock needles are still present but rare compared to the early Holocene. Plant remains recorded in zone 4 are typical of a modern Mountain Hemlock Forest (Brooke *et al.*, 1970).

Zone LPM-5 (Mountain hemlock - Yellow cedar - Heath, 140 - 205 cm, *ca* 4400 - 3400 ^{14}C yr BP):

Zone LPM-5 records an increase in mountain hemlock needles and yellow cedar scale leaves. Heath remains (*Empetrum* and *Cassiope*) appear sporadically. The significance of these small changes is unclear, but they may represent a slight warming or simply variation in sedimentary regime.

Zone LPM-6 (Mountain hemlock, 140 - 0 cm, *ca* 3400 ^{14}C yr BP - present):

In zone LPM-6 mountain hemlock is the most consistently represented needle type. Western hemlock and Sitka spruce needles are rare near the base of the zone and disappear by 2200 ^{14}C yr BP. Shore pine is present sporadically and no seeds were recorded in this zone. Climatic conditions

appear to be the coolest experienced during the Holocene record of Louise Pond. The vegetation remains are representative of present-day conditions.

Pollen Analysis and Local Pollen Assemblage Zones:

Figure 4.3 summarises the sediment stratigraphy, radiocarbon ages and pollen percentage data for Louise Pond. Four local pollen assemblage zones are defined in the pollen diagram.

Zone LP-1 (Mountain hemlock, Spruce - Sitka alder - Western hemlock, 390-350 cm, 9870 ± 120 - 8700 ± 150 ^{14}C yr BP):

Zone LP-1 displays the greatest fluctuations in tree pollen for the Louise Pond sediment record. At the base of Zone LP-1, Sitka alder and spruce pollen dominate the pollen spectrum (~40%), with lesser amounts of mountain and western hemlock. Western and mountain hemlock pollen increase between 372.5 and 362.5 cm (*ca* 9300 and 9100 ^{14}C yr BP). Fern spores attain their highest values here. This zone appears to reflect local presence of spruce, mountain hemlock and western hemlock. The high values of conifer pollen in Zone LP-1 support the interpretation of a local conifer forest based on the plant macrofossil record (LPM-1 and LPM-2).

Zone LP-2 (Western hemlock - Mountain hemlock - Spruce, 350 - 262.5 cm, 8700 ± 150 - *ca* 5400 ^{14}C yr BP):

Zone LP-2 was divided into two subzones. In subzone LP-2a (350 - 320 cm, 8700 ± 150 - *ca* 7300 ^{14}C yr BP) both western and mountain hemlock pollen increase in abundance, while spruce pollen remains high (~ 30%). Sitka alder type pollen and fern spores decline. This may indicate increased deposition of lowland pollen at Louise Pond. The increase in mountain hemlock pollen to ~ 20% suggests that this tree was locally abundant (Mathewes, 1993). In subzone LP-2b (320 - 262.5 cm, *ca* 7300 - *ca* 5400 ^{14}C yr BP) mountain hemlock pollen decreases but remains a significant component (~5-10%) of the pollen record.

Zone LP-3 (Hemlocks - Cupressaceae - Spruce, 262.5 - 140 cm, *ca* 5400 - 3400 ^{14}C yr BP):

In zone LP-3 mountain hemlock, western hemlock, and spruce percentages become relatively stable. Cupressaceae pollen is a significant component above 280 cm (5790 ± 130 ^{14}C yr BP). Various herb pollen such as Asteraceae (Liguliflorae), *Sanguisorba*, *Gentiana douglasiana*, *Coptis asplenifolia* and *Caltha biflora* increase in abundance. Western hemlock and spruce pollen remain high, probably due to extra-local influence. Mountain hemlock and Sitka alder pollen are present but less abundant than western hemlock and spruce. Cupressaceae pollen is probably from local

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yellow cedar, but western redcedar had become established in lowland localities on the Queen Charlotte Islands by this time (Hebda and Mathewes, 1984). *Thelypteris oreopteris* spores increase in abundance; this fern is adapted to open runnels and talus slopes (Calder and Taylor, 1968) and may indicate an increase in bare ground.

Zone LP-4:

In zone LP-4 (Hemlocks - Spruce - Cupressaceae - Pine - Sitka alder, 140 - 0 cm, *ca* 3400 ^{14}C yr BP - present), western hemlock, mountain hemlock and spruce pollen abundances remain similar to Zone LP-3. Zone LP-4 is still dominated by lowland inputs of western hemlock and spruce pollen. Sedge (Cyperaceae), grass (Poaceae), and other herb pollen increase slightly at this time suggesting more open conditions around Louise Pond. This zone closely corresponds with zone LPM-6 of the plant macrofossil record.

Comparison of Pollen and Macrofossil Zones:

The correspondence between the boundaries of pollen and macrofossil zones is very good (Table 4.2). All local pollen assemblage zones begin or end at a corresponding local macrofossil assemblage zone boundary. This unexpectedly high level of correlation has important implications for paleoclimatic analysis.

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Table 4.2
Comparison of pollen and macrofossil zones for Louise Pond

Depth (cm)	Age (yr BP)	Macrofossil Zone	Pollen Zone
0	0	---	
10			
20			
30			
40			
50	1250	LPM-6	LP-4
60			
70			
*85	2100±100		
90			
100	2400		
110			
120			
130			
140	3400	---	
150	3450		
160			
170			
*177.5	4030±100	LPM-5	
190			
200	4300		LP-3
205	4400	---------------------	
220			
230		LPM-4b	
240			
250	5100		
262.5	5400	---	
270			
*282.5	5790±130	LPM-4a	LP-2b
290			
300	6500		
310			
320	7300	---	
330		LPM-3	LP-2a
340			
350 (·352.5)	8700±150	---	
350		LPM-2	
360			
375	9600	---------------------	LP-1
·382.5	9870±120	LPM-1	
390	10,000	---	

* Bulk ^{14}C dates, · AMS ^{14}C dates, yr BP = years before present (1950)

<u>Radiocarbon Dates:</u>

The five bulk sediment (gyttja) ages from Louise Pond (Table 4.1) are all in proper stratigraphic order, as would be expected. However, AMS dates on mountain hemlock needles at 350 - 355 cm and 380 - 385 cm are substantially different from the nearest bulk sample value. Such discrepancies between bulk sediment and macrofossil dates are not uncommon in the basal portions of lake cores, probably due to contamination of sediment by old carbon (Brown *et al.,* 1989; MacDonald *et al.,* 1991). In light of these data, AMS dates are used to estimate the ages of the basal biostratigraphic boundaries.

Conclusions:

At low elevation sites on the Queen Charlotte Islands, such as Cape Ball (Figure 3.1) spruce pollen did not become common until 11,200 ^{14}C yr BP and western hemlock did not expand its range until after 10,200 ^{14}C yr BP (Mathewes *et al.,* 1993). Warming in the early Holocene (after a Younger Dryas-like cooling event) probably accelerated the expansion of spruce and western hemlock in lowlands (Mathewes *et al.,* 1993) and also promoted vertical migration in the mountains, as shown for the Louise Pond watershed. The good correspondence between pollen and macrofossil assemblage zones (Table 4.2) reinforces the assumption that these vegetation changes can be attributed primarily to changes in climate.

The initial deposition of plant macrofossils around 10,000 ^{14}C yr BP records the early colonisation of the watershed by trees, shrubs, and herbs. The immature soils supported mountain hemlock, Sitka spruce, Sitka alder and to a lesser extent, western hemlock. From 9870 ± 120 to 8700 ± 150 ^{14}C yr BP, a well-developed forest with mountain hemlock, Sitka spruce and western hemlock grew around Louise Pond. Whether western hemlock began to replace Sitka spruce through succession, migration or in response to climatic change is unclear, but this change from a mountain hemlock-Sitka spruce forest to a forest rich in western hemlock corresponds with the early Holocene thermal maximum of southern British Columbia (Mathewes and Heusser, 1981; Mathewes, 1985; Clague et al., 1992). This warm period also influenced forest development at low elevations on the Queen Charlotte Islands. According to Warner (1984) the development of spruce-western hemlock forests at Boulton and Serendipity Lakes began around 9400 ^{14}C yr BP and continued until around 5500 ^{14}C yr BP. After 5500 ^{14}C yr BP, decreasing temperature and increasing precipitation promoted the development of forest-bog complexes at these and other sites (Quickfall, 1987).

July temperature in southwestern British Columbia during the early Holocene thermal maximum has been estimated at up to 2°C warmer than present using transfer functions at Marion Lake (Mathewes and Heusser, 1981). Warmer temperatures of at least 0.4 to 0.8°C were estimated at Castle

Peak in the southeastern coastal mountains, using radiocarbon dated wood from above present treeline between 9100 and 8100 ^{14}C yr BP (Clague *et al.,* 1992). Temperature changes of this magnitude or greater must have also occurred at Louise Pond for the watershed to sustain a mesothermal western hemlock forest at 650 m elevation, instead of the present-day Mountain Hemlock Parkland Zone.

The transition to cooler climate began at Louise Pond around 8700 ^{14}C yr BP, based on both pollen and macrofossil data. A decrease in conifer macrofossil deposition and increased lowland pollen influence suggests that forest productivity around Louise Pond was declining. Mountain hemlock largely replaced western hemlock, and yellow cedar became prominent around 5790 ± 130 ^{14}C yr BP, indicating cooler and wetter conditions. An open mountain hemlock-yellow cedar forest is suggested by the macrofossil and pollen records. Mountain hemlock pollen percentages in modern surface samples from the Mountain Hemlock Zone are often less then 10% of total terrestrial pollen, with a minimum value of 2-3% of total terrestrial pollen suggesting local presence near a depositional basin (Mathewes, 1993). An abundance of mountain hemlock and yellow cedar is characteristic of the Mountain Hemlock Forest Subzone of coastal British Columbia (Brooke *et al.,* 1970) and indicates a humid, microthermal climate with high snowfall (Arno and Hammerly, 1977; Klinka *et al.,* 1989). The cooling trend defined by a decrease in western hemlock, Sitka spruce and total needle abundance

is also supported by basal radiocarbon dates from two other subalpine ponds elsewhere on the islands. Shangri-La Bog (Figures 3.1 and 5.1b; Table 5.1) at 600 m elevation has a basal age of 7190 ± 100 ^{14}C yr BP and San Cristoval Pond (SC-1) at 550 m elevation (Figures 3.1 and 5.1a, Table 5.1) was dated at 7180 ± 110 ^{14}C yr BP. The beginning of sedimentary records in these basins marks the formation of permanent water. This indicates that cooling and increased precipitation was a regional rather than local event. It thus appears that wetter and cooler conditions at Louise Pond preceded the beginning of the classical Neoglacial period (6000 ^{14}C yr BP, Porter and Denton, 1967), called the Garibaldi Phase in the south coastal mountains of British Columbia (Ryder and Thomson, 1986).

A brief period of increased macrofossil abundance occurs between *ca* 4400 and 3200 ^{14}C yr BP. Whether this is due to warming or changes in sediment deposition is unclear. Beginning around 3200 ^{14}C yr BP, western hemlock and Sitka spruce macrofossils drop out of the plant macrofossil record, suggesting further cooling and treeline lowering. The timing of this cooling corresponds with the Tiedemann glacial advance in the mountains of southwestern British Columbia between 3300 and 1900 ^{14}C yr BP (Ryder and Thomson, 1986) and the Peyto and Robson glacial advances in the Canadian Rockies from 3300 to 2800 ^{14}C yr BP (Luckman *et al.,* 1993). It appears that the climatic changes which initiated glacial advances in the southwestern mountains and Rockies also influenced the subalpine vegetation of the Queen

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Charlottes. Plant macrofossil abundance remains low at Louise Pond after 3200 ^{14}C yr BP, indicating that Neoglacial climatic conditions have maintained the open mountain hemlock-yellow cedar forest that presently exists at Louise Pond.

CHAPTER 5: HOLOCENE TREELINE AND CLIMATIC CHANGE ON THE QUEEN CHARLOTTE ISLANDS, CANADA: SC1 POND AND SHANGRI-LA BOG[3].

Introduction:

Paleoecological investigations aid in the understanding of vegetation dynamics at various spatial and temporal scales (Moore *et al.,* 1991). Because climate is generally acknowledged as the primary factor in regional vegetation change, paleobotanical analyses can be used to infer how climate changes over time (COHMAP, 1988). The ability to assess the long term effects of climate on vegetation dynamics is becoming increasingly important as society prepares to deal with the potential impacts of global warming. By understanding how ecosystems have responded to climate change in the past, we gain a better understanding of how they may respond to change in the future.

Treeline is defined as the upper limit of tree growth (Kimmins, 1987) in mountainous areas, and is an ecotone defined largely by temperature during the growing season, but also by precipitation and snowpack characteristics throughout the year (Brooke *et al.,* 1970; Tranquillini, 1979; Arno and Hammerly, 1984). Treeline is very sensitive to climatic changes, as many of the tree species exist at their ecological tolerance limits. Most

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[3] Preliminary results were presented at the Canadian Quaternary Association - 1995 (Pellatt and Mathewes, 1995).

palynological studies at high elevation sites in North America are influenced by the abundant upslope transport of lowland pollen (Beaudoin, 1986; Kearney and Luckman, 1983; Pellatt and Mathewes, 1994), which can hamper accurate reconstructions of past treeline vegetation. Detailed reconstructions of treeline have therefore employed wood and/or plant macrofossils to document the past existence of trees above present treeline (Kearney and Luckman, 1983; Luckman and Kearney, 1986; Dunwiddie, 1987; Clague *et al.,* 1992; Luckman *et al.,* 1993; Pellatt and Mathewes, 1994). Plant macrofossils combined with pollen allow the palynologist to reconstruct local vegetation changes related to treeline shifts and also increase the level of taxonomic resolution for trees and other plants (Dunwiddie, 1987; Pellatt and Mathewes, 1994).

Palynological research at Louise Pond, Queen Charlotte Islands, documented several treeline shifts during the Holocene (Pellatt and Mathewes, 1994) and demonstrated the importance of plant macrofossils in reconstructing treeline shifts and climatic changes. The three most dramatic climatic events recorded at Louise Pond are:

1) an early Holocene xerothermic period (*ca* 9500-7000 ^{14}C yr BP)

2) A cool/moist period in the mid-Holocene from *ca* 7000 to *ca* 3500 ^{14}C yr BP), and

3) a period of further cooling in the late Holocene that begins about the time of the Tiedemann glacial advance (3300 to 1900 ^{14}C yr BP) in the Coast

Mountains and the Peyto and Robson glacial advances in the southern Canadian Rocky mountains (3300 - 2800 ^{14}C yr BP) and continues to present.

To test if there is evidence for these three periods of climate change at other high elevation localities on the Queen Charlotte Islands, a sediment core from SC1 Pond was analysed for pollen and plant macrofossils and a core from Shangri-La Bog was analysed for pollen. Synchroneity of vegetation changes at these three sites would support a hypothesis of regional climatic fluctuations as a driving mechanism, whereas differences would argue for greater importance of local, site-specific factors.

Study Sites:

<u>Physiography:</u>

SC1 pond (131°54.4'W, 54°25.0'N) is a small subalpine lake located in the San Cristoval Range on the west coast of northern Moresby Island (Figure 3.1). It is located on a ridge at 550 metres above sea level in the upper reaches of the Mountain Hemlock zone (Figure 5.1a). The pond sits in a granitic bedrock basin where seepage and precipitation are the only water sources. Shangri-La Bog (132°24.5'W, 53°16'N) is located on Mt. Needham, southwest Graham Island at 595 meters above sea level (Figure 5.1b). It is a small shallow mire developed in a bedrock depression within the Mountain Hemlock zone, close to the tree limit.

<u>Vegetation:</u>

Trees growing around SC1 Pond include mountain hemlock and shore pine (*Pinus contorta var. contorta*)   Many trees exhibit stunted growth forms, but a few mountain hemlock exhibit tree form near the head wall of the cirque.   Common shrubs and dwarf-shrubs include Sitka alder (*Alnus viridis*), *Sorbus sitchensis*,   *Vaccinium caespitosum*, *Empetrum nigrum*, *Cassiope mertensiana*, *Cassiope lycopodioides*, and *Kalmia polifolia*.   Herbs and dwarf shrubs of wet soils, such as *Fauria crista-galli*, *Pinguicula vulgaris*, *Geum calthifolium*, *Tofieldia glutinosa*, *Gentiana douglasiana*, *Leutkea pectinata*, *Coptis asplenifolia*, *Veratrum viride*, *Calamagrostis* sp., *Carex* sp., *Lycopodium sitchense*, *Lycopodium clavatum*,   *Huperzia selago*, *Blechnum spicant* and the endemic *Senecio newcombii* also grow around the basin.   Plant cover on the south-facing slopes above the lake basin grades rapidly into a belt of shrubs and   krummholz and then rocky alpine vegetation. (Figure 5.1a).

Trees growing around Shangri-La Bog include mountain hemlock, yellow cedar and shore pine. Non-arboreal vegetation is similar to that of the SC1 Pond area, with Sitka alder, *Vaccinium ovalifolium*, *Pyllodoce glanduliflora*,   *Empetrum nigrum*, *Cassiope mertensiana*, and *Kalmia polifolia.* Herbs and dwarf shrubs of wet soils, such as *Fauria crista-galli*, *Pinguicula vulgaris*, *Gentiana douglasiana*, *Leutkea pectinata*, *Coptis asplenifolia*, *Veratrum viride*, *Carex* sp., *Castilleja* sp., *Lupinus.* sp.,

Pedicularis lanata, *Leptarrhena pyrolifolia*, *Valeriana sitchensis*, *Lycopodium clavatum*, *Huperzia selago*, *Blechnum spicant* and the endemic *Senecio newcombii* also grow around the basin (Figure 5.1b). The vegetation surrounding SC1 Pond and Shangri-La Bog is typical of the upper reaches of the subalpine Mountain Hemlock zone.

Methods:

Sediment Core

A 264.5 cm sediment core from SC1 Pond and an 83 cm core from Shangri-La Bog were collected from the deepest parts of the basins, using a modified Livingstone piston corer, 5 cm in diameter. The core segments were transported to Simon Fraser University (SFU), and stored at 4°C. Sediments were volumetrically subsampled using a calibrated syringe and analysed for pollen and plant macrofossils at 10 cm intervals for SC1 Pond and 5 cm intervals from Shangri-La Bog. Radiocarbon dates on bulk sediments were obtained at selected depths (Table 5.1) to provide an absolute chronology. Ages throughout this study are given as uncalibrated radiocarbon years before present (^{14}C yr BP).

Figure 5.1a

Photograph of SC1 Pond. Note the Mountain Hemlock zone parkland conditions.

Figure 5.1b

Photograph of Shangri-La Bog. Note the Mountain Hemlock zone parkland conditions. Krummholz shorepine and yellow cedar are in the foreground.

Figure 5.1a
left

Figure 5.1b
below

Table 5.1: Radiocarbon Ages for SC1 Pond and Shangri-La Bog Sediment.

	Depth (cm)	Age* (^{14}C yr BP)	Laboratory Number	Material Dated
SC1 Pond	90-95	3460±100	Beta-56062	gyttja
SC1 Pond	195-200	6090±90	Beta-56063	gyttja
SC1 Pond	257-264.5	7180±110	GSC-4040	gyttja
Shangri-La Bog	80-83	7190±100	GSC-3357	coarse sand and plant fragments

*GSC dates have errors presented at ±2σ, Beta ages are ±1σ

Plant Macrofossil Analysis (SC1 Pond)

The volume of 5 cm core segments were determined by displacement in water, and the sediments screened for plant macrofossils using 250 μm mesh screens. Plant remains were picked from screened residues under a Wild dissecting microscope, and identified with the aid of keys (Calder and Taylor, 1968; Dunwiddie, 1985) and comparisons with the SFU plant macrofossil reference collection. Totals of identifiable tips and bases of fragmented conifer needles were divided by 2 and added to the whole needle counts before plotting. Raw data were entered into TILIA v2.0 (Grimm, 1993) and plotted as absolute concentrations per 100 ml sediment. Stratigraphically constrained cluster analysis (CONISS) was used to zone the plant macrofossil data and TILIAGRAPH v1.25 (Grimm, 1991) was used to produce the plant macrofossil diagram (Figure 5.2).

Pollen Analysis (SC1 Pond and Shangri-La Bog)

The methodology used for pollen extraction is described in Moore *et al.,* (1991). Identification of pollen and spores was facilitated with published keys (McAndrews *et al.,* 1973; Faegri and Iversen, 1989; Moore *et al.,* 1991) and the SFU modern reference collection. A Zeiss microscope was used to identify and count palynomorphs. Routine counting was carried out at 500X magnification and critical identifications were made under oil

Figure 5.2

Plant macrofossil diagram for SC1 Pond, also showing bulk sediment dates to the left. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 5.2
SC1 Pond, Queen Charlotte Islands
Macrofossil Diagram
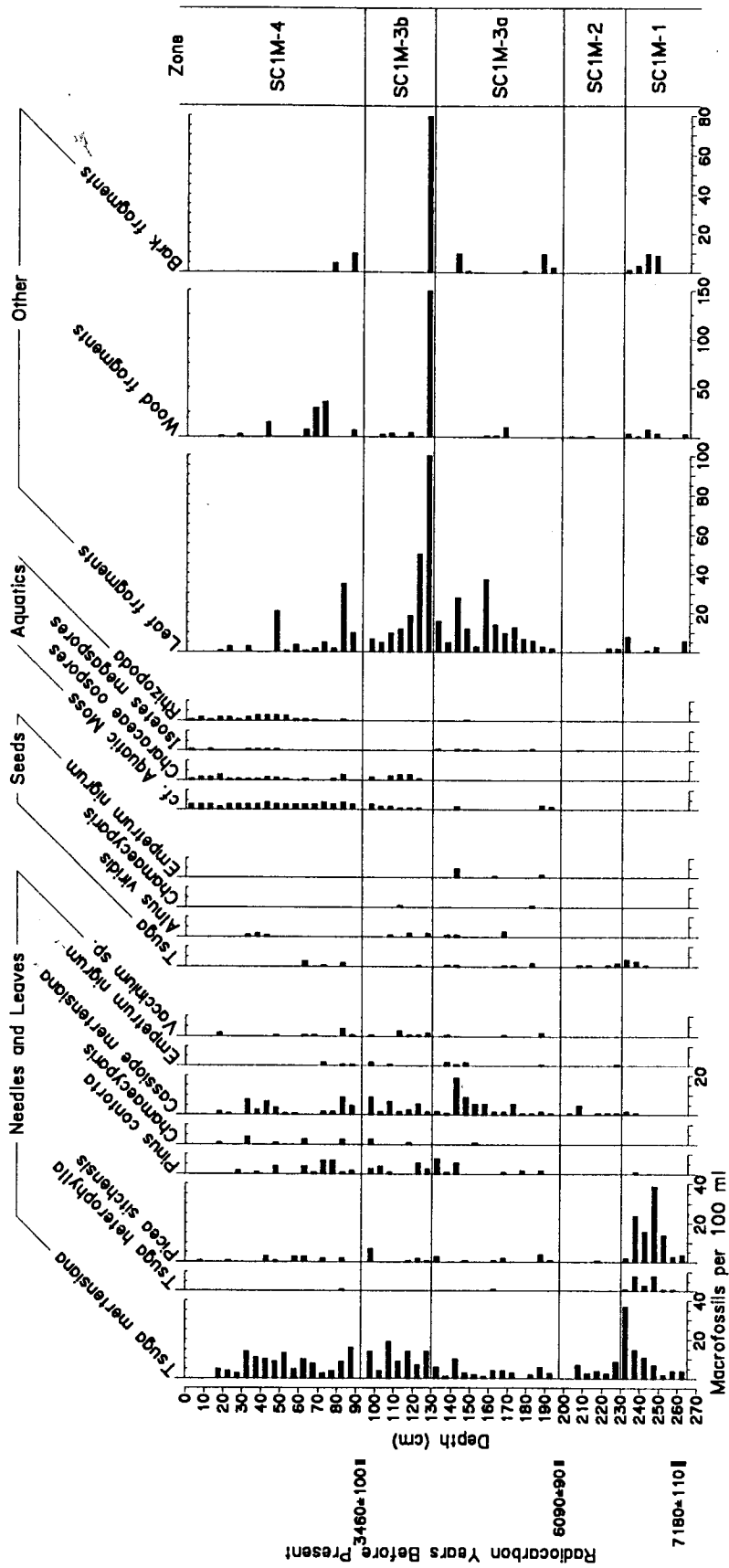
Marlow Pellatt, 1996

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immersion at 1200X. The basic pollen sum used for percentage calculation includes all terrestrial pollen. Raw counts were converted into percentages using TILIA v2.0, and TILIAGRAPH v1.25 was used to generate the pollen diagrams (Figures 5.3 and 5.4). Pollen zonation was performed using CONISS, stratigraphically constrained cluster analysis (Grimm, 1993).

Results and Discussion:

Local Plant Macrofossil Assemblage Zones at SC1 Pond.

Changes in plant macrofossil distribution and macrofossil zonation are shown in Figures 5.2 and 5.5. Photographs of fossil mountain hemlock, western hemlock, Sitka spruce, and lodgepole pine needles are shown in Figure 5.6 to illustrate their morphological differences.

Zone SC1M-1 (Sitka spruce - Mountain hemlock - Western hemlock, 264.5 - 230 cm, 7180±100 - *ca* 6650 ^{14}C yr BP):

Zone SC1M-1a displays maximum abundances of western hemlock and Sitka spruce needles, as well as a peak in mountain hemlock needles at 232.5 cm (*ca* 6690 ^{14}C yr BP). The highest numbers of hemlock seeds occur here and total plant macrofossils (needles, seeds, and other vegetative remains) reach a maximum in this zone.

The results from zone SC1M-1a suggest that climatic conditions were favourable for the local growth of low elevation tree species such as western

Figure 5.3

Percentage pollen diagram for SC1 Pond, with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. Bulk sediment dates are shown on the left. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 5.3
SC1 Pond, Queen Charlotte Islands
Pollen Percentage Diagram
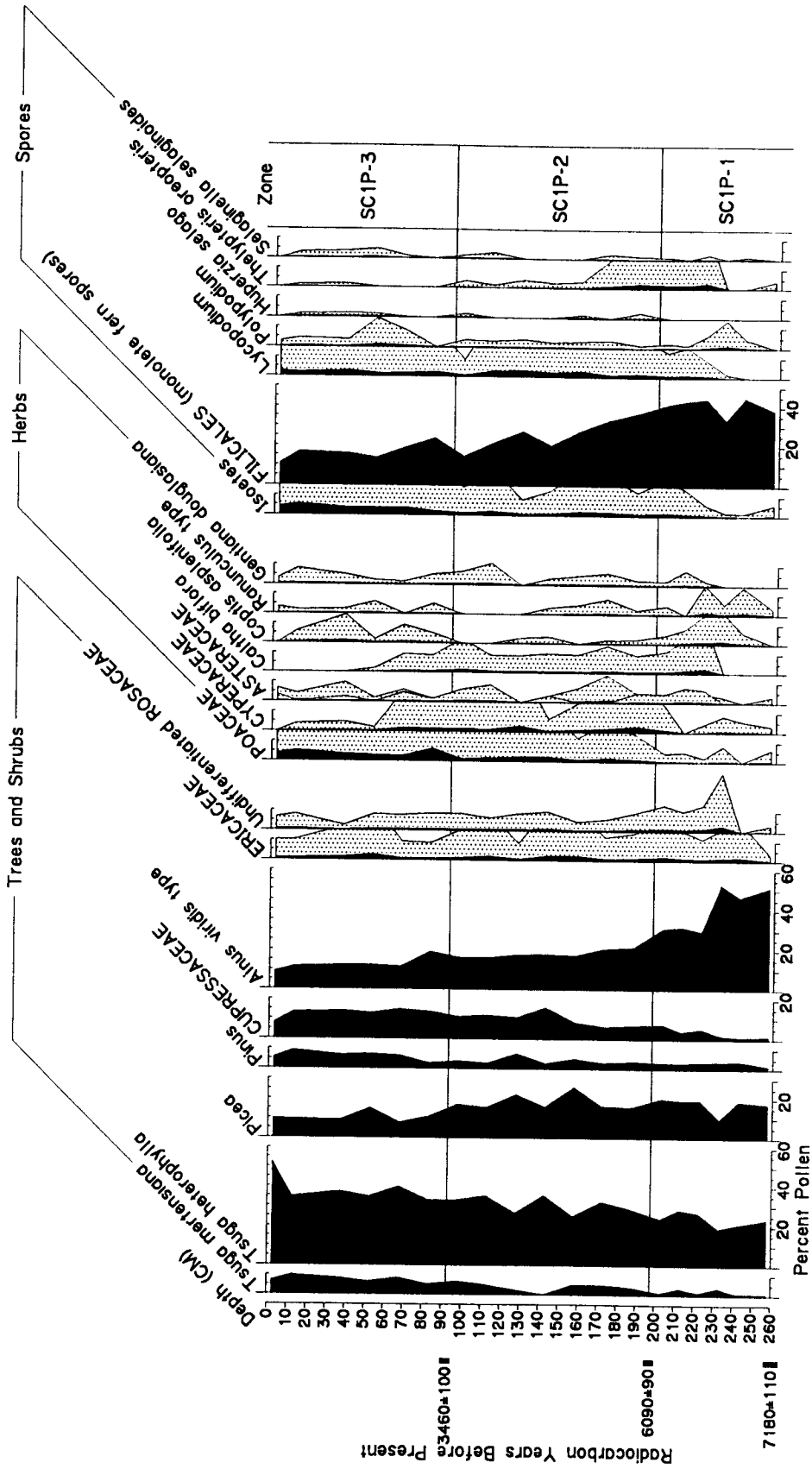
Analyst: Marlow G. Pellatt

Figure 5.4

Percentage pollen diagram for Shangri-La Bog, with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. A basal bulk sediment date is shown on the left. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 5.4
Shangri-La Bog, Queen Charlotte Islands
Pollen Percentage Diagram
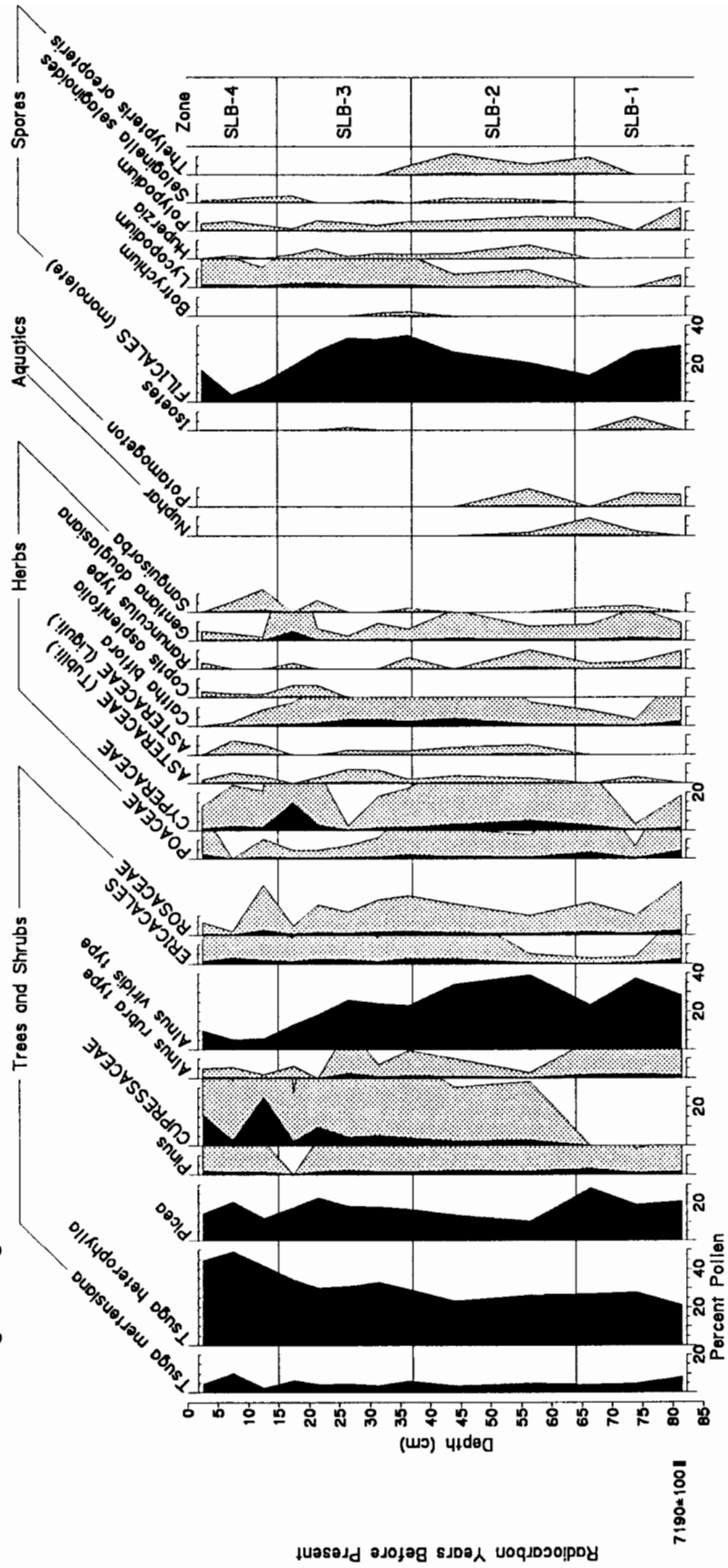
Marlow Pellatt, 1996

FIGURE 5.5
Zone Comparison Among Louise Pond,
SC1 Pond and Shangri-La Bog
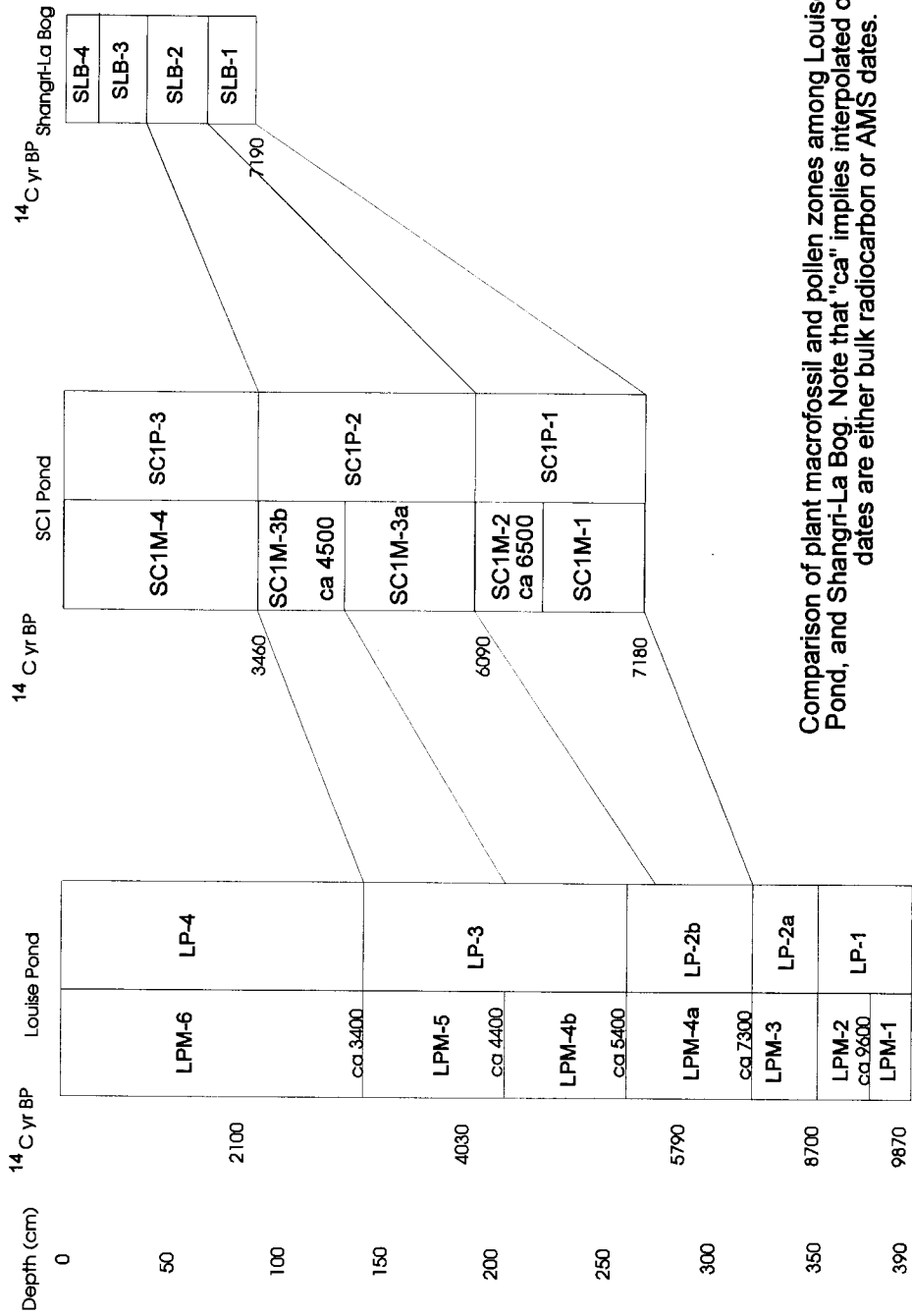
Comparison of plant macrofossil and pollen zones among Louise Pond, SC-1 Pond, and Shangri-La Bog. Note that "ca" implies interpolated date. All other dates are either bulk radiocarbon or AMS dates.

Figure 5.6

Fossil Needles

1) Western hemlock adaxial and abaxial surfaces. Note there are no stomata on the adaxial surface.

2) Mountain hemlock adaxial and abaxial surfaces. Note stomata on both the adaxial and abaxial surfaces.

3) Sitka Spruce.

4) Lodgepole (shore) pine

1

2

3

4
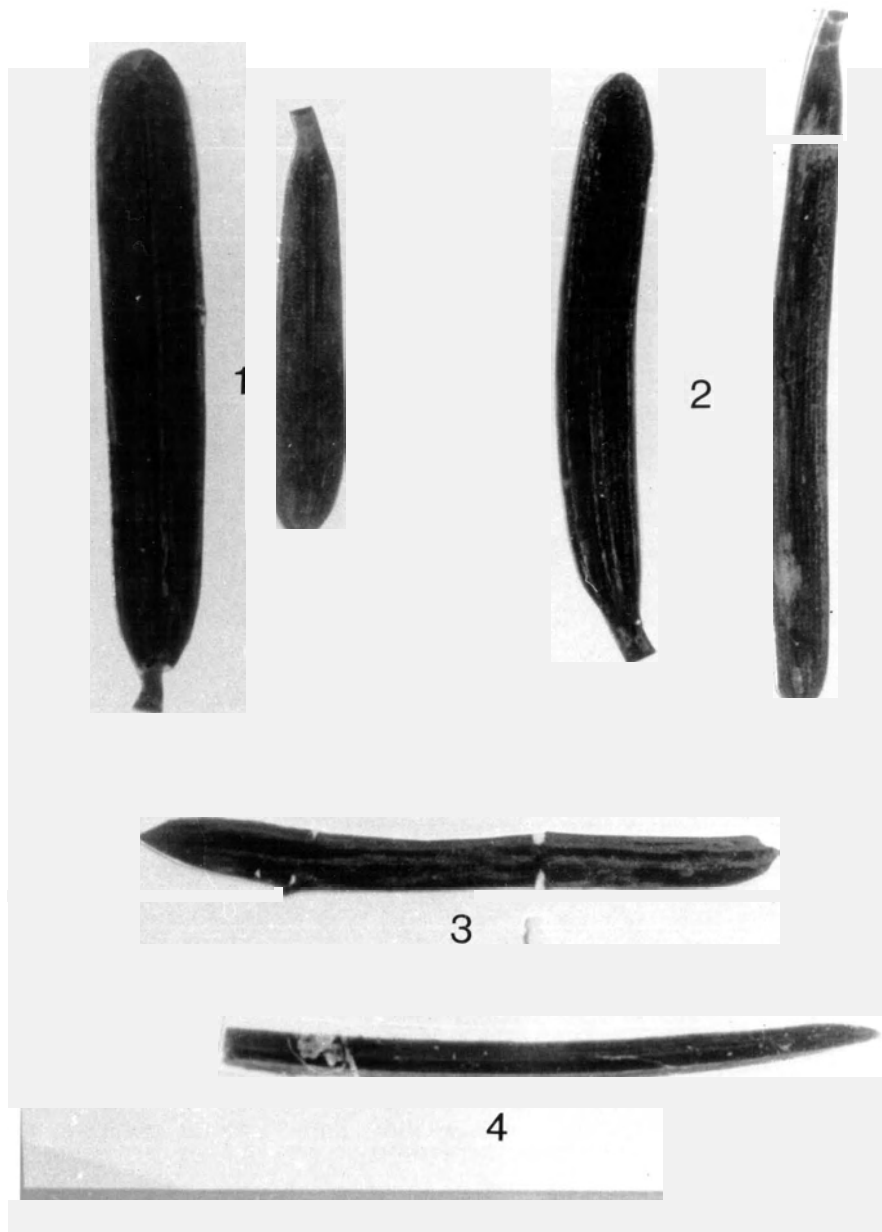
Scale Bar
= 1.5cm

hemlock and Sitka spruce. This zone corresponds to the end of the early Holocene xerothermic period as observed in southern British Columbia and at Louise Pond (Mathewes and Heusser, 1981; Pellatt and Mathewes, 1994).

Zone SC1M-2 (Mountain hemlock, 230 - 195 cm, *ca* 6650 - 6090 ± 90 ^{14}C yr BP):

Zone SC1M-1b exhibits a decrease in needle abundance in relation to zone SC1M-1a, and less indicators of subalpine conditions than zone SC1M-3a. Mountain hemlock is the dominant conifer, but at levels considerably lower than observed in zone SC1M-1a. Western hemlock remains are absent and Sitka spruce only occurs at 217.5 cm (*ca* 6440 ^{14}C yr BP). *Cassiope* needles increase in abundance and mountain hemlock seeds are present.

The results for SC1M-2 suggest climatic deterioration between *ca* 6650 to 6090 ^{14}C yr BP. Climate appears to be cooler and possibly wetter in this zone than in zone SC1M-1. This zone documents the establishment of a subalpine vegetation community.

Zone SC1M-3a (Mountain hemlock - Heaths, 195 - 145 cm, 6090 ± 90 - *ca* 4950 ^{14}C yr BP):

In zone SC1M-3a mountain hemlock needles remain at levels similar to zone SC1M-2. Sitka spruce needles first appears at 187.5 cm (*ca* 5900 ^{14}C yr BP) and occurs sporadically throughout the rest of the zone. Yellow cedar

scale leaves are first noted at 152.5 cm (*ca* 5140 ^{14}C yr BP). *Cassiope* needles, *Empetrum* needles and *Vaccinium* leaves increase in abundance in this zone. Seeds of hemlock, Sitka alder, yellow cedar, and *Empetrum* are present and unidentified leaf fragments are abundant.

Zone SC1M-3a records a significant increase of species common in subalpine forests of coastal British Columbia. Mountain hemlock, *Cassiope* and *Empetrum* remains confirm a subalpine forest had developed and that temperatures were less than in the xerothermic period. This zone correlates with zone LPM-4b at Louise Pond (Figure 5.5), which also records mid-Holocene cooling.

Zone SC1M-3b (Mountain hemlock - Lodgepole pine - *Cassiope* - Sitka alder, 145 - 85 cm, *ca* 4950 - 3460 ± 100 ^{14}C yr BP):

In zone SC1M-3b needles of mountain hemlock, lodgepole pine, and *Empetrum*, as well as *Vaccinium* leaves increase in abundance in comparison to zone SC1M-3a. *Cassiope* needles remain important in this zone, and seeds of hemlock, Sitka alder, yellow cedar, and *Empetrum* are recorded as well. There is also a dramatic spike in abundance of unidentified leaf, wood and bark fragments at 127.5 cm (*ca* 4500 ^{14}C yr BP). Above 127.5 cm, aquatic mosses and Characeae increase.

Precipitation may have increased during this zone. Subalpine indicators reach their maximum abundance, and increases in leaf litter, wood

and bark may indicate increased erosion around the basin. This zone correlates well with zone LPM-5 at Louise Pond, which also records an increase in mountain hemlock needles and other subalpine plant remains at this time (Figure 5.5).

Zone SC1M-4 (Mountain hemlock - Lodgepole pine - *Cassiope* - *Isoetes*, 85 - 0 cm, 3460 ± 100 ^{14}C yr BP to present):

In zone SC1M-4 mountain hemlock, lodgepole pine, *Cassiope mertensiana*, yellow cedar and *Vaccinium* needles and leaves are all well represented. Aquatic mosses, Characeae, *Isoetes* and Rhizopods increase in abundance and remain constant throughout the zone. Sitka spruce needles appear sporadically.

Zone SC1M-4 shows a dramatic increase in aquatic macrofossils suggesting changes in water level, nutrient status, or water temperature. Overall macrofossil abundance is lower in this zone than in zone SC1M-3b. Modern cool/moist conditions are inferred in the late Holocene at SC1 Pond, with plant remains representative of present-day subalpine parkland. The timing of this cooling trend corresponds with the Tiedemann glacial advances in the Coastal Mountains (Ryder and Thomson, 1986) and the Peyto and Robson glacial advances in the Canadian Rocky Mountains (Luckman *et al.*, 1993). It also matches the cooling trend detected in zone LPM-6 (Figure 5.5) at Louise Pond (Pellatt and Mathewes, 1994).

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Pollen Assemblage Zones at SC1 Pond:

Changes in pollen assemblages for SC1 Pond are summarised in Figures 5.3 and 5.5.

Zone SC1P-1 (Sitka alder - Western hemlock - Spruce, 264.5 - 195 cm, 7180±100 - 6090 ± 90 ^{14}C yr BP):

In zone SC1P-1 high levels of Sitka alder type pollen, high Filicales (monolete fern spores), and low initial herb and Cupressaceae (cedar type) pollen occur. Western hemlock, Cupressaceae, mountain hemlock and herb pollen are at the lowest levels recorded in the core.

Climatic interpretation is difficult for this zone. Low frequencies of pollen and spores from subalpine plants suggest that climate was either warmer and drier than present or the pollen production of local plants was extremely low. This zone corresponds well with zone LP-2b from Louise Pond. The presence western hemlock and Sitka spruce needles in the macrofossil diagram indicates that this zone represents the end of the early Holocene xerothermic period.

Zone SC1P-2 (Cupressaceae - *Picea* - Hemlocks - Herbs, 195 - 85 cm, 6090 ± 90 - 3460 ± 100 ^{14}C yr BP):

Zone SC1P-2 shows slight increases in mountain hemlock, western hemlock, and spruce. Increases in Cupressaceae, Cyperaceae (sedge) and herb pollen and corresponding decreases in Sitka alder type pollen and Filicales spores occur in this zone.

The slight increase in mountain hemlock pollen suggests that this tree may have become more abundant locally. Decreases in Sitka alder type pollen and increases in subalpine herb pollen such as Cyperaceae, *Caltha biflora*, *Ligusticum* and *Lycopodium* suggest that a coniferous forest was becoming a more open subalpine parkland beginning around 6090 ± 90 ^{14}C yr BP. The timing of this vegetation change at SC1 Pond is consistent with mid-Holocene cooling observed at Louise Pond (Figure 5.5) and the replacement of mesothermal macrofossil remains with subalpine species in zone SC1M-3a and 3b in the macrofossil diagram (Figure 5.2).

Zone SC1P-3 (Mountain hemlock - Cupressaceae - Poaceae, 85 - 0 cm, 3460 ± 100 ^{14}C yr BP to Present):

Zone SC1P-3 shows further increases in mountain hemlock, Cupressaceae and Poaceae (grass) pollen and an increase in *Isoetes* spores. Zone SC1P-3 shows similar changes to those observed in SC1M-3.

This zone appears to record a late Holocene cooling event similar to that observed in SC1M-3 in which modern subalpine conditions were established. Increases in western hemlock pollen (from extra-local or regional transport) and Poaceae indicate more open conditions at SC-1 Pond. Decreased temperature lead to an open, subalpine parkland. This cooling is synchronous with late-Holocene cooling at Louise Pond and the glacial readvancements in the Coast Mountains and Canadian Rockies (Ryder and Thomson, 1986; Luckman *et al*, 1993).

Pollen Assemblage Zones at Shangri-La Bog:

Four pollen assemblage zones are apparent from visual inspection and stratigraphically constrained cluster analysis. The radiocarbon age from the basal 5 cm long bulk sediment sample at Shangri-La Bog is 7190±100 ^{14}C yr BP. Pollen assemblage zones are displayed in Figures 5.4 and 5.5.

Zone SLB-1 (Spruce - Hemlocks - Sitka alder, 82.5 to 64 cm):

Zone SLB-1 encompasses the lower portion of the sediment core, with a basal radiocarbon age of 7190±100 ^{14}C yr BP. Sitka alder, spruce, and western hemlock pollen, as well as Filicales spores are well represented in this zone. The assemblage of herbaceous pollen types and spores is less diverse in this zone than higher in this core. Mountain hemlock pollen frequencies between 5 and 10 percent indicate that it grew locally

(Mathewes, 1993; Pellatt and Mathewes, 1994). Aquatic pollen and spores reach maximum values in this zone.

Shangri-La Bog became a permanent water body around 7190±100 ^{14}C yr BP based on high levels of aquatic pollen and spores and start of organic matter sedimentation. High percentages of Sitka alder type and spruce pollen (20-30%), with low levels of subalpine herbs suggest that temperatures may have been warmer than present. The establishment of permanent water, Cyperaceae pollen, and aquatic pollen and spores suggest that precipitation increased compared to the early Holocene. This zone corresponds with zone SC1P-1 from SC1 Pond and LP-2B from Louise Pond (Figure 5.5).

Zone SLB-2 (Sitka alder - Cupressaceae - Herbs, 64 to 37 cm):

Zone SLB-2 records high levels of Sitka alder type pollen and increasing fern spores and sedge pollen in comparison to zone SLB-1. Cupressaceae pollen, *Lycopodium* and *Huperzia* spores first appear here. Herbs and Ericales increase in abundance whereas aquatics decrease. *Thelypteris oreopteris* spores are continuously present.

The appearance of Cupressaceae pollen most likely indicates the arrival of western redcedar at elevations below Shangri-La Bog. The arrival of cedar in the Queen Charlotte Islands around 5000 ^{14}C yr BP (Hebda and Mathewes, 1984) and the development of bogs on northern Graham Island

around 5500 ^{14}C yr BP (Quickfall, 1987) may indicate decreasing temperature and increasing precipitation in the Queen Charlotte Islands. A subalpine forest parkland vegetation is reconstructed at Shangri-La Bog based on the local presence of mountain hemlock and increases in pollen of Ericales, Cyperaceae, and *Caltha*. A similar climatic change is observed at SC1 Pond (zone SC1P-2) and at Louise Pond, zones LP-2b and LP-3 (Figure 5.5).

Zone SLB-3 (Hemlocks - Cyperaceae, 37 to 15 cm):

Zone SLB-3 displays increases in western hemlock, Cupressaceae, spruce, Cyperaceae, *Gentiana douglasiana*, *Coptis* and other herbaceous pollen types. Sitka alder type pollen decreases as do fern spores after an initial increase. Subalpine tree, shrub and herb pollen increase in relation to zone SLB-2.

These data suggest an expansion of subalpine conditions. Increases in western hemlock from extra-local or regional origin suggests that open, subalpine parkland had developed at Shangri-La Bog. Cupressaceae (probably the subalpine yellow cedar) pollen may indicate an increase in this tree in the area. Increases in Cyperaceae, *Caltha biflora*, and *Gentiana douglasiana* (swamp gentian) indicate open, wet conditions typical of depressions in mountain hemlock parkland (Pojar and Mackinnon, 1994). This zone corresponds with the lower portion of zone SC1P-3 at SC1 Pond

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and LP-4 at Louise Pond. Decreased temperatures and high precipitation (probably in the form of increased snowfall) seem to characterise this zone, and may correspond to late Holocene cooling in the Pacific Northwest (Porter and Denton, 1967).

Zone SLB-4 (Cupressaceae - Hemlocks, 15 cm to Present):

In zone SLB-4 relatively high levels of mountain hemlock and Cupressaceae pollen occur. Spruce and western hemlock are also high, whereas Sitka alder pollen reaches its minimum value.

Zone SLB-4 displays increases in Cupressaceae, western hemlock and mountain hemlock, with corresponding decreases in Sitka alder and Filicales that may indicate further climatic deterioration at Shangri-La Bog. It is impossible to ascertain whether the Cupressaceae pollen is from western redcedar or yellow cedar, but both species would indicate increased precipitation. Increased precipitation could also be responsible for high western hemlock pollen because increased snowpack would further lower vegetation zones and allow a greater influx of lowland pollen such as western hemlock and western redcedar to reach the bog. This zone corresponds with the upper portion of zone SC1P-3 at SC1 Pond and LP-4 at Louise Pond and represents modern upper subalpine conditions at Shangri-La Bog.

Conclusions:

The similarity of local macrofossil and pollen assemblage zones at SC1 and Louise Ponds (Figure 5.5) suggests that climate changes at these sites on the Queen Charlotte Islands are the result of regional rather than local changes. Not only do inferred vegetation and climate changes occur at similar times on the Queen Charlotte Islands, but these changes occur very close in time to the early Holocene xerothermic period observed in southern British Columbia, mid-Holocene cooling observed at Louise Pond, and with the Tiedemann glacial advances observed in the Coast Range of British Columbia and the Peyto and Robson glacial advances in the Canadian Rockies (Mathewes and Heusser, 1981; Ryder and Thompson, 1986, Luckman *et al.*, 1993; Pellatt and Mathewes, 1994).

Although Shangri-La Bog only has one basal radiocarbon date, similar changes are indicated in the undated pollen assemblage zones (Figures 5.4 and 5.5). These data indicate that climate change at high elevations on the Queen Charlotte Islands were occurring at a regional level. Maximum warmth at high elevations on the Queen Charlotte Islands occurs prior to 7180 ^{14}C yr BP, as indicated by palynological evidence at Louise Pond and the development of permanent water bodies at SC1 Pond and Shangri-La Bog at this time. Plant macrofossil and pollen data at both SC1 and Louise Pond, indicate that temperatures remained well above present until around 6000 ^{14}C yr BP, followed by cooling in the mid and late-Holocene. The time of

the maximum Holocene warmth at SC1 Pond, Shangri-La Bog and Louise Pond correspond well with the early Holocene xerothermic period observed in southwestern British Columbia and the southern Coast Mountains of British Columbia (Mathewes and Heusser, 1981; Clague *et al.,* 1992). These data are also consistent with the inferred maximum Holocene temperatures suggested by Warner (1984) at lowland localities on Graham Island and Fedje (1993) at lowland localities on southern Moresby Island.

It appears that climatic deterioration began with the onset of what is traditionally referred to as Neoglaciation at around 6000 ^{14}C yr BP. Subalpine biogeoclimatic conditions became established around this time.

Modern vegetation conditions became established at SC1 Pond by 3460 ± 100 ^{14}C yr BP and at Shangri-La Bog in pollen zone SCLB-4. The timing for this change to modern conditions also occurs at Louise Pond around 3400 ^{14}C yr BP (Pellatt and Mathewes, 1994). This period of climatic cooling occurred not only on the Queen Charlotte Islands, but also in the coastal mountains of mainland British Columbia (Tiedemann glacial advance - 3300 to 1900 ^{14}C yr BP) and the Canadian Rocky Mountains (Peyto and Robson glacial advances - 3300 and 2800 ^{14}C yr BP) suggesting that late Holocene cooling may well have been a regional event throughout central and southern British Columbia.

CHAPTER 6: POLLEN ANALYSIS AND ORDINATION OF LAKE SURFACE SEDIMENT SAMPLES FROM COASTAL BRITISH COLUMBIA AND NORTHWESTERN WASHINGTON

Introduction:

"How well does a pollen assemblage represent the vegetation and environment from which it originates?" is frequently asked by palynologists. Uncertainties concerning local, extra-local and regional transport and rates of pollen production by various plant species are frequently discussed in the palynological literature (Faegri & Iversen, 1989, p118; Moore *et al.*, 1991). Studies conducted in many areas have concluded that basin size for lakes and wetlands is an important factor in determining the vegetation source area for pollen deposited at the site (Bradshaw & Webb, 1985; Mathewes, 1988). As basin size decreases, the pollen assemblage more strongly represents local vegetation sources (Jacobson & Bradshaw, 1981; Mathewes, 1988). It is also widely recognised that long-distance transport of pollen from forested regions to treeless grasslands and arctic tundra can lead to errors in vegetation reconstructions (Faegri and Iversen, 1989). These problems are likely to be particularly acute in mountainous regions where large differences in vegetation occur over short vertical distances, and in alpine tundra where local pollen production is very low (Heusser, 1969; Hebda and Allen, 1993).

In the Pacific Northwest, previous studies of modern pollen spectra have been from moss polsters, or soil surface litter (Heusser, 1969, 1973, 1985; Hebda, 1983; Hebda and Allen, 1993). Hebda and Allen (1993) examined modern pollen spectra from moss polsters and organic litter samples collected along a transect extending east from Bella Coola, across the Coast Mountains. They noted that four out of five biogeoclimatic zones produced characteristic pollen spectra, with pine being greatly overrepresented (especially in the interior). The vegetational abundance of western hemlock, Douglas-fir, and Cupressaceae tend to be accurately represented by pollen spectra, but spruce and fir were greatly under-represented. Heusser (1973) and Dunwiddie (1987), revealed that pine and western hemlock were over-represented and that fir and mountain hemlock were under-represented in samples collected near Mt. Rainier, Washington, U.S.A.

Pellatt and Mathewes (1994) noted that pollen from lowland taxa (western hemlock and spruce) was abundant in high elevation lakes on the Queen Charlotte Islands. This problem was also evident in the Canadian Rocky Mountains (Kearney and Luckman, 1983; Beaudoin, 1986; Luckman and Kearney, 1986). These studies indicated the need to determine 1) how well pollen assemblages represent present plant communities at the level of biogeoclimatic zones, and 2) whether key indicator species might be used to distinguish local vegetation types. This provided the impetus for the present

study, using only lake and pond surface samples for direct comparison with fossil studies from lake cores.

In this study, I focused on lakes because most high elevation paleoecological study sites in the Cordillera have been lakes (Kearney & Luckman, 1983; Dunwiddie, 1986; Luckman & Kearney, 1986; Pellatt & Mathewes, 1994), and because small lakes offer excellent representation of local and extra-local vegetation assemblages (Jacobson & Bradshaw, 1981; Bradshaw & Webb, 1985; Mathewes, 1988).

This study combines pollen analysis with multivariate techniques to compare forty-two lake surface sediment samples in four biogeoclimatic zones and fourteen biogeoclimatic subzones. This information will be useful in the interpretation of fossil pollen records in the Coastal Western Hemlock (CWH), Mountain Hemlock (MH), Engelmann Spruce-Subalpine Fir (ESSF) and Alpine biogeoclimatic zones. Special emphasis was placed on the Mountain Hemlock zone, since mountain hemlock has been used as an important paleoclimatic indicator species during the late-glacial and Holocene (Mathewes, 1993).

Biogeoclimatic Zones:

British Columbia is a diverse geographic area which has been subdivided into fourteen biogeoclimatic zones (MacKinnon *et al.*, 1992). Biogeoclimatic zones are descriptive classification units used by the B.C.

Ministry of Forests to describe distinct climax plant communities in relation to regional climate and soil (Pojar, 1983a; Meidinger & Pojar, 1991). They are areas of broadly homogeneous climate, reflected by specific patterns of vegetation across the landscape (Pojar, 1983a; MacKinnon et al., 1992). The present study encompasses 1) low elevation sites within the Coastal Western Hemlock Zone, 2) subalpine sites within the Mountain Hemlock Zone and Engelmann Spruce-Subalpine Fir Zone, and 3) Alpine Tundra sites. The biogeoclimatic zones used in this study are discussed in Chapter 2.

Methods:

Pollen Analysis

Using an Ekman grab, surface sediment was collected from forty-two lakes in western British Columbia and northern Washington State (Figure 6.1, Table 6.1). The top 1 cm of sediment was subsampled and placed in a Whirlpak® bag for transport to Simon Fraser University (SFU) where it was stored at 4ºC until analysed. Subsamples of 1 ml were processed for pollen. Volumes were determined by displacement in water, using a 10 ml graduated cylinder. The pollen was extracted from the sediment as described by Moore et al. (1991). Identification of pollen and spores was aided by published keys (McAndrews et al., 1973; Faegri & Iversen, 1989; Moore et al., 1991) and the SFU modern pollen reference collection. A Carl Zeiss binocular compound

Figure 6.1

Map of British Columbia showing the location of the lake surface sediment sample study sites.

Lake Surface Sample Locations

BRITISH COLUMBIA

YUKON

LIARD RIVER

NWT

0   50   100
Miles

Berendon

Stewart

SKEENA RIVER

PEACE RIVER

QUEEN
CHARLOTTE
ISLANDS

FRASER RIVER

PACIFIC
OCEAN

ALBERTA

COLUMBIA RIVER

Blowdown

Garibaldi

VANCOUVER
ISLAND

Mt. Stoyama

North Shore

● = CWH
● = MH
● = ESSF

Mt. Baker

UNITED STATES

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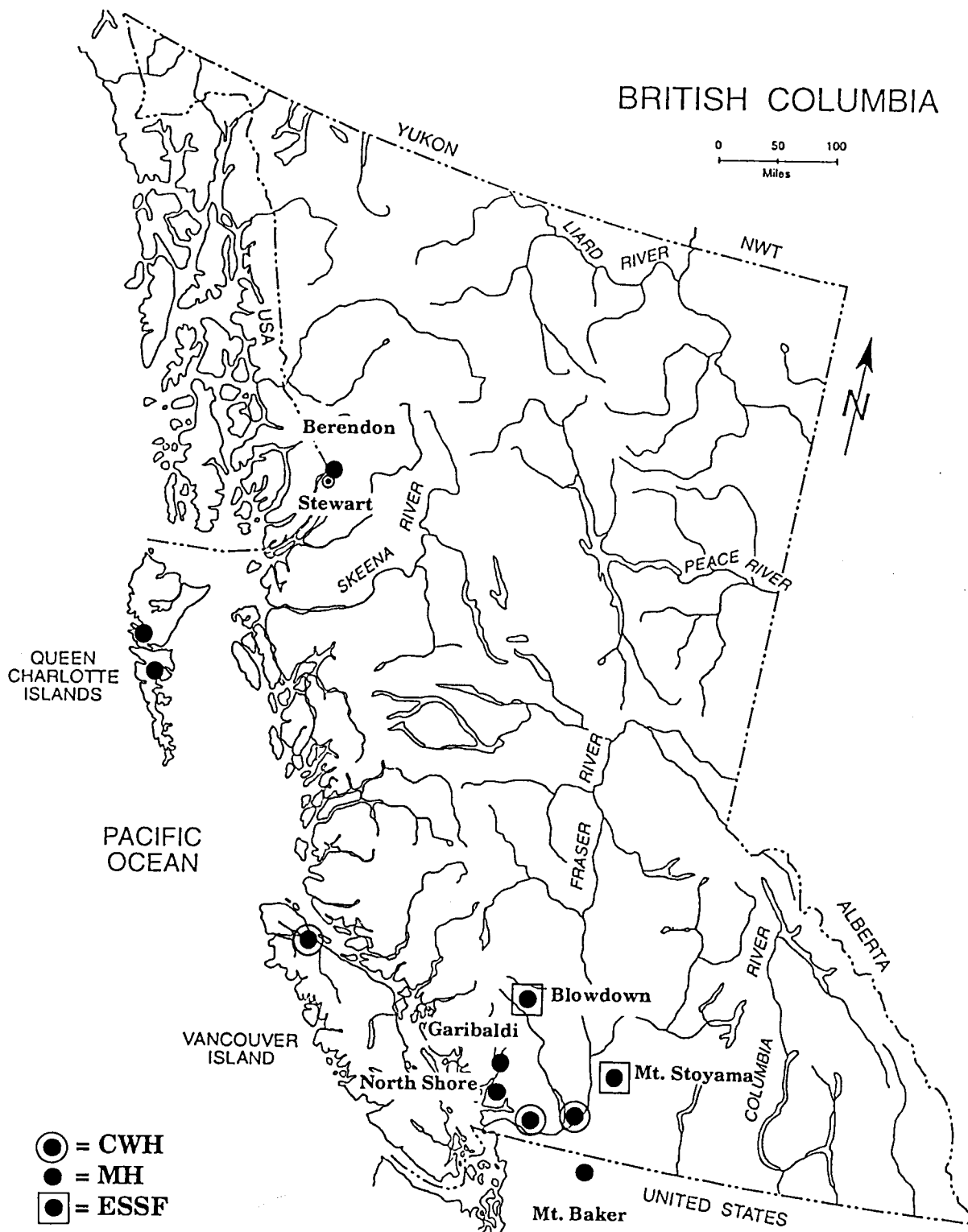
TABLE 6.1: NAMES AND LOCATION OF LAKES SAMPLED FOR SURFACE SEDIMENTS

LAKE NAME	LOCATION	LONGITUDE (W)	LATITUDE (N)	ELEVATION (metres)	BGC ZONE
STUMP	*ALICE LAKE	123°7.3'	49°47.3	200	CWH
NITA	WHISTLER AREA	122°59.6'	50°6.0'	625	CWH
LOST	WHISTLER AREA	122°56.1'	50°7.7'	690	CWH
DEER	*SASQUATCH	121°40.5'	49°22'	60	CWH
HICKS	*SASQUATCH	121°42'	49°20.5'	65	CWH
MARION	UBC FOREST	122°33'	49°19'	305	CWH
SURPRISE	UBC FOREST	122°33'	49°19'	540	CWH
BEAVER	VANCOUVER IS.	127°50'	50°32'	10	CWH
STEWART	STEWART, B.C.	129°59'	55°55'	10	CWH
YEW	*CYPRESS	123°12.7'	49°24'	945	MH
MYSTERY	*MT. SEYMOUR	122°56.1'	49°22.3'	1140	MH
GOLDIE	*MT. SEYMOUR	122°56'	49°22.5'	990	MH
HIGHWOOD	MT. BAKER (USA)	121°40.5'	48°51.9'	1250	MH
PICTURE	MT. BAKER (USA)	121°40.6'	48°51.9'	1250	MH
BAGLEY	MT. BAKER (USA)	121°41.5'	48°51.2'	1280	MH-AT
HAYES	MT. BAKER (USA)	121°43.3,	48°51'	1460	MH
NORTH HAYES	MT. BAKER (USA)	121°43.4'	48°51.6'	1460	MH
NORTH ELFIN	*GARIBALDI	122°59.2'	49°47.25'	1480	MH-AT
SOUTH ELFIN	*GARIBALDI	122°59.25'	49°47.12'	1480	MH-AT
MIMULIS	*GARIBALDI	123°01.8'	49°57.5'	1725	MH-AT
BLACK TUSK	*GARIBALDI	123°01.6'	49°57.6'	1755	MH-AT
LOWER ADIT	*GARIBALDI	122°51.8'	50°02'	1845	MH-AT
UPPER ADIT	*GARIBALDI	122°51.8'	50° 02'	1875	MH-AT
SHANGRI-LA BOG	QCI	132°45.2'	53°16'	550	MH
SC-1 POND	QCI	131°54.4'	54°25'	600	MH
LOUISE POND	QCI	131°45.2'	53°25'	650	MH
TL-2	QCI	132°04'	52°56'	550	MH
TL-8	QCI	132°04'	52°56'	595	MH
RUST	BERENDON GLACIER	~129°59'	~55°55'	855	MH
PECKER	BERENDON GLACIER	~129°59'	~55°55'	870	MH
GRANDUC	BERENDON GLACIER	~129°59'	~55°55'	855	MH
POND-3	BERENDON GLACIER	~129°59'	~55°55'	1130	AT
AQUA INCOGNITA	BLOWDOWN CK	122°10.'	50°20.45'	1970	AT-ESSF
UPPER KIDNEY	BLOWDOWN CK	122°08.75'	50°21.25'	2090	ESSF
UPPER CHLORINE	BLOWDOWN CK	122°09.5'	50°20.6'	2210	AT-ESSF
ROUNDABOUT	MT. STOYOMA	121°12.42'	49°58.7'	1905	ESSF
CABIN	MT. STOYOMA	121°13.2'	49°58.4'	1830	ESSF
STOYOMA TARN	MT. STOYOMA	121°12.8'	49°58.9'	2030	AT-ESSF
SHAVAUN POND	MT. STOYOMA	121°13.8'	49°58.3'	2000	ESSF-AT
NATASHIA POND	MT. STOYOMA	121°13.8'	49°58.3'	2005	ESSF-AT
KELLY POND	MT. STOYOMA	121°13.0'	49°59.3'	1980	AT-ESSF
PELLATT POND	MT. STOYOMA	121°13.85'	49°58.4'	2060	AT-ESSF

* British Columbia Provincial Park

microscope was used to identify and count palynomorphs. Routine counting was carried out at 500X magnification and critical identifications were made under oil immersion at 1200X. The basic pollen sum used for percentage calculation includes all terrestrial pollen. Raw data were converted into percentages using TILIA v2.0 (Grimm, 1993). TILIAGRAPH v1.25 was used to generate the pollen diagram (Figures 6.2 and 6.3).

Statistical Analysis

Three different statistical methods were used to compare the surface sample data. These methods are unconstrained cluster analysis, detrended correspondence analysis, and canonical correspondence analysis.

Cluster Analysis:

Unconstrained cluster analysis of the square-root transformed percentage pollen data was performed using CONISS, a statistical software program contained in the TILIA software package (Grimm, 1993). CONISS performs unconstrained cluster analysis by the method of incremental sum of squares. The method is also known as Ward's method, minimum variance, sum of squares, error sum of squares, and optimal agglomeration (Grimm, 1987). Square root transformation of the percentage data was performed in order to reduce the impact of highly over-represented species such as *Pinus* and increase the influence of local indicator species in the clustering (Hebda

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and Allen, 1993). The clusters dictated by the unconstrained cluster analysis are represented in the dendrogram (Figure 6.2). Cluster analysis was performed using arboreal pollen types with values greater than 2 percent in at least 2 samples (see dendrogram Figure 6.2).

Detrended Correspondence Analysis:

Detrended correspondence analysis (DCA) was performed on the untransformed pollen percentage and environmental data to determine any site, species, and environmental trends not revealed by cluster analysis. Only terrestrial pollen types were included in the analysis, and rare species were downweighted. DCA was also performed to assess the length of the environmental gradients. DCA is a heuristic modification of correspondence analysis that compensates for the axis compression and quadratic "arch" effect commonly experienced with correspondence analysis (Jongman *et al.*, 1987). It allows for the examination of data having a non-linear relationship with environmental gradients. Analysis of all terrestrial pollen types was carried out using CANOCO v 3.0 (ter Braak, 1988, 1989, 1990).

Canonical Correspondence Analysis:

Canonical correspondence analysis (CCA) was performed on the untransformed percentage pollen data to assess the relationship between terrestrial pollen assemblages and eight environmental variables which

characterise the study sites (Tables 6.1 and 6.2). Only terrestrial pollen types were included in the analysis, and rare species were downweighted. Environmental data were collected from Environment Canada climate data and British Columbia Ministry of Forests climate data in various forest district handbooks (Environment Canada, 1980; Lloyd *et al.,* 1990; Banner *et al.,* 1993; Green & Klinka, 1994). CCA is a modification of correspondence analysis, but unlike correspondence analysis, CCA permits ordination axes to be constrained to combinations of known environmental parameters (ter Braak, 1986). CCA selects the linear combination of environmental variables that maximises the dispersion of the species scores (Jongman *et al.,* 1987). Statistical analysis of all terrestrial pollen percentages was performed using CANOCO v 3.0 (ter Braak, 1988, 1989, 1990).

Results:

Pollen and Cluster Analyses:

Distinct pollen assemblages were identified for the Engelmann Spruce-Subalpine Fir, Coastal Western Hemlock, and Mountain Hemlock biogeoclimatic zones on the basis of cluster analysis (Figures 6.2 and 6.3). Differences between geographically distinct regions of the Mountain Hemlock zone are also apparent.

Figure 6.2

British Columbia and N.W. Washington Lake Surface Sediment Samples. Percentage pollen diagram for trees and shrubs, Zones were derived by unconstrained cluster analysis (CONISS).

Figure 6.2
British Columbia Lake Surface Samples
Trees & Shrubs -- Percent Pollen
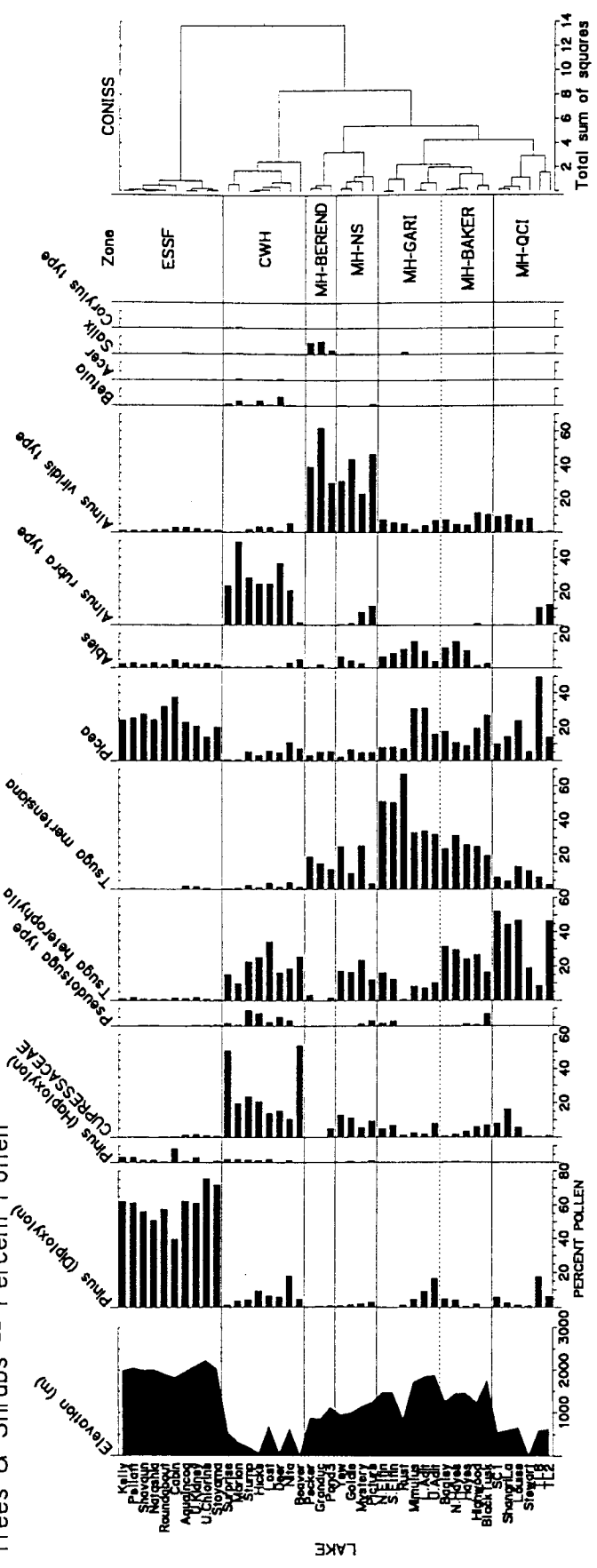
90b

Figure 6.3

British Columbia and N.W. Washington Lake Surface Sediment Samples.

Percentage and presence diagram for herbs and spores. Zones were derived

by unconstrained cluster analysis (CONISS).

● = presence

Figure 6.3
British Columbia Lake Surface Samples
Herb Pollen Percentage & Presence

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TABLE 6.2: Environmental Variables used in Ordination of Pollen Types and Study Sites.

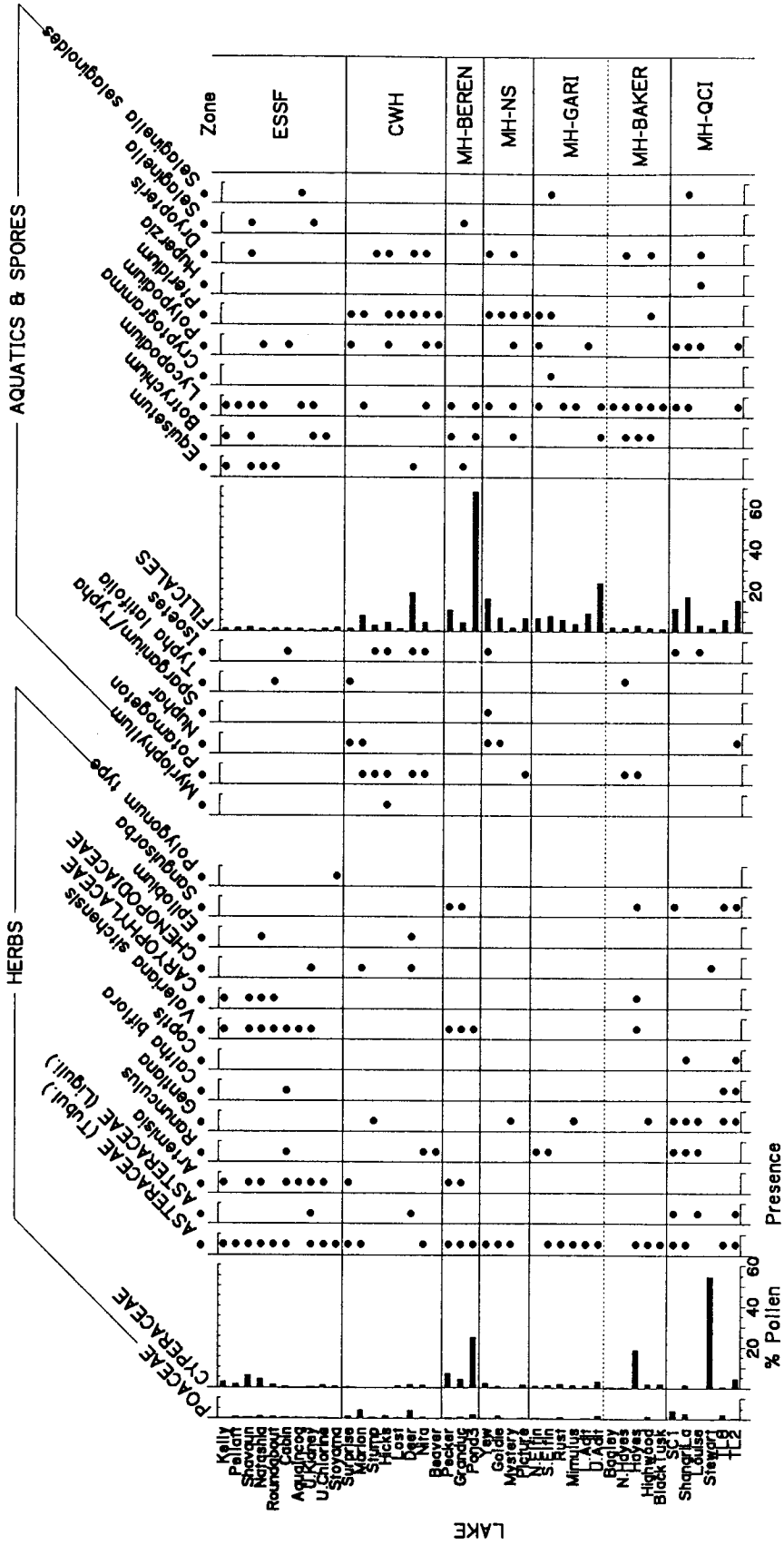| LAKE NAME	Annual PPT (mm)	Growing Season PPT (mm)	Annual Snowfall (mm)	Annual Temp (C)	January Temp (C)	Growing Degree Days	Frost Free Period
STUMP	2682	611	195	8.3	0.5	1633	199
NITA	1415	265	657	5.7	-4.4	1279	116
LOST	1415	265	657	5.7	-4.4	1279	116
DEER	2682	611	195	8.3	0.5	1633	199
HICKS	2682	611	195	8.3	0.5	1633	199
MARION	2682	611	195	8.3	0.5	1633	199
SURPRISE	2682	611	195	8.3	0.5	1633	199
BEAVER	2682	611	195	8.3	0.5	1633	199
STEWART	1843	523	532	5.1	-4.9	800	120
YEW	2565	707	816	4.6	-2.3	933	126
MYSTERY	2565	707	816	4.6	-2.3	933	126
GOLDIE	2565	707	816	4.6	-2.3	933	126
HIGHWOOD	1995	398	1041	1.8	-9.1	629	56
PICTURE	1995	398	1041	1.8	-9.1	629	56
BAGLEY	1995	398	1041	1.8	-9.1	629	56
HAYES	1995	398	1041	1.8	-9.1	629	56
NORTH HAYES	1995	398	1041	1.8	-9.1	629	56
NORTH ELFIN	1995	398	1041	1.8	-9.1	629	56
SOUTH ELFIN	1995	398	1041	1.8	-9.1	629	56
MIMULIS	1995	398	1041	1.8	-9.1	629	56
BLACK TUSK	1995	398	1041	1.8	-9.1	629	56
LOWER ADIT	1995	398	1041	1.8	-9.1	629	56
UPPER ADIT	1995	398	1041	1.8	-9.1	629	56
SHANGRI-LA BOG	2565	707	816	4.6	-2.3	933	126
SC-1 POND	2565	707	816	4.6	-2.3	933	126
LOUISE POND	2565	707	816	4.6	-2.3	933	126
TL-2	2565	707	816	4.6	-2.3	933	126
TL-8	2565	707	816	4.6	-2.3	933	126
RUST	1995	398	1041	1.8	-9.1	629	56
PECKER	1995	398	1041	1.8	-9.1	629	56
GRANDUC	1995	398	1041	1.8	-9.1	629	56
POND-3	1995	398	1041	1.8	-9.1	629	56
AQUA INCOGNITA	1820	345	726	2.5	-9.0	956	47
UPPER KIDNEY	1820	345	726	2.5	-9.0	956	47
UPPER CHLORINE	1820	345	726	2.5	-9.0	956	47
ROUNDABOUT	839	296	635	-0.2	-14.1	579	45
CABIN	839	296	635	-0.2	-14.1	579	45
STOYOMA TARN	839	296	635	-0.2	-14.1	579	45
SHAVAUN POND	839	296	635	-0.2	-14.1	579	45
NATASHIA POND	839	296	635	-0.2	-14.1	579	45
KELLY POND	839	296	635	-0.2	-14.1	579	45
PELLATT POND	839	296	635	-0.2	-14.1	579	45

Climatic Data taken from: Environment Canada, 1980; Lloyd *et al.*, 1990; Banner *et al.*, 1993; Green & Klinka, 1994.

CWH:

The Coastal Western Hemlock zone represents a discrete category based on visual inspection and cluster analysis. Key taxa in the CWH pollen assemblages are western hemlock, Cupressaceae (western redcedar type), red alder, and Douglas-fir. The pollen assemblages for the CWH are clearly different from the MH and ESSF zones (Figure 6.2). The abundance of red alder type (due to recent disturbance such as logging and fire) and Cupressaceae pollen and scarcity of pine and mountain hemlock pollen set this zone apart.

MH:

Most of the sampled lakes are situated in the Mountain Hemlock zone. The MH zone is distinguished by relatively high levels of mountain hemlock pollen (5 to 67% with a mean of ~26%) and Sitka mountain alder (*Alnus viridis*) type pollen (2 to 62%). A distinct increase in mountain hemlock pollen occurred with increased elevation in the CWH and MH zones (Figure 6.4a). Although great variability exists in the mountain hemlock - western hemlock pollen ratio, the value tends to increase with increased elevation (Figure 6.4b). *Abies* pollen (most likely originating from amabilis fir) is common in the MH of southern B.C. Western hemlock and spruce pollen are important components of the pollen assemblage and this can be attributed to the upward transport of pollen from low elevations (Hebda and Allen, 1993;

Pellatt & Mathewes, 1994). Visual inspection and cluster analysis separated the geographic regions within the MH. MH samples from the Queen Charlotte Islands, Berendon Glacier area, Garibaldi area, North Shore mountains (Vancouver area), and Mount Baker (north-west Washington) separated into discrete clusters (with the exception of three lakes).

ESSF:

The most noticeable feature of this zone is the abundance of Diploxylon pine pollen (probably mostly *Pinus contorta*) and consistently high levels of spruce pollen. Diploxylon pine percentages range from ~40 to 76% of the terrestrial pollen sum whereas spruce pollen ranges from 10 to 40%. Diploxylon pine pollen abundance tends to increase with increased elevation (Figure 6.5a); whereas spruce pollen decreases with increased elevation (Figure 6.5b). The spruce/Diploxylon pine percent pollen ratio (spruce/pine ratio) decreases with elevation (Figure 6.5c). Although not abundant, *Abies* and Haploxylon pine (white, *Pinus monticola*, or whitebark pine) are also present in all of the ESSF samples. Cluster analyses indicates that the ESSF samples are distinct from those of the other sampled biogeoclimatic zones (Figures 6.2 and 6.3).

FIGURE 6.4a
Percent Mountain Hemlock Pollen with Increasing Elevation in the CWH and MH
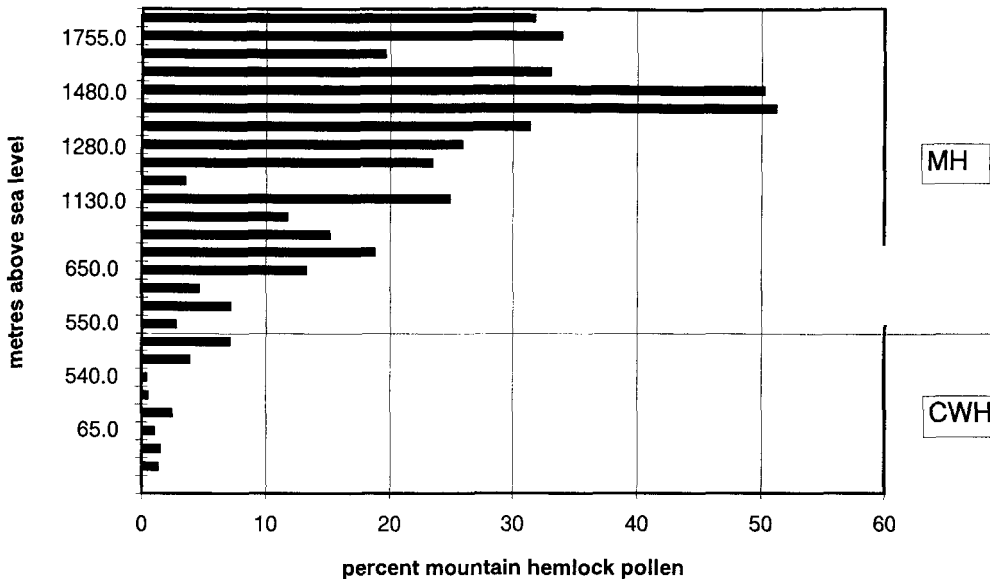
Figure 6.4b
Mountain Hemlock/Western Hemlock Percent Pollen Ratio with Increasing Elevation in the CWH and MH

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Figure 6.5a
Percent Diploxylon Pine Pollen with Increasing Elevation in the ESSF

Figure 6.5b
Percent Spruce Pollen with Increasing Elevation in the ESSF

Figure 6.5c
Spruce\Diploxylon Pine Pollen Percentage Ratio with
Increasing Elevation in the ESSF
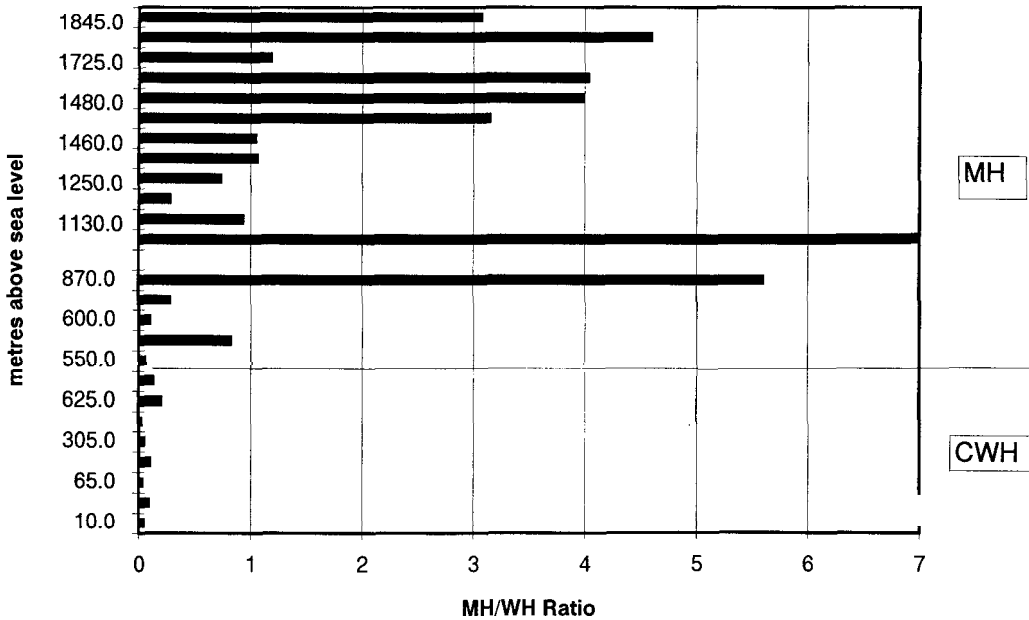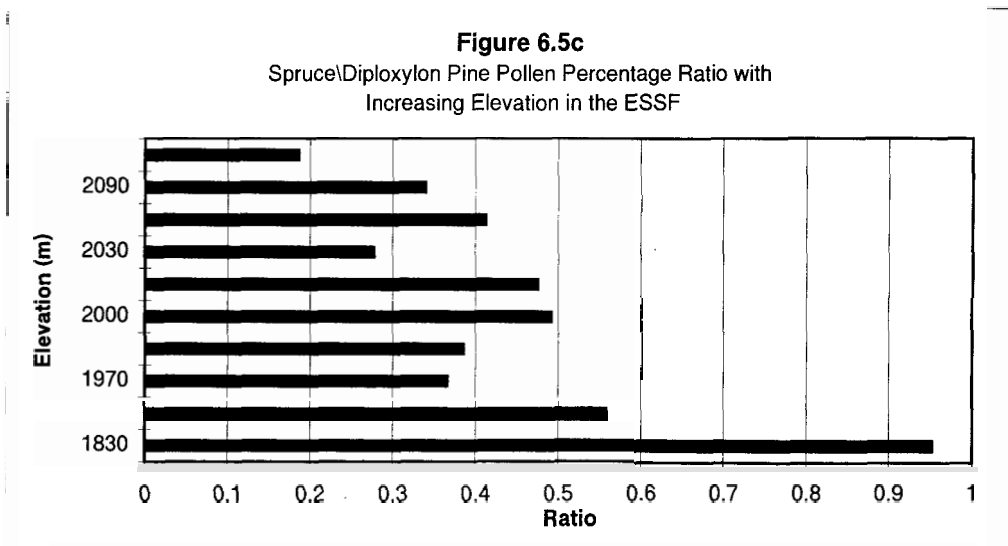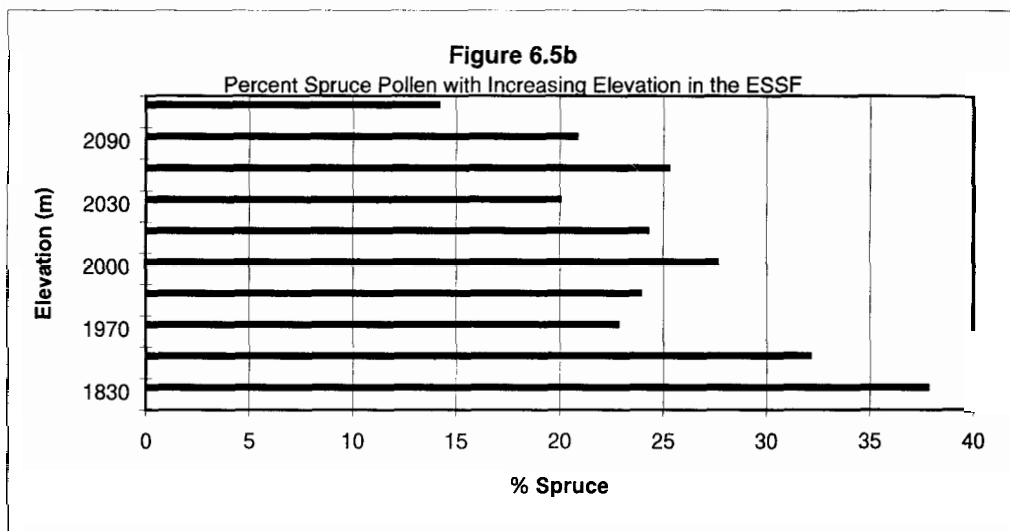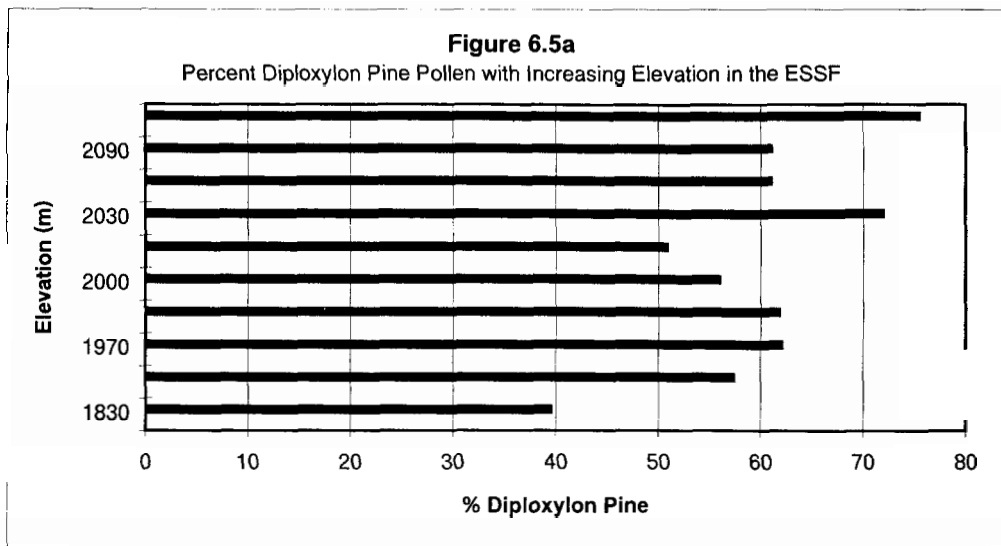
Alpine:

Pollen assemblages from the alpine are represented by sediment collected at the ESSF/Alpine krummholz and MH Parkland/Alpine transition. Pollen assemblages for the alpine sites are similar to those from the nearby subalpine zone. Very few differences were noted among the MH/Alpine transition sites, but an increase in Diploxylon pine pollen percentages was noted in the ESSF/Alpine krummholz. Values of less than 60% Diploxylon pine are characteristic of the ESSF zone. Diploxylon pine pollen increases to greater than 60% at sites in the ESSF/Alpine krummholz (Figure 6.2).

Detrended Correspondence Analysis (DCA):

Detrended correspondence analysis revealed environmental gradient lengths of 2.6 for Axis 1 and 3.1 for Axis 2. Axis 1 explained 44.3% of the species-environment variance whereas axis 2 explained 31.7%. (total of 76.0% of species-environment variance) (Table 6.3). Five distinct groups can be seen in the study site biplot (Figure 6.6). These groups correspond with the CWH, ESSF, Berendon Glacier area MH, Queen Charlotte Islands MH, and the MH of south coastal B.C. and northwestern Washington. The DCA pollen type biplot revealed characteristic indicator species for each zone (Figure 6.7). Pollen from *Acer*, *Betula*, red alder, *Corylus*, and Douglas-fir are characteristic of the CWH. *Salix*, Sitka alder, mountain hemlock,

Table 6.3: Ordination Results for Study Sites, Pollen Types and Environmental Variables.

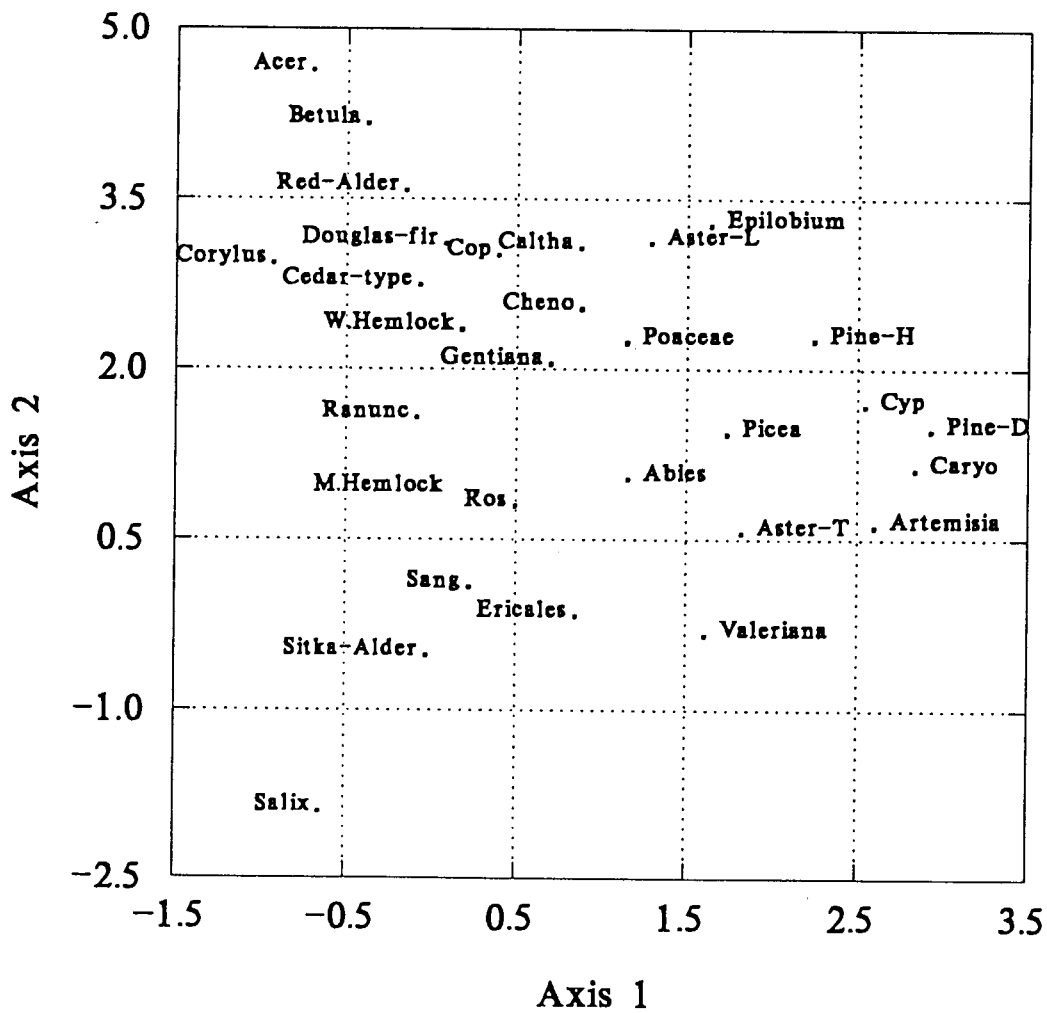| Axis	Detrended Correspondence Analysis		Canonical Correspondence Analysis	
	1	2	1	2
Correlation Matrix Data				
Annual Precipitation	-0.89	0.12	-0.90	0.02
Growing Season Precipitation	-0.38	-0.68	-0.38	-0.71
Annual Snowfall	0.34	-0.06	0.37	0.01
Annual Temperature	-0.67	0.72	-0.68	0.64
Growing Degree Days	-0.51	0.82	-0.50	0.80
January Temperature	-0.79	0.52	N/A	N/A
Frost Free Period	-0.63	0.70	N/A	N/A
Elevation	0.76	-0.44	N/A	N/A
Eigenvalues	0.56	0.35	0.52	0.39
Species-Environment Correlations	0.96	0.95	0.97	0.96
Lengths of Gradient	2.58	3.07	N/A	N/A
Cumulative Percentage Variance				
of Species Data	31.9	51.9	29.6	51.7
of species-environment relation	44.3	76.0	48.1	84.0
Sum of All Unconstrained Eigenvalues	1.748		1.748	
Sum of All Canonical Eigenvalues	1.142		1.076	
Regression/Canonical Coefficient				
Annual Precipitation			0.04	-0.57
Growing Season Precipitation			-6.05	-4.68
Annual Snowfall			-0.66	-3.86
Annual Temperature			-6.56	-2.43
Growing Degree Days			4.37	7.64
Correlation Coefficients				
Annual Precipitation			-0.90	0.02
Growing Season Precipitation			-0.38	-0.71
Annual Snowfall			0.37	0.01
Annual Temperature			-0.68	0.64
Growing Degree Days			-0.50	0.80
Biplot Scores of Environmental Variables				
Annual Precipitation			-0.93	0.02
Growing Season Precipitation			-0.39	-0.74
Annual Snowfall			0.38	0.01
Annual Temperature			-0.71	0.67
Growing Degree Days			-0.52	0.83

Figure 6.6
DCA: Study Sites
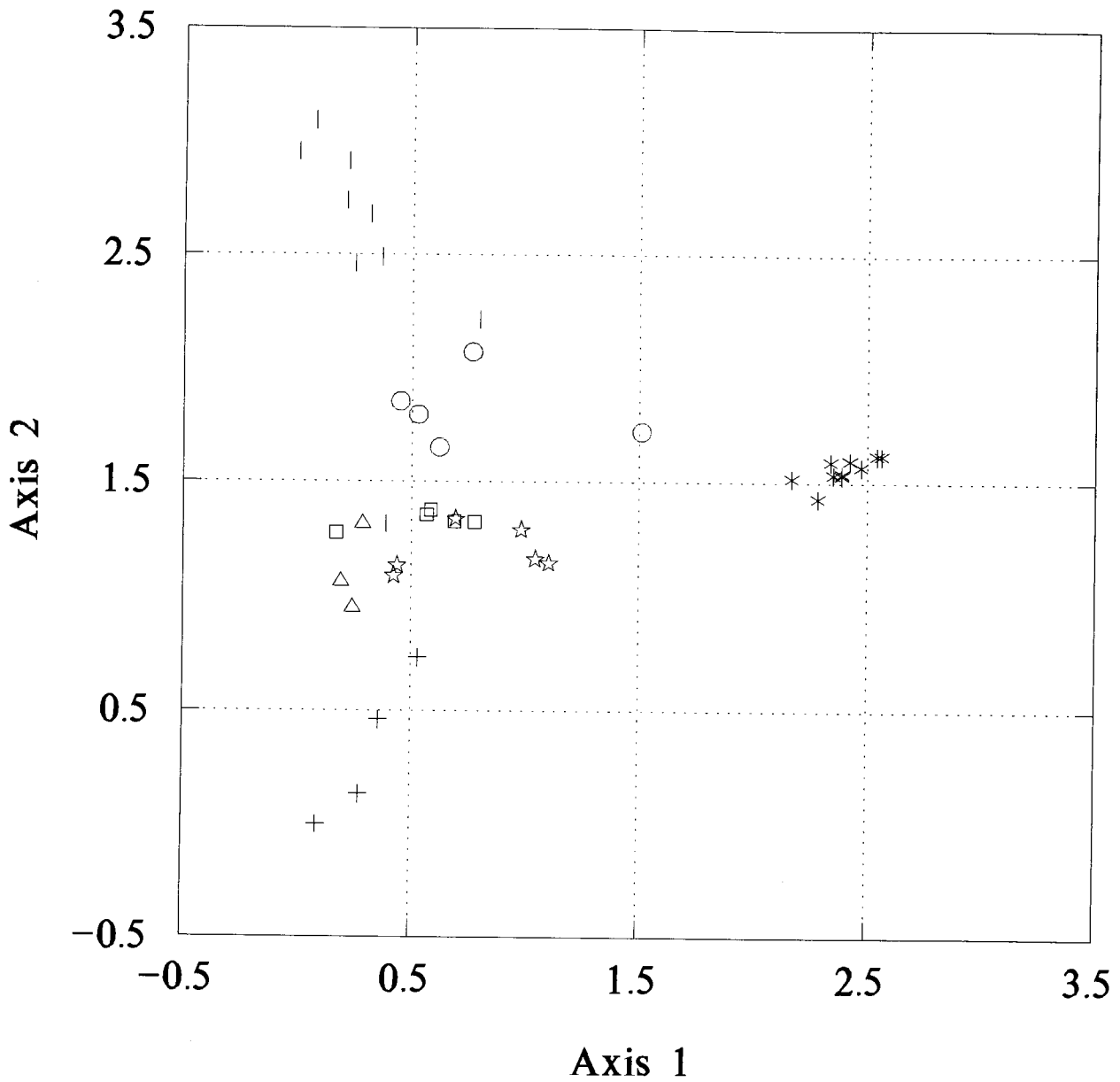
Legend:

O = MH-QCI, Δ = MH-North Shore, ☆= MH-Garibaldi,
□ = MH-Baker, + = MH-Berendon, | = CWH, * = ESSF

Detrended Correspondence Analysis of the B.C. and N.W. Washington lake surface sediment study sites.

Figure 6.7

DCA: Pollen Types

Detrended Correspondence Analysis of the B.C. and N.W. Washington lake surface sediment pollen types.

Ranunculus, and *Sanguisorba* were characteristic of the MH. Diploxylon pine, Caryophyllaceae, Haploxylon pine, spruce, *Artemisia*, and *Valeriana sitchensis* are most common in the ESSF. Some zonal overlap occurs since many species occur in more than one biogeoclimatic zone.

Regression of the DCA axes against environmental variables revealed a high correlation between Axis 1 and annual precipitation (-0.89), January temperature (-0.79), elevation (0.76), and annual temperature (-0.68). High correlations also exist between Axis 2 and growing degree days (0.82), frost free period (0.70), mean annual temperature (0.72) and growing season precipitation (-0.68) (Table 6.3). The high correlation between ordination axes and environmental variables suggests that Axis 1 principally represents precipitation whereas Axis 2 represents a temperature gradient (Figure 6.6).

Canonical Correspondence Analysis (CCA):

Canonical correspondence analysis revealed a strong relationship between biogeoclimatic zones and environmental gradients (Figure 6.8). The first axis explains 48.1% of the species-environmental variance, whereas the second axis accounts for a further 36% (for a total of 84% variance) (Table 6.3). Axes 1 through 4 all explain significant proportions of the variance ($p > 0.01$). With forward selection, five of the eight environmental variables tested (Table 6.2) were found to explain significant proportions of this

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variance (Table 6.3). In order of selection and the amount of additional variance explained, these variables are as follows: annual precipitation (39%), growing degree days (33%), growing season precipitation (9%), annual temperature (8%), and annual snowfall (6%). As shown in Figure 6.8, the study sites cluster into six groups representing ESSF, CWH (south coast), CWH (Whistler), MH (Queen Charlotte Islands and the North Shore), MH (Garibaldi and Mt. Baker) and MH (Berendon Glacier area). The biplot scores of environmental variables (Table 6.3) and the biplot of study sites illustrate the relationship between temperature, precipitation, seasonality and biogeoclimatic zone (Figure 6.8). Annual precipitation is the most highly correlated with Axis 2, thus the results of CCA were very similar to those provided by DCA.

Discussion:

The interaction of temperature, precipitation, elevation and biogeoclimatic zone can be observed from detrended and canonical correspondence analyses. The main environmental variables separating the ESSF from the MH and CWH are annual precipitation and annual snowpack. Thus it appears that precipitation explains most of the variance for ordination axis 1 (Figure 6.8). The major environmental variables separating the CWH from the MH are growing degree days, growing season precipitation and annual temperature. Temperature thus explains most of

Figure 6.8
CCA: Study Sites
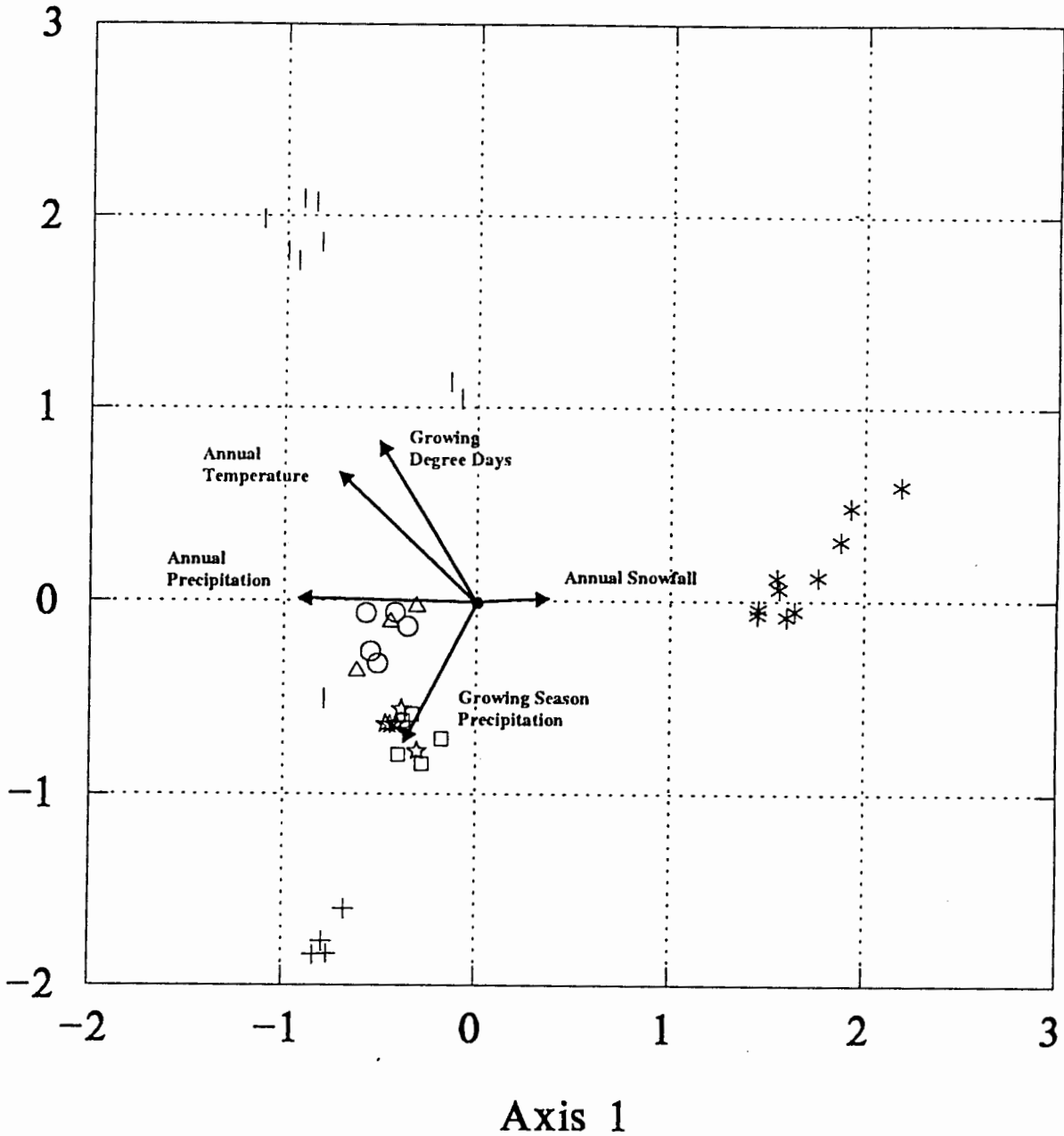
the variation for ordination axis 2 (Figure 6.8). The implications for pollen and statistical analysis are discussed in the following sections.

CWH:

The pollen assemblages of this zone are indicative of the vegetation growing in the vicinity of the study sites. Western hemlock, Cupressaceae (most is likely derived from western redcedar), red alder, and Douglas-fir are characteristic pollen from the CWH (Mathewes & Heusser, 1981; Hebda, 1995). The CWH is distinct from both the MH and ESSF on the basis of cluster analysis, DCA and CCA (Figures 6.2, 6.3, 6.6 and 6.8). As with the pollen diagram (Figures 6.2 & 6.3), DCA also indicates that pollen from red alder, Douglas-fir type, Cupressaceae, *Betula*, *Acer*, and western hemlock are indicative of the CWH. The main environmental gradients, based on CCA, that distinguish the CWH from the MH are temperature-related (primarily growing degree days and annual temperature) whereas precipitation-related environmental gradients (annual precipitation and annual snowfall) distinguish the CWH from the ESSF. This is important for understanding the conditions that contribute to the development of the massive, evergreen forests of the CWH. Because of the mild, wet temperatures in the CWH, conifer growth is not limited to the main growing season for the region (Waring & Franklin, 1979). The conifers in the CWH are not stressed by the extensive winter snowpack of the MH zone, nor by the short, dry growing

season experienced by conifers in the ESSF (Brooke *et al.,* 1970; Arno & Hammerly, 1984). Pollen assemblages for the CWH are similar to those studied by Hebda and Allen (1993) from moss polsters in west central B.C.

MH:

The pollen assemblages of the MH are characterised by high levels of mountain hemlock, Sitka alder, and *Abies* (except on the Queen Charlotte Islands where no *Abies* occurs). The upland transport of western hemlock and spruce pollen from the CWH is strongly reflected in MH pollen assemblages (Pellatt & Mathewes, 1994). Even though there is a strong extra-local component to the pollen assemblages, mountain hemlock pollen frequency generally increases with elevation (Figure 6.5a). Unconstrained cluster analysis separates the MH samples into 5 distinct clusters based on mountain hemlock, western hemlock, spruce and *Abies* percentages (Figure 6.2). DCA and CCA separated the MH into 3 distinct groups representing the MH from the Queen Charlotte Islands, Berendon Glacier area, and southwestern British Columbia - northwestern Washington (Figures 6.6 and 6.8). Pollen types that distinguish different regions of the MH include mountain hemlock, western hemlock, Sitka alder, *Abies*, *Salix* and Ericales (Figure 6.7). As noted previously, environmental variables separating the MH from the CWH are mainly temperature related (ordination axis 2, Figure 6.8). This agrees with previously collected ecological information. Extensive

spring snowpack in the MH restricts many CWH species from entering the MH (Brooke *et al.,* 1970). This snowpack shortens the growing season in the MH, even if precipitation is adequate for tree growth. The ESSF and MH are mainly separated by precipitation variables (annual precipitation and annual snowfall) as can be seen in Figure 6.8. A cold, dry continental climate distinguishes the ESSF from the MH and CWH (Meidinger & Pojar, 1991).

ESSF:

The pollen assemblages in this zone are characterised by Diploxylon pine and spruce. Haploxylon pine and *Abies* are also important pollen types. *Picea* (most likely *Picea engelmannii*), *Abies* (most likely *Abies lasiocarpa*), and Haploxylon pine pollen (most likely *Pinus albicaulis*) are of local origin, whereas, Diploxylon pine pollen (most likely *Pinus contorta*) is of regional and extra-local origin. Diploxylon pine pollen percentages increase with elevation with values exceeding 60% at the krummholz/alpine transition (Figure 6.5a). As Diploxylon pine increases, a corresponding decrease in *Picea* is noted (Figure 6.5b). Decreasing spruce/pine ratios thus appear to be an indicator of increasing elevation in the ESSF (Figure 6.5c). Hebda & Allen (1993) also observed a large over-representation of Diploxylon pine from moss polsters in the ESSF, but more *Abies* than spruce pollen. This is probably because the ESSF in west-central B.C. is much wetter than the ESSF in the southern interior of the province, where lake sediment samples

were taken (Lloyd *et al.,* 1990). Also, *Abies lasiocarpa* (subalpine fir) is characteristic of the highest and/or wettest parts of the ESSF areas (Meidinger & Pojar, 1991). Cluster analysis (Figure 6.2), DCA (Figure 6.6) and CCA (Figure 6.8) strongly separate the ESSF from both the CWH and MH. DCA indicates that Diploxylon pine, Haploxylon pine, spruce, *Abies,* *Valeriana sitchensis, Artemisia,* Ericales and Cyperaceae are all strong indicator species for the ESSF (Figure 6.7). CCA indicates that ordination axis 1, precipitation, is the most important factor in distinguishing the ESSF from both the MH and CWH (Figure 6.8).

Conclusion:

In this study, pollen assemblages from the various biogeoclimatic zones less resemble the actual vegetation as elevation and continentality increase. Over-representation of western hemlock and spruce pollen in the MH, Diploxylon pine in the ESSF, and total arboreal pollen in the alpine was noted in this study. Understanding the extent of regional pollen transport into modern pollen assemblages is extremely important when interpreting paleovegetation changes in Quaternary sediment cores. Indicator species such as mountain hemlock, and Sitka alder in the MH or Diploxylon pine, *Abies,* and spruce in the ESSF are important to paleobotanists in their attempts to interpret analogous fossil pollen assemblages. Through the use of specific subalpine indicator species, the paleobotanist can infer if the

pollen assemblage represents an environment similar to the MH or CWH. This information is very important when attempting to infer paleoclimate at a given study site.

Unconstrained cluster analysis, DCA, and CCA all separated the pollen assemblages according to the biogeoclimatic zones, and in the case of the MH, study areas. This suggests that cluster analysis and ordination techniques are able to differentiate pollen assemblages based on the biogeoclimatic zone. CCA also separated the study sites based on environmental gradients for the study sites, indicating that paleoclimatic information may be inferred in fossil pollen assemblages based on climatic information from modern pollen assemblages. Although further research needs to be done on the subject, preliminary data suggest that increasing levels of mountain hemlock pollen in the MH, and increasing levels of Diploxylon pine in the ESSF may indicate increasingly cold temperatures. The preliminary results concerning changing percentages of pollen with elevation warrants further investigation.

CHAPTER 7: PALEOECOLOGY OF POSTGLACIAL VEGETATION SHIFTS ON MOUNT STOYOMA, SOUTHWESTERN BRITISH COLUMBIA[5].

Introduction:

The postglacial vegetation and climate history of the southern interior of British Columbia has been examined at very few locations (Alley, 1976; Mathewes and King, 1989; Hebda 1995), and all of these are at relatively low elevations. Various low-elevation paleoecological studies have been undertaken in north-central Washington (Mack *et al.,* 1978a, 1978b and 1979; Mehringer, 1985), but a similar lack of high elevation paleoecological investigations is apparent. Thus, it seemed reasonable that a study of treeline and vegetation shifts in the subalpine Engelmann Spruce-Subalpine Fir zone would considerably aid in the understanding of Holocene paleoecology and paleoclimatology in the southern Interior of B.C., as well as allowing a comparison with better-studied coastal localities.

Discrepancies in the timing of climatic changes in the Holocene occur between south coastal B.C., the southern interior of B.C. and northern Washington (Figure 7.1). Late-glacial temperatures were cold until the Holocene in all three areas. Early Holocene warming occurred in south-coastal

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and the southern interior of B.C. between *ca* 10,000 to *ca* 6600 ^{14}C yr BP.
Similar climate changes occurred in the Okanogan Valley in north-central
Washington. A late-glacial cool, moist phase (>11,000 to 10,000 ^{14}C yr BP) was
followed by an early Holocene warm, dry period (10,000 to 6900 ^{14}C yr BP), and
modern climate conditions developed by 5000 ^{14}C yr BP (Mack *et al.,* 1979).

Alley (1976) reconstructed Holocene vegetation and climate at a bog near
Kelowna, B.C. in the Okanagan Valley. Alley inferred moist conditions
sustaining pine; spruce forests prior to 8900 ^{14}C yr BP. After 8400 ^{14}C yr BP,
moist conditions gave way to aridity during which grass and sagebrush
predominated. Alley (1976) correlated this warm, dry interval with the
Hypsithermal. Evidence of dry conditions is supported by the presence of sand
dunes, as indicated by aeolian sediments in Kelowna Bog. At ~6600 ^{14}C yr BP,
the climate became cooler and moister, aeolian activity diminished and the
dunes became stabilised by vegetation. Alley (1976) observed vegetation
changes that he related to increased runoff from the adjacent uplands, and
tentatively correlated with the stades of Neoglaciation recognised in
southcentral B.C. and Washington.

The major difference in climatic interpretations from north-central and
northeastern Washington, in comparison to the Okanagan Valley in south-
central B.C. is the timing of maximum Holocene warmth (Mehringer, 1985;
Hebda, 1995). Hebda indicates that maximum Holocene warmth in the

FIGURE 7.1:
COMPARISON OF CLIMATE CHANGE AT SELECTED SITES
IN THE SOUTHERN INTERIOR OF B.C.
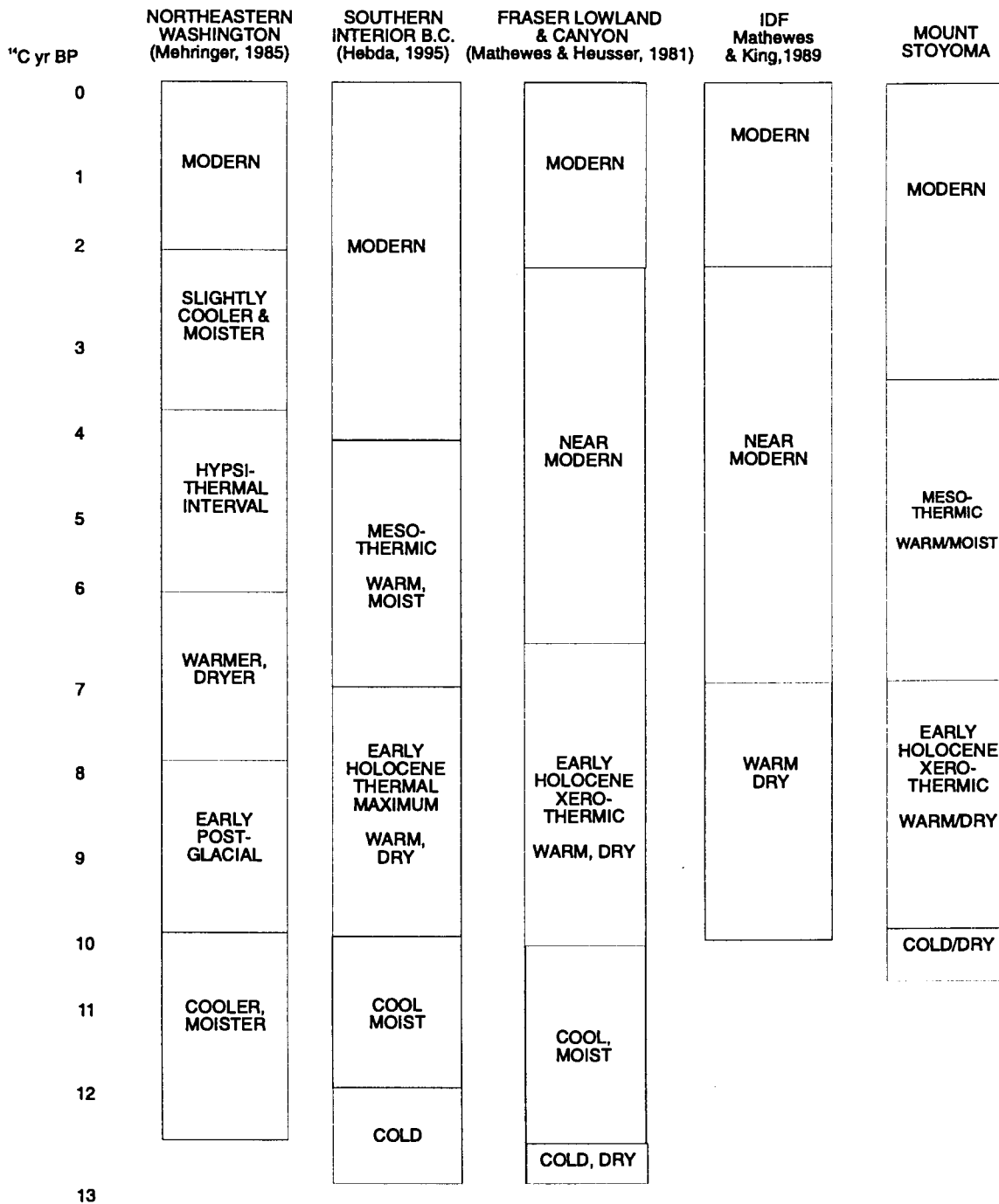
southern interior of B.C. occurred between 10,000 and 8,000 ^{14}C yr BP with relatively warm conditions occurring until 4500 ^{14}C yr BP. In contrast to this, Mack *et al.* (1978b) suggest that maximum Holocene warmth did not occur in the Sanpoil River valley, north-central Washington, until just prior to Mount Mazama tephra deposition (6800 ^{14}C yr BP) and continued to 4000 ^{14}C yr BP. Moist, cool conditions prevail until 2700 ^{14}C yr BP when modern conditions establish. This is consistent with Mehringer's (1985) summary of climate change for northeastern Washington and northern Idaho.

Mathewes and King (1989) analysed four lakes in the Interior Douglas Fir (IDF) zone of southern interior of B.C. for pollen, macrofossils and aquatic molluscs. Sediment deposition at two of the lakes near Lillooet, did not begin until *ca* 6780 ^{14}C yr BP at Phair Lake. This indicates that conditions were too dry for permanent water. Two other lakes near Boston Bar have entire Holocene stratigraphies, in which vegetation assemblages indicate warm, dry conditions in the early Holocene. Mathewes and King (1989) noted abrupt sediment changes at 5650 and 2000 ^{14}C yr BP that corresponded with Neoglacial advances near the coast-interior transition. Changes in pollen and plant macrofossils indicate that the early Holocene xerothermic period occurred prior to Mazama ash deposition (6800 ^{14}C yr BP). Wetter conditions began after Mazama deposition, with modern conditions developing after the deposition of the Bridge River tephra (2410 ^{14}C yr BP).

Pollen and plant macrofossil analyses of high elevation lakes in mountainous areas is useful in the interpretation of local paleoecological and paleoclimatic changes. Plant macrofossil analysis allows for the reconstruction of vegetation changes at a local level, including only those plants in the vicinity of the lake itself. The difficulty encountered when using plant macrofossils as proxy indicators of climate change is that they are not well represented in some lakes. At the same time, the palynologist can use pollen to examine local and regional changes in vegetation through the examination of local indicator species and pollen ratio analysis. Thus the use of plant macrofossil analysis, pollen analysis, tephrachronology, and radiometric dating can give the palynologist a detailed picture of high elevation paleo-ecosystems, and paleoclimatic conditions at a study site.

Extra-local or regional transport of Diploxylon pine in pollen records from the Engelmann Spruce-Subalpine Fir zone forces the palynologist to place greater weight on key indicator species and pollen ratio analysis to infer paleo-treeline shifts (Kearney & Luckman, 1983; Beaudoin, 1986; Luckman & Kearney, 1986; Mathewes, 1988; Evans, 1993; Hebda & Allen, 1993). During a warmer period an increase in treeline elevation is expected (Clague and Mathewes, 1989). This change should be apparent as shifts in pollen and plant macrofossil composition in the sedimentary sequences. Research in the Canadian Rocky Mountains and the eastern Coast Mountains of British Columbia has established the usefulness of using *Picea/Pinus* ratios to infer

altitudinal shifts in vegetation composition (Kearney & Luckman, 1983; Beaudoin, 1986; Luckman & Kearney, 1986; Evans, 1993). Changes in treeline elevation were apparent from comparisons between past and modern pollen ratios. The modern pollen ratios were derived from pollen samples collected along transects at different elevations (Kearney & Luckman, 1983; Beaudoin, 1986; Luckman & Kearney, 1986; Evans, 1993). It was shown that the krummholz zone had lower ratios than the surrounding subalpine forests. Beaudoin (1986) proposed that there was a recognisable relationship between vegetation types which could be used to infer elevation above present treeline. Luckman and Kearney (1986) came to similar conclusions. Although there are some differences in local vegetation and climate for the ESSF in the Canadian Rockies as opposed to the northwestern Cascade Mountains, it is assumed that this technique will be applicable to my study sites.

In the case of this study, sediment cores from three high elevation lakes near Mount Stoyoma, British Columbia were examined for plant macrofossils and pollen. Tephra from Bridge River and Mount Mazama are present in one or more of the lake cores. The current accepted age for the Mount Mazama tephra is 6800 ^{14}C yr BP (Bacon, 1983) and Bridge River Tephra is 2410 ^{14}C yr BP (Clague *et al.*, 1995). The sediment cores were radiocarbon dated at selected intervals (Table 7.1). The lakes used in this study are Cabin Lake, and the informally named 3M Pond and Stoyoma Tarn.

Study Area:

<u>Physiography:</u>

Mount Stoyoma (2283m asl; 121°13' W, 49°59' N) is located in the southwestern interior of British Columbia (see Figures 6.1, 7.2 and 7.3a) at the northern limit of the Cascade Mountains. It supports an Engelmann Spruce-Subalpine Fir forest and Alpine Tundra at higher elevations. The Cascade Mountains of British Columbia merge into the Kamloops [Thompson] Plateau to the east; and are separated from the Coast Mountains to the west by the Fraser River (Holland, 1976). The eastern margin of the Cascade Mountains is a transition zone where summit elevation and dissection progressively decrease as the Kamloops [Thompson] Plateau is reached (Holland, 1976). The Cascade Mountains are composed of Paleozoic and Mesozoic sedimentary and volcanic rocks which are strongly folded, metamorphosed and intruded by granitic batholiths (Holland, 1976). The summits of the peaks and ridges are fairly uniform in elevation which is thought to have occurred due to the dissection of a late Tertiary erosion surface (Holland, 1976). Mount Stoyoma (2283 m), Mount Outram (2440 m), Frosty Mountain (2425 m), Grass Mountain (2311 m), and Tulameen Mountain (2287 m) make up the highest peaks in the Hozameen Range of the Cascade Mountains (Holland, 1976). The peaks and high ridges are serrate and show the effects of intense alpine glaciation. Cirque basins are common on north and northeast slopes of peaks and ridges. At lower elevations between 1830 and 2135 m there are rounded ridges and dome-shaped mountains

which were over-ridden by ice at the maximum of the Cordilleran ice sheet (Holland, 1976).

<u>Vegetation:</u>

Mount Stoyoma is located in the central dry climate region of the Kamloops Forest Region (Lloyd *et al.,* 1990). The biogeoclimatic zones with increasing elevation in this forest region are the Ponderosa Pine (PP), Interior Douglas Fir (IDF), Montane Spruce (MS), Engelmann Spruce-Subalpine Fir (ESSF), and Alpine (AT) zones (Figure 2.1).

This study focuses on the upper limit of the ESSF near treeline. A general description of the ESSF zone is presented in chapter 2. The biogeoclimatic subzone in which the study sites are located is the dry, cold Engelmann Spruce-Subalpine Fir subzone variant 2 (ESSFdc2) (Lloyd *et al.,* 1990). Typical trees and shrubs encountered in the ESSFdc2 are subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), whitebark pine (*Pinus albicaulis*), black huckleberry (*Vaccinium membranaceum*), and white-flowered rhododendron (*Rhododendron albiflorum*). Typical herbs and mosses in the ESSFdc are grouseberry (*Vaccinium scoparium*), five-leaved bramble (*Rubus pedatus*), mountain arnica (*Arnica latifolia*), Sitka valerian (*Valeriana sitchensis*), and red-stemmed feathermoss (*Pleurozium schreberi*) (Lloyd *et al.,* 1990).

<u>Climate</u>:

The climate of the southern interior region, which extends eastward from the crest of the Coast and Cascade Mountains to the Interior plains and northward to about 58°N, is characterised by strong climatic

contrasts (Ryder, 1989b). Temperatures and humidity are controlled partly by modified maritime air masses which have lost much of their moisture while crossing the Coast Mountains. However incursions of continental arctic air in winter and continental tropical air in summer produce extreme and variable conditions. Precipitation is more evenly distributed throughout the year in the southern interior than on the coast, although the proportion of snow to rain is greater (Ryder, 1989b).

Climatic variables for the ESSFdc are as follows (Table 6.2); average annual precipitation is 839 mm, growing season precipitation is 296 mm, annual snowfall is 635 mm, average annual temperature is -0.2°C, January temperature is -14.1°C, growing degree days are 579 and the frost free period is 45 days (Lloyd *et al.*, 1990).

<u>Study Sites</u>:

Three lakes along an elevational gradient were selected for coring (Figure 7.2). These lakes are Cabin Lake (Figures 7.3b), 3M Pond (Figure 7.4a), and Stoyoma Tarn (Figure 7.4b).

Cabin Lake is located at 1850 m asl in the dry southern Engelmann Spruce-Subalpine Fir parkland (ESSFpe) (Mitchell and Green, 1981). It is about 4 hectares in area with a maximum water depth of 4.2 metres. A small intermittent inlet stream runs into the north end of the pond. It carried water in July, 1995 but was dry in late August. An outlet stream drains the south end of the lake when water levels permit.

Cabin Lake is surrounded by a well developed Engelmann spruce forest interspersed with subalpine fir on the east, south, and part of the west slope. A fire has burned much of the slope north of the lake. Some of the common trees and shrubs surrounding Cabin Lake are Engelmann spruce (the dominant tree species), subalpine fir, white-flowered rhododendron, *Leutkea pectinata*, *Vaccinium membranaceum*, *Vaccinium scoparium*, *Phyllodoce empetriformis*, and *Cassiope mertensiana*. Some of the common herbs include *Valeriana sitchensis*, *Veronica* cf. *wormskjoldii*, *Castilleja miniata*, *Saxifraga ferruginea*, *Senecio triangularis*, *Leptarrhena pyrolifolia*, *Lupinus arcticus*, *Caltha leptosepala*, *Arnica* cf. *cordifolia*, *Anemone occidentalis*, *Caltha biflora*, *Pyrola* sp., *Carex* sp., and *Eriophorum* sp.

3M-Pond exists in a depression at 1950 m asl. The pond is about 0.5 hectares in area with a maximum water depth of 1 metre. The surrounding bedrock is granite and many large rocks are strewn around the pond. 3M Pond is located in the Dry Southern Engelmann Spruce-Subalpine Fir Parkland (ESSFpe) -- Dry Southern Alpine Tundra (ATd) transition (Mitchell and Green,

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1981). Trees and shrubs observed at 3M Pond include subalpine fir, Engelmann spruce, whitebark pine, white mountain-heather (*Cassiope mertensiana*), pink mountain-heather (*Phyllodoce empetriformis*), and partridgefoot (*Luetkea pectinata*). Herbs include tow-headed baby (*Anemone occidentalis*), common paintbrush (*Castilleja miniata*), Arctic lupine (*Lupinus arcticus*), small-flowered penstemon (*Penstemon procerus*), *Arnica*, *Erigeron* cf. *peregrinus*, *Solidago multiradiata*, *Sibbaldia procumbens*, *Carex nigricans*, *Carex* sp., *Dicranum* sp., and *Equisetum variegatum*.

Stoyoma Tarn is located in a granitic cirque at 2050 m asl. Steep drop-offs occur at the north and south end of the tarn with mountain slopes rising to the west and east. The tarn is about 0.5 hectares with a water depth of about 1.5 m. Stoyoma Tarn is at treeline, in the upper reaches of the ESSF in the Dry Southern Engelmann Spruce-Subalpine Fir Parkland (ESSFpe) -- Dry Southern Alpine Tundra (ATd) transition (Mitchell and Green, 1981). Trees and shrubs observed at Stoyoma Tarn include subalpine fir (the major tree species), Engelmann spruce, whitebark pine, common juniper (*Juniperus communis*), white mountain-heather (*Cassiope mertensiana*), pink mountain-heather (*Phyllodoce empetriformis*), and partridgefoot (*Luetkea pectinata*). Herbs include tow-headed baby (*Anemone occidentalis*), common paintbrush (*Castilleja miniata*), Arctic lupine (*Lupinus arcticus*), small-flowered penstemon (*Penstemon procerus*), lance-leaved stonecrop (*Sedum lanceolatum*), *Arnica*,

Figure 7.2

Aerial photograph of Mount Stoyoma showing Cabin Lake, 3M Pond and Stoyoma Tarn. (Adapted from Maps, B.C.: 30BC86067 No.230).
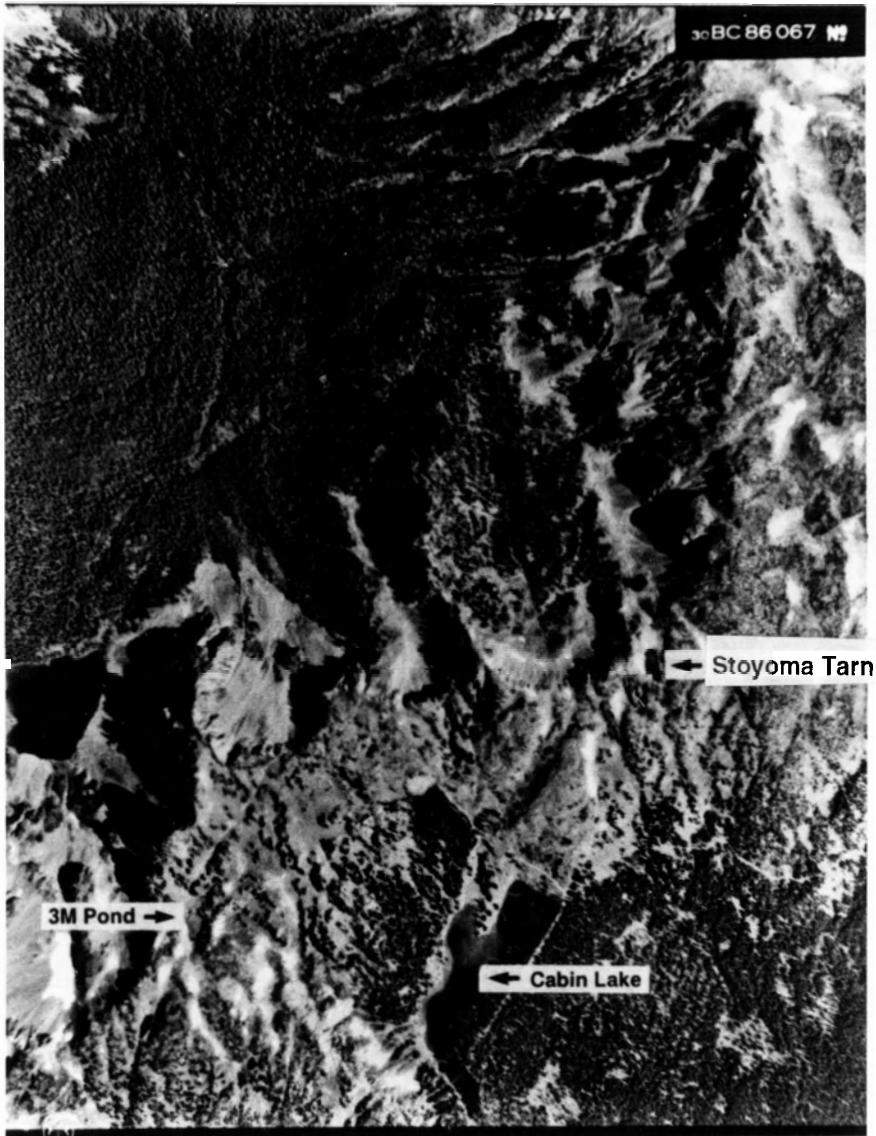
Air Photograph of Study Area

Labels on photograph: 3oBC 86 067 N9; Stoyoma Tarn; 3M Pond; Cabin Lake

Figure 7.3a

Photograph of Mount Stoyoma. Northern Cascade Mountains.

Figure 7.3b

Photograph of Cabin Lake showing ESSF forest surrounding the lake.

Figure 7.3a

Figure 7.3b

Figure 7.4a

Photograph of 3M Pond showing ESSF parkland around the lake.

Figure 7.4b

Photograph of Stoyoma Tarn showing krummholz around the lake.

Figure 7.4a

Figure 7.4b

Erigeron cf. *peregrinus*, *Solidago multiradiata*, *Sibbaldia procumbens*, *Carex nigricans*, *Carex* sp., *Dicranum* sp., and *Equisetum variegatum*.

These lakes represent the subalpine Engelmann Spruce-Subalpine Fir Biogeoclimatic Zone to the subalpine/alpine transition zone, more commonly referred to as treeline. Pollen and plant macrofossil analyses, radiometric dating and tephrachronology were undertaken to document vegetation and climate change on Mount Stoyoma during the Holocene. Chironomid head capsule analysis is concurrently being undertaken by M.J. Smith on lake sediments from Cabin Lake and 3M Pond. The paleoecology and paleoclimatology of these three lakes will be discussed in the next three sections.

Methods:

Methods for coring, pollen and plant macrofossil analysis are the same as described in chapter 4. Cores were taken with a modified Livingstone piston corer in the deepest part of the basins. Core length for Cabin Lake is 399 cm, Stoyoma Tarn is 73 cm, and for 3M Pond is 73 cm. Mount Mazama tephra (6800 ^{14}C yr BP) is present in all three cores. Bridge River tephra (2410 ^{14}C yr BP) is present in the Cabin Lake sediment core. Tephra was identified using microprobe analysis by Jerry Osborne and Glen DePaoli at the University of Calgary. Radiocarbon ages can be seen in Table 7.1. Interpolated radiocarbon ages were calculated using regression analysis (Grimm, 1993). Subsampling for pollen analysis was at 2 cm intervals for 3M Pond and Stoyoma Tarn, and at 5

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cm intervals for Cabin Lake. Subsampling for plant macrofossil analysis was at 2 cm intervals for 3M Pond and Stoyoma Tarn, and at 5 cm intervals for Cabin Lake, except in the basal 91 cm of clay and silt where 2 cm intervals were used. Pollen and plant macrofossil diagrams were prepared using TILIA v2.0 and TILIAGRAPH v1.25 (Grimm, 1993). Visual zonation was statistically validated using CONISS to perform stratigraphically constrained cluster analysis (Grimm, 1993). Diploxylon pine (*Pinus contorta* type) pollen is greatly overrepresented in pollen assemblages from the ESSF (Hebda, 1995). This pollen is of regional and extra-local origin and does not represent the local vegetation at Cabin Lake, 3M Pond and Stoyama Tarn. In order to increase the resolution of local pollen types, pollen diagrams with Diploxylon pine removed from the pollen sum were prepared. Spruce/Diploxylon pine percent ratios (spruce/pine ratios) were calculated and plotted for the study sites. These ratios are compared with the spruce/pine ratios calculated for the ESSF lake surface sediment samples discussed in Chapter 6.

Table 7.1: AMS radiocarbon dates for the Mount Stoyoma study sites.

Sample Identification	Sample Description	Weight used (mg)	IsoTrace Lab Number	Age ^{14}C yr BP
Stoyoma Tarn ST94-II-33.5 (70-73 cm)	conifer needles	7	TO-5327	1480±110
Stoyoma Tarn ST94-I-23 (22-24cm)	conifer needles	7	TO-5328	5370±70
3M Pond 3M94-B-21 (65-67 cm)	conifer needles	3	TO-5329	10000±320
3M Pond 3M94-A-25 (24-26 cm)	conifer needles	7	TO-5330	3530±60
Cabin Lake CLJL94-5-12 306 cm	carbonized wood sample		TO-5205	8910±120
Cabin Lake CL94(old) D2-72 cm	wood fragment		TO-4325	9319±120

Errors presented at ±1s

Results and Discussion:

<u>Pollen Assemblage Zones at Cabin Lake.</u>

The Cabin Lake pollen assemblage is shown in Figure 7.5. A pollen diagram with Diploxylon pine removed from the pollen sum is shown in Figure 7.6. Spruce/pine ratios are plotted in Figure 7.7. An Elaeagnaceae trichome from the lower clay sediments is shown in Figure 7.8a.

Zone CP-1(Diploxylon pine - Spruce - Poaceae - *Artemisia*, 399-312 cm, late-glacial):

In Zone CP-1 lodgepole pine type (Diploxylon pine) pollen percentages exceed 80%, the highest levels recorded in the core. Spruce pollen is also an important component of the assemblage, peaking at 350 cm along with Sitka alder and a number of subalpine/alpine or open/dry herb pollen types. Characteristic subalpine/alpine herbs such as grass (Poaceae), sedge (Cyperaceae), *Artemisia*, Caryophyllaceae, *Epilobium*, Asteraceae, *Selaginella rupestris* type, and *Botrychium* reach their highest levels in the core. The sediments in this zone are composed of clay with sand/silt bands (Figures 7.5, 7.6 & 7.8b). Total pollen concentration was extremely low throughout most of this zone, and dramatically increases at the clay/gyttja interface (314 cm).

There is a significant decrease of Diploxylon pine between 334 and 354 cm. Corresponding to this pine decrease is a significant increase in spruce, Sitka alder, Poaceae, *Artemisia*, Filicales, *Polypodium*, and *Botrychium*. This zone

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Figure 7.5

Percentage pollen diagram for Cabin Lake, with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. Two AMS dates on conifer needles is shown on the left. Pollen concentrations are X100. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 7.5
Cabin Lake, B.C.
Percent Pollen & Spores

127b
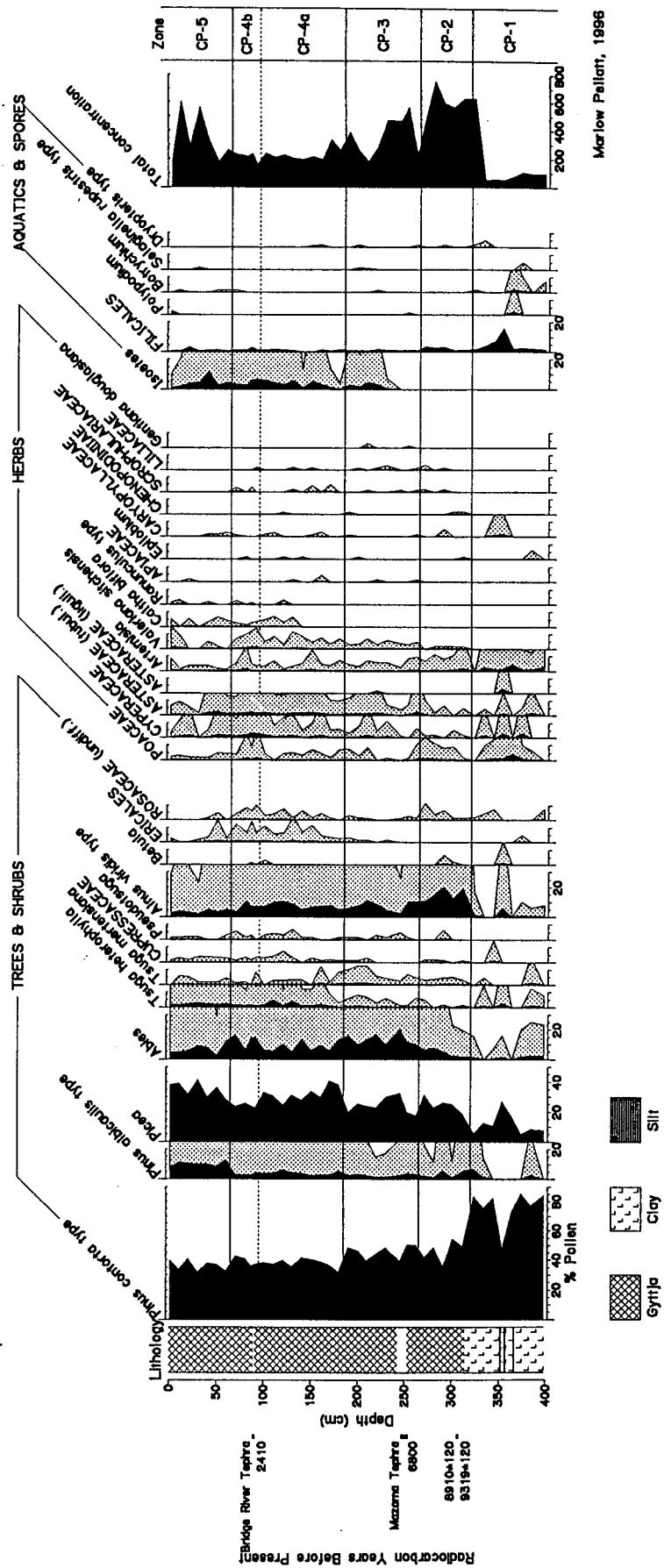
Figure 7.6

Percentage pollen diagram with Diploxylon pine removed for Cabin Lake, with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. Two AMS dates on conifer needles is shown on the left. Pollen concentrations are X100. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 7.6
Cabin Lake, B.C.
Pollen Percentage Diagram
Diploxylon Pine Removed from Sum

128b

FIGURE 7.7

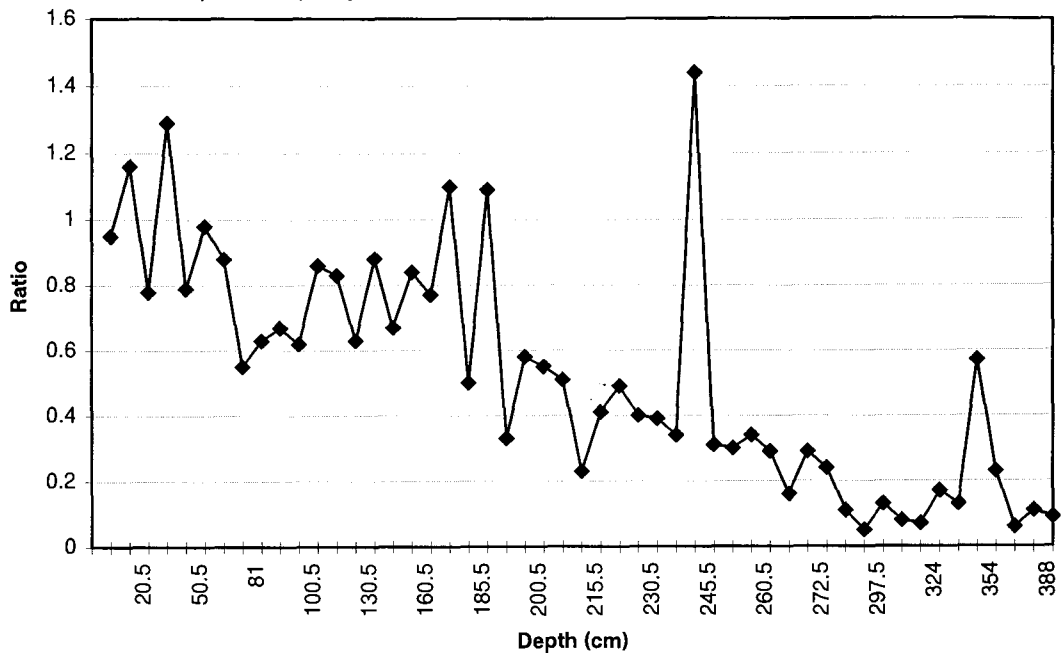Spruce/Diploxylon Pine Pollen Percentage Ratio, Cabin Lake

Figure 7.8a

Photograph of Elaeagnaceae trichome from silt band in basal clays (350 cm).

Figure 7.8b

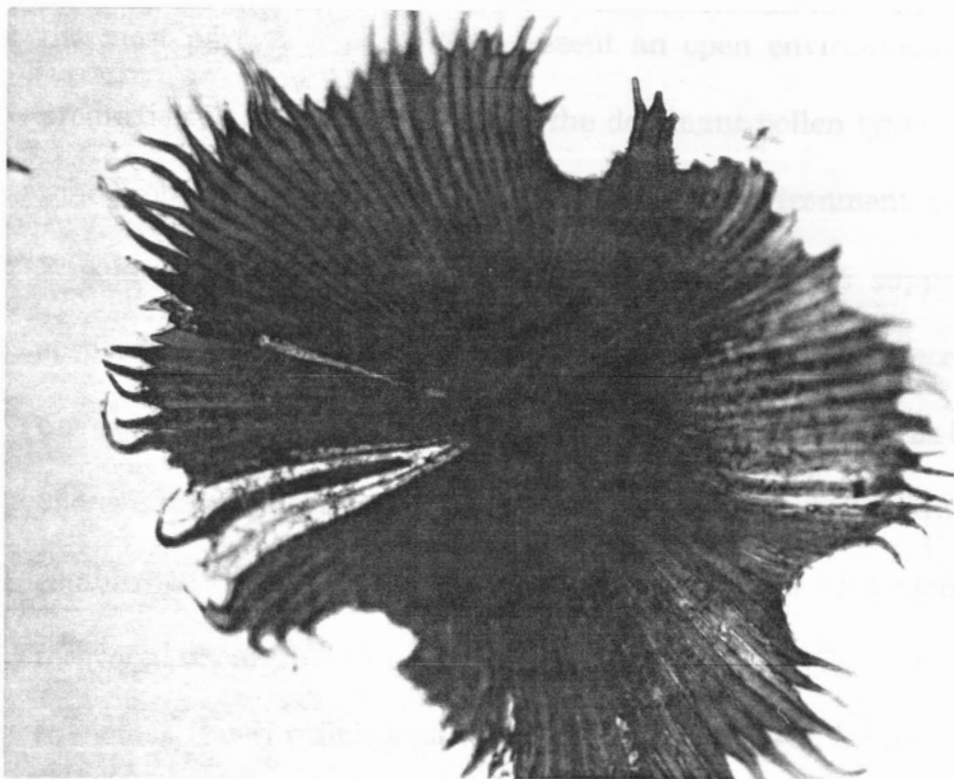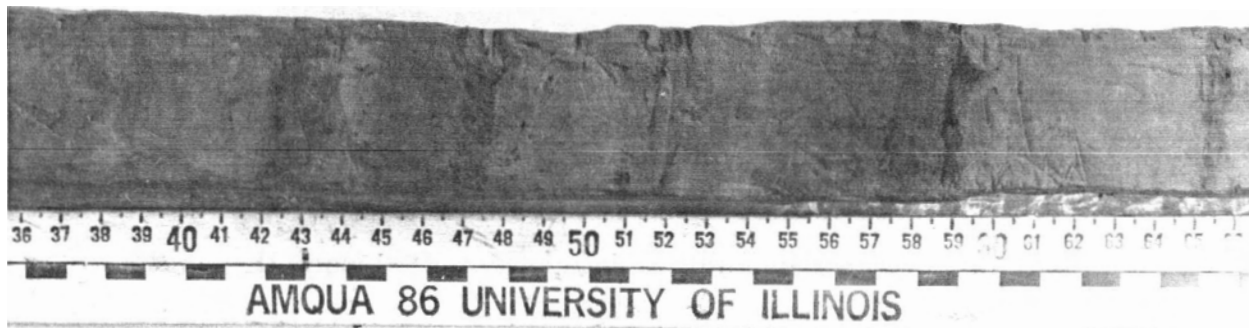Photograph of silt bands in basal clays sediments from Cabin Lake.

Figure 7.8a

Figure 7.8b

CABIN LAKE
DRIVE 5

predates 9319 ± 120 ^{14}C yr BP and most likely represents late-glacial time. For the most part, it appears to represent an open environment with low pollen productivity. Pine and spruce are the dominant pollen types, even though this zone probably represents an alpine tundra like environment with only scattered Engelmann spruce krummholz. This interpretation is supported by the low spruce/pine ratios seen at this depth in Figure 7.7. The decrease of pine and corresponding increases in spruce, *Abies*, and associated herbs between 334 and 354 cm, may indicate a warming trend in which pioneering tree species became established (Figure 7.5 & 7.6). This assumption is supported by macrofossils recovered from the same depth. These macrofossils include Elaeagnaceae trichomes, dwarf willow leaf fragments and buds, a cf. *Dryas* leaf fragment, and a *Phyllodoce* needle. This event is brief and is truncated by a resurgence of pine between 314 and 334 cm. Although undated, it appears that this increase in pine (and corresponding decrease in spruce, *Abies*, and herbs) may represent the re-establishment of alpine tundra at Cabin Lake as a result of a cooling event. At present, Diploxylon pine values greater than 60% at present (see chapter 6) indicate open, alpine conditions. As values of Diploxylon pine increase with elevation in the ESSF, the values of 80% in this zone indicate alpine-like conditions. It appears that vegetation in this zone went from alpine tundra (354 to 388 cm), to early successional subalpine parkland (334-354 cm), back to alpine tundra (314 to 354 cm). In other words, climate changed from cold to cool, then back to cold. Although this interval has not yet been radiocarbon dated, the first

cold phase (388-354) may represent Older Dryas-like conditions, the warmer phase (334-354 cm) may represent Allerod like conditions and the second cold phase (312-334 cm) may be attributable to a Younger Dryas-like cooling event. AMS radiocarbon dates from this pollen zone are needed to confirm this assumption.

Zone CP-2 (Diploxylon pine - Spruce - Sitka alder, 312-270 cm, >9319±120 to *ca* 7000 ^{14}C yr BP):

In Zone CP-2, lodgepole pine type pollen decreases relative to CP-1, but remains at over 40% of the pollen sum. Sitka alder type pollen achieves its highest levels in the sediment core. Levels of spruce increase throughout this zone and whitebark pine type (Haploxylon pine) pollen are fairly high. *Artemisia* and Poaceae are the dominant herbs. *Valeriana sitchensis* and Liliaceae enter the pollen record in this zone. Total pollen concentration is at its highest in this zone, attaining values of over 800,000 grains per ml. AMS radiocarbon dates of 9319±120 ^{14}C yr BP, obtained from a piece of wood at 306 cm, (6 cm above the gyttja/clay interface) and 8900±120 ^{14}C yr BP at 304 cm (see Table 7.1 for ^{14}C yr BP).

Relatively high levels of spruce and *Abies* pollen suggest that trees typical of the ESSF zone were present at this time. The high abundance of Diploxylon pine (~40 to 50%) and Sitka alder pollen are most likely of regional and extra-local origin and suggest open conditions at Cabin Lake (Hebda and Allen, 1993).

Significant levels of spruce and *Abies*, in conjunction with initially high levels of Sitka alder suggest an environment with no modern analogue in the early Holocene. The absence of cool or moist indicators such as Ericales (heaths and *Empetrum*) and the significant presence of shade intolerant taxa like whitebark pine type, Poaceae and *Artemisia* suggest a dry/open climate with good growing conditions. This interpretation is indirectly supported by the high total pollen concentrations. Relatively high spruce (probably *Picea engelmannii*) and Haploxylon pine (probably whitebark pine) pollen values, and low *Abies* pollen values (probably subalpine fir) suggest warmer/drier conditions than present. This interpretation is consistent with the early Holocene xerothermic period noted in coastal British Columbia (Mathewes, 1973; Mathewes and Heusser, 1981; Hebda, 1995).

Zone CP-3 (Diploxylon pine - Spruce - *Abies*, 270-190 cm, *ca* 7000 - 4800 ^{14}C yr BP):

In Zone CP-3 levels of lodgepole pine type and spruce pollen remain relatively constant. *Abies* pollen significantly increases from the previous zone whereas whitebark pine (Haploxylon) type and Sitka alder decrease. Mount Mazama (6800 ^{14}C yr BP) tephra occurs from 246 to 253 cm in the lower portion of this zone.

This zone appears to be a period of vegetation and climatic transition at Cabin Lake. It appears that *Abies* (probably subalpine fir) becomes the

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dominant tree surrounding Cabin Lake. Because *Abies* is under-represented in pollen assemblages (Dunwiddie, 1987; Hebda & Allen, 1993), 20% abundance suggests that *Abies* dominated the surrounding forest (Hebda and Allen, 1993). High *Abies* values and other subalpine indicators of moisture, such as Cyperaceae, *Gentiana douglasiana*, and Ericales, indicate that conditions were wetter than noted in either zones CP-1 or CP-2. High pollen concentration (Figure 7.5 & 7.6) in conjunction with low spruce/pine ratios (Figure 7.7) indicate that climate was warmer than present. The increase in some subalpine taxa indicate that temperature was beginning to decrease during this zone. This zone corresponds with the mesothermic period observed in coastal British Columbia (Hebda, 1995). The inferred paleoclimate is similar to that observed in coastal British Columbia and does not concur with the timing of the Hypsithermal (~6,000 to 4,000 ^{14}C yr BP) in northeastern Washington (Mehringer, 1985).

Zone CP-4a (Diploxylon pine - Spruce - Western hemlock - Cyperaceae - Ericales, 190-95 cm, 4800 - 2410 ^{14}C yr BP):

In Zone CP-4a lodgepole pine type pollen decreases to about 40% of the pollen sum. Spruce pollen increases and *Abies* decreases from CP-3 but remains as an important component of the pollen sum. Cupressaceae, Ericales, Rosaceae, and Cyperaceae all increase in abundance. *Caltha biflora* and *Ranunculus* type enter the pollen record and *Isoetes* remains important. Regional transport of western hemlock pollen (*Tsuga heterophylla*) increases.

The increased values of Ericales, *Caltha biflora*, *Ranunculus* type, Rosaceae, and Cyperaceae pollen indicate that typical subalpine vegetation had become established. A significant decrease in pollen concentration occurs, to levels that are only lower in zone CP-1 (late-glacial). Values of regionally transported western hemlock pollen attain their highest values in this zone, suggesting a decrease in local pollen productivity and decreased temperature and precipitation at lower elevations as observed in the Fraser Canyon (Mathewes and King, 1989). It appears that climate was cooler than in zones CP-2 and 3, with increased importance of Engelmann spruce in the surrounding forest.

Zone CP-4b (Diploxylon pine - Spruce - *Abies*, 95-65 cm):

In CP-4b *Abies*, lodgepole pine type, Poaceae and Cyperaceae pollen increase whereas spruce pollen decreases. Subalpine/alpine herbs remain diverse and pollen concentrations remain low. Bridge River tephra (2410 ^{14}C yr BP) occurs at the base of this zone.

Increases in *Abies* and Cyperaceae indicate that conditions may have been wetter than those observed in CP-4a, but with similar cool conditions. This increased wetness, corresponding with cool/wet temperatures after Bridge River tephra (*ca* 2410 ^{14}C yr BP) may be the same climatic factors that promoted glacial advances in the Northern Cascade Mountains (moraines of the Burroughs Mountain Stade 2050 ^{14}C yr BP), and the Canadian Rocky

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Mountains (Porter and Denton, 1967; Luckman *et al.*, 1993), as well as cool/moist conditions in the Interior Douglas Fir (IDF) zone of the Fraser Canyon (Mathewes and King, 1989).

Zone 4a indicates cool conditions with increasing precipitation in Zone 4b. Cool/moist conditions in CP-4b correspond with the development of modern forests in the Fraser Canyon (Mathewes, 1973), and in the interior Pacific Northwest, U.S.A. (Mehringer, 1985). At the same time pollen ratio analysis suggests that local spruce production was low, indicating that the environment was likely more open than in zone CP-4a.

Zone CP-5 (Diploxylon pine - Spruce - whitebark pine, 65-0 cm):

In Zone CP-5 whitebark pine type, spruce, and *Isoetes* pollen and spores increase. *Abies*, Sitka alder, and Ericales decrease. Pollen concentration increases to levels not seen since CP-3 and CP-2. Diversity of subalpine/alpine herbs decreases. An increase in spruce/pine ratio values is observed (Figure 7.7).

This zone represents modern conditions at Cabin lake. High values of whitebark pine and Engelmann spruce indicate that conditions are drier then in Zones 4a and 4b. This drier, possibly warmer phase appears to correspond with conditions in the interior Pacific Northwest, U.S.A. (Mehringer, 1985), but still represents cooler conditions than observed in the early Holocene xerothermic and mesothermic periods.

Local Plant Macrofossil Assemblage Zones at 3M Pond.

Plant macrofossil distribution and zonation is presented in Figure 7.9.

Zone 3M-1 (Lateglacial, 73-65 cm, >10,000±320 ^{14}C yr BP):

In zone 3M-1 only a few unidentifiable needle fragments are present. This zone encompasses the clay sediments and has an AMS needle date of 10,000±320 ^{14}C yr BP at 65-66 cm.

This zone represents lateglacial time, in which cold conditions restricted conifer growth around 3M Pond. Alpine tundra conditions most likely occurred around 3M Pond at this time.

Zone 3M-2 (Subalpine fir - Whitebark pine, 65-40 cm, 10,000±320 to 6800 ^{14}C yr BP):

In Zone 3M-2 needles from subalpine fir, Engelmann spruce and whitebark pine are present but the overall needle abundance is very low. *Carex* seeds occur in the upper portion of this zone.

This zone has low levels of conifer deposition until 54 cm, at which time subalpine fir, and then later, Engelmann spruce needle abundance increases. A basal whitebark pine needle at 65 cm may indicate relatively dry conditions in the early Holocene, with increasing precipitation suggested by the presence of subalpine fir and *Carex* beginning just before Mazama time.

Zone 3M-3 (Subalpine fir - Engelmann spruce - Whitebark pine - *Carex*, 40-24 cm, 6800 to 3530±60 ^{14}C yr BP):

In Zone 3M-3 subalpine fir, Engelmann spruce and whitebark pine needles reach their maximum abundance. The number of *Carex* seeds increase in the zone and an Engelmann spruce cone is present. Charcoal fragments reach their maximum in this zone.

Maximum plant macrofossil deposition indicates that growing conditions for subalpine fir, Engelmann spruce, and whitebark pine were at an optimum during this time. The presence of an Engelmann spruce cone indicates that the climate at 3M Pond was favourable for its sexual reproduction. It appears that conditions were warmer than present but wetter than in zone 3M-2. This zone corresponds to the mesothermic period.

Zone 3M-4 (Engelmann spruce, 24-0 cm, 3530±60 ^{14}C yr BP to Present):

In Zone 3M-4 subalpine fir and Engelmann spruce needles decrease. Whitebark pine needles are absent and subalpine fir needles disappear between 10 and 0 cm. Engelmann spruce seeds exist between 15 and 25 cm. Charcoal and Cladocera ephippia are important components of the macrofossil record.

Decreased needle abundance and diversity indicate that cool, modern conditions had established at 3M Pond. Subalpine fir drops out of the plant macrofossil record, and whitebark pine is absent. Engelmann spruce appears to be the dominant conifer as represented by both needles and seeds. This zone

corresponds with widespread regional cooling throughout British Columbia, neoglacial cooling attributable to the Tiedemann, Peyto and Robson glacial advances, as well as cooling observed at Kelowna Bog and the Fraser Canyon (Alley, 1976: Mathewes and King, 1989; Pellatt and Mathewes, 1994; Hebda, 1995).

Pollen Assemblage Zones at 3M Pond:

Relative pollen abundance is shown in Figures 7.10 and 7.11 (Diploxylon pine removed from pollen sum), and spruce/pine ratios are plotted in Figure 7.12.

Zone 3MP-1 (Diploxylon pine - Spruce - Sitka alder - *Artemisia*, 73-64 cm, >10,000±320 ^{14}C yr BP):

In zone 3MP-1 high values of Diploxylon pine, spruce, Sitka alder, *Artemisia* pollen and Filicales spores are characteristic. Non-arboreal pollen values are high, and pollen concentration is very low. Willow pollen is present in this zone. Peaks of Sitka alder type and *Artemisia* pollen and Filicales spores occur at 70 cm. Spruce/pine ratios are relatively low indicating open conditions (Figure 7.12).

This zone occurs in late-glacial clays. Low pollen concentrations indicate that pollen productivity was either low at this time, or that sedimentation rates

Figure 7.9

Plant macrofossil diagram for 3M Pond, AMS dates on conifer needles are shown

on the left. Zones were derived by stratigraphically constrained cluster analysis

(CONISS

Figure 7.9
3M Pond, B.C.
Macrofossils per 10 ml sediment

Marlow Pellatt, 1996
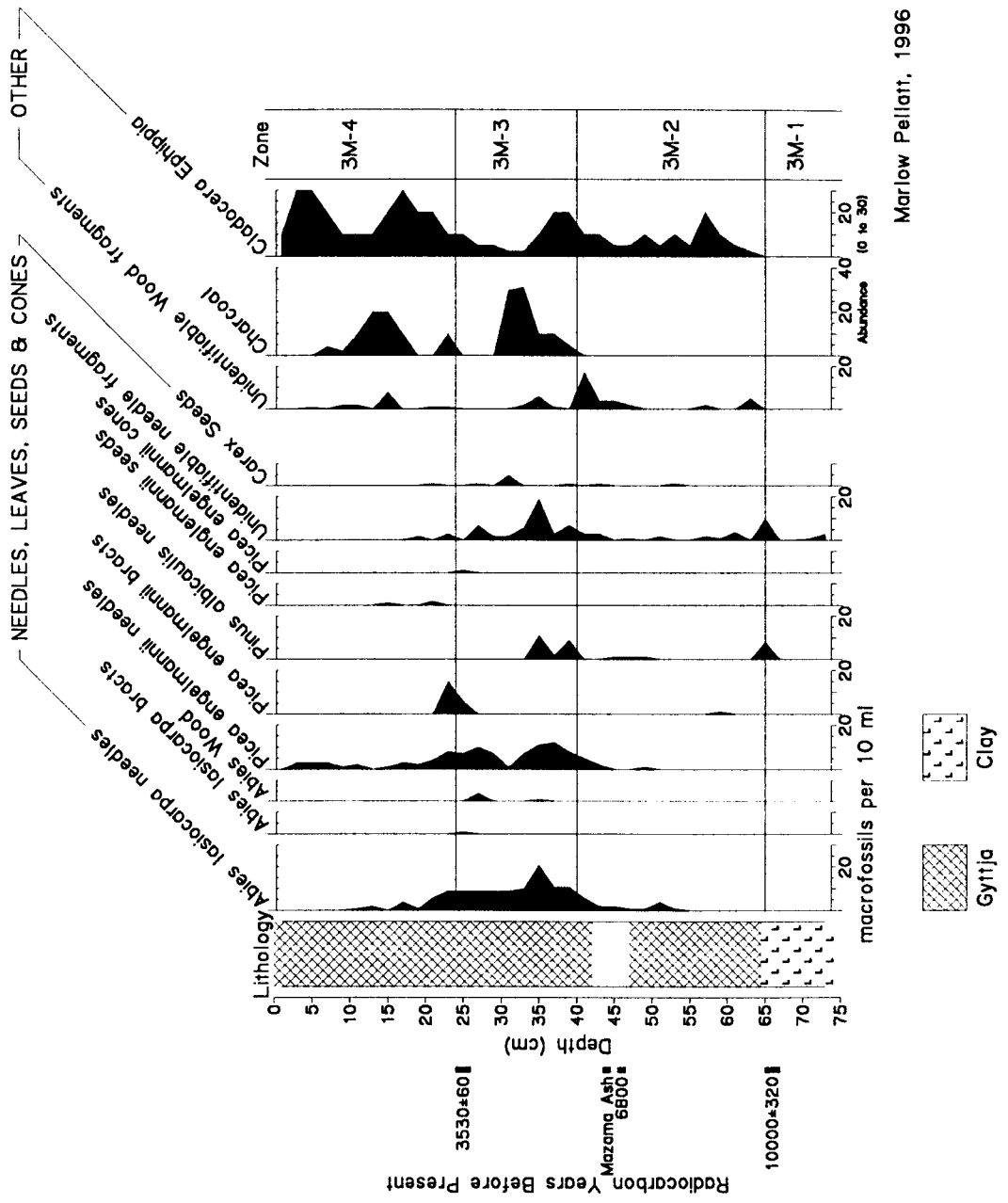
were high. Vegetation was probably representative of an open, alpine habitat. This conclusion is supported by high values of Diploxylon pine, high non-arboreal pollen percentages and a low spruce/pine ratio value. The absence of plant macrofossils in zone 3M-1 of the macrofossil diagram supports this assumption (Figure 7.9).

Zone 3MP-2 (Diploxylon pine - Sitka alder - Spruce - Non-arboreal pollen, 64-44cm, 10,000±320 to 6800 ^{14}C yr BP) :

In zone 3MP-2 high values of Diploxylon pine, *Abies*, Sitka alder type pollen and Filicales spores are recorded. Willow pollen, *Botrychium*, and *Selaginella rupestris* type spores are notable components of the pollen assemblage. Pollen concentration peaks at 62.5 cm. Non-arboreal pollen is important in characterising this zone.

This zone encompasses the early Holocene. Spruce/pine ratios indicate relatively open conditions. Ericales pollen is lower than in higher zones, and significant levels of willow, Poaceae and *Artemisia* pollen suggest that conditions were relatively dry. Although pollen concentration is high, there are few other indicators of warmer temperature.

Zone 3MP-3 (Diploxylon pine - Spruce - Haploxylon pine - *Abies* - Ericales, [44] -21 cm, 6800 to 3530±60 ^{14}C yr BP) :

In zone 3MP-3 Diploxylon pine, Sitka alder type and *Artemisia* pollen, and Filicales spores decrease. Willow drops out of the pollen record, and non-arboreal pollen declines. Spruce, whitebark pine type, Ericales and Cyperaceae pollen percentages increase. Pollen concentration remains fairly high. Spruce/pine ratios increase, indicating local ESSF forest development (Figure 7.7).

Pollen changes indicate that an ESSF forest became established at 3M Pond. This is supported by the significant increase in subalpine fir, Engelmann spruce and whitebark pine needles in the corresponding macrofossil zone 3M-3. Increased Cyperaceae pollen corresponds with increased *Carex* seeds in the macrofossil diagram. This zone corresponds with the mesothermic period and appears to have had the best growing conditions for spruce and *Abies*. Increased precipitation and temperatures warmer than present are supported by the high levels of local conifers (spruce and *Abies*). Cooler temperatures than in the early Holocene are indicated by increased Ericales and *Caltha biflora* pollen. Spruce/pine ratios indicate that treeline was higher than present.

Figure 7.10

Percentage pollen diagram for 3M Pond, with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. AMS dates on conifer needles are shown on the left. Pollen concentrations are X10. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 7.10
3M Pond, B.C.
Percent Pollen and Spores

Marlow Pellatt, 1996

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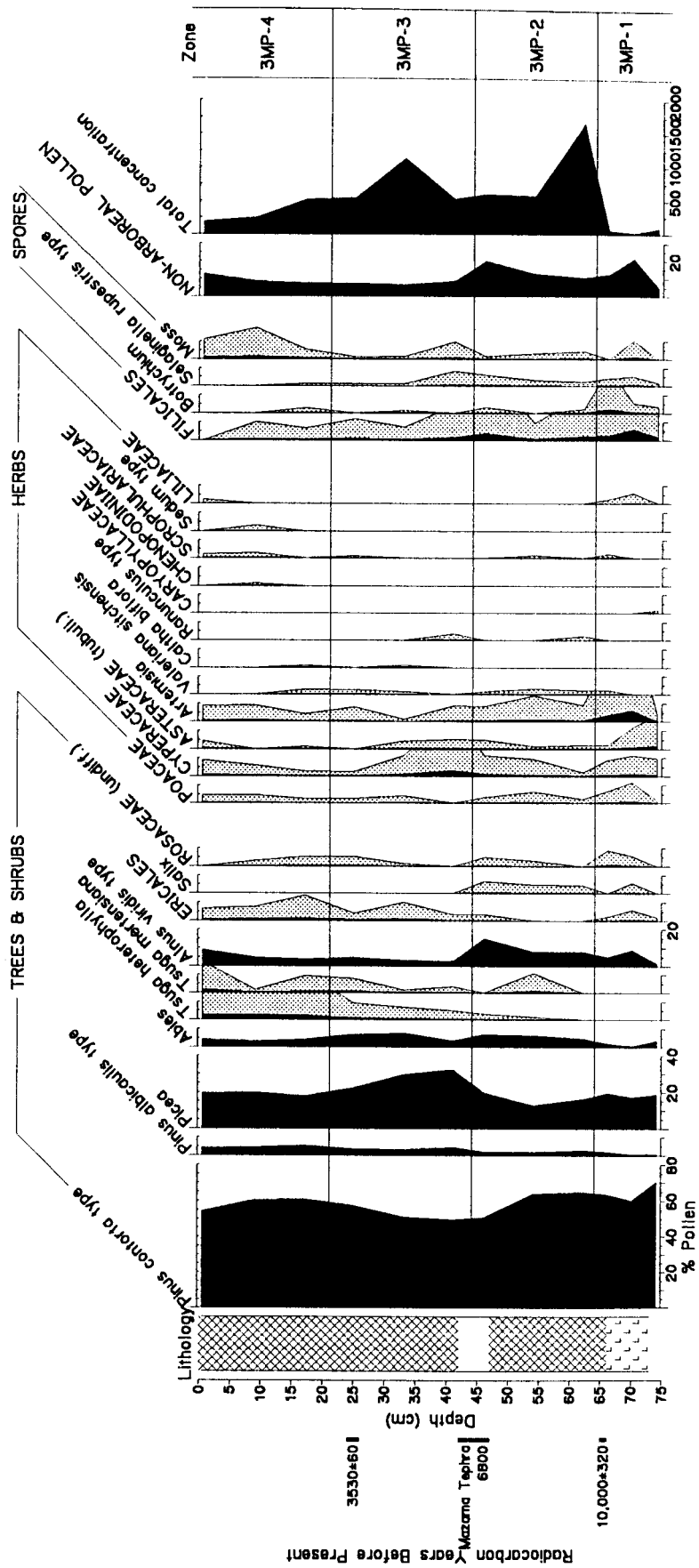
Figure 7.11

Percentage pollen diagram for 3M Pond (Diploxylon pine removed from sum), with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. AMS dates on conifer needles are shown on the left. Pollen concentrations are X10. Zones were derived by stratigraphically constrained cluster analysis (CONISS).
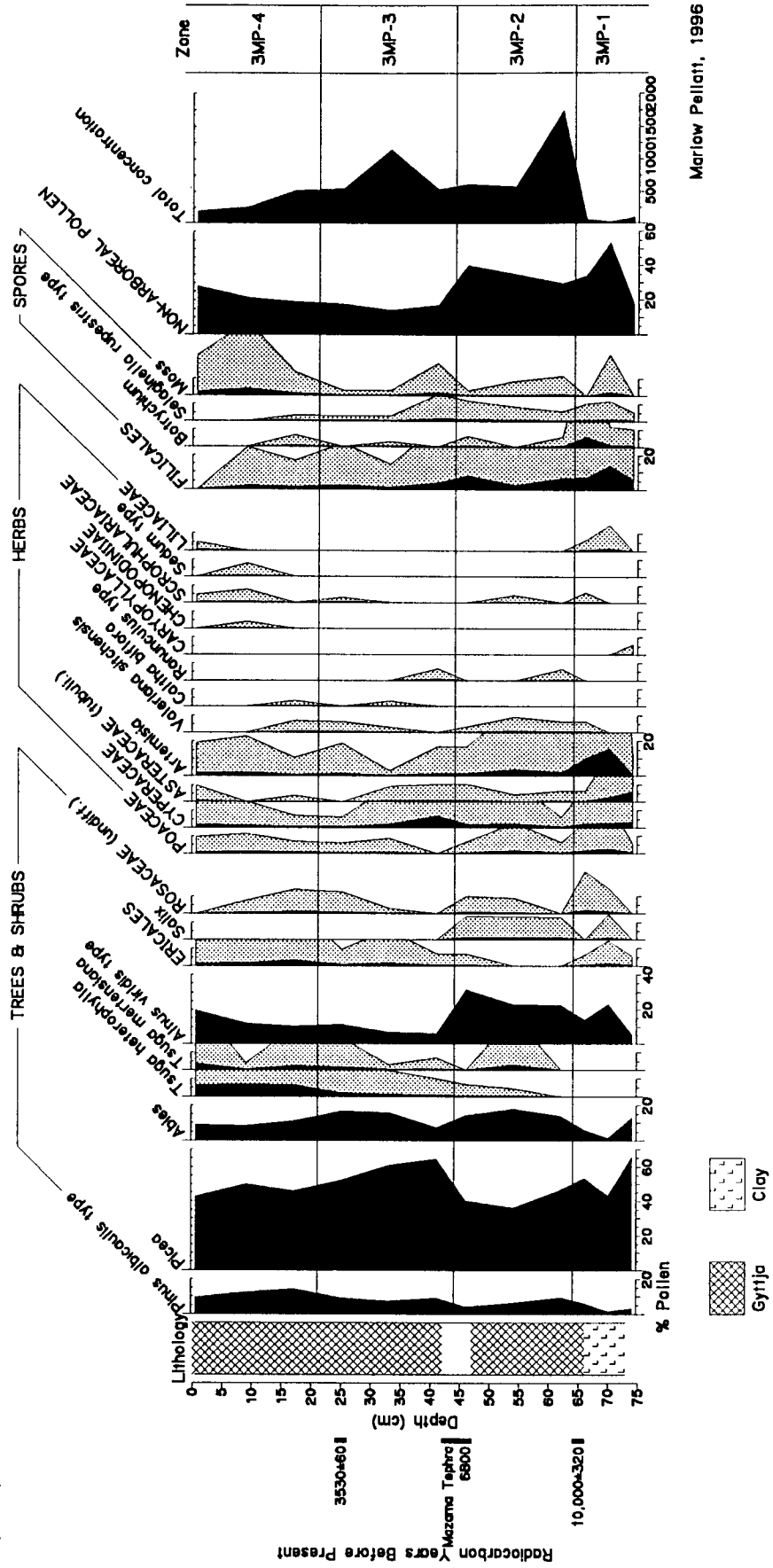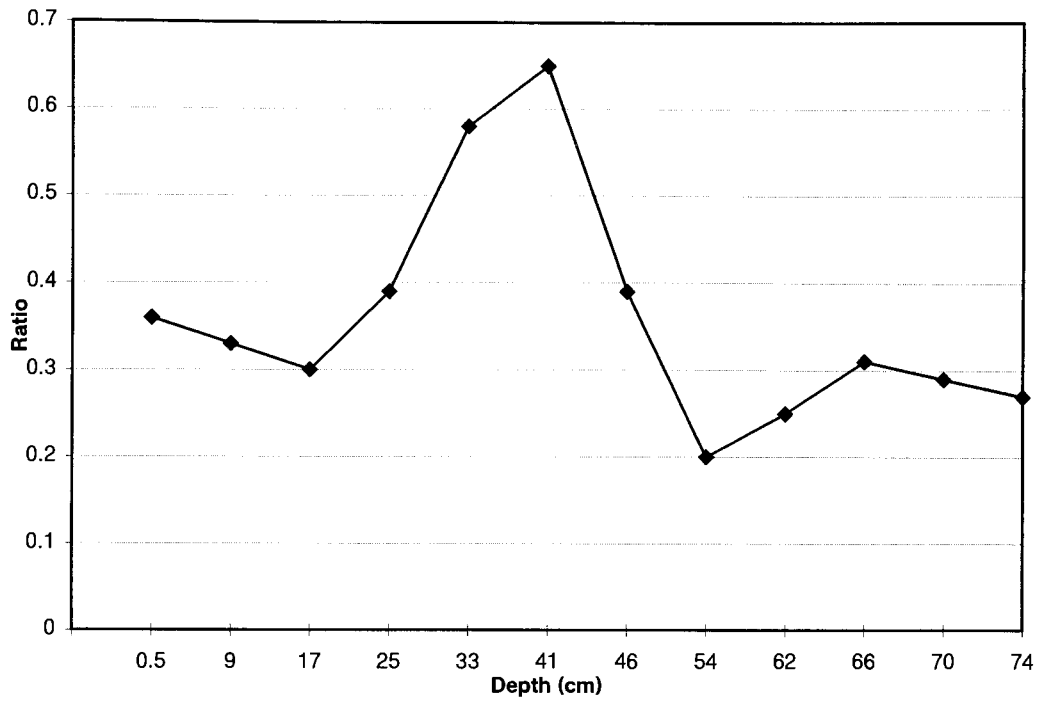
Figure 7.11
3M Pond, B.C.
Percent Pollen & Spores
Diploxylon Pine Removed from Sum

Marlow Pellatt, 1996

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FIGURE 7.12
Spruce/Diploxylon Pine Pollen Percentage Ratio, 3M Pond

Zone 3MP-4 (Diploxylon pine - Spruce - Western hemlock, 21-0 cm, 3530±60 ^{14}C yr BP to present):

In zone 3MP-4 Diploxylon pine pollen remains high. Spruce and *Abies* pollen percentages decrease throughout the zone, whereas western hemlock and mountain hemlock percentages increase. Moss spores and non-arboreal pollen also increase. Pollen concentration decreases to levels that are only lower in the late Pleistocene (3MP-1). Spruce/pine ratios decrease indicating more open conditions throughout this zone.

This zone represents the transition to modern subalpine conditions at 3M Pond. Decreased local pollen percentages and high levels of regionally transported western and mountain hemlock support the assumption of decreased local pollen productivity and inferred temperature, corresponding to glacial advances in the British Columbia Coast Mountain and the Canadian Rockies. Decreased spruce/pine ratios support this assumption, indicating more open conditions representative of modern subalpine parkland.

Local Plant Macrofossil Assemblage Zones at Stoyoma Tarn:

Plant macrofossil distribution and zonation is presented in Figure 7.13.

Zone STM-1 (Subalpine fir - Engelmann spruce, 72-52 cm):

Zone STM-1 ends prior to the Mount Mazama tephra deposition (6800 ^{14}C yr BP) and probably begins near the Pleistocene/Holocene boundary. Subalpine

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fir, Engelmann spruce, and whitebark pine needle abundance is relatively low. A *Cassiope mertensiana* scale leaf was present in the basal sample of this zone (73 cm). Rock fragments and sand are common at the base.

Moderate needle abundance throughout the zone indicates that trees were growing around Stoyoma Tarn. Macrofossil abundance is higher than present, but lower than in zone STM-2, indicating parkland conditions. It appears that precipitation was limiting for good tree growth in this zone. Because there is no accurate radiocarbon date for pre-Mazama time at Stoyoma Tarn, a limiting age for this zone can not be determined. Consequently it is unknown if this zone ends at the Holocene/Pleistocene boundary.

Zone STM-2 (Subalpine fir - Engelmann spruce - Whitebark pine - *Carex*, 52-34 cm, >6800 ^{14}C yr BP):

In Zone STM-2 subalpine fir, Engelmann spruce and whitebark pine needles attain their maximum abundance. *Carex* and whitebark pine seeds also increase in this zone. Whitebark pine needles dramatically increase just after the deposition of the Mazama tephra (36 cm).

High needle abundance indicates good growing conditions for subalpine fir, Engelmann spruce and whitebark pine, suggesting that temperatures were warmer at Stoyoma Tarn and indicating maximum Holocene warmth prior to 6800 ^{14}C yr BP. Vegetation changes in this zone are correspond to those

observed at Cabin Lake and 3M Pond ~~early~~ during the early Holocene xerothermic period, suggesting warm conditions at Stoyama Tarn.

Zone STM-3 (Subalpine fir, Engelmann spruce, *Carex*, 34-22 cm, 6800 - 5370±70 ^{14}C yr BP):

In Zone STM-3, subalpine fir, Engelmann spruce and whitebark pine needles decline relative to zone STM-2. Abundance of *Carex* and whitebark pine seeds remains relatively constant. A spike in charcoal fragments and an overall increase in Cladocera ephippia occur in this zone.

In this zone a significant decline in whitebark pine needles occurs but subalpine fir and Engelmann spruce needles remain important. It appears that vegetation and inferred climate were both changing. The prominence of subalpine fir in conjunction with a peak in *Carex* seeds (32-34 cm) suggest that precipitation was increasing at Stoyoma Tarn. This is supported by the decline in whitebark pine, which prefers drier sites than subalpine fir and Engelmann spruce (Klinka *et al.*, 1990). Temperatures were likely warmer than present corresponding with warm, moist conditions associated with the mesothermic period.

Zone STM-4 (Subalpine fir - Whitebark pine, 22 - 0 cm, 5370±70 ^{14}C yr BP to present):

In Zone STM-4 a decrease in Engelmann spruce and whitebark pine needles occur, together with the occurrence of *Cassiope* scale leaves and *Phyllodoce* needles. Subalpine fir is the important plant macrofossil in this zone, decreasing in younger sediments. *Carex* and whitebark pine seeds disappear from the record. An Engelmann spruce seed occurs at 7 cm. Charcoal remains are common as in STM-3 and Cladocera ephippia also remain abundant.

This zone represents the establishment of the modern krummholz/alpine conditions at Stoyoma Tarn. Subalpine fir needles, *Cassiope* scale leaves, and *Phyllodoce* needles indicate cool, relatively moist conditions. This assumption is supported by the drastic decrease in whitebark pine and Engelmann spruce needles.

Using a dry adiabatic lapse rate of 6.5°C/km (Clague and Mathewes, 1989), changes in temperature can be estimated by the difference in elevation between ESSF forest and subalpine/krummholz vegetation in the mid to late-Holocene. At present there is at least 100 metres of elevation difference between ESSF forest and krummholz. If peak needle abundance during the mid-Holocene is taken to represent ESSF forest, than paleo-treeline at Stoyoma

Figure 7.13

Plant macrofossil diagram for Stoyoma Tarn, AMS dates on conifer needles are shown on the left. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 7.13
Stoyoma Tarn, B.C.
Macrofossils per 10 ml sediment
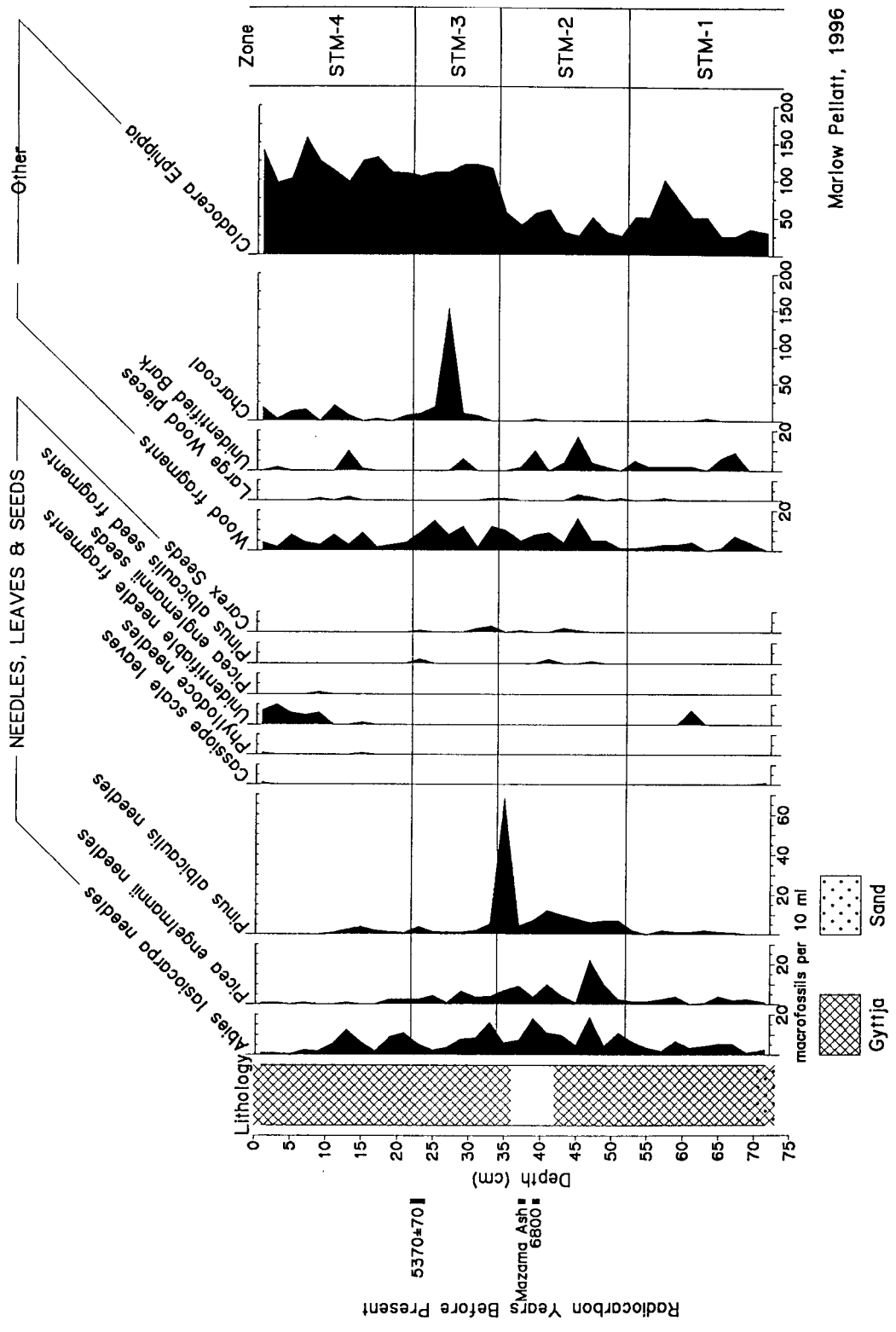
Tarn was at least 100 metres higher in the past; thus temperature was at least 0.65°C warmer prior to 5370±70 14C yr BP. This data is consistent with inferred temperature changes at Castle Peak, B.C. in the Coast Mountains (Clague and Mathewes, 1989). It also supports the existence of the mesothermic period in the southern interior of B.C. (Hebda, 1995).

Pollen Assemblage Zones at Stoyoma Tarn.

Relative pollen abundance is shown in Figures 7.14 and 7.15 (Diploxylon pine removed from pollen sum), and spruce/pine ratios are plotted in Figure 7.16. These ratios are compared with the spruce/pine percent ratios calculated for the ESSF lake surface sediment samples discussed in Chapter 6.

Zone STP-1 (Diploxylon pine - Spruce - Sitka alder - *Artemisia*, 73-60 cm):

In zone STP-1 lodgepole pine (*Pinus contorta* type) pollen is dominant; other important trees and shrubs are Sitka alder (*Alnus viridis*), whitebark pine type, spruce, willow (*Salix*) and Cupressaceae. Even though lodgepole pine type is the major component of the pollen assemblage, it is lower than elsewhere in the core. Corresponding with lower lodgepole pine type pollen percentages is higher Sitka alder type pollen. Important herbs include *Artemisia*, Asteraceae, Cyperaceae, *Dryopteris* type and *Selaginella rupestris* type pollen and spores. The sediment in this zone consists of gyttja with sand mixed in the basal 3 cm of the core.

Although Diploxylon pine is the dominant pollen type in this zone, spruce/pine ratios indicate are relatively high. As there are no Sitka alder macrofossils, the high pollen percentages for this species may be due to extra-local or regional transport. If Sitka alder type pollen is considered to be of regional and extra-local origin, then spruce/pine ratios would be much lower, indicating open conditions. Relatively high levels of spruce, *Abies*, whitebark pine type, *Salix*, and Cupressaceae (possibly juniper) pollen indicate drier conditions at Stoyoma Tarn possibly analogous to a subalpine parkland. It is difficult to ascertain whether conditions were warmer at this time, but moderate needle abundance in the plant macrofossil diagram (Figure 7.13), and high levels of Sitka alder and whitebark pine type pollen suggest that conditions were drier than elsewhere in the sediment core. This zone, as well as zone STP-2, corresponds with the Early Holocene xerothermic period.

Zone STP-2 (Diploxylon pine - Spruce - Sitka alder, 60-50 cm):

In zone STP-2 a marked increase in lodgepole pine type pollen occurs. This increase corresponds with a decrease in Sitka alder type, spruce, *Abies*, and whitebark pine type pollen.

Regionally transported pollen remains important, with increased lodgepole pine type pollen compensating for decreased Sitka alder. Pollen ratios suggest that open conditions existed at Stoyoma Tarn, corresponding with

Figure 7.14

Percentage pollen diagram for Stoyoma Tarn, with 10 X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. AMS dates on conifer needles are shown on the left. Pollen concentrations are X10. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 7.14
Stoyoma Tarn, B.C.
Percent Pollen & Spores

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Figure 7.15

Percentage pollen diagram for Stoyoma Tarn (Diploxylon pine removed), with 10X exaggeration curves (stippled) to highlight abundances of infrequent pollen types. AMS dates on conifer needles are shown on the left. Pollen concentrations are X10. Zones were derived by stratigraphically constrained cluster analysis (CONISS).

Figure 7.15
Stoyoma Tarn, B.C.
Percent Pollen & Spores
Diploxylon Pine Removed from Sum

Marlow Pellatt, 1996

154b
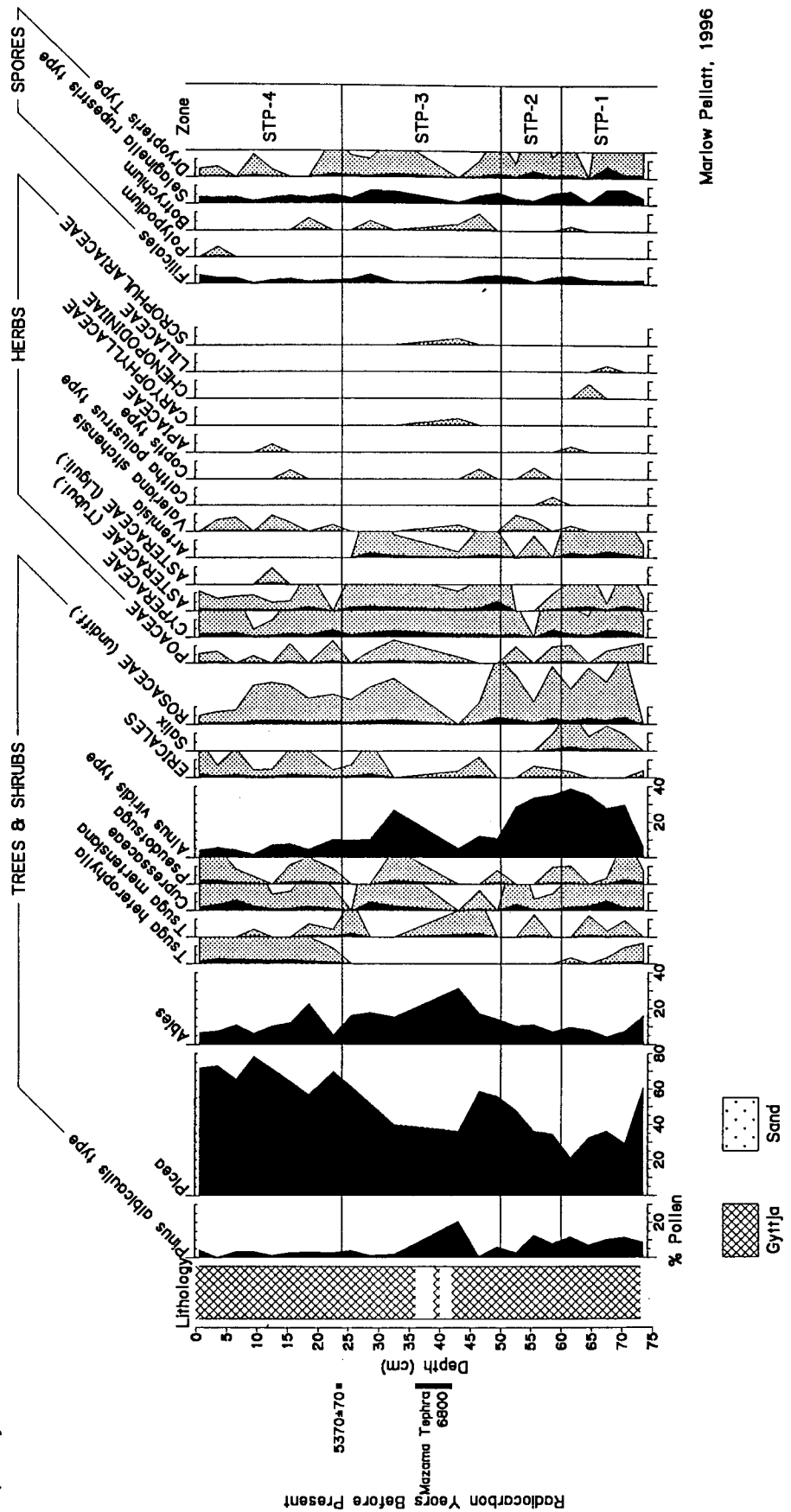
Figure 7.16:
Spruce/Diploxylon Pine Pollen Percentage Ratio, Stoyoma Tarn

moderate plant macrofossil abundance throughout most of this zone. Early Holocene xerothermic conditions appear to continue on from STP-1.
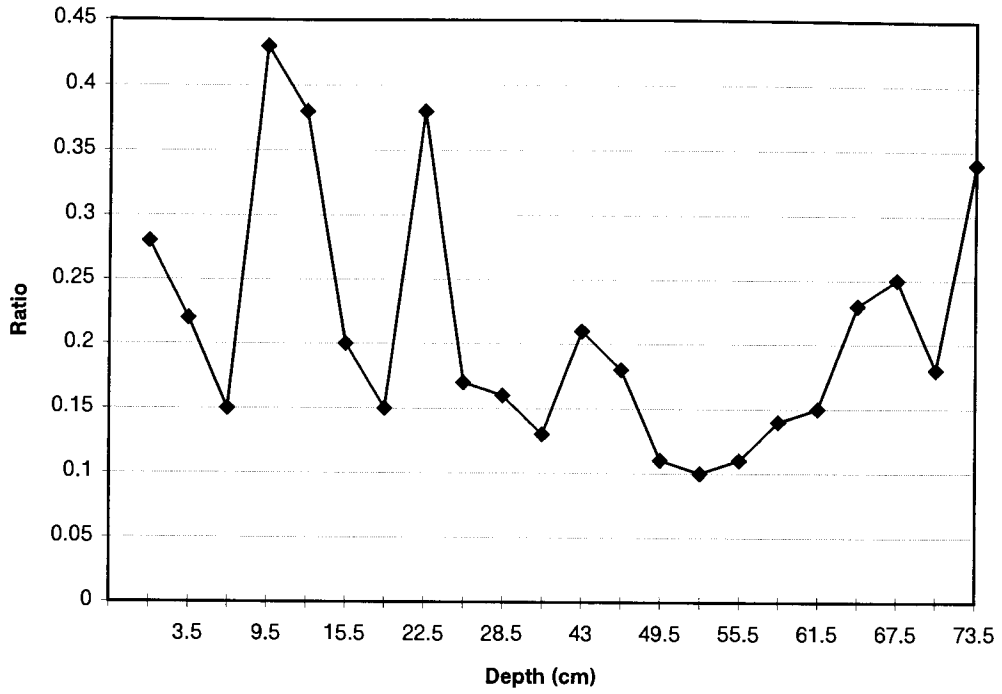
Zone STP-3 (Diploxylon pine - Spruce - *Abies*, 50-24 cm, >6800 to 5370±70 ^{14}C yr BP):

In zone STP-3 lodgepole pine type pollen remains at very high levels. Spruce pollen is relatively high, and *Abies* reaches its highest values in the core. Whitebark pine type pollen peak at 43 cm. Sitka alder peaks at 32 cm, but otherwise remains at lower values than in zones STP 1 and 2. Spruce/pine ratios increase slightly from the STP-2 indicating greater local pollen production (Figure 7.16).

High values of *Abies* and spruce suggest that local pollen production was higher than at present. Relatively high percentages of *Abies* indicates its local presence (Hebda and Allen, 1993) and increased precipitation in relation to STP-1 and 2. High needle abundance in the zone STM-3 (Figure 7.13) and relatively high spruce/pine ratios suggest that temperature was warmer than at present. This zone corresponds with the mesothermic period.

Zone STP-4 (Diploxylon pine - Spruce, 24-0 cm, 5370±70 ^{14}C yr BP to present):

In zone STP-4 lodgepole pine type pollen remains high and spruce pollen reaches attains its highest values in the core. *Valeriana sitchensis* and Ericales pollen increase. Sitka alder type pollen decreases. Regionally transported

western hemlock pollen (*Tsuga heterophylla*) has its greatest influence on this zone.

Increased spruce, Ericales, *Valeriana sitchensis*, and Rosaceae pollen may indicate cooling at Stoyoma Tarn. Subalpine conditions appear to have become well established in this zone, suggesting that modern climate conditions had developed. Western hemlock pollen is of regional origin and may indicate increased moisture in the distant CWH (Mathewes and King, 1989).

Conclusions:

Three climatic periods are documented at high elevation lakes on Mount Stoyoma. These periods are the early Holocene xerothermic period, the mesothermic period, and modern conditions. Temperature was at least 0.65°C warmer in the mid-Holocene, with vegetation changing from an ESSF forest to krummholz at Stoyoma Tarn over the last 5370±70 ^{14}C yr BP.

The oldest paleobotanical evidence from Cabin Lake indicates continental, alpine tundra conditions existed in what appears to be late-glacial time. Elaeagnaceae trichomes (possibly from *Shepherdia canadensis*), cf. *Dryas* leaf fragments, dwarf willow remains and a *Phyllodoce* needle attest to a possible Allerod-like period, prior to a Younger Dryas-like event. Preliminary results from chironomid-based temperature reconstructions of the Cabin Lake core show a typical late-glacial chironomid community through most of this zone. A small peak in temperate chironomids support the hypothesis that Allerod and Younger

Dryas-like conditions occurred at Cabin Lake (Smith *et al.*, 1996). Pollen and plant macrofossil AMS dates will test this hypothesis.

Early Holocene conditions at Mount Stoyoma may well represent a non-analogous vegetation assemblage. High values of lodgepole pine type and Sitka alder type pollen indicate open parkland conditions in the early Holocene. Conifer needles at Stoyoma Tarn in the early Holocene indicate parkland conditions with Engelmann spruce and subalpine fir. These parkland conditions indicate that treeline, and hence temperature, was higher than at present. Additional evidence of the early Holocene warmth comes from the presence of warm-adapted chironomids between 330 and 265 cm at Cabin Lake and a diverse warm-water chironomid community between 66 and 44 cm at 3M Pond (Pellatt *et al.*, 1995; Smith *et al.*, 1996).

During the early Holocene, spruce and *Abies* pollen increase at all three study sites, and Engelmann spruce and subalpine fir needles increase in abundance at 3M Pond and Stoyoma Tarn. This paleobotanical evidence implies that ESSF forests developed as precipitation increased toward the end of the early Holocene xerothermic period (Mathewes and King, 1989; Hebda, 1995).

Hebda (1995) suggests that a climatic period termed the "mesothermic" be incorporated into the climatic periods of British Columbia. He suggests that this period may be an extension of the Hypsithermal, extending the timing of Holocene maximum warmth to around 4000 ^{14}C yr BP. This would incorporate the timing of the Hypsithermal in most of Canada. Paleobotanical evidence on

Mount Stoyoma supports this hypothesis. Warm, moist conditions, relative to present climate, led to the development of ESSF forest at all three study sites. This is especially apparent at 3M Pond and Stoyoma Tarn, where treeline appears to have been higher than present during the mesothermic period. Increased spruce/pine ratios at all study sites indicate that closed forest conditions existed. There appears to be variability in the timing of the termination of the mesothermic period at the study sites, ending first at Stoyoma Tarn, the highest (2050 m asl) and last at Cabin Lake, the lowest (1850 m asl). Mesothermic conditions are evident at 3M Pond between *ca* 6800 and 3500 ^{14}C yr BP as indicated by a gradual decrease in the diversity of warm-water chironomid taxa and a gradual replacement by cool water taxa between 44 and 28 cm (Pellatt *et al.*, 1995; Smith *et al.*, 1996).

These changes can also be attributed to regional cooling that culminated with neoglacial cooling and glacial readvancement after 5000 ^{14}C yr BP (Porter and Denton, 1967). Increased *Abies* and Cupressaceae pollen, *Isoetes* spores, and conifer needles at the study site indicate increased precipitation. Temperatures appear to decrease in the mid to late-Holocene, as indicated by decreasing needle abundance at Stoyoma Tarn by 5370±70 ^{14}C yr BP and 3M Pond by 3530±60 ^{14}C yr BP. It appears that the impact of mid to late-Holocene cooling differed temporally and spatially on Mount Stoyoma. Stoyoma Tarn (2050m asl) began to cool, and modern krummholz vegetation began to develop by 5370±70 ^{14}C yr BP. ESSF forest conditions transformed to parkland and then

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to krummholz as late-Holocene cooling progressed. ESSF forests persisted at 3M Pond (1950m asl), as indicated by needle abundance and pollen zonation, until around 3530±60 ^{14}C yr BP. After this time modern ESSF parkland developed. Modern pollen assemblages appear at Cabin Lake (1850m asl) after deposition of the Bridge River tephra (2410 ^{14}C yr BP). Dry adiabatic lapse rate indicates that temperature was at least 0.65°C warmer prior to 5370±70 ^{14}C yr BP. This data is consistent with inferred temperature changes at Castle Peak, B.C. in the Coast Mountains (Clague and Mathewes, 1989). It also supports the existence of the mesothermic period in the southern interior of B.C. (Hebda, 1995). Vegetation and climate change of the same magnitude occurred at 3M Pond around 3530±60 ^{14}C yr BP, showing a time lag of *ca* 2000 ^{14}C years between the timing of ESSF forest decline at Stoyoma Tarn and 3M Pond. This climatic deterioration at 3M Pond occurs at the same time as glacial readvances in the Coast and Rocky Mountains and can be inferred from the absence of warm-water chironomid taxa and complete replacement by cold-water taxa between 27 cm and the surface sediments of 3M Pond (Pellatt *et al.*, 1995; Smith *et al.*, 1996).

CHAPTER 8: REGIONAL SYNTHESIS OF TREELINE PALEOECOLOGY FOR THE CENTRAL COAST AND SOUTHWESTERN BRITISH COLUMBIA.

Vegetation and climate change since the glacial maximum are well-documented for south-coastal British Columbia, north-coastal Washington State, and the Queen Charlotte Islands. The Coast Mountains of British Columbia support many glaciers at present and were the "heartland" of glaciers comprising the Cordilleran Ice Sheet (Booth, 1987; Ryder and Clague, 1989; Mann and Hamilton, 1995). After the Vashon Stade maximum, glacial retreat was rapid after 14,000 ^{14}C yr BP, and besides some brief cooling events such as the Sumas readvance (11,400 ^{14}C yr BP) and a Younger Dryas like event 10,800 ^{14}C yr BP, the Cordilleran Ice Sheet had retreated from southwestern B.C. by 10,000 ^{14}C yr BP (Booth, 1987, Ryder and Clague, 1989; Mathewes, 1993; Mathewes *et al.,* 1993; Mann and Hamilton, 1995; Peteet, 1995)

Rapid warming had occurred by 10,000 ^{14}C yr BP in southwestern B.C. and the Queen Charlotte Islands (Mathewes, 1973; Warner, 1984; Mathewes, 1985; Pellatt and Mathewes, 1994; Hebda, 1995). Milankovitch orbital theory suggests that maximum Holocene warmth in the Northern Hemisphere should occur around the Pleistocene/Holocene boundary (Clague and Mathewes, 1989). Evidence of an early Holocene xerothermic period at

sites in southwestern B.C., Vancouver Island and the Queen Charlotte Islands supports this assumption (Mathewes, 1973; Mathewes and Heusser, 1981; Warner, 1984; Walker, 1988; Mathewes, 1985; Clague and Mathewes, 1989; Clague *et al.*, 1992, Pellatt and Mathewes, 1994; Hebda, 1995). Climatic deterioration and treeline shifts were underway by 5000 ^{14}C yr BP with widespread glacial advances and alpine development occurring by 3500 ^{14}C yr BP (Ryder and Thomson, 1986; Luckman *et al.*, 1993; Pellatt and Mathewes, 1994).

Climatic change in the southern interior of British Columbia is similar to that of southwestern and coastal B.C., except that early Holocene warmth appears to have extended to around 4500 ^{14}C yr BP (Hebda, 1995). Paleobotanical evidence indicates that the mesothermic period had warmer than present temperatures, with precipitation equivalent to modern conditions, but more than in the early Holocene xerothermic (Figure 7.1). The transition from xerothermic to mesothermic conditions in the southern interior parallels the transition from xerothermic to early Neoglacial conditions in southwestern and coastal B.C. (Figure 7.1).

Summaries of vegetation and climate change at the lakes examined in this study are shown in Figure 8.1. Wherever possible, paleo-vegetation assemblages are assigned to an equivalent biogeoclimatic zone and climate period. The early Holocene xerothermic period occurs at subalpine sites on the Queen Charlotte Islands between *ca* 9800 and 5400 ^{14}C yr BP, sustaining

FIGURE 8.1:
HOLOCENE CLIMATE AND VEGETATION AT
STUDY SITES ON THE QUEEN CHARLOTTE
ISLANDS AND MOUNT STOYOMA
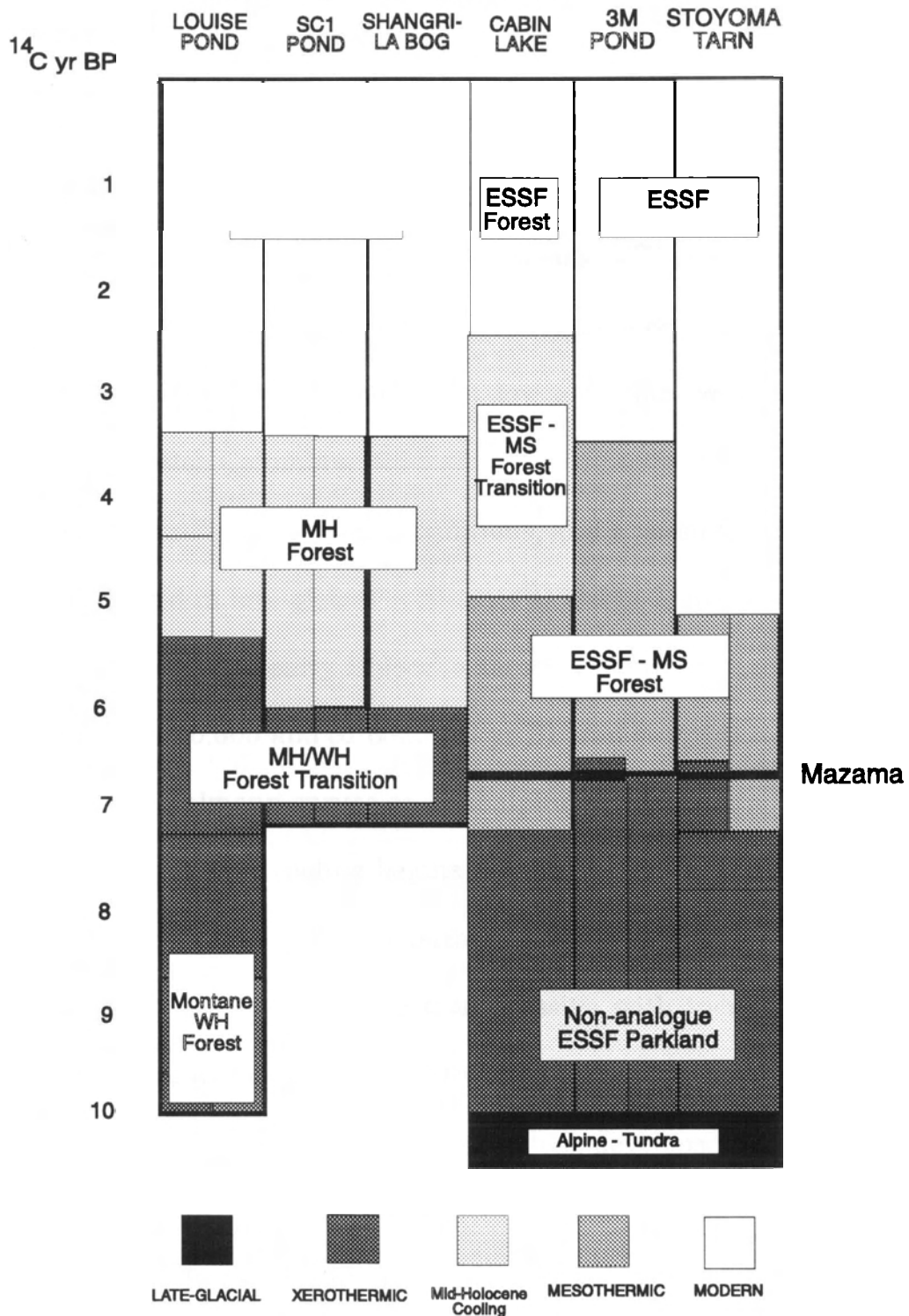
a montane CWH forest. Decreasing temperature and increased moisture begin between 6000 and 5400 ^{14}C yr BP with cool/moist, modern conditions establishing around 3500 ^{14}C yr BP. Montane CWH forests go through a transition from CWH to MH zone between *ca* 7200 to 6000 ^{14}C yr BP. As temperature decreases, MH forest conditions become established between *ca* 6000 and 5400 ^{14}C yr BP eventually reaching modern MH parkland conditions by *ca* 3500 ^{14}C yr BP. The paleobotanical evidence from the subalpine study sites on the Queen Charlotte Islands document the same regional climate events that occurred at low elevation sites in coastal and southwestern British Columbia.

As shown in Figure 8.1, cool conditions, and a possible Younger Dryas-like event occurred in late-glacial sediments at Cabin Lake and 3M Pond (*ca* >10,000 ^{14}C yr BP). The early Holocene xerothermic period occurs on Mount Stoyoma between 10,000 and *ca* 6800 ^{14}C yr BP and sustains a non-analogue parkland with Engelmann spruce and subalpine fir. Increasing precipitation in conjunction with slow cooling begins after *ca* 6800 ^{14}C yr BP, in which a closed, ESSF forest developed. The termination of mesothermic conditions on Mount Stoyoma appear to be time transgressive with increased elevation. Decreasing temperatures are felt at Stoyoma Tarn at *ca* 5400 ^{14}C yr BP, at which time ESSF parkland and then krummholz develops. The change from ESSF forest to ESSF parkland occurs at 3M Pond around 3500 ^{14}C yr BP, and modern ESSF forest conditions appear to develop at Cabin Lake by 2410

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[14]C yr BP. The timing of the climatic periods and zonal vegetation changes on Mount Stoyoma are very similar to those observed by Mathewes and King (1989) in the IDF zone of the Fraser Canyon, and by Hebda (1995) in the southern interior (Figure 7.1). Climatic periods at Mount Stoyoma consist of the early Holocene xerothermic period, the mesothermic period and Neoglaciation.

The main discrepancy between climate change on the Queen Charlotte Islands and Mount Stoyoma (southern interior) is the severity of post-xerothermic climatic deterioration. It appears that although precipitation increased after the early Holocene xerothermic period at both localities, significant cooling began on the Queen Charlotte Islands sooner than in the interior (Warner, 1984; Pellatt and Mathewes, 1994; Hebda, 1995; Mann and Hamilton, 1995). Stoyoma Tarn, does display increased needle abundance and pollen concentrations after Mazama time, but begins to develop modern conditions around 5400 ^{14}C yr BP. Adiabatic lapse rates indicate that a temperature decrease of at least 0.65°C occurred at Stoyoma Tarn between 5400 ^{14}C yr BP and present. It may well be that minimum temperatures for forest development were reached by this time.

Overall it appears that the early Holocene xerothermic period and the late-Holocene cooling that resulted in the Tiedemann, Peyto, and Robson glacial advances were regional in nature, effecting high elevation forests both on the Queen Charlotte Islands and the southern interior of B.C. In contrast,

the mesothermic period is expressed in the southern interior of B.C. but not on the Queen Charlottes. The maximum cold, wet conditions responsible for glacial advancement throughout the Canadian Cordillera after 3500 ^{14}C yr BP appear to be regional in nature, and are reflected in the development of modern forest subalpine/alpine conditions in the southern interior and the Queen Charlotte Islands (Figure 8.1).

A better understanding of how pollen assemblages represent the Mountain Hemlock, Coastal Western Hemlock, and Engelmann Spruce-Subalpine Fir biogeoclimatic zones was obtained through the study of the pollen in lake surface sediments and multivariate analysis (Chapter 6). Although bias from the upward transport of lowland pollen occurs at subalpine and alpine study sites, the pollen assemblages are unique for each biogeoclimatic zone, as well as for the areas of geographic origin within the Mountain Hemlock zone. Multivariate analysis of the pollen data assigned the pollen assemblages to their specific biogeoclimatic zones. CCA indicated that annual precipitation and growing degree days are the main environmental variables in separating the groups into their biogeoclimatic zones. These data will help in future interpretation of fossil pollen assemblages and the environmental variables that affect them.

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