POST-GLACIAL CLIMATE AND VEGETATION CHANGE IN THE SEYMOUR-BELIZE INLET COMPLEX, CENTRAL COASTAL BRITISH COLUMBIA, CANADA

by

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GENERAL ABSTRACT

Pollen and spores preserved in the sediments of Two Frog Lake and Tiny Lake in the Seymour-Belize Inlet Complex of the central mainland British Columbia coast, document post-glacial changes in regional climate and vegetation and a high-resolution (26-year) palynological record from Frederick Sound reveals that the late Holocene climate of the Seymour-Belize Inlet Complex has been variable. Following ice-retreat prior to 11,040 ± 50 (13,030 cal. yr BP), an open *Pinus contorta* woodland developed under a cool and dry early Late-Glacial climate. At ca. 11,800 yr BP (ca. 14,500 cal. yr BP) climate amelioration resulted in the replacement of these woodlands by a mixed conifer forest. Early Holocene warming ca. 10,500 yr BP (ca. 12,000 cal. yr BP) resulted in a successional mosaic of *Tsuga heterophylla*, *Picea*, *Pseudotsuga menziesii* and *Alnus* at Two Frog Lake but *P. menziesii* was absent at Tiny Lake where conditions may have been too wet or because this taxon never reached this more northerly site. At ca. 8000 yr BP (ca. 9200 cal. yr BP) a transition to moister and cooler conditions facilitated the expansion of *T. plicata* at both lake sites. The timing of this event pre-dates the onset of a near modern climate in south coastal British Columbia by at least 1000 years, but is consistent with the onset of moistening at more northerly sites. The Frederick Sound record documents a decline in *T. plicata* between ca. 2600-1900 yr BP (ca. 2700-1900 cal. yr BP) in response to the development of a cooler and drier climate that punctuated the otherwise wet conditions of the late Holocene in this region, although the role of biotic factors, such as a pathogen attack and/or selective human felling, cannot be ruled out. Comparison with a proxy reconstruction of the relative position and/or intensity of the Aleutian Low pressure system suggests that millennial scale atmospheric variability has affected the climate and vegetation of the Seymour-Belize Inlet Complex throughout most of the late Holocene.

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ORIGINAL CONTRIBUTIONS

The following outlines the contributions of other researchers to this thesis. Helen M. Roe and R. Timothy Patterson collected the sub-bottom profiles of Two Frog Lake and Tiny Lake as well as the sediment cores from Two Frog Lake and Frederick Sound (VEC02A04) in April, 2002. Jennifer M. Galloway, Eduard G. Reinhardt and Andrew Wigston collected the Tiny Lake sediment core in October 2002. Helen M. Roe and Christine T. Doherty retrieved the measurements for the elevations of Two Frog Lake and Tiny Lake, respectively. Audrey Dallimore, Cynthia Wright and Richard Thomson collected the oceanographic data from the Seymour-Belize Inlet Complex in 2000, 2002 and 2003. Logistical support for field work was provided by the crew of the CCG *Vector*. Christine T. Doherty logged the Two Frog Lake and Tiny Lake sediment cores, provided the photograph of the Tiny Lake sedimentological contact, sub-sampled the Tiny Lake sediment core and preformed percent loss-on-ignition analysis on both of the cores. Audrey Dallimore provided the negative X-ray of the sedimentological contact of the Two Frog Lake core, logged the VEC02A04 sediment core and sub-sampled both cores for pollen analysis. Eduard G. Reinhardt performed the grain size analysis on the VEC02A04 sediment core. Radiocarbon analysis was preformed at IsoTrace Laboratories, Toronto, NERC Radiocarbon Laboratories and the SUERC AMS ^{14}C Facility in the United Kingdom and Beta-Analytic Inc., Florida. Jennifer M. Galloway chemically prepared the sediment samples for palynolgical analysis, identified and enumerated all pollen and spores and compiled the data. Jennifer M. Galloway interpreted the results of each sediment core and wrote this dissertation in its entirety.

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CHAPTER ONE

GENERAL INTRODUCTION

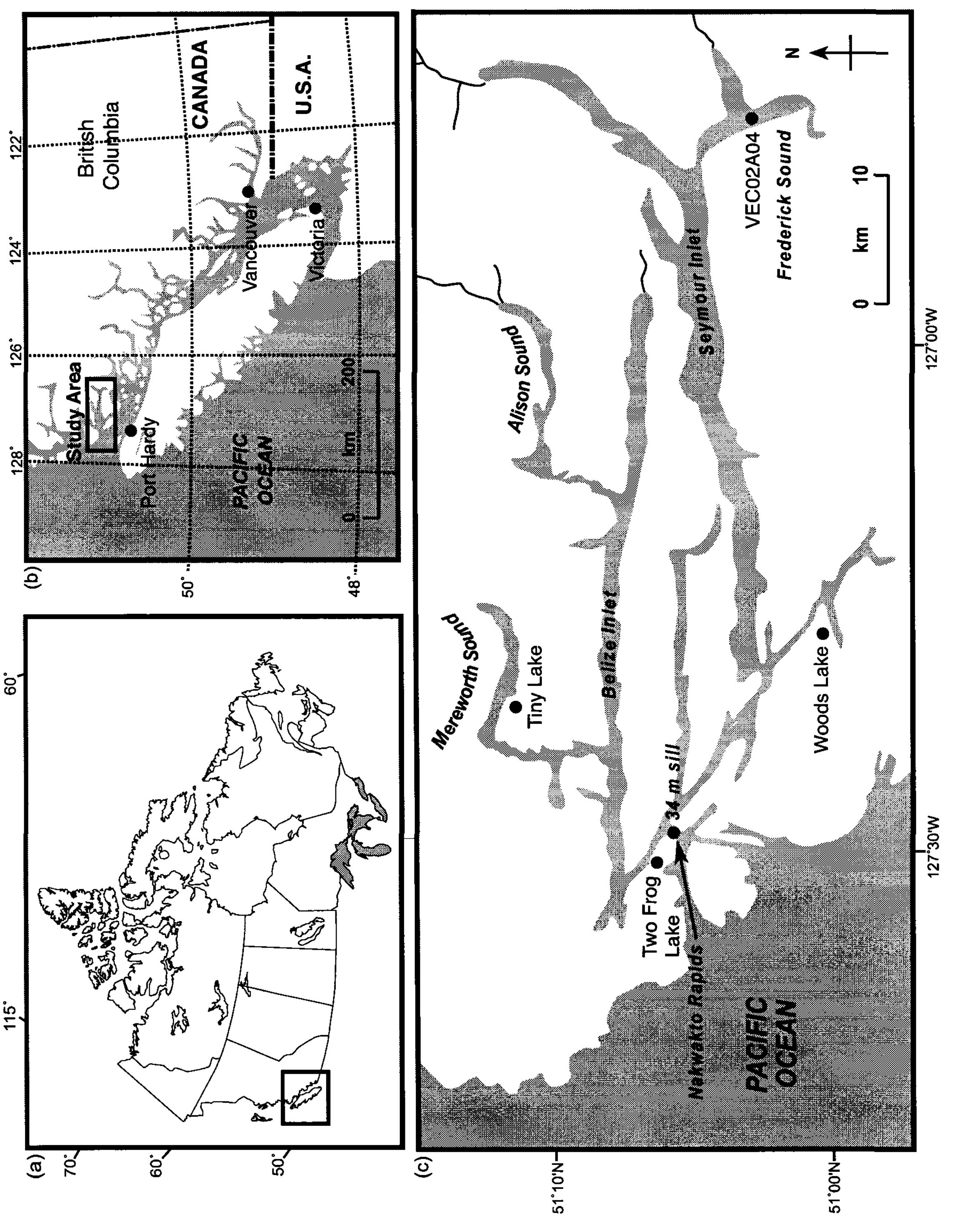
This dissertation has been divided into three main chapters, each of which investigates the pollen and spore assemblages of a different sediment core from the Seymour-Belize Inlet Complex (SBIC; Fig. 1.1). Carleton University permits the presentation of theses in a "paper format" whereby each chapter is designed as a stand-alone paper in order to expedite publication. Due to the chosen format there are some redundancies in this thesis, especially in the opening sections of each chapter. Additionally, because each sediment core was collected from within the Coastal Western Hemlock biogeoclimatic zone (CWHZ) in similar sub-zones and variants (the Southern Very Wet Hypermaritime Coastal Western Hemlock Variant and the Submontane Wet Maritime Coastal Western Hemlock Variant; Green and Klinka 1994), the vegetation and climate histories of each core are similar and this was expected.

Pollen and spores, the male reproductive cells of seed bearing plants and cryptogams, respectively, are well preserved in lacustrine and marine sediments and have been the focus of several detailed late Quaternary paleoecological and paleoclimate investigations in coastal British Columbia (e.g., Mathewes 1973; Hebda 1983; Heusser 1983; Pellatt and Mathewes 1997; Pellatt et al. 2001; Brown and Hebda 2002; Lacourse 2005). This research indicates that the climate of the Holocene Epoch (ca. 10,000 ^{14}C yr BP-present) has been highly variable and has provided information that has been used to place current and forecasted climate change into a geological perspective (Hebda 1998). This approach can provide insights on how the coastal temperate rainforests of the Pacific Northwest may respond to future climate variability, which is important since these forests are significant both ecologically and economically (Franklin and Dyrness 1973). Due to the interaction of the ocean-atmosphere system in Pacific Canada and the topographical complexity of British Columbia, vegetation and climate histories can differ greatly even between nearby sites, necessitating the need for further research in coastal regions of the province (Brown and Hebda 2002a). Previous work in coastal British Columbia has intensively focused on the Fraser Lowlands (e.g., Mathewes 1973; Wainman and Mathewes 1984), Vancouver Island (e.g., Hebda 1983; Hebda 1997; Brown and Hebda 2002a,b; 2003; Lacourse 2005), the Queen Charlotte Islands (e.g., Pellatt and Mathewes 1997) and only a few studies have looked at the paleoclimate and paleoecology of the northern mainland coast (Turunen and Turunen 2003), leaving the central mainland coast of British Columbia neglected as a study region.

This study uses pollen and spores preserved in the sediments of two small coastal isolation basins, Two Frog Lake and Tiny Lake, located in the SBIC on the central mainland coast of British Columbia, to reconstruct a post-glacial vegetation and climate history for this remote region. Additionally, a sediment core retrieved from Frederick Sound, an anoxic marine fjord located at the southeastern extent of the SBIC, is analyzed using high-resolution (26-year) palynology in order to investigate late Holocene climatic variability. It is hypothesized that the vegetation and climate histories of Two Frog Lake and Tiny Lake will be broadly similar to each other and to previously reconstructed histories from other sites in coastal British Columbia because climate is the proximate control on regional vegetation dynamics (Lacourse 2005; Bartlein et al. 2006). However, because of the importance of local influences on vegetation, it is also expected that the forest histories of these two sites may differ in detail from each other and from previous work. A major short-coming of previous work has been that only one lake site was routinely investigated for each region. This can lead to faulty assumptions since the significance of local factors is not accounted for. By studying two closely spaced sites, a more robust reconstruction of regional climate may be synthesized and the influence of local factors can be identified. The analysis of the Frederick Sound core was comparable in resolution to only a few previous pollen studies in coastal British Columbia, and to none in the CWHZ (Pellatt et al. 2001). This level of detail is not routine in palynological studies because it is incredibly time consuming. This approach is also not widely applied since it has traditionally been thought that high-resolution pollen work was unimportant since vegetation is believed to respond to climate change on a centennial time scale (Lacourse 2005). However, this assumption may not detect subtle changes in vegetation that could potentially hold significance and it is hypothesized that a high-resolution approach will document late Holocene climate and vegetation changes not detectable in previous work.

In order to place the climate and vegetation histories of Two Frog Lake, Tiny Lake and Frederick Sound into a regional perspective, results are compared to other more intensively investigated regions of the province such as the Fraser Lowlands (Mathewes 1973) and Vancouver Island (Hebda 1983; Heusser 1983; Brown and Hebda 2002; Lacourse 2005) as well as to proxy reconstructions of Holocene air-mass circulation (COHMAP Members 1988; Anderson et al. 2005).

Figure 1.1: (a) Map of North America showing the location of the study site (after Vazquez-Riveiros et al. in preparation), (b) map of southwestern British Columbia showing the location of the Seymour-Belize Inlet Complex and (c) map of the Seymour-Belize Inlet complex showing the location of Two Frog Lake, Tiny Lake, Woods Lake (mentioned in text) and Frederick Sound.


(a)
115°
60°
70°
60°
50°
(b)
122°
124°
126°
128°
50°
48°
British Columbia
CANADA
U.S.A.
Vancouver
Victoria
Study Area
Port Hardy
PACIFIC OCEAN
0 km 200
(c)
Alison Sound
Seymour Inlet
VEC02A04
Frederick Sound
0 km 10
N
Mereworth Sound
Tiny Lake
Belize Inlet
Woods Lake
34 m sill
Two Frog Lake
Nakwakto Rapids
PACIFIC OCEAN
127°00'W
127°30'W
51°10'N
51°00'N

CHAPTER TWO

A PALYNOLOGICAL RECORD OF POST-GLACIAL CLIMATE AND FOREST DYNAMICS FROM TWO FROG LAKE, CENTRAL MAINLAND COAST OF BRITISH COLUMBIA

Abstract

Pollen and spores preserved in the radiocarbon dated sediments of Two Frog Lake, a small coastal basin located on the central mainland coast of British Columbia, indicate that this region has undergone considerable climate and vegetation change since deglaciation. Prior to 11,040 ± 50 (13,030 cal. yr BP), and possibly as early as ca. 12,000 yr BP, ca. 14,900 cal. yr BP), an open *Pinus contorta* woodland dominated the landscape under a cool and dry Late-Glacial climate. This woodland was replaced at ca. 11,800 yr BP (ca. 14,500 cal. yr BP) by a conifer forest dominated by *Picea* when the climate became moister. Peaks of *Alnus* and *Tsuga mertensiana* at 11,040 ± 50 (13,030 cal. yr BP) may be a response to a Younger Dryas-like climate reversal. Early Holocene warming and drying began at ca. 10,200 yr BP (ca. 12,300 cal. yr BP) and resulted in a forest mosaic of *T. heterophylla*, *Picea*, *Pseudotsuga menziesii* and *Alnus* that persisted until ca. 8000 yr BP (ca. 9200 cal. yr BP). At this time the climate became moister and possibly cooler, which facilitated the development of a late-successional *Thuja plicata* forest. The initial expansion of *T. plicata* and climate moistening at ca. 8000 yr BP (ca. 9200 cal. yr BP) at Two Frog Lake predates the transition to moister conditions in southern British Columbia by at least 1000 years and in Washington by at least 500 years. By ca. 6300 yr BP (ca. 7200 cal. yr BP) *T. plicata* had nearly replaced *T. heterophylla* at Two Frog Lake. The late Holocene forests at Two Frog Lake are exceptional in their near mono-specific composition and longevity in coastal British Columbia, which indicates that late Holocene forest histories can be highly site specific in the Pacific Northwest.

2.1 Introduction

Previous research on the post-glacial climate and vegetation history of coastal British Columbia has focused on southern Vancouver Island (Brown and Hebda 2002a, 2003) and the Fraser lowlands on the southern mainland coast (Mathewes 1973; Mathewes and Rouse 1975; Mathewes and Heusser 1981) and studies in central and northern British Columbia have been restricted to northern Vancouver Island (Hebda 1983; Lacourse 2005), the Queen Charlotte Islands (Pellatt and Mathewes 1994; Pellatt and Mathewes 1997) and to only a few sites on the northern mainland coast of the province (Turunen and Turunen 2003). This research indicates that considerable climate change has occurred since deglaciation.

The Cordilleran ice sheet had retreated from the southern regions of mainland British Columbia by ca. 13,000 ^{14}C yr BP (yr BP; Barrie and Conway 1999) and parts of Vancouver Island even earlier (Hebda 1983). Relative sea level fell rapidly after this time due to isostatic rebound (Clague et al. 1982) and *Pinus contorta* Dougl. ex Loud. rapidly colonized the landscape, migrating from the south or from scattered refugia, to become widely distributed across British Columbia under a cool and dry climate (Heusser 1956; Mathewes 1973; Hebda 1983; Brown and Hebda 2002a; Lacourse 2005). *Picea* A. Dietr., *Tsuga heterophylla* (Raf.) Sarg., and *Abies* Mill. replaced *P. contorta* when humidity increased and fertile soils were established in the still cool late Late-Glacial (Mathewes 1973; Mathewes and Rouse 1975; Brown and Hebda 2002a). A rapid shift to a warm and dry climate occurred at ca. 10,000 yr BP and *Pseudotsuga menziesii* (Mirb.) Franco and *Alnus* B. Ehrh. replaced or joined *Picea, T. heterophylla* and *Abies* in coastal forests depending on the severity of drought, location of precipitation gradients and fire occurrence (Mathewes 1973; Mathewes and Heusser 1981; Hebda 1983; Cwynar 1987; Brown and Hebda 2002a; Brown and Hebda 2003; Lacourse 2005). At ca. 7000 yr BP a shift to moister conditions facilitated the development of closed, late-successional forests of *T. heterophylla* (Hebda 1983; Lacourse 2005), but the timing and the pace of this climate transition were variable in coastal British Columbia (Walker and Pellatt 2003). The late Holocene (5000 yr BP-present) has been described as a period of relative climatic stability with moderate temperatures and high moisture but the development of an even cooler and moister climate, correlative with Neoglacial advances in the Canadian Rocky Mountains and the Coast Mountains, allowed for peak expansion of *Thuja plicata* Donn ex D. Don in coastal forests at ca. 3500 yr BP (Hebda and Mathewes 1984; Ryder and Thompson 1986; Luckman et al. 1993; Clague and Mathewes 1996; Lacourse 2005).

Although a regional framework of post-glacial climate and environmental change has been formulated from this previous work, the inconsistencies in the timing and response of vegetation to post-glacial climate change in coastal British Columbia highlight a need for further research (Walker and Pellatt 2003). In particular, the timing of the termination of the early Holocene xerothermic interval, which appears to have been time transgressive in coastal British Columbia (Walker and Pellatt 2003). This study uses pollen and spores preserved in the sediments of Two Frog Lake (TFL) in the Seymour-Belize Inlet Complex (SBIC; Fig. 2.1), central coastal mainland of British Columbia, to reconstruct the climate and vegetation history of this region. This site was selected as part of a larger, multi-disciplinary project studying late Quaternary climate, vegetation and relative sea-level change in the SBIC region by investigating a series of low-lying coastal isolation basins with a range of sill heights. This study succeeds previous palynological work at Woods Lake in the SBIC (Stolze 2004; Fig. 2.1). Due to accessibility through the dense coastal vegetation, lakes close to the shore of the SBIC were considered preferential to more inland locations. This research will offer new insights into the vegetation and climate dynamics of this understudied region and will provide some spatial coherency between sites previously investigated in Alaska, southern British Columbia and the northwestern United States (Heusser 1977; Barnosky 1981; Heusser 1983; Peteet 1991; McLachlan and Brubaker 1995; Hansen and Engstrom 1996; Grigg and Whitlock 1998). Results are compared to previous palynological records from Bear Cove Bog (Hebda 1983) and Misty Lake (Lacourse 2005) on northern Vancouver Island, which are the closest sites previously studied to the SBIC, and from Woods Lake (Stolze 2004).

2.2 Study area

The SBIC is situated on the central coastal mainland of British Columbia, approximately 40 km NE of Port Hardy, Vancouver Island (Fig. 2.1). This complex consists of a series of glacially scoured marine fjords, which vary in depth from 50 m to greater than 600 m. The topography of the region is characterized by very steep-sided forested slopes that average 100-300 m elevation, but reach up to 900 m in places. The underlying bedrock of the region consists of Mesozoic aged granitic and volcanic rocks. Soils tend to be poorly developed and acidic, derived from the underlying granites and influenced by input from the coniferous canopy (Pojar and MacKinnon 1994).

The SBIC lies within the Coastal Western Hemlock biogeoclimatic zone (CWHZ), which spans the mid- to low elevation coast of British Columbia and extends north into Alaska and south into Washington and Oregon. The climate of this zone is characterized by cool summers and mild winters and is influenced during the winter by the Aleutian Low pressure system and in the summer by the North Pacific High pressure system (Trenberth and Hurrell 1994). Biogeoclimatic zones of British Columbia are sub-divided into sub-zones and variants (Green and Klinka 1994). The SBIC lies within the Southern Very Wet Hypermaritime Coastal Western Hemlock Variant (CWHvh1) of the CWHZ (Meidinger and Pojar 1991; Green and Klinka 1994; Pojar and Mackimmon 1994). This variant is geographically restricted to the coastal fringes of northern Vancouver Island and the low-lying outer coastline of the mainland from Wells Passage north to Smith Inlet (Green and Klinka 1994). The climate of the CWHvh1 is cool, with a mean annual temperature of 9.1 °C (range 5.4-9.4 °C), and wet, with a mean annual precipitation of 3120 mm (range 2009-3943 mm; unknown observation period; Green and Klinka 1994).

The vegetation of the CWHvh1 is dominated by *Tsuga heterophylla* (Raf.) Sarg. (western hemlock; botanical names for arboreal taxa follow Duhamel 1963) with *Thuja plicata* Donn ex D. Don (western redcedar; Meidinger and Pojar 1991; Allen et al. 1999). *Picea sitchensis* (Bong.) Carr. (Sitka spruce) occupies well-drained sites, such as marine terraces and floodplains, and *Abies amabilis* (Dougl.) Forb. (amabilis fir) grows in moist sites on deep, well-drained soils (Meidinger and Pojar 1991; Pojar and MacKinnon 1994). In the sub-alpine regions of the study area, *Tsuga mertensiana* (Bong.) Carr. (mountain hemlock) grows in wet sites with deep organic soils and *Chamaecyparis nootkatensis* (D. Don) Spach (yellow cedar) is common in moist to wet rocky or boggy sites (Pojar and MacKinnon 1994). *Pinus contorta* Dougl. ex Loud. (lodgepole pine) is common in low elevation dry or boggy sites while *Pinus monticola* Dougl. (western white pine) grows in dry to moist open sites (Pojar and MacKinnon 1994). *Taxus brevifolia* Nutt. (western yew) is a common mid-canopy or understory component in mature *T. heterophylla-T. plicata* forests (Bolsinger and Jamarillo 1990; Pojar and MacKinnon 1994). *Acer glabrum* Torr. var. *douglasii* (Hook.) Dipp. (Douglas maple) grows as a shrub or small tree on open, dry ridges as well as in moist, well-drained sites (Pojar and MacKinnon 1994). Both *Alnus rubra* Bong. (red alder) and shrubby *A. sinuata* (Regel) Rydb. (Stika alder), also known as *A. crispa* (Ait.) Pursh ssp. *sinuata* (Regel) Hulten. (green alder), are common in the CWHvh1 where they occupy open disturbed sites, such as avalanche tracks, and riparian habitats (Pojar and MacKinnon 1994). *Alnus sinuata* may also grow in open dry sites (Hebda 1997). *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir) is notably absent from the CHWvh1 (Allen et al. 1999). An understory of ferns, bryophytes and shrubs, namely *Gaultheria shallon* Pursh. (salal), form an important ecological component of the forests of the CWHvh1 (Meidinger and Pojar 1991; Klinka et al. 1996; Newmaster et al. 2003).

Two Frog Lake (informal name) is located 3.59 m above sea level and lies 30 m inland from Seymour inlet (51°06.361'N, 127°32.082'E; Fig. 2.1). TFL is a small (8 ha), single basin, un-stratified, freshwater lake with a maximum depth of 4.7 m and a maximum length of 400 m (Fig. 2.2).

2.3 Methods

2.3.1 Core collection

A sub-bottom profile of TFL was collected using a shallow tow seismic profiler (Knudson 320 B/P) with a dual frequency transponder (50 kHz and 200 kHz; Fig. 2.2). The profile indicated that the sediments of TFL likely contained two lithological units: a basal minerogenic clay unit and an overlying organic sediment unit (Fig. 2.2). A 525 cm sediment core was collected from the deepest point of the lake in April 2002 using a Livingstone corer with an internal barrel diameter of 5 cm deployed from a wooden raft anchored over the core site (Fig. 2.2; Wright et al. 1984). The core was transported in the original aluminum core barrels to the Pacific Geoscience Centre, Sidney, British Columbia. The sediment core was extruded using a wooden dowel and cut in half lengthwise. One half was preserved in plastic food wrap and aluminum foil as an archive. The other half of the sediment core was logged, X-rayed (Fig. 2.2) and sub-sampled for palynological and loss-on-ignition analysis (LOI; Boyle 2004). Sub-samples were stored in plastic food bags. The archival core remained at the Pacific Geoscience Centre while the sediment samples were shipped to Carleton University, Ottawa where they were stored in a cold room at 4°C before further study. Bulk sediment samples were selected from the sub-sampled material for radiocarbon dating.

2.3.2 Chronology and sedimentology

Of the 525 cm sediment core, a basal unit (5.25-4.91 m) consists of glaciomarine clay that is sharply overlain by a lacustrine dy unit that is relatively homogeneous throughout the remainder of the core (Fig. 2.2; Doherty 2005). Dy can be defined as a sticky, gel-like mud that is composed entirely of humic colloids (Faegri and Iversen 1989). The humic material is produced by reactions in terrestrial soil and is brought to the basin by ground or surface water where it precipitates as dy. Dy is common in oligotrophic lakes in British Columbia and can be identified by the colour of the supernatant liquid following chemical treatment with potassium hydroxide (Faegri and Iversen 1989; Hebda 1997). The humic material which constitutes dy dissolves completely in potassium hydroxide, leaving a dark brown extract (Faegri and Iversen 1989). In contrast, gyttja is a common sediment type in highly productive lakes and is composed predominantly of microscopic fragments of the biota of the basin, which are not soluble in potassium hydroxide and will produce a yellowish or greenish supernatant liquid (Faegri and Iversen 1989). The sediments of TFL likely contain some gyttja but will be considered dy based upon reaction with potassium hydroxide (Faegri and Iversen 1989).

Since no macrofossils were retrieved from the TFL core, five bulk sediment samples were submitted for AMS radiocarbon dating to IsoTrace Laboratories, University of Toronto, Toronto, and to Beta-Analytic, Florida (Table 2.1). The ratios of $^{13}C/^{12}C$ (‰) were not reported from IsoTrace Laboratories. Conventional radiocarbon ages were calibrated to calendar years before present using the INTCAL98 database and C14CAL98 computer program (Stuiver et al. 1998).

To avoid problems associated with the ocean reservoir effect on radiocarbon, a basal date for the TFL sediment core was obtained from ~50 cm above the contact between clay and overlying dy. However, Late-Glacial reservoir effects has been observed in limnic sediments from southwestern British Columbia and Washington, possibly due to the incorporation of old carbon from carbonate reserves, graphite containing minerals and/or marine sediments contained in exposed glacial tills

(Sutherland 1980; Hutchinson et al. 2004). The Late-Glacial limnic reservoir effect declines approximately 1000 years after lake inception as forest and soil development reduce the exposure and weathering rates of tills (Engstrom et al. 2000; Hutchinson et al. 2004). No Late-Glacial lacustrine sediment reservoir correction was applied to the basal date of 11,040 ± 50 yr BP (13,030 cal. yr BP) at TFL and it is possible that this age may be as much as ~630 years too old (cf. Hutchinson et al. 2004).

An age-depth model based on conventional radiocarbon ages and calibrated radiocarbon ages was generated using linear interpolation and model dates were estimated to the nearest 50 years (Fig. 2.3; Bennett 1994; Telford et al. 2004). The lines were not forced through 0 yr BP at 0 cm, but they intercepted near 0 yr BP in both cases. Linear interpolation was selected to generate the age-depth model because this method accounts for potential changes in sedimentation rate better than linear regression (Telford et al. 2004). It is known that this model cannot be correct, since changes in sedimentation rate are unlikely to be coincidental with the horizons chosen for radiocarbon dating, but linear interpolation as an age-depth modeling method is rarely "unacceptably wrong" (Bennett and Fuller 2002). One radiocarbon date (7270 ± 70 yr BP; 8603 cal. yr BP) was considered erroneous since it was out of stratigraphic order and was excluded from the age-depth model. Since younger material is rarely injected into older sediments on the scale of a meter, this date may have measured to young either by analytical error or contamination following collection (e.g., injection of young carbon by fungal growth). Age ranges for pollen zones were estimated from this model based on calculated sedimentation rates for each section of the model (Fig. 2.3). No tephras were observed in the TFL sediment core, which was expected since neither the Mazama nor

Bridge River ash plumes are known to have reached this coastal region of the province (Clague et al. 1995). Trends in organic content of the TFL sediment core were determined by percent loss-on-ignition (Fig. 2.4; Boyle 2004).

2.3.3 Pollen and spores

Sixty-five sediment sub-samples (50 mm^3 wet sediment) were prepared for pollen analysis following a modified version of the methods described by Faegri and Iversen (1989). Preparation involved hot treatment of sediment with 10% hydrochloric acid to dissolve carbonates, 10% potassium hydroxide to dissolve humic material, and acetolysis to digest cellulose. Samples were not sieved and hydrofluoric acid treatment was not applied. Sieving is time consuming and particle size was uniform and working with hydrofluoric acid is dangerous and siliceous material did not interfere with routine pollen counting. Pollen slurries were stained with aqueous safranin to aid identification, dehydrated with alcohol (ethanol and tertiary butanol) and suspended in silicone oil with a viscosity near 2000 cSt (Faegri and Iversen 1989). A known quantity of *Lycopodium clavatum* spores was added to each sample prior to processing in order to calculate pollen concentrations (one tablet per sample, batch No. 938 934, n=10,679 +/- 953 std. error spores/tablet; Benninghoff 1962; Stockmarr 1971).

All prepared samples were analyzed for pollen and spores, which were enumerated at 400x magnification with an Olympus BX51 transmitted light microscope at intervals of 8 cm or 12 cm from 0-515 cm of the sediment core. Total pollen counts per slide, excluding exotic *Lycopodium* spores, range from a minimum of 292 to a maximum of 1663, except in the basal clay sediments (499–515 cm), where pollen concentrations were very low and less than 100 grains were counted. Pollen identification was aided by use of the keys of McAndrews et al. (1988), Faegri and Iversen (1989) and Kapp et al. (2000) as well as a set of reference slides (Aerobiology Institution and Research Pollen Reference Slide Set, Brookline, MA). Pollen and spores were identified to the lowest possible taxonomic unit (Appendix 2.1). *Pinus* pollen was identified as diploxylon-type or haploxylon-type (Faegri and Iversen 1989). *Juniperus* L. (juniper), *Chamaecyparis nootkatensis* (D. Don) Spach (yellow cedar), *Taxus brevifolia* Nutt. (western yew) and *T. plicata* pollen are grouped together as Cupressaceae since they are difficult to differentiate by light microscopy. *Larix* Mill. (larch) and *P. menziesii* pollen are morphologically similar but since *Larix* is uncommon in coastal British Columbia (Duhamel 1963) and is often poorly preserved in sediment records, this pollen is attributed to *P. menziesii*. In cases where uncertainty exists, taxa are suffixed with "-type" (Janssen 1967). Pteropsida (monolete) spores include all monolete members of the class Pteridophyta except Polypodiaceae, the only family where the perine is commonly preserved. In this case, spores could be identified as *Polypodium vulgare* L.-type (Common polypody; Moore et al. 1991). Small (5-8 µm), inaperturate spores with thin exines devoid of visible sculpturing elements were identified as *Polytrichum*-type spores (Anderson et al. 1990; Kapp et al. 2000). Stanley (1966), and later Heusser (1983), used variable safranin stain acceptance to identify pre-Pleistocene re-worked pollen from Holocene marine sediments. A similar phenomenon was observed for exotic and fossil *L. clavatum* spores in the TFL sediment core, permitting differentiation of fossil *L. clavatum* from exotic *L. clavatum* (Faegri and Iversen 1989).

The main pollen sum (PS) includes total terrestrial pollen and spores plus all non-obligate aquatic taxa. Spores of ferns and mosses were included in the PS since these plants are important components of Pacific Northwest communities (Meidinger and Pojar 1991; Newmaster et al. 2003). Aquatic taxa (*Nuphar* Sm. pond lily, *Typha* L. cat-tail) frequencies were expressed as a percentage of the total PS. Calculation of pollen concentration followed Stockmarr (1971).

2.3.4 Cluster Analysis

Pollen percentage and concentration data were graphed using Tilia version 2.0 (Fig. 2.4; Grimm 1993). The pollen data for both datasets were reduced into pollen zones for interpretative and comparative value (Birks 1972). The pollen zone may be defined as a body of sediment with a homogeneous fossil pollen and spore assemblage that is distinct from stratigraphically adjacent sediment bodies, or by the increase, decrease and/or occurrence of a maximum or minimum of a pollen or spore type (Birks 1972; Faegri and Iversen 1989). In either case, the definition of a pollen zone is based solely on fossil content, with no consideration of lithology, inferred environment, chronology and/or regional correlation (Gordon and Birks 1972). Pollen zones were defined using cluster analysis, which was performed using the computer program CONISS (Grimm 1987). The data was stratigraphically constrained and the analysis uses the incremental sum of squares method, which aims to minimize within zone variance (Grimm 1987). By stratigraphically constraining the cluster analysis, only vertically adjacent samples were agglomerated in a hierarchical fashion (Grimm 1987; Bennett 1996). With this constraint, revertances in the dataset will be recognized as separate zones. A square root transformation was performed on all data, which "up-weights" rare pollen types by converting positively of negatively skewed distributions to a normal curve (Grimm 1987; Bennett 1996). A dendrogram was produced that visually illustrates the hierarchical relationship of clusters defined by the analysis (Grimm 1987). With CONISS, no assumptions can be made of the statistical significance of clusters since the pollen zones are defined by cutting the dendrogram at a height determined by the researcher (Grimm 1987; Bennett 1996). This practice is subjective but permits the freedom to define pollen zones based on ecological, rather than numerical, "significance" (Faegri and Iversen 1989). In most cases, stratigraphically constrained cluster analysis will produce similar results to visual inspection, but using a program such as CONISS provides a means for reproducibility (Gordon and Birks 1972; Grimm 1987).

Cluster analysis was performed on both the pollen percentage and pollen concentration datasets but since pollen concentration can be affected by sediment flux, pollen zones were delineated using the analysis on percentage data only (Faegri and Iversen 1989).

2.4 Results

Twenty-eight taxa were identified from 57 sediment horizons throughout the Two Frog Lake sediment core (Appendix 2.2). The frequency pollen and spore percentage diagram is divided into five zones (TFP-A, TFP-B, TFP-C, TFP-D and TFP-E; Fig. 2.4). Cluster analysis of the pollen concentration data yielded the same zone boundary for pollen percentage zone TFP-A, did not recognize pollen percentage zone TFP-C and subdivided pollen percentage zone TFP-E into two sub-zones at 0.80 m.

2.4.1 Zone TFP-A (515-499 cm; ca. 12,000-11,800 yr BP; ca. 14,900-14,500 cal. yr BP)

The sediments of TFP-A consist of light gray homogenous silts and that contain fine sand and have low percent LOI (1-10%; Fig. 2.4). This zone is characterized by high relative abundances of *Pinus* diploxylon-type pollen, which reach 93% at 515 cm. Cupressaceae pollen fluctuates between <10% and 23%. *Picea*, *T. heterophylla* and *Betula* pollen are present in this zone at frequencies less than 5%. Non-arboreal pollen (NAP) reaches 8 % at 499 cm and consists of pollen and spores of Rosaceae, Ericaceae, *P. vulgare*-type and Pteropsida (monolete). Pollen and spore concentrations increase from 107 grains/mm^3 to 895 grains/mm^3 at 507 cm, and *Pinus* diploxylon-type pollen represents 833 grains of this peak.

2.4.2 Zone TFP-B (499-412 cm; ca. 11,800-10,200 yr BP; ca. 14,500-12,300 cal. yr BP)

A diffuse transition (1mm-1cm; Schnurrenberger et al. 2003) from the basal silt unit to overlying medium brown, but grading upward to black, massive dy sediments with higher percent LOI (35-60%) occurs at 493 cm. Radiocarbon dates of 11,040 ± 50 yr BP (13,030 cal. yr BP; Table 2.1) and 7270 ± 70 yr BP (8603 cal. yr BP) were obtained from 445 cm and 489 cm, respectively. Pollen zone TFP-B is characterized by a decline in *Pinus* diploxylon-type pollen from 39% to 19% and an increase in *Picea* (33%) and *Alnus* (40%) pollen. *Tsuga heterophylla* pollen peaks to 52%, declines to 0% and then increases to 30% by the end of the zone. *Tsuga mertensiana* pollen reaches a core maximum of 2% at 442 cm and Cupressaceae pollen peaks to 60% at 436 cm but otherwise is present ~2-3%. *Abies* pollen is present ~0-2% and *Acer* pollen occurs ~1% in this zone. NAP reaches 18% at 4.58 m and consists mainly of *Polytrichum*-type (14%), Pteropsida (monolete) (~2%), *P. vulgare*-type (3%) and *Equisetum* spores (3%). Pollen and spore concentrations peak at 11,847 grains/mm^3 at 483 cm and arboreal pollen (AP) constitutes 10,658 grains/mm^3. The pattern of *T. heterophylla* and *Pinus* diploxylon-type pollen concentrations follow trends of the total pollen and spore concentration and comprise 6194 and 2534 grains/mm^3 of the peak, respectively.

2.4.3 Zone TFP-C (412-304 cm; ca. 10,200-8000 yr BP; ca. 12,300-9200 cal. yr BP)

The sediments of TFP-C consist of homogeneous black dy with relatively high percent LOI values (40-50%). A radiocarbon date of 8620 ± 40 yr BP (9595 cal. yr BP) was obtained from 310 cm. This zone is characterized by a continued decline in *Pinus* diploxylon-type pollen and by an increase in *Tsuga heterophylla* (40%), *Alnus* (47%), *Picea* (20%) and *P. menziesii* pollen (2%). NAP, excluding *Polytrichum*-type spores, reaches a maximum of 7% at 320 cm. NAP taxa registering greater than 1% in this zone include *Polypodium vulgare*-type (3%), *Equisetum* (3%) and Pteropsida (monolete) spores (6%). *Polytrichum*-type spores peak at 312 cm to 55%. Pollen and spore concentrations reach 6387 grains/mm^3 at 396 cm and AP comprises 5925 grains/mm^3 of this peak, largely represented by *Alnus* (3314 grains/mm^3) and *Picea* pollen (854 grains/mm^3).

2.4.4 Zone TFP-D (304-252 cm; ca. 8000-6300 yr BP; ca. 9200-6300 cal. yr BP)

The sediments of TFP-D consist of homogenous black dy. Percent LOI values peak to 75% mid-zone and then decrease to 65%. A radiocarbon date of 7550 ± 70 yr BP (8303 cal. yr BP) was obtained from 293 cm. This zone is characterized by a decline in *Pinus* and *Picea* pollen to 1%, a decline in *Alnus* pollen to 10% and an increase in Cupressaceae pollen to 60%. *Tsuga heterophylla* pollen reaches 34% mid-zone but declines to 23% by the end of the zone. NAP increases from 3% to13% throughout the zone. Pteropsida (monolete) spores reach 4%, *P. vulgare*-type spores reach 1% and *Equisetum* spores reach 8% in this zone. Pollen and spore concentrations increase to 5767 grains/mm^3 at 272 cm and AP pollen comprises 4336 grains/mm^3 of this total. Cupressaceae pollen concentrations increase from 132 to 3289 grains/mm^3 while *T. heterophylla* pollen concentrations occur between 540 grains/mm^3 and 1247 grains/mm^3.

2.4.5 Zone TFP-E (252-0 cm; ca. 6300 yr BP-present; ca. 6300 cal. yr BP-present)

The sediments of this zone consist of homogenous black dy and have percent LOI values that fluctuate between ~50-40%. A radiocarbon date of 2210 ± 40 yr BP (2225 cal. yr BP) was obtained from 81 cm. This zone is dominated by Cupressaceae pollen, which peaks to 89% at 120 cm and maintains a proportion greater than 70% throughout the zone. *Pinus* haploxylon-type pollen increases to 10% near the end of the zone. *Tsuga heterophylla* pollen is present at frequencies of 5-10% and *Alnus* pollen is present ~3%. NAP peaks to 7% near the end of the zone and includes *Ophioglossum, L. clavatum* and *Huperzia* spores. Pollen and spore concentrations increase to 11,832 grains/mm^3 but decline to 2563 grains/mm^3 by the end of the zone. AP concentrations follow the trend in total pollen and spore concentrations and are largely represented by Cupressaceae pollen, which fluctuates between 10,067 grains/mm^3 and 1964 grains/mm^3.

2.5 Discussion

2.5.1 The early Late-Glacial (TFP-A; 515-499 cm; ca. 12,000-11,800 yr BP; ca. 14,900-14,500 cal. yr BP)

Pinus diploxylon-type pollen is dominant in this basal zone, but over-representation of *Pinus* is common because this taxon is a copious pollen producer and its pollen is adapted to wind transport (Hebda and Allen 1993; Brown and Hebda 2002a). Marine inundation of TFL at this time, indicated by clay sediments with low organic content and salt-water diatoms in this section of the core (Doherty 2005), may have contributed to the large abundance of *Pinus* in this zone because this taxon is well adapted for aquatic transport and marine sediments can selectively corrode other pollen types (Havinga 1964; Heusser and Balsam 1977; Havinga 1984; Doherty 2005). However, modern pollen spectra studies from the CWHZ forests of the Bella Coola Valley, north of the SBIC, show that *Pinus* pollen percentages over 80% are indicative of local occurrence (Hebda and Allen 1993). Macrofossil studies place *P. contorta* on the mainland coast and adjacent islands of British Columbia during the early Late-Glacial so this species is a likely source for the *Pinus* diploxylon-type pollen at TFL (Mathewes 1973; Hebda 1983; Wainman and Mathewes 1987; Brown and Hebda 2002a; Brown and Hebda 2003; Lacourse et al. 2003). The age-depth model estimates an age for this section of ca. 12,000-11,800 yr BP (ca. 14,900-14,500 cal. yr BP). This age conforms well to previously reported dates of the *Pinus* biogeochron in coastal British Columbia (Hebda 1983; Hebda and Whitlock 1997; Brown and Hebda 200a2; Lacourse 2005).

Pinus is capable of forming long-lived stands in cool and dry habitats or on edaphically poor sites where other taxa are limited (Lotan and Critchfield 1990). However, *Pinus* may have occurred locally at TFL for only 200 years and was replaced by *Picea*, a more shade-tolerant taxon at ca. 11,800 yr BP (ca. 14,500 cal. yr BP). It is therefore possible that its occurrence at TFL during the early Late-Glacial represents an early successional stage in the development of *Picea* forests (Pfister and Daubenmire 1975). However, in modern descriptions of successional pathways in moist environments, *Alnus* is often the pioneering taxon that *Picea* succeeds, not *Pinus* (Fonda 1974; Chapin et al. 1994; Fastie 1995). Additionally, *Picea* is also capable of colonizing poor quality substrates (Hebda 1983; Harris 1990). This suggests that a cool and dry climate may have permitted *Pinus* to occur at TFL by excluding *Picea* and other early successional mesic taxa such as *Alnus* (Mathewes 1973; Brown and Hebda 2002a; Lacourse 2005). The presence of *Pinus* on unglaciated sites on the Queen Charlotte Islands also suggests that its dominance at this time was not merely successional or edaphic, supporting the interpretation that a cool and dry climate permitted the persistence of *Pinus* at TFL at this time (Heusser 1956; Mathewes 1973; Warner et al. 1982; Hebda 1983; Brown and Hebda 2002a; Lacourse 2005).

The early Late-Glacial geographical distribution of *P. contorta* was ubiquitous in the western North America, which suggests that a cool and dry climate was regional in extent (Mathewes 1973; Heusser 1977; Hebda 1983; Peteet 1991; McLachlan and Brubaker 1995; Hansen and Engstrom 1996; Grigg and Whitlock 1998; Fedje and

Josenhans 2000; Brown and Hebda 2002a; Lacourse 2005). A Late-Glacial cool and dry climate in the Pacific Northwest may be attributed to the Laurentide Ice Sheet, which cooled adjacent air and generated a strong glacial anti-cyclone that delivered cool and dry easterly winds to western North America (Whitlock 1992; Barltein et al. 1998; COHMAP Members 1988; Brown and Hebda 2002a).

Low pollen concentrations in TFP-A and the shade intolerant ecology of *Pinus* suggest that the *P. contorta* woodlands at TFL were open (Hebda 1983; Brown and Hebda 2002a; Lacourse 2005). The Cupressaceae pollen in TFP-A may be from shrubby *J. communis* L. (common juniper), which could have grown in a dry open *Pinus* woodland (Pojar and MacKinnon 1994). *Polytrichum*-type spores are present in this section and may be attributable to *P. juniperinum* and/or *P. piliferum*, which are common mosses on disturbed, dry mineral substrates and may have occupied exposed rocky outcrops or poorly developed soils at TFL (Pojar and MacKinnon 1994). The presence of *Nuphar* pollen in this section suggests that shallow and fresh water habitats occurred in the vicinity of TFL (Janssen 1967), which may have been marginally occupied by *Betula papyrifera* Marsh var. *commutata* (Regel) Fern. (western white birch), a potential source for the *Betula* pollen at this time (Pojar and MacKinnon 1994).

2.5.2 The late Late-Glacial (TFP-B; 499-412 cm; ca. 11,800-10,200 yr BP; ca. 14,500-12,300 cal. yr BP)

A decline in *P. contorta* pollen at this time is accompanied first by an increase in *Alnus* pollen and then by a rise in *Picea* pollen. The rise of *Picea* during the late Late-Glacial at TFL may be due to edaphic development, succession, a migration lag or climate change. Since *Picea* is capable of growth on nutrient poor substrates soil development probably did not facilitate the expansion of this taxon in the early Late-Glacial (Krajina 1969; Mathewes 1973; Fonda 1974; Hebda 1983; Packee 1990; Chapin et al. 1994). A migration lag was also probably not a factor in the rise of *Picea* at TFL since the presence of glacial refugia on Beringia suggests that invasion of this site by *Picea* would have been relatively rapid following deglaciation, had climate conditions been favorable (Fastie 1995; Brubaker et al. 2005). Soil moisture is restrictive for modern *P. sitchensis* communities, as well as for *Alnus* in the Pacific Northwest (Fonda 1974; Cwynar 1987; Lacourse 2005). This suggests that a moister climate at TFL, relative to early Late-Glacial conditions, permitted replacement of the open *Pinus* woodlands that previously dominated the landscape first by *Alnus* and then by a mid-successional *Picea-Alnus* community (Fonda 1974; Wainman and Mathewes 1987; Brown and Hebda 2002a; Brown and Hebda 2003; Lacourse 2005). The occurrence of this community elsewhere in coastal British Columbia at this time suggests that a regional cool and moist climate controlled vegetation change in coastal British Columbia during the late Late-Glacial (Mathewes 1973; Brown and Hebda 2002a; Brown and Hebda 2003; Lacourse 2005). High pollen concentrations relative to TFP-A in this section suggest that the forest canopy was denser than during the early Late-Glacial, but the low shade-tolerance of *Picea* and *Alnus* indicates that the landscape was still open (Taylor 1990). Relatively higher pollen concentrations may therefore be an artifact of slower sedimentation. A cooler and moister climate may be attributed to the waning Laurentide Ice Sheet. As the continental ice sheet and associated glacial anti-cyclone receded, westerly, moisture-laden winds were delivered to this region (Whitlock 1992; Whitlock and Bartlein 1997; Bartlein et al. 1998; COHMAP Members 1988).

The initial increase of *Alnus* pollen at TFL began at ca. 11,800 yr BP (ca. 14,500 cal. yr BP) and this taxon persisted in relatively high abundances throughout TFP-B. Both *A. rubra* and *A. sinuata* occur at present in the SBIC, and both species are probably represented in this section since they coexisted on northern Vancouver Island at this time (Lacourse 2005). The *Alnus* rise at TFL is broadly concurrent with other records from coastal British Columbia (Cwynar 1987; Pellatt et al. 2002; Lacourse 2005) and although its initial rise was probably a response to the development of a moist climate, its persistence at TFL suggests that a change in regional climate or a shift in the disturbance regime occurred at this time, possibly associated with a cooling (Mayle et al. 1993; Cwynar 1987; Brown and Hebda 2002a). In modern successional sequences in Washington and Alaska, *Alnus* is completely replaced by *P. sitchensis* within 400 years and by a *P. sitchensis-T. heterophylla* community within 750 years (Fonda 1974; Fastie 1995). Cooling at TFL may have caused solifluction disturbance that permitted *Alnus* to persist within the *Picea* forest and to remain as an important component of the vegetation at TFL for an unusually long period of time (Fonda 1974; Fastie 1995; Brown and Hebda 2002a). *Tsuga mertensiana* pollen briefly increases in abundance at 11,040 ± 50 yr BP (13,030 cal. yr BP) to 2%, indicating that this tree migrated down-slope to occur locally at TFL, possibly in response to climate cooling since this species is an accurate indicator of cool and moist climates today (Hebda 1983; Dunwiddie 1987; Mathewes 1993; Lacourse 2005). A subsequent peak of Cupressaceae at TFL may be due to a similar down-slope migration of *C. nootkatensis* in response to a cooler climate.

Younger Dryas cooling has previously been documented in sedimentological, palynological and foraminiferal records from the Pacific Northwest region (Engstrom et al. 1990; Mathewes 1993; Mathewes et al. 1993; Patterson et al. 1995; Hansen and Engstrom 1996; Brown and Hebda 2002a; Friele and Clague 2002; Pellatt et al. 2002; Lacourse 2005) and may have even been a global event (Peteet 1995). The timing of vegetation changes at TFL may be associated with this climate reversal, which occurred between 11,000-10,000 yr BP in coastal British Columbia (Mathewes et al. 1993), or with a similar climate reversal during the late Late-Glacial (Pellatt et al. 2002).

The rise of *T. heterophylla* following the *Picea-Alnus* phase is consistent with descriptions of modern successional sequences in moist environments where due to the superior shade tolerance and longevity of *T. heterophylla*, this species replaces *Picea* in 160 years (Fastie 1995). *Tsuga heterophylla* requires nutrient rich soils and the *Alnus* phase likely facilitated the expansion of this taxon at TFL by increasing soil nitrogen availability in the immature landscape (Crocker and Major 1955; Fonda 1974; Chapin et al. 1994; Fastie 1995; Lacourse 2005).

2.5.3 The early Holocene (TFP-C; 412-304 cm; ca. 10,200-8000 yr BP; ca. 12,300-9200 cal. yr BP)

The presence of *Pseudotsuga menziesii* pollen at frequencies of ca. 2% in this zone indicates that this taxon was probably a component of early Holocene forests at TFL since it is commonly under-represented in modern pollen spectra (Tsukada 1982; Hebda 1983). Its occurrence indicates that open and dry habitats were available at TFL at this time, suggesting that the early Holocene climate at this site was drier and probably warmer than during the late Late-Glacial (Lotan and Critchfield 1990; Brown and Hebda 2002a; Lacourse 2005). However, the relatively high occurrence of shade-tolerant *T. heterophylla* pollen and the persistence of *Abies* pollen in this section show that moist sites within a closed forest canopy also persisted at TFL throughout this interval (Krajina 1969; Packee 1990).

A warmer and drier climate may have affected the fire disturbance regime at TFL by increasing the abundance of dry fuel (Brown and Hebda 2002b). Increased fire occurrence may have played a role in shaping the vegetation at TFL by maintaining open sites for shade-intolerant *Alnus*, which reaches peak proportions at this time that are sustained throughout the zone, and *P. menziesii*, a fire-adapted taxon (Fonda 1974; Ishii and Ford 2002). However, *Pteridium* spores, a common indicator of fire, are low in this section and *P. menziesii* is capable of persistence within *T. heterophylla* canopies without intense disturbance (Krajina 1969; Franklin and Dyrness 1973; Klinka et al. 1996; Ishii and Ford 2002). Nonetheless, *Alnus* would have begun to be replaced by more shade tolerant taxa within 100 years in the absence of disturbance (Fonda 1974; Harrington 1990). *Polytrichum juniperinum* is a common moss on recently burned sites in the CHWZ today and may be a possible source for the relatively high *Polytrichum*-type spores in this section (Pojar and MacKinnon 1994). A community of *Picea, P. menziesii, T. heterophylla* and *Alnus* also occurred on southern Vancouver Island, the Fraser Lowlands and in Washington where a warm and dry climate and increased fire occurrence were influential in maintaining a successional mosaic (Cwynar 1987; Brown and Hebda 2002a; Hallett et al. 2003).

Warmer and drier conditions at this time can be attributed to an orbitally controlled solar insolation maximum (Berger and Loutre 1991). Due to the tilt of the earth's axis was greater in the early Holocene (ca. 10,000-8000 yr BP) than today and this caused summers to be warmer than present, winters to be cooler than present and indirectly resulted in a more persistent North Pacific High pressure system that delivered warm and dry easterly winds to coastal British Columbia (Heusser et al. 1985; Mathewes and Heusser 1981; Hebda 1983; COHMAP Members 1988; Berger and Loutre 1991; Whitlock 1992).

2.5.4 The early Holocene to mid-Holocene (TFP-D 304-252 cm; ca. 8000-6300 yr BP; ca. 9200-6300 cal. yr BP)

Cupressaceae pollen began to increase ca. 8000 yr BP (ca. 9200 cal. yr BP) at TFL while pollen types that were previously abundant (e.g., *Picea*, *Abies*, *Alnus*) declined. The Cupressaceous pollen in this section is likely attributable to *T. plicata* since macrofossil evidence places this species in the Puget Lowlands as early as 7460 yr BP (QL-1435; Barnosky 1981) and at a stratigraphically correlative level in nearby Woods Lake (Fig. 2.1; Stolze 2004). If the climate was very cool, this pollen type may be attributable to *C. nootkantensis*. *Juniperus* is an unlikely possibility since this shrub commonly colonizes dry and open habitats.

Thuja plicata is capable of survival and growth on a wide range of soil conditions but cold winter temperatures and low moisture are restrictive (Minore 1990). It is possible that a higher water table at TFL, caused by a rise in relative sea level, permitted the expansion of *T. plicata* at this time but reconstructions of relative sea level for this region suggest shore lines were lower than at present until sometime in the late Holocene (Clague et al. 1982). Additionally, a very large change in sea-level would be required in order to raise the water table on the steep sides slopes surrounding TFL, and there is no evidence for such a change. The expansion of *T. plicata* may then be indicative of the onset of Holocene climate moistening, and possibly cooling, at ca. 8000 yr BP (ca. 9200 cal. yr BP) at TFL. A moister and cooler climate would have permitted the expansion of this species and reduced fire occurrence, thus permitting complete or near complete canopy closure and the exclusion of shade intolerant taxa such as *Picea* and *Alnus* from forests at TFL (Fonda 1974; Harrington 1990; Masters 1990; Minore 1990). Based on modern descriptions of succession and the composition of forests of the CWHZ, *T. heterophylla* would be expected to increase in abundance at TFL to become the climax taxon following the *Picea* phase, but even though *T. heterophylla* was present in the late-successional forests at TFL at this time, it was replaced by *T. plicata* throughout the span of this zone (Fonda 1974; Chapin et al. 1994; Fastie 1995; Klinka et al. 1996). This may be the result of an abrupt onset of wet and cool conditions favorable to *T. plicata* at TFL or may be associated with site specific factors such as topography, localized edaphic conditions and/or disturbance, since *T. plicata* can outgrow *T. heterophylla* on very nutrient rich soils (Krajina 1969; Franklin and Dyrness 1973; Minore 1990), and *T. plicata* seedlings are adapted to growth in full sunlight, conferring advantage following low intensity disturbances (Krajina 1969; Franklin and Dyrness 1973; Minore 1990; Weber et al. 2003).

The possible onset of cooler and moister conditions occurred earlier at TFL than at most other sites in coastal British Columbia and Washington where a cool and moist climate did not develop until after ca. 6600 yr BP and ca. 7500 yr BP, respectively (Fig. 2.5; Mathewes 1973; Barnosky 1981; Leopold et al. 1982; Hebda and Mathewes 1984; Wainman and Mathewes 1987; McLachlan and Brubaker 1994; Hebda 1995; Pellatt et al. 2001; Brown and Hebda 2002a). The timing of this climate transition at TFL is comparable to more northerly sites such as Diana Lake Bog (54°09'N, 130°15'W) on the northern mainland coast of British Columbia and southwestern Alaska where Holocene climate moistening and cooling began at ca. 8000 yr BP (Turunen and Turunen 2003; Axford and Kaufman 2004). The Aleutian Low pressure system intensified at this time in response to an orbitally induced decrease in solar insolation (COHMAP Members 1988). A more intense Aleutian Low would have generated more intense mid-latitude cyclones and steered them into northern British Columbia and Alaska, which would have resulted in high precipitation in the SBIC region relative to southern British Columbia at this time (Klein 1949; Heusser et al. 1985; Mantua and Hare 2002; Dean and Kemp 2004).

2.5.5 The mid to late Holocene (TFP-E; 252-0 cm; ca. 6300 yr BP–present; ca. 7200 cal. yr BP-present)

Cupressaceae (likely *T. plicata*) was the dominant taxon at TFL in the mid to late Holocene, with relative pollen abundances of > 70% sustained throughout this interval while *T. heterophylla* was relatively unimportant with pollen frequencies between below 10%. The predominance of Cupressaceae pollen in this zone could be an artifact of over-representation but modern pollen spectra studies in the CWHZ forests of the Bella Coola

Valley, north of the SBIC, found that Cupressaceae pollen in lake sediments is generally representative of forest cover (Hebda and Allen 1993).

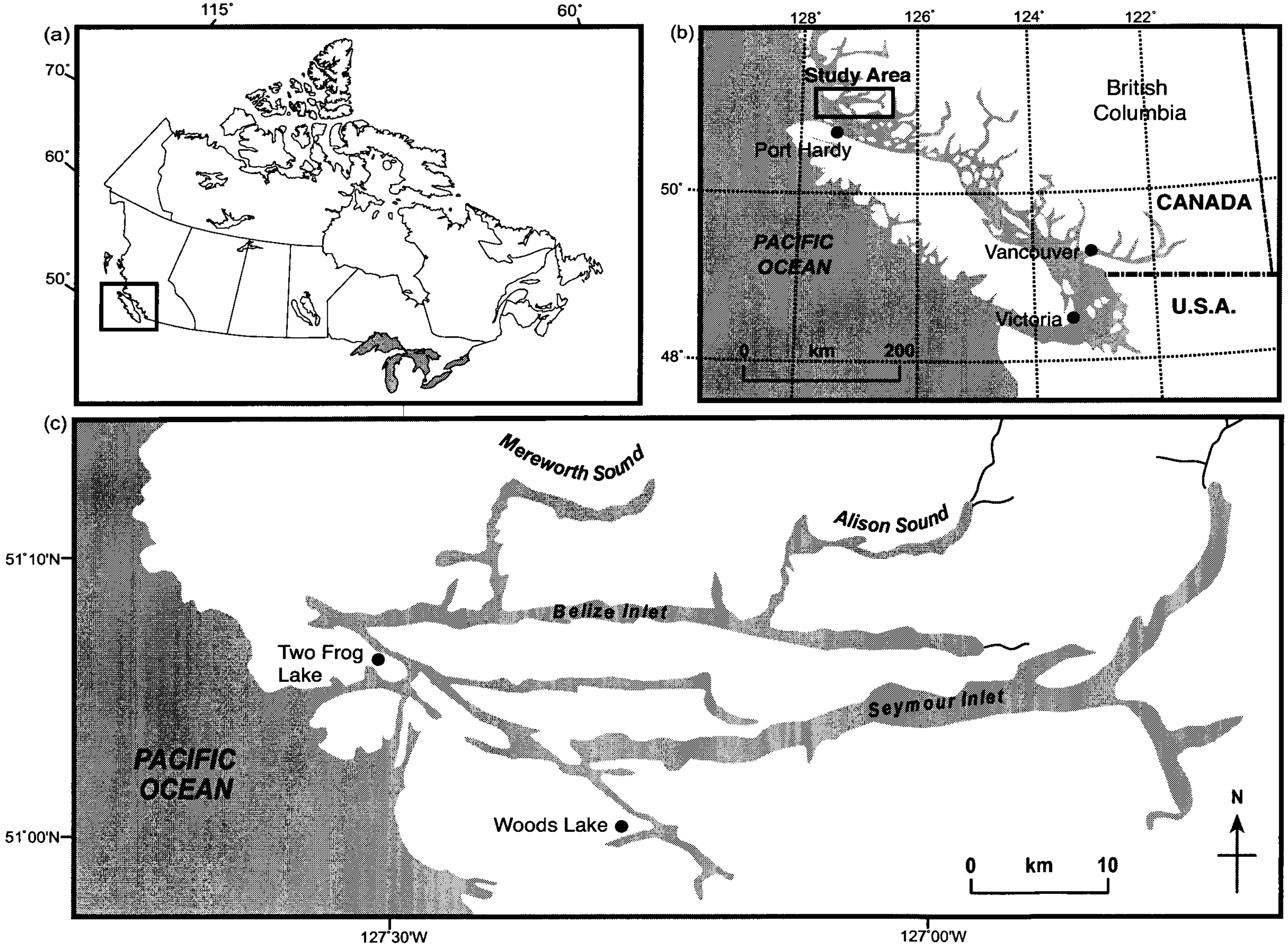
Thuja plicata had risen to become the mono-specific dominant at TFL by ca. 6300 yr BP (ca. 7200 cal. yr BP), probably in response to the development of a modern cool and moist climate in this region (Krajina 1969; Hebda 1983; Minore 1990). *Thuja plicata* did not reach maximum expansion elsewhere in coastal British Columbia until after ca. 3500 yr BP when a modern climate with cool and wet summers and mild winters, associated with mid-Neoglacial activity in the Canadian Rocky Mountains and Coast Mountains, had developed (Porter and Denton 1967; Mathewes 1973; Hebda 1983; Hebda and Mathewes 1984; Ryder and Thompson 1986; Heusser 1983; Luckman et al. 1993; Pellatt and Mathewes 1994, 1997; Pellatt et al. 2001; Brown and Hebda 2002a; Lacourse 2005).

In southern British Columbia and on the coastal islands, including near by Bear Cove Bog and Misty lake, *T. plicata* was a co-dominant tree in late-successional *T. heterophylla* forests (Hebda 1983; Lacourse 2005) but it also exhibited mono-specific dominance in late Holocene forests at Crocker Lake and Cedar Swamp on the Olympic Peninsula and at Davis Lake and Lake Washington in the Puget Lowlands of Washington since establishment as the climax species by ca. 6000 yr BP (Barnosky 1981; Leopold et al. 1982; McLachlan and Brubaker 1994). This similarity may be due to a parallel early to mid-Holocene climate and forest history since *T. heterophylla* remained as a subordinate tree throughout the early to mid-Holocene at these sites, as it did at TFL. At Cedar Swamp, a changing hydrological regime was important in the establishment of *T. plicata* populations but this was not the case at the other sites where the development of a wet climate ca. 7500 yr BP is thought to be responsible for the rise of this taxon. The relative sea-level history of the central mainland coast is poorly constrained but present heights were reached in the Bella Bella region north of the SBIC after ca. 4000 yr BP (Clague et al. 1982) making a transgression an unlikely mechanisms for the predominance of *T. plicata* at this time. It is possible that the early and perhaps abrupt onset of a moist and cool climate and/or site specific variables at TFL allowed *T. plicata* to become established as the forest dominant prior to *T. heterophylla*, and thus permitted this species to maintain a climax position throughout the late Holocene.

2.6 Conclusions

Pollen and spores preserved in the sediments of Two Frog Lake show that this site has experienced considerable climate change since the Late-Glacial (11,040 ± 50 yr BP; 13,030 cal. yr BP). The early Late-Glacial (ca. 12,000-11,800 yr BP; ca. 14,900-14,500 cal. yr BP) was cool and dry and the landscape was dominated by an open *P. contorta* woodland. This woodland was replaced ca. 11,800 yr BP (ca. 14,500 cal. yr BP) when a moister but still cool climate developed and permitted colonization by *Alnus* and later by *Picea*. At 11,040 ± 50 (13,030 cal. yr BP) *T. mertensiana* moved down-slope to join the local vegetation at TFL in response to a cool and moist climate associated with a Younger Dryas-like climate reversal. This cooling event may have disturbed successional trends and permitted *Alnus* to persist in *Picea* forests at TFL for nearly 1000 years. Early Holocene (ca. 10,200-8000 yr BP; ca. 12,300-9200 cal. yr BP) warming, and possibly an increase in fire disturbance, resulted in a successional mosaic of *T. heterophylla*, *Picea*, *P. menziesii* and *Alnus*. Late-Glacial and early Holocene vegetation dynamics at Two Frog Lake are similar to those described elsewhere in coastal British Columbia, suggesting that climate was the ultimate control on regional vegetation at this site during the first 3000 years after deglaciation. The climate became moister and cooler at ca. 8000 yr BP (ca. 9200 cal. yr BP), which facilitated the development of a late-successional forests dominated by *T. plicata.* The timing of this climate transition, and the initial expansion of *T. plicata*, predates the event in south coastal British Columbia and the northwestern United States, possibly due to the development of a regionally heterogeneous climate influenced by a dynamic Aleutian Low pressure system. By ca. 6300 yr BP (ca. 7200 cal. yr BP) *T. plicata* had markedly increased to become the dominant taxon in extant forests at Two Frog Lake in response to the development of an even moister and cooler modern climate. The composition and longevity of this forest at TFL are exceptional in coastal British Columbia and may be associated with the early to mid-Holocene climate and forest history at this site as well as with local factors such as edaphic conditions, site topography and disturbance.

Figure 2.1: (a) Map of North America showing the location of the study site (after Vazquez-Riveiros et al. in preparation), (b) map of southwestern British Columbia showing the location of the Seymour-Belize Inlet Complex and (c) map of the Seymour-Belize Inlet complex showing the location of Two Frog Lake and Woods Lake (mentioned in text).


(a)
115°
60°
70°
60°
50°
(b)
128°
126°
124°
122°
50°
48°
Study Area
Port Hardy
British Columbia
CANADA
U.S.A.
Vancouver
Victoria
PACIFIC OCEAN
0 km 200
(c)
Mereworth Sound
Alison Sound
Belize Inlet
Seymour Inlet
Two Frog Lake
Woods Lake
PACIFIC OCEAN
N
0 km 10
51°10'N
51°00'N
127°30'W
127°00'W

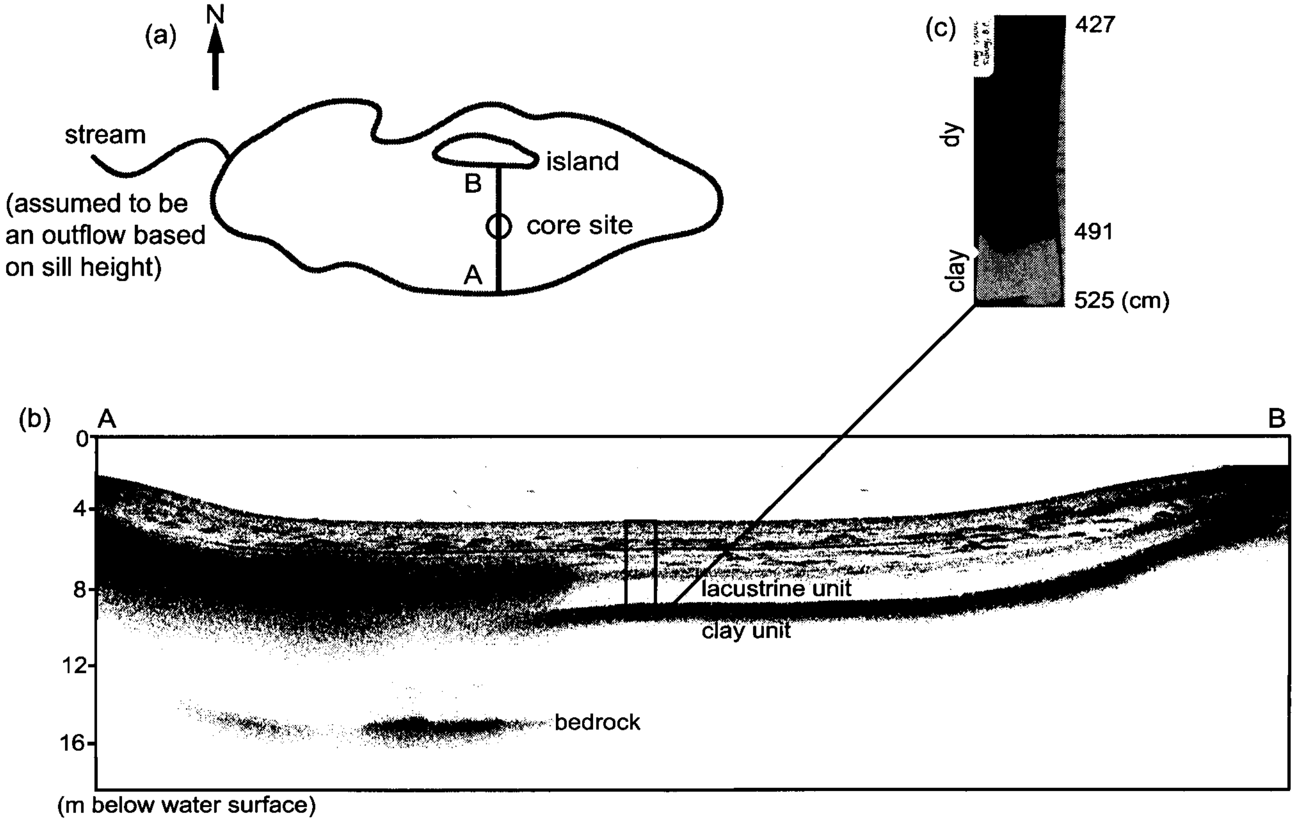
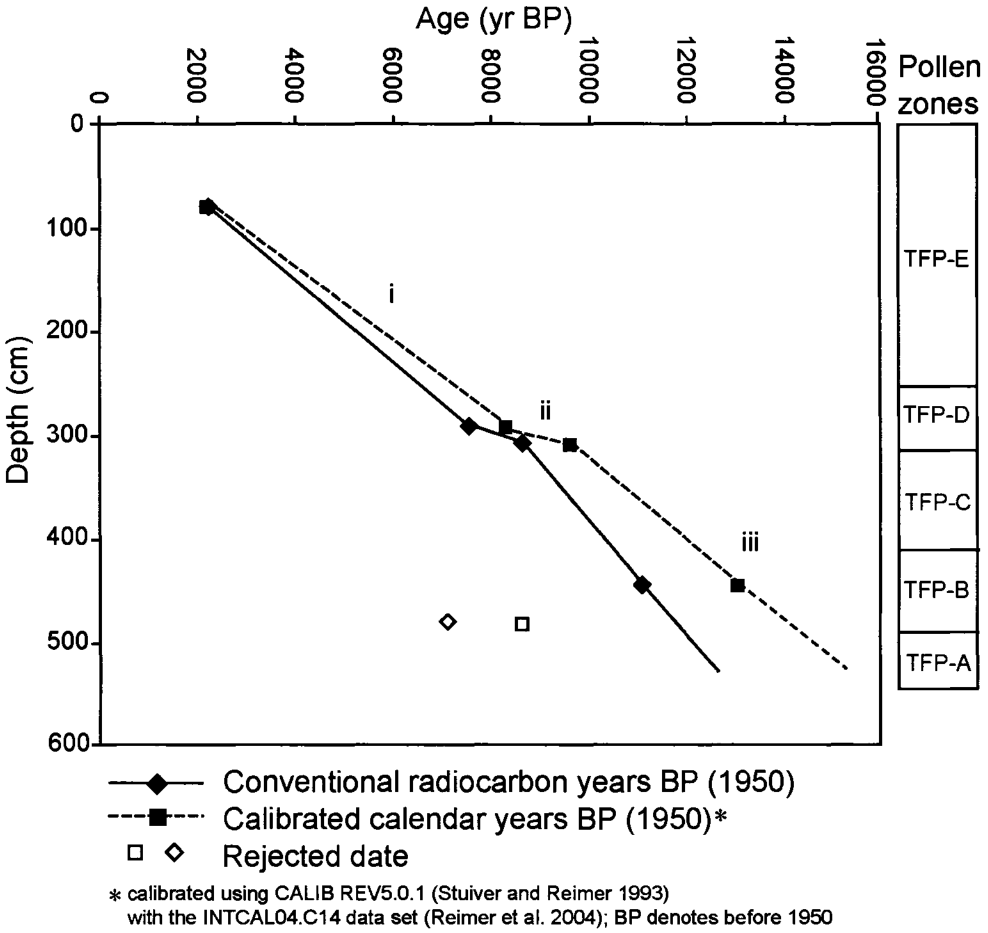


Figure 2.2: (a) Schematic of Two Frog Lake showing the core site and the sub-bottom profile transect, (b) sub-bottom profile showing the sedimentary infill of the Two Frog Lake basin and (c) a negative X-ray of the lower portion of the Two Frog Lake sediment core showing the sedimentological contact between basal clay and overlying dy.



i sedimentation rate = 0.040 cm/radiocarbon year; 0.035 cm/calendar year
ii sedimentation rate = 0.016 cm/radiocarbon year; 0.013 cm/calendar year
iii sedimentation rate = 0.056 cm/radiocarbon year; 0.034 cm/calendar year

Figure 2.3: Age-depth model for the Two Frog Lake sediment core. Pollen zones are shown to the right of the diagram.

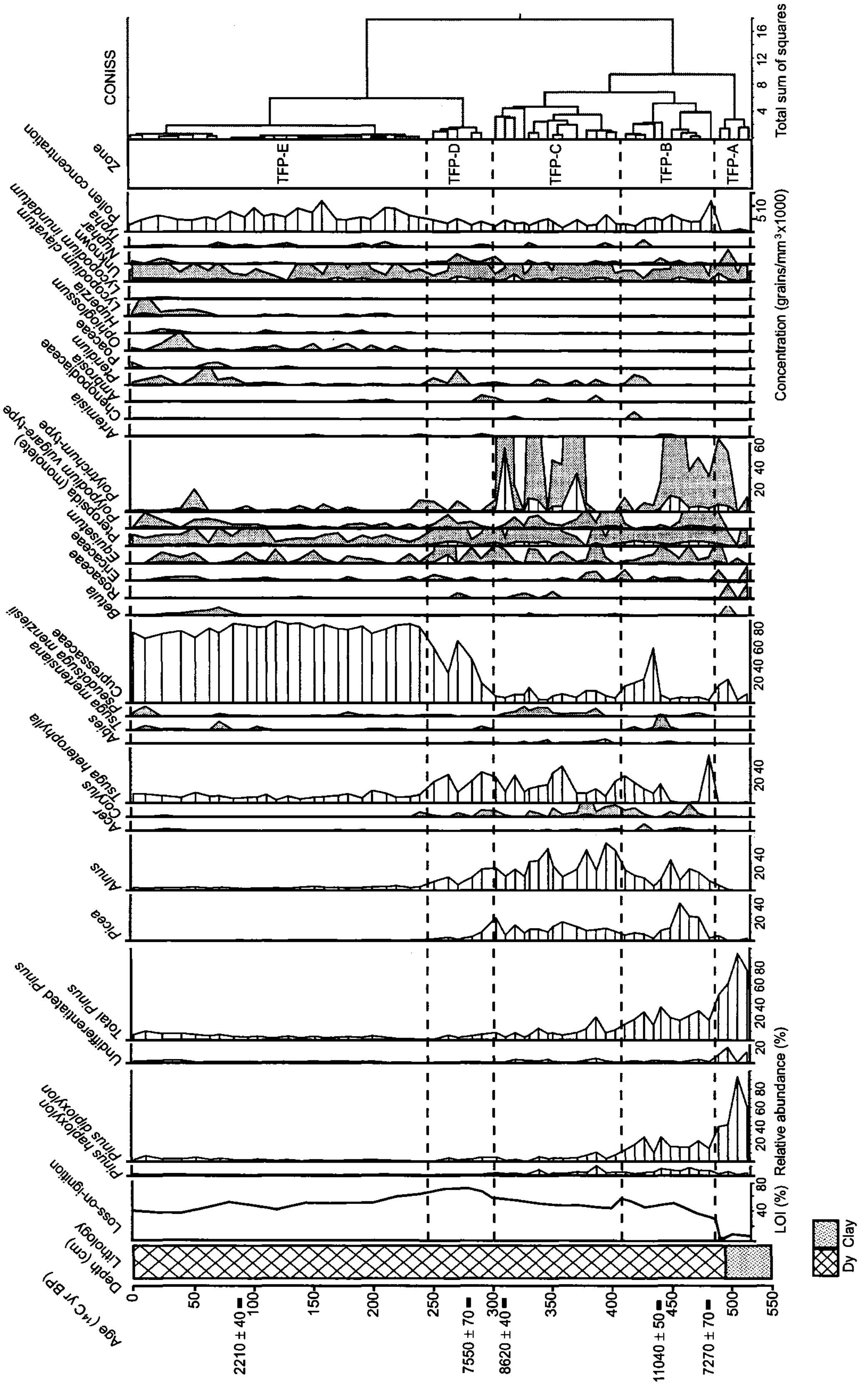

Age (14C yr BP)
Depth (cm)
Lithology
Loss-on-ignition
Pinus haploxylon
Pinus diploxylon
Undifferentiated Pinus
Total Pinus
Picea
Alnus
Acer
Corylus
Tsuga heterophylla
Abies
Tsuga mertensiana
Pseudotsuga menziesii
Cupressaceae
Betula
Rosaceae
Ericaceae
Equisetum
Pteropsida (monolete)
Polypodium vulgare-type
Polytrichum-type
Artemisia
Chenopodiaceae
Ambrosia
Pteridium
Poaceae
Ophioglossum
Huperzia
Lycopodium clavatum
Lycopodium inundatum
Unknown
Nuphar
Typha
Pollen concentration
Zone
CONISS
0
50
100
150
200
250
300
350
400
450
500
550
2210 ± 40
7550 ± 70
8620 ± 40
11040 ± 50
7270 ± 70
TFP-A
TFP-B
TFP-C
TFP-D
TFP-E
LOI (%)
40 80
Relative abundance (%)
20 40 60 80
20
20 40
Concentration (grains/mm³x1000)
5 10
Total sum of squares
4 8 12 16
Dy
Clay

Figure 2.5: Comparison of post-glacial climate changes at selected palynological sites along the Pacific Northwest coast.

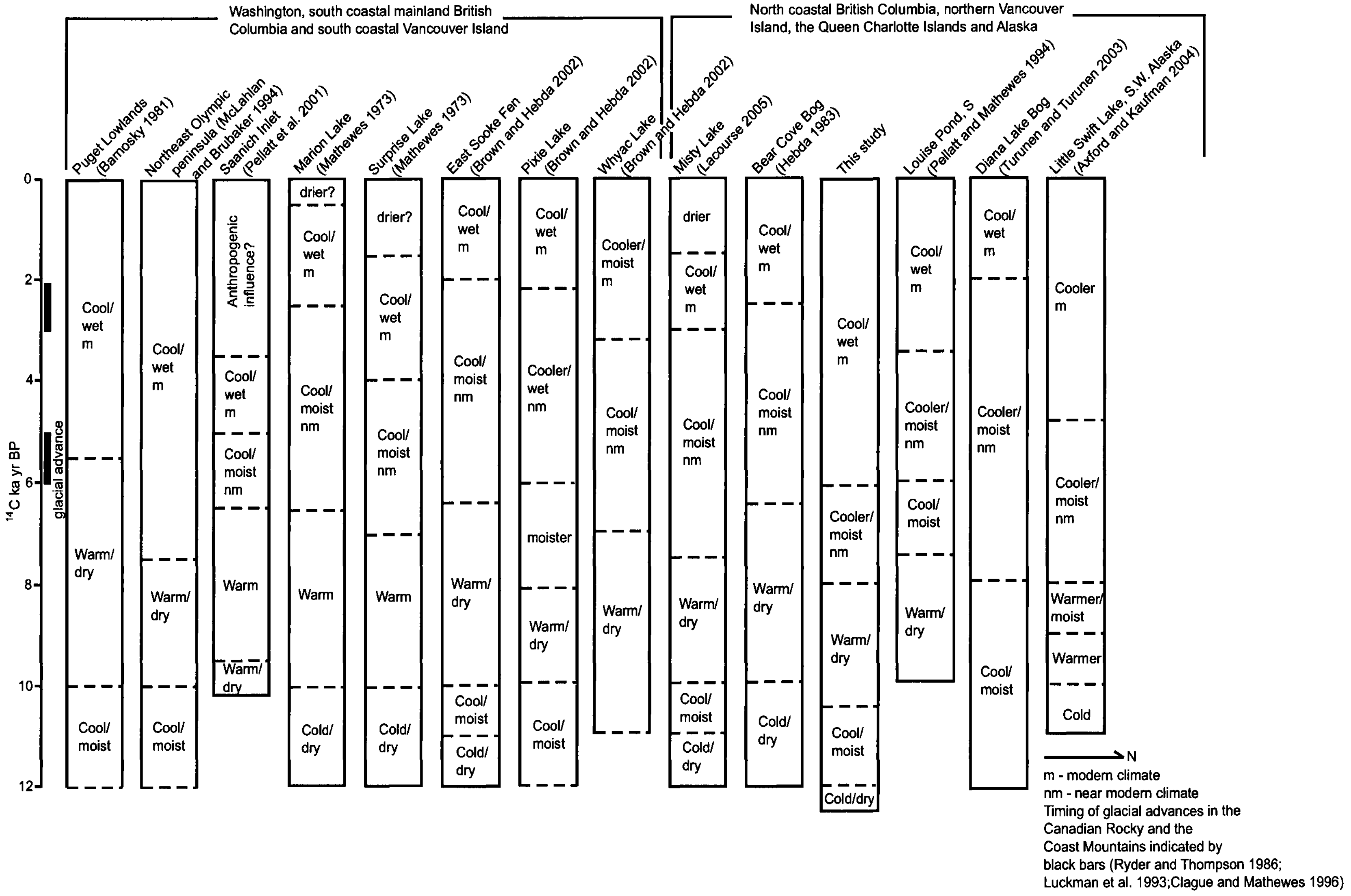

Washington, south coastal mainland British Columbia and south coastal Vancouver Island
North coastal British Columbia, northern Vancouver Island, the Queen Charlotte Islands and Alaska
Puget Lowlands (Barnosky 1981)
Northeast Olympic peninsula (McLahlan and Brubaker 1994)
Saanich Inlet (Pellatt et al. 2001)
Marion Lake (Mathewes 1973)
Surprise Lake (Mathewes 1973)
East Sooke Fen (Brown and Hebda 2002)
Pixie Lake (Brown and Hebda 2002)
Whyac Lake (Brown and Hebda 2002)
Misty Lake (Lacourse 2005)
Bear Cove Bog (Hebda 1983)
This study
Louise Pond, S (Pellatt and Mathewes 1994)
Diana Lake Bog (Turunen and Turunen 2003)
Little Swift Lake, S.W. Alaska (Axford and Kaufman 2004)
¹⁴C ka yr BP
0
2
4
6
8
10
12
glacial advance
Cool/ wet m
Warm/ dry
Cool/ moist
Cool/ wet m
Warm/ dry
Cool/ moist
Anthropogenic influence?
Cool/ wet m
Cool/ moist nm
Warm
Warm/ dry
drier?
Cool/ wet m
Cool/ moist nm
Warm
Cold/ dry
drier?
Cool/ wet m
Cool/ moist nm
Warm
Cold/ dry
Cool/ wet m
Cool/ moist nm
Warm/ dry
Cool/ moist
Cold/ dry
Cool/ wet m
Cooler/ wet nm
moister
Warm/ dry
Cool/ moist
Cooler/ moist m
Cool/ moist nm
Warm/ dry
drier
Cool/ wet m
Cool/ moist nm
Warm/ dry
Cool/ moist
Cold/ dry
Cool/ wet m
Cool/ moist nm
Warm/ dry
Cold/ dry
Cool/ wet m
Cooler/ moist nm
Warm/ dry
Cool/ moist
Cold/dry
Cool/ wet m
Cooler/ moist nm
Cool/ moist
Warm/ dry
Cool/ wet m
Cooler/ moist nm
Cool/ moist
Cooler m
Cooler/ moist nm
Warmer/ moist
Warmer
Cold
N
m - modern climate
nm - near modern climate
Timing of glacial advances in the Canadian Rocky and the Coast Mountains indicated by black bars (Ryder and Thompson 1986; Luckman et al. 1993;Clague and Mathewes 1996)

Table 2.1: Conventional radiocarbon and calibrated calendar ages of the Two Frog Lake sediment core.

Lab no.	Sample Depth (cm)	Material	Conventional ^{14}C yr BP	Calendar yr BP (95% C.I.)*
Beta-185142	81	Dy-gyttja	2210 +/- 40	2330-2120 (2225)
TO-10766	293	Dy-gyttja	7550 +/- 70	8425-8180 (8303)
Beta-185141	310	Dy-gyttja	8620 +/- 40	9660-9530 (9595)
Beta-185143	445	Dy-gyttja	11040 +/- 50	13170-12890 (13030)
TO-10777	489	Dy-gyttja	7270 +/- 70	8185-7940 (8063)

*calibrated using INTCAL98 (Stuiver et al. 1998); BP denotes before 1950

Appendix 2.1: List of taxa identified from the Two Frog Lake, Tiny Lake and Frederick Sound sediment cores*.

Identified taxon	**Common name**
1. Coniferous arboreal or shrub taxa	
Pinaceae	Pine family
Abies Mill.	Fir
Picea A. Dietr.	Spruce
Pinus L.	Pine
Pinus contorta Dougl. ex Loud	Lodgepole pine
Pinus monticola Dougl.	Western white pine
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Tsuga heterophylla (Raf.) Sarg.	Western hemlock
Tsuga mertensiana (Bong.) Carr.	Mountain hemlock
Cupressaceae	Cypress family
Thuja plicata Donn ex D. Don	Western redcedar
2. Deciduous arboreal and shrub taxa	
Acer L.	Maple
Alnus B. Ehrh.	Alder
Betula L.	Birch
Cornus L.	Dogwood
Corylus Marsh.	Hazel
Populus L.	Poplar
Salix L.	Willow
3. Non-arboreal taxa	
Agoseris L.	Dandelion
Ambrosia L.	Ragweed
Arceuthobium Bieb.	Mistletoe
Artemisia L.	Sagebrush
Botrychium Swartz, 1806	Grape fern
Brassica L.	Mustard
Cheilanthes Swartz, 1806	Lip fern
Chenopodiaceae	Goosefoot family
Equisetum L.	Horsetail and souring rush
Ericaceae	Heath
Eupatorium L.	Thoroughwort
Huperzia (*selago*) (L.) Bernh. ex Schrank and Mart.	Fir clubmosss
Impatiens L.	Impatiens
Lilaceae	Lily family
Lycopodium clavatum L.	Running clubmoss
Lycopodium inundatum (L.) Holub	Bog clubmoss
Ophioglossum L.	Adder's tongue
Poaceae	Grass family

Polypodium vulgare L.	Common polypody
Polytrichum Willd. or Hedw.	Haircap moss
Pteridium Gled. ex Scop.	Bracken
Pteropsida (monolete)	Ferns
Ranunculus L.	Buttercup
Rosaceae	Rose family
Selaginella Beauv.	Spike-moss
Triglochin L.	Arrowgrass
Vitis L.	Grape
4. Aquatic taxa	
Sagittaria L.	Arrow-head
Typha L.	Cat-tail
Nuphar Sm.	Pond-lily
Nymphaea L.	Waterlily

* Botanical nomenclature based on Wherry (1961), Duhamel (1963), Hitchcock and Cronquist (1973), Anderson et al. (1990) and Pojar and MacKinnon (1994).

Appendix 2.2: Pollen and spore counts for the Two Frog Lake sediment core.

Depth (cm)	*Pinus haploxylon*	*Pinus diploxylon*	Undifferentiated *Pinus*	Total *Pinus*	*Picea*	*Alnus*	*Acer*	*Corylus*	*Tsuga heterophyla*	*Abies*	*Tsuga mertensiana*	*Pseudotsuga menziesii*	Cupressaceae	*Betula*	Rosaceae	Ericaceae	*Equisetum*	Pteropsidea (monolete)	*Polypodium vulgare*-type	*Polytrichum*–type	*Artemisia*	Chenopodiaceae	*Ambrosia*
0	7	9	7	23	0	13	0	0	44	1	0	2	331	0	0	0	0	4	0	0	0	0	0
10	5	40	12	57	2	16	0	0	60	0	3	7	436	0	0	0	0	4	8	0	0	0	0
24	10	27	21	58	1	25	2	2	72	0	1	0	668	2	0	2	8	8	6	0	0	0	0
40	8	19	16	43	1	19	1	0	38	1	1	0	499	2	0	2	3	6	0	1	0	0	0
52	2	27	3	32	1	22	0	0	68	0	0	0	424	3	0	2	5	9	4	11	0	0	0
64	7	17	6	30	1	18	0	0	57	0	0	0	635	5	0	0	0	2	6	0	0	0	0
72	5	23	8	36	1	22	0	0	50	1	6	2	494	6	0	0	0	10	4	0	0	0	0
84	3	20	10	33	1	27	1	0	56	1	0	1	946	4	0	1	2	9	3	0	0	0	0
96	1	11	9	21	4	15	0	0	48	0	0	1	661	0	0	1	7	14	2	3	0	0	0
104	4	35	9	48	1	37	0	0	87	2	5	0	1109	0	0	2	4	21	4	0	0	0	0
112	3	11	3	17	2	18	0	0	75	1	1	0	694	0	0	2	1	12	1	0	0	0	0
120	2	8	9	19	0	24	0	1	32	0	0	0	844	1	0	1	11	3	1	1	0	0	0
130	5	14	9	28	1	15	0	0	56	1	0	0	666	0	0	0	0	4	1	0	0	0	0
140	3	5	12	20	3	41	0	0	54	3	0	0	1092	1	1	1	4	8	3	5	0	0	0
152	4	17	15	36	3	43	0	0	65	0	0	1	835	1	0	0	11	6	0	0	1	0	0
150	3	16	12	31	4	56	0	0	113	0	0	1	1414	0	0	1	6	15	2	9	0	0	0
172	1	5	11	17	1	21	1	0	52	0	0	1	519	0	0	0	0	7	0	0	0	0	0
180	3	9	8	20	0	20	0	0	65	0	0	3	529	0	0	2	4	2	2	2	0	0	0
192	1	11	7	19	3	25	1	0	44	2	0	1	675	1	0	0	3	7	3	0	0	0	1
200	4	13	9	26	1	24	0	0	87	2	1	1	489	0	0	0	2	4	1	0	0	0	0
212	11	17	1	29	3	52	1	0	130	3	1	0	1040	0	0	0	0	12	5	0	0	0	2
220	2	8	4	14	0	63	0	0	77	0	2	2	1058	0	0	0	0	8	0	0	0	0	0
232	1	5	2	8	1	26	0	0	61	3	0	0	760	0	0	3	7	3	3	1	0	0	0
240	0	3	1	4	4	29	0	4	67	0	0	1	625	0	0	0	1	5	0	7	1	0	0
252	0	2	1	3	9	58	0	1	141	1	0	1	367	0	0	3	6	9	2	5	0	0	0
264	1	16	3	20	14	62	0	0	132	2	0	1	138	0	0	1	32	16	5	0	0	0	0
272	1	3	1	5	3	14	0	1	26	0	0	0	154	0	1	0	0	8	1	2	0	0	0
284	2	10	3	15	15	51	0	0	87	5	0	0	172	0	0	1	5	2	2	0	0	0	0
292	3	25	3	31	49	126	0	4	181	5	2	0	115	0	0	0	2	6	1	0	1	0	3
304	7	14	2	23	76	75	0	2	86	3	0	0	21	0	0	0	5	10	0	3	0	0	1
312	6	5	4	15	34	90	0	1	73	2	0	2	31	0	0	1	7	4	2	326	0	0	0
320	7	9	14	30	69	95	0	0	123	0	0	2	36	0	1	0	1	14	4	9	0	1	0
328	1	0	11	12	38	70	0	0	56	10	0	5	41	0	2	0	0	17	1	0	0	0	0
332	6	3	7	16	38	99	0	2	49	1	0	2	51	1	1	0	4	10	3	35	0	0	0
340	30	27	8	65	65	170	0	2	95	7	0	5	19	0	0	0	6	16	6	51	0	0	0

Depth (cm)	*Pinus haploxylon*	*Pinus diploxylon*	Undeterminable *Pinus*	Total *Pinus*	*Picea*	*Alnus*	*Acer*	*Corylus*	*Tsuga heterophyla*	*Abies*	*Tsuga mertensiana*	*Pseudotsuga menziesii*	Cupressaceae	*Betula*	Rosaceae	Ericaceae	*Equisetum*	Pteropsidea (monolete)	*Polypodium vulgare*-type	*Polytrichum*--type	*Artemisia*	Chenopodiaceae	*Ambrosia*
348	0	19	24	43	62	301	1	0	130	25	0	6	19	0	2	1	0	28	3	0	0	0	2
352	12	19	6	37	78	139	0	5	168	0	0	2	37	0	3	0	3	12	2	23	0	0	1
360	5	13	1	19	79	57	0	1	156	4	0	1	36	0	0	1	4	5	1	16	0	0	0
372	20	24	4	48	94	147	1	3	67	5	0	2	34	0	0	0	1	5	5	212	0	0	0
380	7	20	8	35	32	129	0	9	29	5	0	1	37	0	0	2	1	0	5	2	0	0	0
420	4	58	6	68	26	50	0	3	69	1	1	0	65	0	0	0	1	15	0	0	0	2	0
428	18	178	5	201	47	89	5	2	102	1	0	0	167	0	0	0	4	28	1	5	0	0	0
436	26	70	21	117	16	34	0	0	75	0	2	0	437	0	0	3	6	29	1	4	0	0	0
442	40	153	10	203	62	69	0	0	116	6	13	1	45	0	0	1	9	17	2	15	1	0	0
450	50	152	18	220	124	302	2	5	19	22	3	0	31	0	0	3	10	19	1	128	2	1	0
458	28	101	3	132	258	68	2	1	1	2	0	0	34	0	0	2	3	20	4	74	0	0	0
466	41	80	12	133	135	119	1	7	3	4	0	1	25	0	0	0	8	21	16	18	0	0	0
474	28	126	20	174	140	108	0	2	8	0	0	2	31	0	0	1	2	26	15	26	0	0	0
483	91	245	20	356	47	168	2	0	870	7	0	1	46	0	0	0	10	65	30	52	0	0	0
491	3	79	18	100	11	12	0	0	0	0	0	0	37	0	0	2	5	6	3	13	0	0	0
499	3	31	13	47	0	1	0	0	0	0	0	0	19	1	1	0	0	1	0	4	0	0	0
507	3	554	5	562	2	2	0	0	2	0	0	0	18	0	0	0	3	1	0	0	0	0	0
515	2	46	9	57	2	0	0	0	1	0	0	0	7	0	1	1	0	3	0	1	0	0	0

Depth (cm)	*Pteridium*	Poaceae	*Ophioglossum*	*Huperzia*	*Lycopodium clavatum*	*Lycopodium inundatum*	Unknown	Main pollen sum	*Nuphar*	*Typha*	Aquatic pollen sum	Total pollen sum*	Exotic *Lycopodium*
0	1	2	1	0	1	0	9	432	1	0	1	433	36
10	3	0	0	0	3	0	13	612	0	0	0	612	30
24	7	0	5	3	3	1	17	891	4	1	5	896	30
40	0	0	10	1	3	0	5	636	0	0	0	636	30
52	4	0	2	0	3	0	9	599	0	0	0	599	30
64	14	3	0	0	2	0	7	780	0	0	0	780	30
72	3	3	1	0	0	0	10	649	0	2	2	651	31
84	7	0	0	0	0	0	7	1099	0	0	0	1099	30
96	1	0	1	0	0	0	4	783	0	1	1	784	30
104	3	0	4	0	0	0	14	1341	1	0	1	1342	31
112	2	0	2	2	1	0	6	837	0	0	0	837	30
120	2	0	4	1	0	0	4	949	1	1	2	951	30
130	0	1	1	0	1	0	0	775	0	2	2	777	30
140	0	0	1	0	0	0	23	1260	0	0	0	1260	30
152	2	0	6	1	0	0	13	1024	0	0	0	1024	30
150	0	0	0	0	0	0	10	1662	1	0	1	1663	30
172	1	0	2	1	0	0	20	643	0	0	0	643	30
180	1	0	4	0	1	0	7	662	0	0	0	662	32
192	0	0	0	2	0	0	20	807	0	2	2	809	31
200	1	0	3	0	1	0	7	650	0	0	0	650	30
212	1	1	0	0	3	0	7	1290	0	5	5	1295	30
220	0	0	5	0	0	0	21	1250	0	1	1	1251	30
232	1	0	0	1	0	0	7	885	0	0	0	885	30
240	0	0	0	0	0	0	8	756	0	0	0	756	30
252	4	0	1	0	0	0	3	614	1	0	1	615	30
264	1	0	0	0	0	0	4	428	1	0	1	429	30
272	3	0	0	0	0	0	50	268	2	0	2	270	10
284	0	0	0	0	0	0	7	362	1	0	1	363	32
292	1	0	0	0	0	0	13	540	1	1	2	542	31
304	1	0	0	0	0	0	2	308	2	0	2	310	34
312	1	0	0	0	0	0	7	596	0	0	0	596	30
320	0	0	0	0	0	0	25	410	0	0	0	410	30
328	0	0	0	0	0	0	25	277	0	0	0	277	30
332	0	0	0	0	0	0	3	315	1	1	2	317	30
340	3	0	0	0	0	0	13	523	0	0	0	523	30

Depth (cm)	*Pteridium*	Poaceae	*Ophioglossum*	*Huperzia*	*Lycopodium clavatum*	*Lycopodium inundatum*	Unknown	Main pollen sum	*Nuphar*	*Typha*	Aquatic pollen sum	Total pollen sum*	Exotic *Lycopodium*
348	2	0	0	0	0	0	10	635	1	0	1	636	30
352	0	0	0	0	0	0	5	515	0	0	0	515	30
360	0	0	0	0	0	0	13	393	0	0	0	393	65
372	3	0	0	0	0	0	9	636	0	0	0	636	31
380	0	0	0	0	0	0	13	300	0	0	0	300	30
420	3	0	0	0	0	0	3	307	0	0	0	307	32
428	5	0	0	0	0	0	2	659	1	4	5	664	30
436	0	0	0	0	1	0	8	733	1	0	1	734	30
442	0	0	0	1	0	0	6	567	3	0	3	570	30
450	1	0	0	0	0	0	10	903	1	0	1	904	30
458	0	0	0	0	0	0	25	626	2	0	2	628	30
466	1	0	0	0	0	0	10	502	0	0	0	502	30
474	0	0	0	1	0	0	12	548	1	0	1	549	30
483	1	0	0	0	0	0	9	1664	1	0	1	1665	30
491	0	0	0	0	0	0	15	204	0	0	0	204	238
499	0	0	0	0	0	0	2	76	1	0	1	77	104
507	0	0	0	0	0	0	5	595	0	0	0	595	142
515	0	0	0	0	0	0	2	75	0	0	0	75	150

CHAPTER THREE

POST-GLACIAL CLIMATE AND VEGETATION CHANGE ON THE CENTRAL MAINLAND COAST OF BRITISH COLUMBIA: PALYNOLOGICAL EVIDENCE FROM TINY LAKE IN THE SEYMOUR-BELIZE INLET COMPLEX

Abstract

Pollen and spores preserved in the sediments of Tiny Lake in the Seymour-Belize Inlet Complex of central mainland British Columbia were analyzed in order to document regional post-glacial vegetation and climate change. Following deglaciation prior to 11,763 ± 87 yr BP (13,815 cal. yr BP) an open *Pinus contorta* woodland occupied the landscape and the climate was cool and dry. By 11,763 ± 87 yr BP (13,815 cal. yr BP) a shift to moister conditions resulted in the replacement of this woodland by a mixed conifer forest of *Pinus*, *Picea* and *Abies*. *Tsuga heterophylla* was a brief component of this community but was replaced by *Picea*, possibly in response to disrupted succession associated with climate cooling. Early Holocene warming at ca. 10,200 yr BP (ca. 12,300 cal. yr BP) resulted in a forest mosaic of *Tsuga heterophylla* and *Alnus*. *Pseudotsuga menziesii* was notably absent from this community, indicating that Holocene forest histories have been site specific in coastal British Columbia as well as within the Seymour-Belize Inlet Complex. Climate moistening at ca. 8000 yr BP (ca. 9200 cal. yr BP) facilitated the development of late-successional forests dominated by *T. heterophylla* with *T. plicata.* At 6860 ± 50 yr BP (7692 cal. yr BP), *T. plicata* increased in abundance and replaced *T. heterophylla* as the forest dominant in response to the development of a cool and moist modern climate. The initial increase of *T. plicata* at this site as well as at Two Frog Lake at ca. 8000 yr BP (ca. 9200 cal. yr BP) predates its rise elsewhere in coastal British Columbia, possibly due to regional climate heterogeneity associated with a dynamic Aleutian Low pressure system.

3.1 Introduction

The coastal temperate forests of the Pacific Northwest are unique in their coniferous dominance, longevity and biomass production and are important both ecologically and economically (Waring and Franklin 1979; Franklin and Dryness 1973). Paleoecological studies can provide an important long-term perspective, not available from the relatively brief instrumental record, on post-glacial climate variability and the development of extant forest communities (Ricklefs 1987; Hebda 1998). This geological perspective is necessary in order to place current and predicted climate change into an appropriate context and to anticipate how future climate variability might affect the coastal temperate rainforests of British Columbia (Hebda 1998).

Previous palynological research in coastal British Columbia has shown that considerable climate change has occurred since the last deglaciation. Following the retreat of the Cordilleran ice sheet from southern British Columbia at ca. 13,000 ^{14}C yr BP (yr BP), the climate was cool and dry and the newly exposed landscape was rapidly colonized by *Pinus contorta* (Heusser 1956; Mathewes 1973; Howes 1983; Hebda 1983; Barrie and Conway 1999; Brown and Hebda 2002a; Pellatt et al. 2002; Lacourse 2005). The climate became moister near the end of the Late-Glacial (ca. 12,000-10,000 yr BP) and *Picea* and *Abies* joined *P. contorta* to form mixed conifer stands (Mathewes 1973; Mathewes and Rouse 1975; Heusser 1983; Brown and Hebda 2002a; Lacourse 2005). At the Pleistocene/Holocene boundary, approximately 10,000 yr BP, rapid warming and drought resulted in the replacement of these forests by a mosaic of *Pseudotsuga menziesii*, *Tsuga heterophylla* and *Alnus* (Mathewes 1973; Mathewes and Rouse 1975; Heusser 1983; Pellatt and Mathewes 1997; Brown and Hebda 2002a; Lacourse 2005).

The transition to a moist, near modern climate was time transgressive in coastal British Columbia, but generally occurred between 7000-6000 yr BP and initiated the development of modern temperate rainforests dominated by *T. heterophylla* and *Thuja plicata* (Mathewes 1973; Mathewes and Rouse 1975; Hebda 1983; Pellatt and Mathewes 1997; Walker and Pellatt 2003; Lacourse 2005). The climate of the late Holocene (5000 yr BP-present) was cooler and moister than any other time in the Epoch and was a time of renewed glacial activity in the Canadian Rocky Mountains and the Coast Mountains of British Columbia. The development of a wet and cool modern climate ca. 3500 yr BP permitted *T. plicata* to expand in coastal forests and form extant communities of *T. heterophylla* and *T. plicata* (Franklin and Dyrness 1973; Mathewes 1973; Hebda 1983; Ryder and Thompson 1986; Luckman et al. 1993; Lacourse 2005).

This study uses pollen and spores preserved in the sediments of Tiny Lake to reconstruct a post-glacial vegetation and climate history for this site. It is part of a larger project investigating marine and lacustrine records collected from the Seymour-Belize Inlet Complex (SBIC) in order to produce a regional synthesis of post-glacial climate, vegetation and relative sea level change of the central mainland coast of British Columbia. This region of the coast is an area of interest because although it supports an economically important tract of the coastal temperate rainforest (Franklin and Dryness 1973), it has been poorly studied and represents a serious spatial gap between sites previously studied to the north on the Queen Charlotte Islands (e.g., Pellatt and Mathewes 1997), the northern mainland coast (Turunen and Turunen 2003) and Alaska (e.g., Engstrom et al. 1990; Hansen and Engstrom 1996; Axford and Kaufman 2004) and the more intensively studied southern coast (e.g., Mathewes 1973; Mathewes and Heusser 1981; Hebda 1983; Hebda 1997; Brown and Hebda 2002a,b; 2003; Lacourse 2005).

This study succeeds two previous palynological investigations of small coastal lakes within the SBIC: Two Frog Lake and Woods Lake (Stolze 2004). This previous work suggests that the SBIC experienced the development of a near modern climate at ca. 8000 yr BP (ca. 9200 cal. yr BP), which is earlier than sites to the south of this study region. Tiny Lake was chosen for investigation as a follow up to these studies in order to provide a more robust regional climate reconstruction of the SBIC by employing a consenus approach since post-glacial vegetation and climate histories can differ greatly, even between nearby sites (e.g., Walker and Pellatt 2001; Brown and Hebda 2002a). Results are compared to previous palynological investigations on northern Vancouver Island as well as to pollen spectra from Two Frog Lake and Woods Lake (Hebda 1983; Stolze 2004; Lacourse 2005).

3.2 Study area

The SBIC is a series of glacially scoured fjords penetrating the central mainland coast of British Columbia approximately 40 km NE of Port Hardy, Vancouver Island (Fig. 3.1). Regional bedrock consists of Mesozoic aged granites and volcanic rocks. Soils derived from this underlying bedrock tend to be poorly developed and are acidic (Meidinger and Pojar 1991). The SBIC is located within the Coastal Western Hemlock biogeoclimatic zone (CWHZ) and more specifically, within the Southern Very Wet Hypermaritime Coastal Western Hemlock Variant (CWHvh1; Meidinger and Pojar 1991; Green and Klinka 1994; Pojar and Mackimmon 1994). The CWHZ extends north from

Oregon and Washington, along the low elevation coast of British Columbia, west of the Coast Mountains and into southern Alaska (Meidinger and Pojar 1991). The CWHvh1 is restricted to the coastal fringes of northern Vancouver Island and the low-lying mainland coastline between Wells Passage and Smith Inlet (Green and Klinka 1994). The climate of the CWHvh1 is cool, with a mean annual temperature of 9.1 °C (range 5.4-9.4 °C) and wet, with a mean annual precipitation of 3120 mm (range 2009-3943 mm; unknown observation period; Green and Klinka 1994).

Tsuga heterophylla (Raf.) Sarg. (western hemlock) dominates the forests of the CWHvh1. *Thuja plicata* Donn ex D. Don is also common (western redcedar; Allen et al. 1999). *Picea sitchensis* (Bong.) Carr. (Sitka spruce) occurs in well-drained moist sites such as marine terraces and floodplains where it is tolerant of salt spray and *Abies amabilis* (Dougl.) Forb. (amabilis fir) grows in low-lying moist sites on deep, well-drained soils in the CWHvh1 (Pojar and MacKinnon 1994). At higher elevations, *Tsuga mertensiana* (Bong.) Carr. (mountain hemlock) grows in wet sites with deep organic soils and *Chamaeocyparis nootkatensis* (D. Don) Spach (yellow cedar) is common in moist to wet, rocky or boggy sites (Pojar and MacKinnon 1994). *Pinus contorta* Dougl. ex Loud. (lodgepole pine) grows in low elevation dry or boggy sites and *Pinus monticola* Dougl. (western white pine) occupies dry to moist open sites (Pojar and MacKinnon 1994). *Taxus brevifolia* Nutt. (western yew) is a common but subordinate tree in mature *T. heterophylla-T. plicata* forests of the CWHvh1 (Bolsinger and Jamarillo 1990; Pojar and MacKinnon 1994). *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir) is absent from the CWHvh1, which is notable since this species is generally well distributed in coastal British Columbia (Pojar and MacKinnon 1994; Allen et al. 1999). Deciduous taxa present in the forests of the CWHvh1 include *Acer glabrum* Torr. var. *douglasii* (Hook.) Dipp. (Douglas maple), which occurs as a shrub or small tree on dry open ridges as well as in moist, well-drained sites, and *Alnus* B. Ehrh. (Pojar and MacKinnon 1994). Both *Alnus rubra* Bong. (red alder) and shrubby *A. sinuata* (Regel) Rydb. (Stika alder), also known as *A. crispa* (Ait.) Pursh ssp. *sinuata* (Regel) Hulten. (green alder), are present in the CWHvh1 where they occupy open disturbed sites, such as avalanche tracks, and riparian habitats (Pojar and MacKinnon 1994). *Alnus sinuata* can also occupy open dry sites (Hebda 1997). An understory of ferns, bryophytes and shrubs, namely *Gaultheria shallon* Pursh. (salal), form an important aspect of the CWHvh1 ecosystem (Meidinger and Pojar 1991; Klinka et al. 1996; Newmaster et al. 2003).

Tiny Lake (51° 11'40N, 127° 22'48W) is a small (48 ha), deep (z_{max} 32 m) lake located 250 m south of Mereworth Sound, an inlet at the northern extent of the SBIC (Fig. 3.1). This lake is a coastal isolation basin separated from Mereworth Sound by a 3.28 m sill and has a small stream at the northern margin of the basin (Fig. 3.2). Tiny Lake is located approximately 12 km northeast of Two Frog Lake and 22 km north of Woods Lake (Fig. 3.1).

3.3 Methods

3.3.1 Core collection

Sub-bottom profiling using towed sonar equipment (Knudson 320 B/P) with a dual frequency transponder (50 kHz and 200 kHz) was used to identify potential coring locations within the lake. The profile identified two deep basins in Tiny Lake, a 24 m deep northern basin and a 32 m deep southern basin, separated by a sill 18 m below the water surface. The profile also revealed that two distinct lithological units, probably a basal clay section overlain by organic sediment, occurred in the basin sedimentary infill (Fig. 3.2).

A 352 cm sediment core was collected from the southern basin at a depth of 8 m using a Livingstone corer with an internal barrel diameter of 5 cm off of an anchored wooden raft (Fig. 3.2; Wright et al. 1984). Logistical constraints did not permit coring in the deepest point of the lake. The sediment core was transported horizontally in the original aluminum core barrels within one week following collection to Carleton University where they were stored in a cold room at 4°C until April of 2003. At this time, the sediment core was extruded with a wooden dowel, photographed and logged. One half of the core was preserved in plastic food wrap and aluminum foil as an archive. The remaining half was sub-sampled at continuous intervals of 8 or 12 cm, except where sediment was unavailable, for pollen analysis (between 169 and 220 cm and between 268 and 304 cm). Sediment was not available from these intervals of the Tiny Lake core because all of the material was used up in other analyses. The core was also sub-sampled for pollen analysis at 0.5 to 2 cm intervals around the basal sedimentological transition from clay to organic material. Sediment was also collected for percent loss-on-ignition analysis (LOI; Bolye 2004).

3.3.2 Chronology

Bulk sediment samples were selected from sub-sampled material for radiocarbon dating. One sample (SUERC-3090; Table 3.1) was sent to the NERC Radiocarbon Laboratory for sample preparation and then to the SUERC AMS Facility in Glasgow, Scotland, for radiocarbon dating by atomic mass spectrometry (AMS). Pretreatment of the sample at the NERC Radiocarbon Laboratory involved acid washes to remove carbonates and an alkali wash to remove humic material. A second sample (BETA-206929) was sent to Beta-Analytic Inc., Florida, for AMS radiocarbon dating. At this facility the only pretreatment were acid washes. Due to funding limitations, it was necessary to send the two samples to different facilities. Three additional samples have been sent for AMS radiocarbon dating to IsoTrace Laboratories, Toronto, and results are pending.

3.3.3 Pollen and spores

Pollen preparation followed methods described by Faegri and Iversen (1989). Forty-five 50 mm^3 aliquots of wet sediment were subjected to hot treatment of 10% hydrochloric acid and 10% potassium hydroxide followed by acetolysis. Neither sieving nor hydrofluoric acid treatment were performed. Slurries were stained with safranin to aid identification, dehydrated sequentially with alcohol (ethanol and tertiary butanol) and stored in silicone oil. A known quantity of *Lycopodium clavatum* spores were added to each sample prior to processing in order to calculate pollen concentrations (one tablet per sample, batch No. 938 934, n=10,679 +/- 953 std. error spores/tablet; Benninghoff 1962; Stockmarr 1971). Pollen and spores were identified and counted at 400x magnification with an Olympus BX51 transmitted light microscope. Sediments were examined at a higher resolution (every 0.5-2 cm) at and around the sedimentological transition from basal clay to dy (343.5 cm). Total terrestrial pollen and spores counted per slide were consistently above 300 except at one horizon (340 cm) where 182 grains and spores were enumerated.

Pollen keys by McAndrews et al. (1988), Faegri and Iversen (1989) and Kapp et al. (2000) and reference slides (Aerobiology Institution and Research Pollen Reference Slide Set, Brookline, MA) aided pollen identification. Pollen was identified to the lowest possible taxonomical unit (Appendix 2.1). *Pinus* L. pollen was identified as diploxylon-type, haploxylon-type or was undifferentiated (Faegri and Iversen 1989). *Juniperus* L. (juniper), *Chamaecyparis nootkatensis* (D. Don) Spach (yellow cedar), *Taxus brevifolia* Nutt. (western yew) and *T. plicata* pollen were grouped together as Cupressaceae since their pollen is difficult to differentiate using light microscopy. *Larix* Mill. (larch) and *P. menziesii* pollen are morphologically similar, but since *Larix* is uncommon in coastal British Columbia (Duhamel 1963), this pollen is attributed to *P. menziesii*. In cases where uncertainty exists, pollen and spore taxa are suffixed with "-type" (Janssen 1967). Pteropsida (monolete) spores include all monolete members of the class Pteridophyta except Polypodiaceae because the perine is commonly preserved in this family. In this case, spores could be identified as *Polypodium vulgare*-type (Moore et al. 1991). Small (5-8 µm), inaperturate spores with thin exines devoid of noticeable sculpturing elements were identified as *Polytrichum*-type spores (Anderson et al. 1990; Kapp et al. 2000). Fossil *L. clavatum* is distinguished from exotic *L. clavatum* based on differential preservation and stain acceptance (Stanley 1966; Heusser 1983).

The main pollen sum (PS) includes all total terrestrial pollen and spores, including fern and moss spores since these groups constitute an important component of the vegetation of the CWHZ (Newmaster et al. 2003). The frequency of aquatic taxa

(*Sagittaria*, *Typha* and *Nuphar*) was calculated from the total pollen sum. Calculation of absolute pollen abundance followed Stockmarr (1971). Percentage and concentration pollen data were graphed using Tilia version 2.0 (Grimm 1993). The CONISS program for stratigraphically constrained cluster analysis using a square root data transformation was applied to aid pollen diagram zonation (Gordon and Birks 1976; Grimm 1987; Faegri and Iversen 1989).

3.4 Results

3.4.1 Chronology

The Tiny Lake record begins in the Late-Glacial based on a conventional radiocarbon age of 11,763 ± 87 yr BP (13,815 cal. yr BP) obtained from a bulk sediment sample at 338 cm (Table 3.1). An AMS radiocarbon age of 6860 ± 50 yr BP (7692 cal. yr BP) was obtained from a second bulk sediment sample at 88 cm. Bulk sediment samples, which are known to often yield dates that are too old (Brown et al. 1989), were used in this study because no macrofossils were obtained. Radiocarbon dates were calibrated using CALIB REV5.0 with the INTCAL04 dataset (Reimer et al. 2004; Stuiver et al. 2005). To avoid problems caused by the ocean reservoir effect since sea-levels were known to be higher than present in the early Late-Glacial throughout most of the coastal mainland of British Columbia (Clague et al. 1982), the bulk sediment sample for the basal date was taken from the lowest portion of the freshwater sediment unit, which yields a minimum age for the isolation from the sea (Pienitz et al. 1991; Doherty 2005). It does not date the actual sedimentological contact, but represents a later stage in the basin isolation process when extreme tides across the basin ceased and lacustrine sedimentation had commenced. Individual dates should be treated with caution and ideally several dates should be obtained from each basin in order to verify the accuracy of the results (Kaland et al. 1984). Due to financial constraints this was not possible, but the reliability of the two ages at Tiny Lake are supported by a suite of dates obtained from nearby Two Frog Lake by bio-(pollen) and lithostratigraphic correlation (Fig. 3.1). No Late-Glacial lacustrine radiocarbon reservoir correction was applied to the basal date, although, due to incorporation of old carbon from weathering of exposed glacial tills the age may be as much as ~630 years too old (Hutchinson et al. 2004). No tephras were observed in the Tiny Lake sediment core (Clague et al. 1995).

3.4.2 Pollen, spores and sedimentology

Thirty-eight pollen and spore taxa were identified from 45 horizons in the Tiny Lake sediment core. Five pollen assemblage zones (TP) are recognized based on CONISS and visual inspection (Fig. 3.3; Table 3.2; Appendix 3.1; Appendix 3.2). Age ranges for pollen zones were estimated based on biostratigraphic similarities with the dated Two Frog Lake sediment core (Fig. 3.4).

3.4.2.1 Zone TP-A (352-345 cm; prior to 11,763 ± 87 yr BP; prior to 13,815 cal. yr BP)

The sediments of this basal pollen zone consist of homogenous gray (Munsell colour 1/4/10Y) silty clay with sand and gravel and have a low percent LOI (~1%). These sediments were deposited under marine conditions, when the basin received a regular influx of oxygenated marine water from Mereworth Sound (Doherty 2005).

A high percentage of *Pinus* pollen (69%), mostly diploxylon-type *Pinus* pollen (50%), characterizes this pollen zone. Also present in this section, but in low relative abundances, are *Picea* (1-4%), *T. heterophylla* (0-6%), *Alnus* (3-8%) and *Salix* (0-2%) pollen. Cupressaceae pollen reaches 10% in this zone. Relatively high *Polytrichum*-type spores (~20%) and the presence of *Triglochin* L. (sea-arrow grass) pollen (~2%) are notable. Total terrestrial pollen concentrations in this zone fluctuate between 668 grains/mm^3 to 3695 grains/mm^3 and are largely represented by *Pinus* grains (concentration range of 360-1905 grains/mm^3).

3.4.2.2 Zone TP-B (345-240 cm; prior to 11,763 ± 87-ca. 10,200 yr BP; 13,815-ca. 12,300 cal. yr BP)

The basal sediments of this zone are homogeneous gray (24/5Bg) clays with silt, have percent LOI values of ca. 18% and were also deposited under marine conditions (Doherty 2005). At 343.5 cm, which represents the isolation of the basin from the sea, sediments grade upward over approximately 0.5 cm into gray (1/4/10Y) clay and dy that were probably deposited when relative sea-level was at the sill level of the basin (Doherty 2005). Tiny Lake may have experienced estuarine conditions during this phase, with occasional exchange of fresh and marine waters (Retelle et al. 1989; Corner and Haugane 1993; Corner et al. 1999; Doherty 2005). A radiocarbon date of 11,763 ± 87 yr BP was obtained from 338-336 cm.

At the beginning of this zone *Pinus* pollen decreases in this zone from 30% to 10% while increases in the relative abundances of *Picea* pollen (42%), *Abies* pollen (6%) and *Alnus* pollen (13%) occur. *Tsuga heterophylla* pollen peaks to 33% in this zone before declining to zero by the end of the zone, where *Pinus* pollen increases towards the to reach 30% in relative abundance. *Tsuga mertensiana* pollen is sporadically present near ~1% and Pteropsida (monolete) spores increase to 27%. Total terrestrial pollen concentrations are relatively high in this section (1790 grains/mm^3-5162 grains/mm^3).

3.4.2.3 Zone TP-C (240-135; ca. 10,200-8000 yr BP; ca. 12,300-9200 cal. yr BP)

The sediments of this pollen zone are characterized by black (10Yr/2/1) dy with minor changes in colour (5Yr/2.5/1 between 222-200 cm and 7.4 Yr/2.5/1 between 200-135 cm where a small proportion of fine sand occurs) and a high percent LOI (20-50%). Lake isolation probably produced changes in the inorganic/organic content of the sediment, with a gradual decrease in the supply of minerogenic material and a corresponding increase in organic sediments when lacustrine sedimentation predominated after the threshold of the basin emerged above high tide level (Seppa and Tikkanen 1998; Doherty 2005).

Pinus pollen decreases in this zone from 40% to less than 10% while *Alnus* pollen increases to 47%. *Picea* and *Abies* pollen decrease in relative abundances to less than 17% and 6%, respectively. *Pseudotsuga menziesii* is present at ~1% towards the end of this zone. The presence of Rosaceae (0-2%), *Artemisia* and *Sagittaria* pollen are notable (~0-1%). Total terrestrial pollen concentrations fluctuate in this zone between 1316 and 4465 grains/mm^3.

3.4.2.4 Zone TP-D (135-90 cm; ca. 8000-6860 ± 50 yr BP; 9200-7692 cal. yr BP)

The sediments of this zone consist of massive black (7.5Yr/2.5/1) dy with a small sand fraction, which fines upwards. The percent LOI of the sediments in this zone increases to 61% but subsequently declines to ~35%. *Alnus* pollen decreases to 7%, *Pinus* pollen decreases to 5% and *T. heterophylla* pollen increases to 49% in this zone. Cupressaceae pollen begins to increase (~15%) and *Abies* pollen occurs up to 9%. Pteropsida (monolete) spores decrease from ~20% to 7% by the end of the zone. Rosaceae and Lilaceae pollen is present at relative abundances of 5% and 1%, respectively. Total terrestrial pollen concentrations range from 1500 to 3688 grains/mm^3.

3.4.2.5 Zone TP-E (90-0 cm; 6860 ± 50 yr BP-present; 7692 cal. yr BP-present)

The sediments of this zone consist of massive black (10Yr/2/1) dy that is highly organic (LOI ~40-67%). A radiocarbon date of 6860 ± 50 yr BP was obtained from 88 cm.

This zone is characterized by an increase in Cupressaceae pollen to 73% and a decline in *T. heterophylla* pollen to less than 34%. The relative abundances of *Picea* and *Abies* pollen are low (4%) and Pteropsida (monolete) spores decrease to 2%. Total pollen concentrations fluctuate between 1144 and 2656 grains/mm^3 and are largely represented by Cupressaceae grains that fluctuate between 655 and 1609 grains/mm^3 in this zone.

3.5 Discussion

3.5.1 The Late-Glacial (TP-A and TP-B; 352-240 cm; prior to 11,763 ± 87-ca. 10,200 yr BP; 13,815-12,300 cal. yr BP)

Isolation of Tiny Lake from Mereworth Sound occurred prior to 11,763 ± 87 yr BP (13,815 cal. yr BP) and a sill height of 3.29 m represents an estimate of relative sea level change at that time. The sea-level history of the central mainland coast is poorly constrained with data only available from the Bella Bella region to the north of the SBIC where it is estimated that present day sea-levels were not reached until the late Holocene (Clague et al. 1982). The presence of *Triglochin* pollen at 340.0 cm suggests that following basin isolation salt marsh communities existed in the vicinity of Tiny Lake (Hughes and Mathewes 2003). *Pinus* diploxylon pollen is also prevalent in this section and based on macrofossil evidence from other sites, this pollen type is probably attributable to *P. contorta* (Hebda 1983; Wainman and Mathewes 1987; Lacourse et al. 2003). *Pinus* pollen is notoriously over-represented in lake sediments since pollen grains are adapted for wind and aquatic dispersal (Heusser and Balsam 1977) but modern pollen spectra studies suggest that *Pinus* pollen percentages of ~60% at Tiny Lake in this section may be indicative of local growth (Hebda and Allen 1993). Since *P. contorta* is shade intolerant, this tree probably grew as a few scattered individuals around Tiny Lake during this interval.

The newly deglaciated and emerged landscape was probably in the process of secondary succession at this time, suggested by the presence of *Alnus* pollen in this section (Fonda 1974). *Alnus* was not present at Two Frog Lake during the early Late-Glacial, possibly because the climate was too dry. The *Alnus* in this section is probably attributable to *A. sinuata*, which is capable of growth on nutrient poor soils in dry open habitats.

High relative abundances (up to 20%) of *Polytrichum*-type spores at Tiny Lake during this interval are worthy of note and are probably attributable to *P. piliferum* and/or *P. juniperinum*, which are common on disturbed, dry minerogenic substrates (Crocker and Major 1955; Pojar and MacKinnon 1994). *Juniperus communis* is also capable of growth in harsh environments on dry rocky exposures, so this shrub is a possible source of the Cupressaceae pollen in this section (Pojar and MacKinnon 1994). The unstable landscape at Tiny Lake may have promoted *Pinus* dominance during this interval, but *Picea* is also capable of colonizing mineral substrates (Harris 1990; Peterson et al. 1997). *Pinus contorta* was geographically widespread during the early Late-Glacial, occupying other sites in the SBIC (Stolze 2004), the coastal islands (Hebda 1983; Fedje and Josenhans 2000; Brown and Hebda 2002a; Stolze 2004; Lacourse 2005), the southern mainland coast (Mathewes 1973) as well as in Washington and Alaska (Heusser 1977; Peteet 1991; McLachlan and Brubaker 1995; Hansen and Engstrom 1996; Grigg and Whitlock 1998), suggesting that regional climate controlled its distribution. The persistence of *Pinus* during the early Late-Glacial on unglaciated sites on the Queen Charlotte Islands provides additional evidence that its dominance in the Pacific Northwest at this time was not merely edaphic or successional (Heusser 1956; Warner et al. 1982; Mathewes and Clague 1982; Hebda 1983; Mathewes et al. 1995). A cool and dry Late-Glacial climate would have excluded *Picea* and other more shade tolerant mesic taxa, which usually replace *Pinus* after 50-200 years (Pfister and Daubenmire 1975), and thus sustained an open *Pinus* woodland at Tiny Lake at this time (Mathewes 1973; Heusser 1977; Heusser et al. 1980; COHMAP Members 1988; Mathewes et al. 1993; Hebda 1995; Brown and Hebda 2002a; Lacourse 2005).

At 11,763 ± 87 yr BP (13,815 cal. yr BP), a rise in *Picea* and *Abies* pollen occurred accompanied by a marginal decline in *Pinus* pollen. Based on modern pollen rain in the CWHZ, *Picea* pollen percentages of 20-30% at Tiny Lake translate to approximately 10% ground cover and *Abies* pollen percentages of 5-10% are indicative of local occurrence (Hebda and Allen 1993). Thus, a mixed conifer forest of *Picea, Abies* with persistent *P. contorta* replaced the open *Pinus* woodland. *Tsuga mertensiana* pollen percentages of ~1% in this zone are probably due to an extra-local component (Peteet 1986). Since *Picea* is capable of growth on a wide range of substrates it is unlikely that soil development or succession was the ultimate cause of its expansion, although the presence of *Alnus* probably facilitated the growth of this tree by increasing soil nitrogen availability in poorly developed, newly exposed soils (Hebda 1983; Chapin et al. 1994; Fastie 1995). It is unlikely that migration lags were factors in the delayed development of this forest since a possible refugium for *Picea* and *Abies* existed on Beringia during the last glacial maximum, which suggests that long-distance northerly migration may not have been the predominant mode of postglacial re-colonization (Brubaker et al. 2005). Additionally, both of these taxa were present in the Fraser Lowlands during the Port moody Interstade 18,000 yr BP (Lian et al. 2001). Both *Abies* and *Picea* require moderate amounts of moisture and it is plausible that a moistening climate in central coastal British Columbia permitted colonization of Tiny Lake by these taxa. Relatively high pollen concentrations (1790-5162 grains/m^3 in TP-B), abundance of understory vegetation (e.g., Pteridophytes) and a low relative abundance of shade intolerant taxa such as *Alnus* suggest that the forest canopy was relatively closed.

Tsuga heterophylla briefly became an important component of forests around Tiny Lake after 11,763 ± 87 yr BP (13,815 cal. yr BP) when the longevity and superior shade tolerance of this taxon probably allowed it to temporarily replace *Picea* (Fonda 1974). Shortly after rise of *T. heterophylla*, a reversal of successional trends occurred when *Picea* regained dominance and *P. contorta* increased to proportions of 30%. It is possible that Younger-Dryas-like cooling arrested successional trends, as may have occurred at Two Frog Lake around 11,040 ± 50 (13,030 cal. yr BP) and Misty Lake on northern Vancouver Island between 10,600-10,400 yr BP (11,660-11,480 cal. yr BP), but additional chronological control is required in order to constrain the timing of these successional events (Fonda 1974; Mathewes 1993; Chapin et al. 1994; Lacourse 2005).

3.5.2 The early Holocene (TP-C; 240-135cm; ca. 10,200-8000 yr BP; 12,300-9200 cal. yr BP)

Tiny Lake pollen zone TP-C is interpreted as being of early Holocene age based on pollen stratigraphic similarities to a dated correlative zone (TFP-C) in the Two Frog Lake sediment core (Fig. 3.4). *Alnus* pollen increases to reach peak values (~50%) at this time at Tiny Lake and may be correlated to the ubiquitous *Alnus* rise in the Pacific Northwest at ca. 10,500 yr BP (Mathewes 1973; Heusser 1977; Hebda 1983; Heusser 1983; McLachlan and Brubaker 1995; Whitlock et al. 2000; Brown and Hebda 2002a; Hallett et al. 2003).

An increase in *T. heterophylla* in this interval suggests that a forest mosaic of *T. heterophylla* and *Alnus* replaced the previous community of *Picea*, *Abies* and *Pinus* at Tiny Lake. The climate at this time was probably warmer than during the cool Late-

Glacial, indicated by the presence of *T. heterophylla* which thrives in mild conditions, and moist, since drought would have been restrictive for both *T. heterophylla* and *Alnus* (Mathewes 1973; Cwynar 1987; Hebda 1983). *T. heterophylla* was also present in the early Holocene at Two Frog Lake and Woods Lake at this time, indicating that its presence in this section is not a local phenomenon because it was regionally distributed in the SBIC at this time.

Climate models, pollen transfer functions and other palynological reconstructions from the Pacific Northwest document a shift to a warm and dry climate at ca. 10,000 yr BP when an orbitally induced maximum in solar insolation and the retreating Laurentide Ice Sheet affected temperatures and moisture in the Pacific Northwest (Mathewes 1973; Mathewes and Heusser 1981; Hebda 1983; COHMAP Members 1988; Berger and Loutre 1991; Brown and Hebda 2002a; Lacourse 2005). A warm and dry early Holocene climate allowed *P. menziesii* to expand in range northward to occupy sites on northern Vancouver Island (Heusser et al. 1980; Hebda 1995; Lacourse 2005) as well as at Two Frog Lake and Woods Lake in the SBIC (Stolze 2004) but this taxon probably did not grow during the early Holocene at Tiny Lake since pollen percentages of only 1% are not considered indicative of local occurrence (Tsukada 1982; Hebda 1983). Meso-scale (10-100 km) climate variability within the SBIC and/or site-specific soil conditions at Tiny Lake may have resulted in the exclusion of *P. menziesii* from this site (Turunen and Turunen 2003). Two Frog Lake and Woods Lake are located approximately 12 and 22 km south, respectively, of Tiny Lake so it is also possible that *P. menziesii* never reached Tiny Lake during its early Holocene northward migration on the coastal mainland of British Columbia. *Pseudotsuga menziesii* was present in greater abundances at Woods

Lake (~4%; Stolze 2004) than at Two Frog Lake (~2%) and was also absent in early Holocene pollen spectra from Diana Lake Bog, north of the SBIC (Turunen and Turunen 2003), lending support to this hypothesis.

An increase in regional fire disturbance may have promoted the early Holocene expansion of *Alnus* at Tiny Lake through the generation of canopy gaps and alteration of soil characteristics (Cwynar 1987; Long et al. 1998; Hallett and Walker 2000). Disturbed soils would have promoted the growth of *Artemisia* and open sites may have allowed Rosaceae to increase in relative abundance at this time (Pojar and MacKinnon 1994; Brown and Hebda 2002a). However, *Alnus* is capable of growth on a wide range of substrates and a changing hydrological or nutrient cycling regime associated with a warmer and drier climate may also have been responsible for its expansion at this time (Harrington 1990; Hu et al. 2001). An increase of *Typha* and *Sagittaria* pollen and the occurrence of fine sands in this section of the sediment core may be evidence for a lowered water level at Tiny Lake. Lowered water levels would have exposed shore-line habitat that would have been colonized by *A. rubra*, which was the predominant *Alnus* species during the early Holocene at Misty Lake (Lacourse 2005).

3.5.3 The early Holocene to mid-Holocene (TP-D; 135-90 cm; ca. 8000-6860 ± 50 yr BP; ca. 9200-7692 cal. yr BP)

An increase of *T. heterophylla*, Cupressaceae (probably *T. plicata*) and *Abies* pollen occurs at ca. 8000 yr BP (ca. 9200 yr BP). *Thuja plicata* is a co-climax species with T. *heterophylla* in wet regions of coastal British Columbia today, so the increase of its pollen at this time is interpreted to mark the onset of Holocene climate moistening and cooling at Tiny Lake (Krajina 1969; Mathewes 1973; Hebda 1983; Heusser 1983; Minore 1990; Packee 1990; Klinka et al. 1996; Pellatt et al. 2001; Brown and Hebda 2002a; Lacourse 2005). At more northerly sites, such as Diana Lake Bog (54°09'N, 130°15'W) on the northern mainland coast of British Columbia and in southwestern Alaska, the transition to a moister and cooler climate also began at ca. 8000 yr BP (ca. 10,000 cal. yr BP; Turunen an Turunen 2003; Axford and Kaufman 2004). In south coastal British Columbia and Washington palynological studies do not document this climate transition until ca. 6600 yr BP and ca. 7500 yr BP, respectively (Fig. 2.5; Mathewes 1973; Heusser et al. 1980; Barnosky 1981; Leopold et al. 1982; Hebda 1983; Hebda and Mathewes 1984; Heusser et al. 1985; McLachlan and Brubaker 1994; Pellatt and Mathewes 1994, 1997; Brown and Hebda 2002a; Lacourse 2005). A possible mechanism for climatic heterogeneity in coastal British Columbia and Washington during the early to mid Holocene may have been a dynamic Aleutian Low pressure system. If the Aleutian Low was on average more eastward and/or intense at this time than during the early Holocene, it would have displaced the polar jet stream southward of its usual position over the Gulf of Alaska (Mantua and Hare 2002; Dean and Kemp 2004). Since storm tracks are directed along this ribbon of fast moving air, a southward-displaced jet stream would have steered North Pacific storm tracks into northern British Columbia, possibly resulting in a wetter climate in the SBIC relative to south coastal British Columbia. It is interesting to note that the timing of the transition to a moist modern climate in Washington is similar to the existing data from the SBIC (i.e., Two Frog Lake, Woods Lake and this study). The meteorology of coastal British Columbia and atmospheric dynamics associated with the Aleutian Low are substantially more complex than what has been described here, and depending on the position of a ridge of high pressure over western North America that is commonly associated with a more intense Aleutian Low, some North Pacific storms may have also been diverted southwards into the northwestern United States (Klein 1949). More research in the SBIC and central and north coastal sites would substantiate the hypothesis of an Aleutian Low-driven climate at this time by better constraining the onset of *T. plicata* expansion and climate moistening and cooling in this region and by determining the geographical extent of these phenomena.

3.5.4 The mid to late Holocene (TP-E; 90-0 cm; 6860 ± 50 yr BP-present; 7692 cal. yr BP-present)

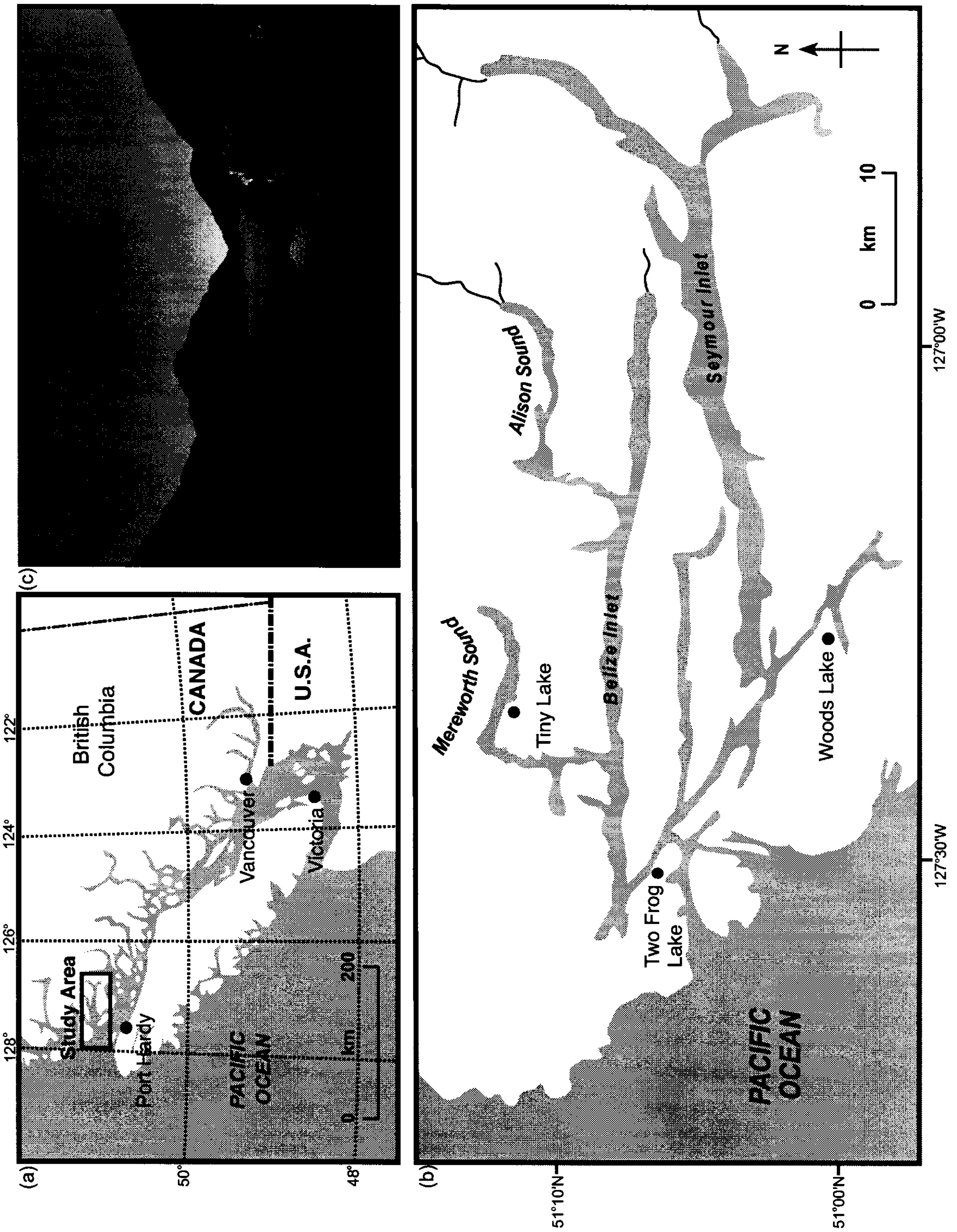
At 6860 ± 50 yr BP (7692 cal. yr BP) Cupressaceae (likely *T. plicata*) markedly increased and replaced *T. heterophylla* as the dominant taxon in coastal forests, although *T. heterophylla* did remain as an important component. Since *T. plicata* requires wet and cool environments with nutrient rich soils, these conditions must have been established at Tiny Lake by this time (Krajina 1969). Site-specific edaphic qualities, disturbance regimes and topography can result in *T. plicata* dominance in coastal forests of British Columbia but so can an exceptionally wet climate (Krajina 1969; Franklin and Dyrness 1973; Minore 1990; Weber 2003). *Thuja plicata* was the mono-specific dominant at Two Frog Lake and Woods Lake (Stolze 2004), which suggests that a regionally wet and cool climate may have promoted *T. plicata* dominance in late Holocene forests in the SBIC. However, the late Holocene persistence of *T. heterophylla* at Tiny Lake indicates that localized factors favorable to *T. heterophylla* have also been an important control on late Holocene forest dynamics at this site.

Other sites in coastal British Columbia document *T. heterophylla* as the dominant taxon in late Holocene forests, or register *T. plicata* and *T. heterophylla* as co-dominants because these taxa are ecologically similar, but also probably because *T. plicata* did not reach maximum expansion in more southern sites until 3500 yr BP when a sufficiently cool and moist climate developed , therefore forest history may have been important at this site (Krajina 1969; Mathewes 1973; Hebda 1983; Lacourse 2005). The relatively early expansion of *T. plicata* and its dominance in late Holocene forests at Tiny Lake, and elsewhere in the SBIC, indicates that late Holocene forest and climate dynamics have been site specific across western North America during the late Holocene (e.g., Brown and Hebda 2002a).

3.6 Conclusions

Palynological analysis of a sediment core collected from Tiny Lake reveals that this region has undergone considerable climate and vegetation change over at least the past 11,763 ± 87 years (13,815 cal. years). Post-glacial climate dynamics recorded at Tiny Lake are comparable to those documented elsewhere in coastal British Columbia but the Holocene vegetation history at this site differs in detail from previous work. Following deglaciation of Tiny Lake, an open *P. contorta* woodland occupied the landscape at Tiny Lake when the climate was regionally cool and dry. This woodland was replaced at 11,763 ± 87 yr BP (13,815 cal. yr BP) by a mixed conifer forest of *P. contorta*, *Picea* and *Abies* when the climate became more humid. Early Holocene forests were dominated by a successional mosaic of *T. heterophylla* and *Alnus* and were distinct in coastal British Columbia because *P. menziesii* was absent. This taxon migrated as far north as Two Frog Lake but either did not reach this site or was competively excluded by *T. heterophylla* on moist sites. At ca. 8000 yr BP (ca. 9200 cal. yr BP), the development of a moister and cooler climate allowed *T. heterophylla-T. plicata* forests to develop. The initial rise of *T. plicata* and onset of moist and cool conditions at this site precedes the termination of the early Holocene xerothermic interval in south coastal British Columbia by approximately 1000 years (Mathewes and Heusser 1981). *Thuja plicata* increased to become the dominant taxon in late Holocene forests at Tiny Lake after 6860 ± 50 yr BP (7692 cal. yr BP) when an even cooler and moister modern climate developed. The Holocene climate and vegetation history at Tiny Lake was compared to two other pollen records from the SBIC, Woods Lake and Two Frog Lake. Patterns of vegetation change are broadly similar, providing a consensus reconstruction of climate change that suggests that climate has been the proximate control on post-glacial forest dynamics of this region and that site-specific factors were secondary in controlling vegetation change.

Figure 3.1: (a) Map of North America showing the location of the study site (after Vazquez-Riveiros et al. in preparation), (b) Photograph of Mereworth sound showing the steep topography of this region and (c) map of the Seymour-Belize Inlet complex showing the location of Two Frog Lake, Tiny Lake and Woods Lake (mentioned in text).


(a)
(b)
(c)
128°
126°
124°
122°
50°
48°
Study Area
Port Hardy
British Columbia
CANADA
U.S.A.
Vancouver
Victoria
PACIFIC OCEAN
0 km 200
Mereworth Sound
Tiny Lake
Belize Inlet
Alison Sound
Seymour Inlet
Two Frog Lake
Woods Lake
PACIFIC OCEAN
0 km 10
N
51°10'N
51°00'N
127°30'W
127°00'W

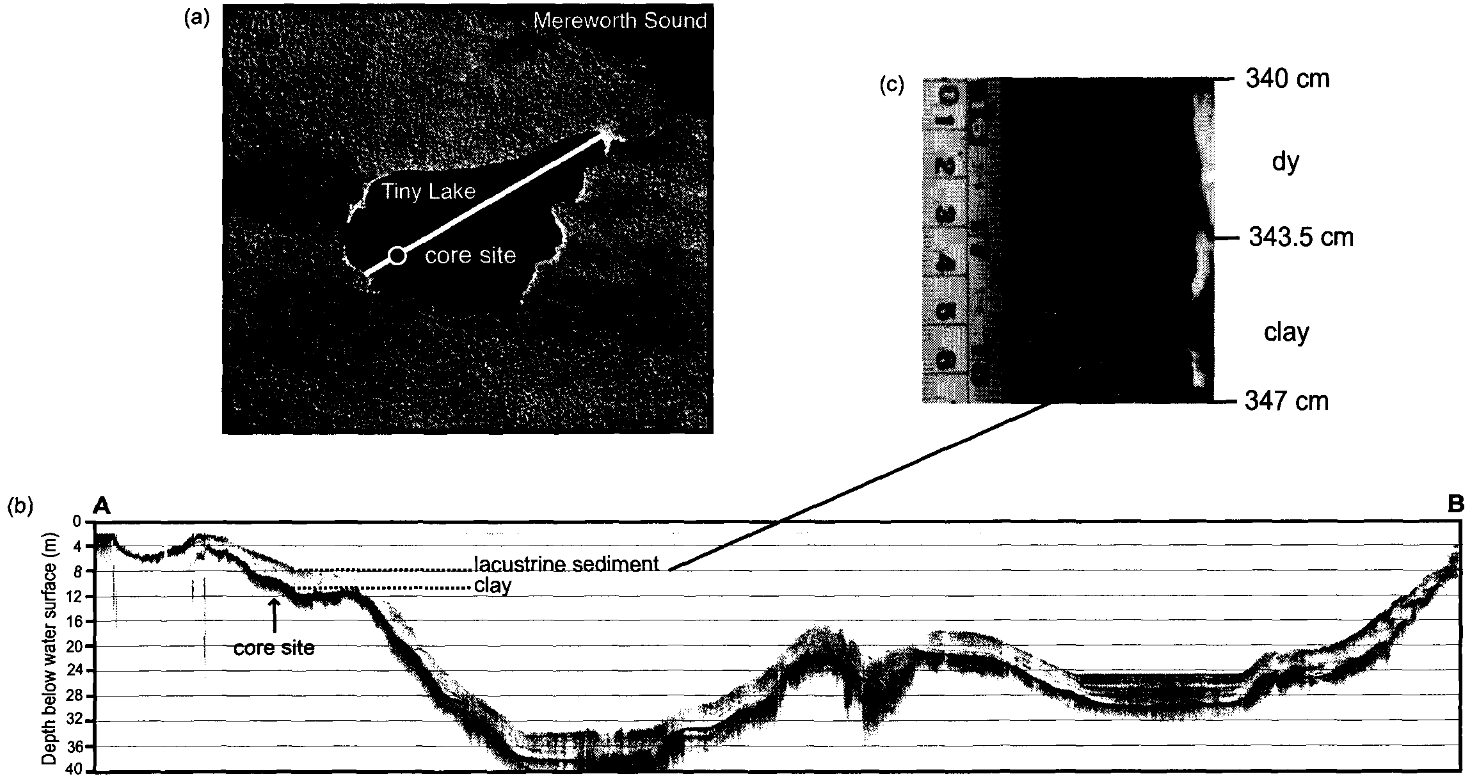
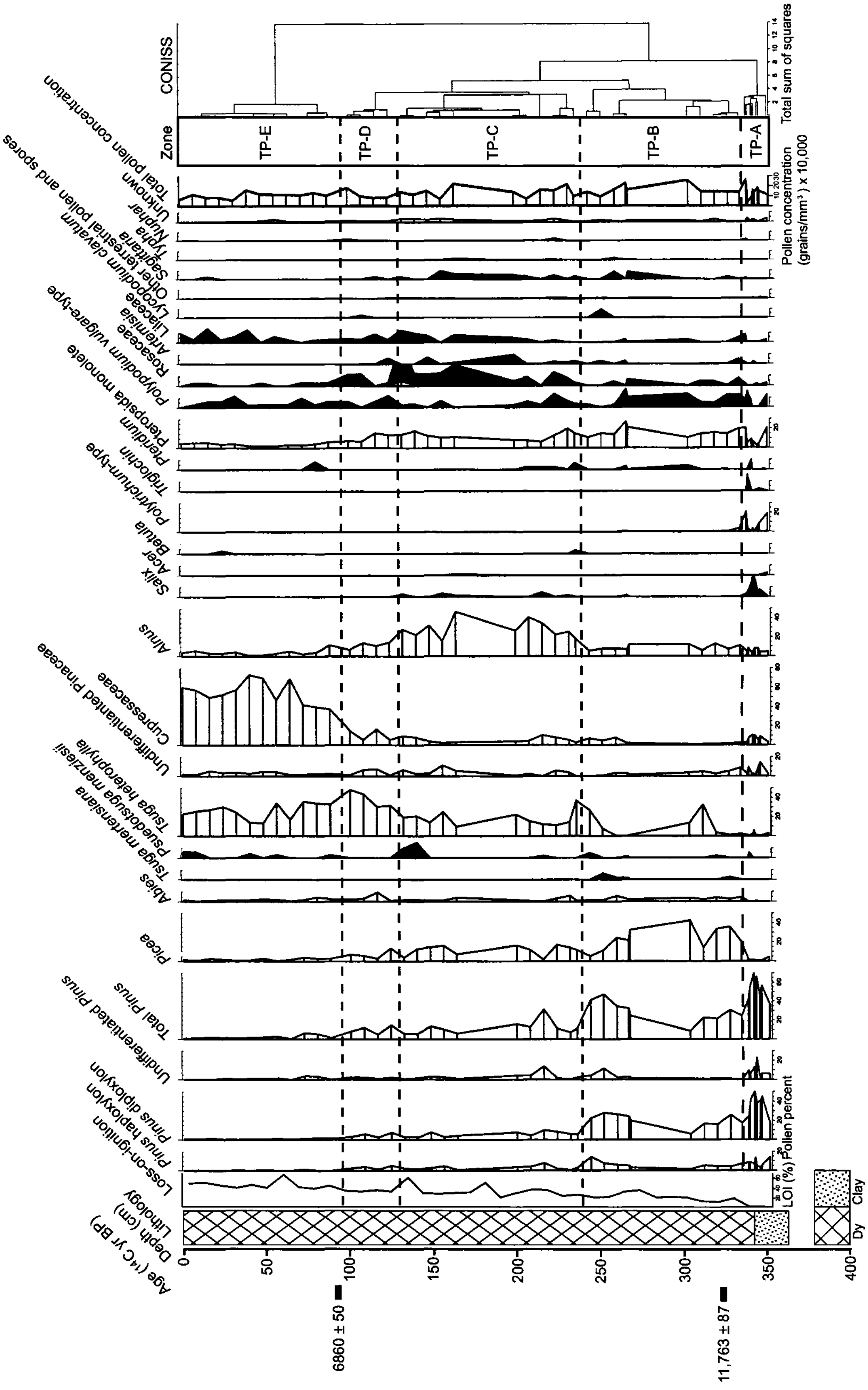


Figure 3.2: (a) Air photo of Tiny Lake with schematic diagram overlain showing the coring location and the transect of the sub-bottom profile, (b) sub-bottom profile of Tiny Lake showing the sedimentary infill of the basin and (c) a photograph of the lower portion of the Tiny Lake sediment core showing the sedimentological contact between basal clay and overlying dy.

Figure 3.3: Summarized pollen percentage diagram for the Tiny Lake core. Lithology, chronology and percent loss-on-ignition of data are displayed on the left side of the diagram. Shaded areas represent a 10% exaggeration of select taxa.


Age (¹⁴C yr BP)
Depth (cm)
Lithology
Loss-on-ignition
Pinus haploxylon
Pinus diploxylon
Undifferentiated Pinus
Total Pinus
Picea
Abies
Tsuga mertensiana
Pseudotsuga menziesii
Tsuga heterophylla
Undifferentiated Pinaceae
Cupressaceae
Alnus
Salix
Acer
Betula
Polytrichum-type
Triglochin
Pteridium
Pteropsida
Polypodium monolete
Rosaceae
Artemisia
Liliaceae
Lycopodium clavatum
Other terrestrial pollen and spores
Sagittaria
Typha
Nuphar
Unknown
Total pollen concentration
Zone
CONISS
TP-E
TP-D
TP-C
TP-B
TP-A
0
50
100
150
200
250
300
350
400
6860 ± 50
11,763 ± 87
Dy
Clay
LOI (%)
Pollen percent
Pollen concentration (grains/mm³) x 10,000
Total sum of squares

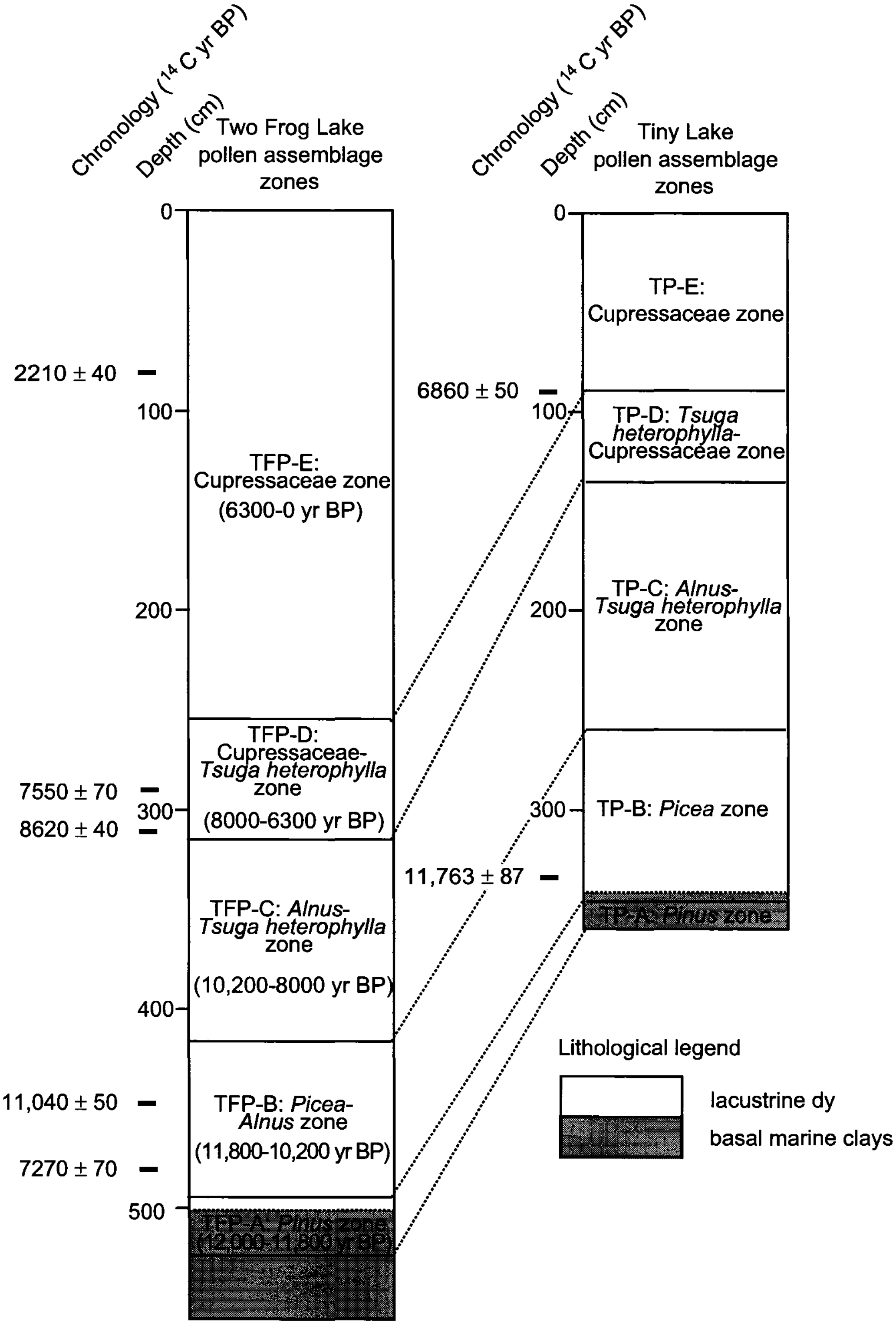


Figure 3.4: Comparitive stratigraphy diagram for the Two Frog Lake and Tiny Lake sediment cores. Age ranges in brackets are estimates from the age-depth model for Two Frog Lake.

Table 3.1: Conventional radiocarbon and calibrated ages of the Tiny Lake sediment core.

Laboratory Code	Depth (cm)	Material	$^{13}C/^{12}C$ ratio (‰)	Conventional ^{14}C age yr BP	Calibrated age yr BP (95% C.I.)†
BETA-206929	88	dy-gyttja	-27.8	6860 ± 50	7692
SUERC-3090	338-336	dy-gyttja	-29.0*	11,763 ± 87	13,815

* Conventional radiocarbon date corrected using a $^{13}C/^{12}C$ ratio (‰) of -25.0

† Calibrated using CALIB REV5.0.1 (Stuiver and Reimer 1993)
with the INTCAL04.C14 data set (Reimer et al. 2004); BP denotes before 1950

Table 3.2: Summary of pollen percentage and concentration results of the Tiny Lake sediment core.

Pollen assemblage zone	Depth (cm)	Arboreal pollen percentage	Non arboreal pollen percentage	Total pollen concentration (grains/mm^3)
TP-A	352-345	*Pinus*, 37-64%; Cupressaceae, 3-11%; *Alnus*, 3-8%; *T. heterophylla*, 0-6%; *Picea*, 1-4%; *Salix*, 0-2%	*Polytrichum*-type, 0-21%; Pteropsida (monolete), 3-20%; *Triglochin*, 0-2%; *Polypodium vulgare*-type 0-1%	648-3695
TP-B	345-240	*Pinus*,9-30% ; *Picea*, 5-42%; *T. heterophylla*, 0-33%; *Alnus*, 6-13%; Cupressaceae, 1-8%; *Abies*, 2-6%	Pteropsida (monolete), 11-27%; *Polytrichum*-type, 0-3%; *Polypodium vulgare*-type, 0-2%	1790-5162
TP-C	240-135	*Alnus*, 16-47%, *T. heterophylla*, 10-37%; *Pinus*, 6-32%; *Picea*, 2-17%; Cupressaceae, 2-11%; *Abies*, 0-6%	Pteropsida (monolete), 6-18%; Rosaceae, 1-2%; *Polypodium vulgare*-type, 0-1%; *Sagitarria*, 0-1%; *Artemisia*, 0-1%	1316-4465
TP-D	135-90	*T. heterophylla*, 20-49%; *Alnus*, 7-28%; Cupressaceae, 6-17%; *Pinus*, 5-15%; *Picea*, 3-14%; *Abies*, 1-9%	Pteropsida (monolete), 7-16%; Rosaceae, 0-5%; *Polypodium vulgare*-type, 0-1%; *Iris*, 0-1%	1500-3688
TP-E	90-0	Cupressaceae, 38-73%; *T. heterophylla*, 13-36%; *Pinus*, 0-7%; *Abies*, 1-4%; *Picea*, 0-4%	Pteropsida (monolete), 2-6%; *Polypodium vulgare*-type, 0-1%; Lilaceae, 0-1%	1144-2656

Appendix 3.1: Arboreal pollen counts for the Tiny Lake sediment core.

Depth (cm)	*Pinus haploxylon*	*Pinus diploxylon*	Undifferentiated *Pinus*	Total *Pinus*	*Picea*	*Abies*	*Tsuga heterophylla*	*Tsuga mertensiana*	*Psuedotsuga menziesii*	Undetermined Pinaceae	Cupressaceae	*Alnus*	*Salix*	*Acer*	*Betula*
0	0	3	0	3	5	5	71	0	2	7	186	12	0	0	0
8	1	2	1	4	3	2	86	0	2	5	192	19	0	0	0
16	1	6	0	7	9	4	92	0	0	18	170	11	0	0	0
24	0	1	4	5	6	5	101	0	0	12	176	10	0	0	1
32	1	1	1	3	2	4	81	0	0	14	190	14	0	0	0
40	0	3	4	7	5	8	64	0	2	12	335	4	0	0	0
48	2	2	3	7	9	8	45	0	0	16	238	4	0	0	0
56	0	4	5	9	1	6	110	0	1	14	152	9	0	0	0
64	0	1	0	1	5	2	56	0	0	5	226	17	0	0	0
72	4	4	12	20	12	6	111	0	0	6	130	7	0	0	0
80	0	8	12	20	10	16	127	0	0	9	149	15	0	0	0
88	0	5	0	5	9	9	109	0	1	8	125	38	0	0	0
100	13	16	13	42	35	11	251	0	0	7	78	35	0	0	0
108	13	19	8	40	18	11	144	0	0	21	18	45	0	0	0
116	4	9	3	16	9	31	103	0	0	25	56	36	0	0	0
124	17	24	7	48	44	3	103	0	0	3	18	47	0	0	0
132	8	11	3	22	14	7	77	0	4	25	37	110	1	0	0
140	5	8	5	18	40	6	65	0	5	8	25	70	0	0	0
148	12	32	13	57	62	4	59	0	0	12	16	137	0	0	0
156	14	9	8	31	49	4	76	0	0	34	7	48	1	0	0
164	4	28	6	38	46	26	62	0	0	36	19	303	1	1	0
200	15	31	18	64	67	7	91	0	0	3	16	109	0	0	0
208	14	14	14	42	40	2	51	0	0	8	15	135	0	0	0
216	35	44	62	141	7	1	54	0	1	0	47	155	2	0	0
224	8	35	5	48	73	14	48	0	0	25	34	96	0	0	0
232	4	35	4	43	86	36	89	0	0	23	32	157	1	0	0
236	10	17	7	34	35	3	112	0	0	1	8	55	0	0	1
244	55	88	17	160	20	6	103	0	2	0	27	22	0	0	0
252	23	87	36	146	35	5	23	2	0	2	14	23	0	0	0
260	27	122	10	159	111	26	1	1	0	16	35	36	0	0	0
267	33	156	20	209	139	15	2	1	1	20	11	44	1	0	0
268	14	91	7	112	150	10	3	0	0	7	10	54	0	0	0

Depth (cm)	*Pinus haploxylon*	*Pinus diploxylon*	Undifferentiated *Pinus*	Total *Pinus*	*Picea*	*Abies*	*Tsuga heterophylla*	*Tsuga mertensiana*	*Psuedotsuga menziesii*	Undetermined Pinaceae	Cupressaceae	*Alnus*	*Salix*	*Acer*	*Betula*
304	11	43	8	62	307	28	98	0	0	26	6	88	0	0	0
312	22	66	3	91	57	9	131	0	0	20	3	23	0	0	0
320	20	72	6	98	154	19	16	0	1	12	5	59	0	0	0
328	15	100	3	118	138	10	3	1	0	19	6	26	0	0	0
335	28	68	1	97	79	18	8	0	0	34	9	43	0	0	0
339	60	185	70	315	18	2	6	0	0	19	19	36	2	0	0
340	15	76	10	101	2	0	0	0	1	17	13	15	1	0	0
342.5	21	156	41	218	5	0	7	0	0	1	33	9	5	0	0
343	60	208	0	268	4	2	26	0	0	12	42	24	10	0	0
344	17	148	89	254	3	2	2	0	0	0	38	30	8	0	0
346	17	213	4	234	3	0	3	0	0	50	23	40	2	0	0
347	22	183	26	231	2	0	0	0	0	58	36	15	3	0	0
352	53	67	23	143	17	1	11	0	0	9	11	18	0	1	0

Appendix 3.2: Non-arboreal pollen and spore counts for the Tiny Lake sediment core.

Depth (cm)	Polytrichum-type	Triglochin	Pteridium	Pteropsida (monolete)	Polypodium vulgare-type	Rosaceae	Artemisia	Liliaceae	Lycopodium clavatum	Ericaceae	Impatiens	Brassica	Plantanus	Poaceae	Vitis	Ambrosia	Arceuthombium	Eupatorium	Cheilanthes	Huperzia	Equisetum	Botychium	Selaginella	Unknown I*	Unknown	Main pollen sum	Sagittaria	Typha	Nuphar	Total pollen sum*	Exotic Lycopodium
0	0	0	0	15	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	311	0	0	0	311	51
8	0	0	0	18	1	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	336	0	0	0	336	30
16	0	0	0	20	2	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	340	1	0	0	341	41
24	0	0	0	13	2	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	334	0	0	0	334	41
32	0	0	0	14	4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	332	0	0	0	332	62
40	0	0	0	11	1	0	0	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	459	0	0	0	459	30
48	0	0	0	7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	341	0	0	0	341	30
56	0	0	0	7	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	322	0	0	0	322	30
64	0	0	0	11	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	328	0	0	0	328	30
72	0	0	0	9	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	307	0	0	0	307	30
80	0	0	3	16	1	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	373	0	0	0	373	30
88	0	0	0	21	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	332	0	0	0	332	34
100	0	0	0	38	3	6	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	9	518	0	0	1	519	30
108	0	0	0	23	0	4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	330	0	0	0	330	36
116	0	0	0	53	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	337	1	0	0	338	45
124	0	0	0	44	4	1	2	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	4	325	0	0	0	325	42
132	0	0	0	55	1	18	0	5	0	0	0	1	0	1	0	2	0	0	0	0	0	0	0	0	14	394	1	0	0	395	30
140	0	0	0	55	1	4	0	3	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	11	315	0	0	0	315	30
148	0	0	0	54	0	5	3	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	12	425	0	0	0	425	30
156	0	0	0	33	2	4	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	11	302	3	0	0	305	49
164	0	0	0	75	0	14	1	5	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	18	648	4	1	0	653	31
200	0	0	0	34	1	2	4	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	406	2	0	0	408	31
208	0	0	1	26	2	3	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	332	1	0	0	333	52
216	0	0	1	28	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	447	0	0	0	447	30
224	0	0	1	56	6	6	1	1	0	1	0	0	0	0	0	4	1	0	0	0	0	0	0	0	14	429	2	0	1	432	30
232	0	0	0	121	4	5	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	10	612	0	0	0	612	30
236	0	0	2	46	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	302	1	0	0	303	34
244	0	0	0	43	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	388	0	0	0	388	30
252	0	0	0	47	0	0	1	0	3	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	7	310	0	0	0	310	37
260	0	0	0	64	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	5	458	4	1	0	463	30
267	5	0	2	174	12	0	2	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	643	0	0	0	643	30
268	0	0	0	97	5	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	460	4	0	0	464	30
304	0	0	3	79	10	0	0	2	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	13	725	0	0	0	725	30

Depth (cm)	*Polytrichum*-type	*Triglochin*	*Pteridium*	Pteropsida (monolete)	*Polypodium vulgare*-type	Rosaceae	*Artemisia*	Lilaceae	*Lycopodium clavatum*	Ericaceae	*Impatiens*	*Brassica*	*Plantanus*	Poaceae	*Vitis*	*Ambrosia*	*Arceuthombium*	*Eupatorium*	*Cheilanthes*	*Huperzia*	*Equisetum*	*Botychium*	*Selaginella*	Unknown I*	Unknown	Main pollen sum	*Sagittaria*	*Typha*	*Nuphar*	Total pollen sum†	Exotic *Lycopodium*
312	0	0	0	59	2	2	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	400	0	0	0	400	30
320	2	0	0	73	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	14	458	0	0	0	458	34
328	1	0	0	56	5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	386	1	0	0	387	30
335	13	0	1	78	5	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	393	0	0	0	393	30
339	155	0	2	150	6	1	1	6	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	5	745	1	0	1	747	30
340	5	3	0	8	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	7	182	0	0	0	182	60
342.5	0	0	3	29	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	314	0	0	0	314	35
343	15	0	0	31	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	1	0	11	450	0	0	0	450	30
344	0	0	0	22	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	14	9	385	0	0	0	385	30
346	27	1	0	13	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	117	2	519	0	0	0	519	30
347	35	2	0	18	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	2	0	0	2	407	0	0	0	407	30
352	73	0	0	78	5	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	14	386	0	0	0	386	38

*Unknown I: *Small palynomorph (5-8 μm), no aperatures visible, echinate with spines of differing size*

†Total pollen sum = main pollen sum + aquatics

CHAPTER FOUR

A HIGH-RESOLUTION LATE HOLOCENE RECORD OF FOREST HISTORY AND CLIMATE FROM AN ANOXIC FJORD, CENTRAL COASTAL BRITISH COLUMBIA

Abstract

Pollen and spores preserved in a radiocarbon dated sediment core retrieved from Frederick Sound, an anoxic fjord in the Seymour-Belize Inlet Complex of central coastal British Columbia, were used to reconstruct a regional climate and vegetation history from ca. 4200 cal. yr BP (ca. 3800 ^{14}C yr BP) to ca. 1000 cal. yr BP (ca. 1200 ^{14}C yr BP) with a time resolution of 26 calendar years (21 radiocarbon years). Cupressaceae (likely *Thuja plicata*) was the dominant arboreal taxon throughout the record but declined in abundance between ca. 2800-1900 cal. yr BP (ca. 2600-1900 ^{14}C yr BP). It is postulated that a brief dry and cool climate punctuated the otherwise wet conditions of the late Holocene in the Seymour-Belize Inlet Complex and was the proximate cause of the decline of *T. plicata*, although the role of biotic factors, such as a pathogen attack or selective human felling, cannot be ruled out. Neither a decline in *T. plicata* nor a dry climate is widely recognized in the coastal Pacific Northwest at this time, but the timing of vegetation change broadly corresponds to proposed changes in the intensity and position of the Aleutian Low pressure system, which suggests that millennial scale variability of this semi-permanent air mass has affected the climate and vegetation of the Seymour-Belize Inlet Complex throughout most of the late Holocene. This study validates the use of high-resolution palynology in paleoecological and paleoclimatological research since a lower-resolution study would probably not have recognized the *T. plicata* decline.

4.1 Introduction

Lakes of coastal British Columbia have been the focus of several detailed late Quaternary investigations using pollen and spores fossilized in sedimentary successions (e.g., Heusser 1956; Mathewes 1973; Hebda 1983; Brown and Hebda 2002; Lacourse 2005). This research has shown that considerable climate and vegetation change has occurred since deglaciation ca. 13,000 ^{14}C yr BP (Barrie and Conway 1999) and that climate in the last 5000 years, representing the late Holocene, has also been highly variable (Hebda 1983; Brown and Hebda 2002a; Lacourse 2005).

Pollen and spores are also well preserved in coastal marine sediments where they are representative of terrestrial vegetation and climate (Heusser and Florer 1973; Heusser and Balsam 1977; Heusser 1983; Heusser 1988; Heusser and Van de Geer 1994; Mudie and McCarthy 1994; Lyle et al. 2000). Marine inlets inundating the coast of British Columbia provide unique settings for paleoclimate investigations since sills prevent dense, oxygen rich ocean water from entering the inner basins, resulting in anoxic to dysoxic conditions that exclude bioturbating organisms and prevent oxidative corrosion of pollen grains (Nederbragt and Thurow 2001; Dallimore et al. 2004). However, few studies have focused on these environments due to the logistical difficulties of marine coring. To date, Saanich Inlet and Effingham Inlet on southeastern and southwestern Vancouver Island, respectively, are the only two marine fjords that have been extensively investigated in coastal British Columbia (Heusser 1983; Dallimore 2001; Pellatt et al. 2001; Nederbragt and Thurow 2001; Chang et al. 2003; Patterson et al. 2004a,b; Patterson et al. 2005). Additionally, few high-resolution studies (e.g., decadal time scale) of climate have been conducted in coastal British Columbia since this approach is laborious and time consuming (Nederbragt and Thurow 2001; Pellatt et al. 2001). High-resolution (e.g., decadal scale) studies can produce a detailed paleovegetation record from which both high and low frequency climate oscillations may be recognized, and thus provide information not available from the relatively short instrumental record or from low-resolution (e.g., centennial scale) proxy climate reconstructions.

This study uses pollen and spores preserved in the radiocarbon dated sediments of Frederick Sound, an anoxic marine fjord located at the southeastern extent of the Seymour-Belize Inlet Complex (SBIC), to produce a high-resolution (26-year) record of the late Holocene climate and vegetation dynamics of this region. This research is part of a larger project investigating marine and lacustrine sediments collected from basins within the SBIC to produce a coherent regional synthesis of post-glacial vegetation, climate and relative sea-level change of the poorly studied central mainland coast of British Columbia. Results will be compared to previous proxy climate reconstructions in the SBIC and elsewhere in coastal British Columbia as well as to changes in air mass circulation in the Pacific Northwest in order to place the findings of this study into a broader perspective.

4.2 Study area

4.2.1 Physical setting

The SBIC is a series of glacially scoured, topographically restricted fjords that penetrate the central mainland coast of British Columbia approximately 40 km NE of Port Hardy (Fig. 4.1). Seymour inlet is connected to Queen Charlotte Sound at Nakwakto Rapids where a 34 m bedrock sill and strong estuarine circulation is responsible for making this the fastest tidal channel in the world (8 m/s; Thomson 1981). The landscape surrounding the SBIC is rugged and steep, reaching up to 900 m in some locations, and is largely unpopulated. This region of the mainland coast falls within the Coastal Western Hemlock biogeoclimatic zone (CWHZ) and within the Submontane Wet Maritime Coastal Western Hemlock Variant (CWHvm1), which occurs on windward slopes from 0 m to 650 m above sea level in elevation inland from the immediate coast north of the Fraser River (Meidinger and Pojar 1991; Green and Klinka 1994; Pojar and Mackimmon 1994). The climate of the CWHvm1 is cool, with a mean annual temperature of 8.3 °C (range 7.0-10.1 °C), and wet, with a mean annual precipitation of 2682 mm (range 1555-4387 mm; unknown observation period; Green and Klinka 1994).

Forests of the CWHvm1 are dominated by *Tsuga heterophylla* (Raf.) Sarg. (western hemlock; botanical names follow Duhamel 1963) and *Abies amabilis* (Dougl.) Forb. (amabilis fir) with *Thuja plicata* Donn ex D. Don (western redcedar; Meidinger and Pojar 1991; Greena and Klinka 1994; Allen et al. 1999). At higher elevations, *Tsuga mertensiana* (Bong.) Carr. (mountain hemlock) occurs in wet sites with deep organic soils and *Chamaecyparis nootkatensis* (D. Don) Spach (yellow cedar) is common in moist to wet, rocky or boggy sites (Pojar and MacKinnon 1994). *Taxus brevifolia* Nutt. (western yew) is an important mid-canopy or understory tree in mature *T. heterophylla-T. plicata* forests of this region (Bolsinger and Jamarillo 1990; Pojar and MacKinnon 1994). *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir) occurs in minor amounts in the CHWvm1 (Green and Klinka 1994). Deciduous trees that grow in the CWHvm1 are *Acer glabrum* Torr. var. *douglasii* (Hook.) Dipp. (Douglas maple), which occurs as a shrub or small tree on open, dry ridges as well as in moist, well-drained sites, and *Alnus*

B. Ehrh. (Alder), which is common in open, wet sites, such as avalanche tracks, burns and along freshwater shore-lines (Pojar and MacKinnon 1994). Both *A. rubra* Bong. (red alder) and shrubby *A. sinuata* (Regel) Rydb. (Stika alder), also known as *A. crispa* (Ait.) Pursh ssp. *sinuata* (Regel) Hulten. (green alder), occur in this region (Pojar and MacKinnon 1994). Various ferns, bryophytes and shrubs form a dense understory in the forests of the CWHvm1 (Meidinger and Pojar 1991; Green and Klinka 1994; Klinka et al. 1996; Newmaster et al. 2003).

Mesozoic aged granitic and volcanic rocks dominate the bedrock of this region. Soils are poorly developed and acidic, derived from the underlying igneous material and influenced by input from the coniferous canopy (Pojar and MacKinnon, 1994; Klinka et al. 1996).

Frederick Sound is a 10 km long glacially scoured fjord located at the southeastern end of Seymour Inlet. The sound is 240 m deep and is topographically restricted by a 7m bedrock sill at its mouth (Fig. 4.1). Oxygen and temperature profiles obtained from repeated measurements in Frederick Sound during August 2000, April 2002, April 2003 and October 2003 indicate that waters are thermally stratified throughout most of the year, resulting in bottom water dysoxia or anoxia (dissolved O_2 <1 mL/L; Fig. 4.1; unpublished cruise reports 2000, 2002, 2003).

4.2.2 Climate setting

The Aleutian Low (AL) has a strong influence on the climate of British Columbia (Klein 1949). This semi-permanent cyclone intensifies over the Aleutian Islands of Alaska during the winter months (November to March) and delivers warm and moist maritime air from the south/southwest to the coast of British Columbia, causing wet and mild winters (Fig. 4.2; Favorite 1976; Trenberth and Hurrell 1994; Latif and Barnett 1996). During the summer months (April to October), the AL retreats and the North Pacific High (NPH) pressure system intensifies and moves northward. This anticyclone brings cool and dry continental air from the north/northeast into coastal British Columbia and is responsible for the warm and dry summers experienced in this region (Trenberth and Hurrell 1994).

The relative intensity and position of the AL has changed abruptly with a cyclicity of 50-70 years over at least the last 200 years (the Pacific Decadal Oscillation), and with a longer, undefined period over the last 7500 years (Trenberth and Hurrell 1994; Christoforou and Hameed 1997; Mantua et al. 1997; Minobe 1999; Mantua and Hare 2002; Spooner et al. 2003; Dean and Kemp 2004; Patterson et al. 2004; Anderson et al. 2005; MacDonald and Case 2005). These oscillations have affected the climate and economically important ecosystems of coastal British Columbia by influencing ocean currents, the position of winter storm tracks and precipitation and temperature trends over western North America (Cayan and Peterson 1989; Trenberth and Hurrell 1994; Latif and Barnett 1996; Cayan et al. 1989; Ware and Thomson 2000; Finney et al. 2002; Mantua and Hare 2002; Spooner et al. 2003; Dean and Kemp 2004; MacDonald and Case 2005; Anderson et al. 2005).

4.3 Methods

4.3.1 Core collection

Scientific cruises to the SBIC aboard the CCGS *Vector* occurred in April and October of 2002. Inlets and sounds in the SBIC were profiled with a 3.5 kHz air gun to locate relatively gas-free sites within the first couple of meters of sediment in order to identify locations where a complete sediment core could be retrieved. Nine freeze cores and 8 piston cores (10 cm diameter) were obtained from the deepest parts of the basins and away from the shores to reduce incidence of slumped deposits in this tectonically active area (Blais 1995). A 1224 cm long piston core, VEC02A02, was retrieved from a depth of 240 m in Frederick Sound and was chosen for this study because a large percent (41%) of the sediments were laminated and because the fjord was found to be dysoxic to anoxic, which would prevent bioturbation (unpublished cruise reports 2000, 2002, 2003).

The VEC02A04 sediment core was extruded and cut in half length-wise. One half of the sediment core was cut into 62 slabs (20 cm long x 3 cm wide x 1 cm thick), X-rayed and logged at the Pacific Geoscience Centre, Sidney, British Columbia. After inspection, these slabs were wrapped in plastic food wrap and aluminum foil to be preserved as an archive. The remaining half of the sediment core was sub-sampled for palynological analysis and sent in plastic food bags to Carleton University for storage in a cold room (4°C). Macrofossils were picked from the sediment to be used for radiocarbon dating.

4.3.2 Pollen and spores

Pollen analysis followed methods described by Faegri and Iversen (1989). Briefly, 50 mm^3 aliquots of wet sediment were sub-sampled and subjected to hot treatment of 10% hydrochloric acid and 10% potassium hydroxide followed by acetolysis. Hydrofluoric acid treatment was not applied since during preliminary analysis of pollen slides silicate microfossils and mineral material did not hinder identification of pollen or spores. Slurries were stained with safranin to aid pollen and spore identification, sequentially dehydrated with alcohol (ethanol and tertiary butanol) and stored in silicone oil. A known quantity of *Lycopodium clavatum* spores was added to each sample prior to processing in order to calculate pollen concentrations (one tablet per sample, batch No. 938 934, n=10,679 +/- 953 std. error spores/tablet; Benninghoff 1962; Stockmarr 1971). Pollen and spores were enumerated at 400x magnification with an Olympus BX51 transmitted light microscope at intervals of 10 cm throughout the entire sediment core except where sediment was lost on core recovery (Fig. 4.3). In total, 116 samples were analyzed and total pollen and spores counted per slide were consistently above 300 except at 6 horizons (420, 460, 607, 684, 704 and 744 cm). A minimum count of 171 occurred at 420 cm.

Pollen keys by McAndrews et al. (1988), Faegri and Iversen (1989) and Kapp et al. (2000) and reference slides (Aerobiology Institution and Research Pollen Reference Slide Set, Brookline, MA) aided pollen identification. Pollen was identified to the lowest possible taxonomical level (Appendix 2.1). *Pinus* L. pollen was identified as diploxylon-type, haploxylon-type or was undifferentiated (Faegri and Iversen 1989). *Juniperus* L. (juniper), *Chamaecyparis nootkatensis* (D. Don) Spach (yellow cedar), *Taxus brevifolia* Nutt. (western yew) and *Thuja plicata* Donn ex. D. Don (western redcedar) pollen were grouped together as Cupressaceae, since their pollen is difficult to differentiate using light microscopy. *Larix* Mill. (larch) and *P. menziesii* pollen are morphologically similar, but since *Larix* is uncommon in coastal British Columbia (Duhamel 1963), this pollen is attributed to *P. menziesii.* In cases where uncertainty exists, pollen and spore taxa are suffixed with "-type" (Janssen 1967). Pteropsida (monolete) spores include all monolete members of the class Pteridophyta except Polypodiaceae, the only family where the perine is commonly preserved. In this case, spores could be identified as *Polypodium vulgare*-type (Moore et al. 1991). Small (5-8 μm), inaperturate spores with thin exines devoid of visible sculpturing elements were identified as *Polytrichum*-type spores (Anderson et al. 1990; Kapp et al. 2000). Fossil *L. clavatum* was differentiated from exotic spores by differential preservation and safranin stain acceptance (Stanley 1966; Heusser 1983).

The main pollen sum includes all total terrestrial pollen and spores, including fern and moss spores, while the total pollen sum includes the aquatic taxa *Potamogeton, Typha* and *Nuphar.* Calculation of pollen concentration followed Stockmarr (1971). Percent pollen data was graphed using Tilia version 2.0 (Grimm 1993) and the CONISS program for stratigraphically constrained cluster analysis (square root data transformation) was applied to aid pollen diagram zonation (Gordon and Birks 1976; Grimm 1987; Faegri and Iversen 1989).

4.4. Results

4.4.1 Chronology

Eight plant macrofossil samples retrieved from the VEC02A04 core were submitted for radiocarbon analysis to IsoTrace Laboratories, University of Toronto, Toronto. One sample could not be dated so only seven AMS radiocarbon dates were obtained (Table 4.1). All dates have been corrected for isotopic fractionation, although

$^{13}C/^{12}C$ results were not reported by IsoTrace Laboratories, and were calibrated to calendar years BP using the computer program CALIB REV5.0 with the INTCAL04 dataset for terrestrial material (Reimer et al. 2004; Stuiver et al. 2005).

Two age-depth models, one using conventional radiocarbon ages and one using calibrated radiocarbon ages, were generated using linear regression on the youngest dates that fell in stratigraphic order. Both sets of age information were used because of two opposing schools of thought; some researchers feel that age-depth models should be based only on un-calibrated radiocarbon dates since calibration adds "another layer of complexity" (Bennett and Fuller 2002), but others feel that since calibrated ages remove the "wiggle" of radiocarbon dates, hence models based on these ages will be more precise (Telford et al. 2004). It was also desirable to estimate both conventional radiocarbon and calendar ages for pollen zones because it would ease comparison with previous research where only one or the other age-depth model was generated (e.g., Wigston 2006). All of the material used for dating in the VEC02A04 core was terrestrial in origin (twig, wood fragment and pine cone) and therefore was treated as a sedimentary detrital particle (i.e., transported from the source). It was assumed that carbon acquisition ceased upon the death of the plant, and since an unknown time interval may have preceded final deposition of material, the youngest ages that occurred in stratigraphic order reported for the VEC02A04 core were considered the most likely to approximate the age of deposition. These criteria eliminated 4 ages and left only 3 on which to base the age-depth model (Fig. 4.4). The 3 remaining dates are considered to be maximum ages of the sedimentary horizons in which they are found.

Linear regression was chosen over linear interpolation as the age-depth modeling method in this study because changes in sediment flux were not identifiable from the spread of the three usable dates. Linear regression could generate an average sedimentation rate and statistically quantify the relationship between the three dates. Although it is recognized that in sedimentary successions that have been deposited over large periods of time where dates are in stratigraphic order, r^2 will always be high (Telford et al. 2004), high r^2 values for VEC02A04 age-depth model (r^2=0.977 for the regression line of calibrated radiocarbon ages and r^2=0.970 for the regression line of the conventional radiocarbon ages) may support the choice to exclude the other dates. The r^2 values for the age-depth model using all dates were low (r^2=0.691 for conventional radiocarbon ages and r^2=0.683 for calibrated radiocarbon ages). The low r^2 values in this case do not represent changes in sedimentation rate but rather error incorporated by including ages of deposition that are known to be spurious.

The average sedimentation rate was calculated to be 0.39 cm/calendar year and 0.48 cm/radiocarbon year from the slopes of the respective linear regression lines of the age-depth model (Fig. 4.4). The top of the core has an estimated age of ca. 1000 cal. yr BP (ca. 1200 ^{14}C yr BP) based on the x-intercept of the regression lines. The uppermost 113 cm of sediment are known to have been lost on recovery of the core but the average sedimentation rate suggests that as much as 390 cm (y-intercept for the calibrated radiocarbon curve) may be missing from the top of the sediment core. The base of the sediment core is calculated to be ca. 4200 cal. yr BP (ca. 3800 ^{14}C yr BP), giving an interval of deposition of ca. 3100 cal. years (ca. 2500 ^{14}C years). From the calculated sedimentation rates, the time estimated to have lapsed between the 10 cm intervals analyzed for pollen is ca. 26 cal. years (ca. 21 ^{14}C years). Age ranges of pollen assemblage zones were estimated from the average sedimentation rates and rounded to the nearest 100 years.

4.4.2 Sedimentology

Visual inspection of the sediments and X-ray images of the 1224 cm long VEC02A04 sediment core indicated that the core is largely composed of organic-rich dark olive-grey material with a grain size of fine sand (less than 250 μm) to mud (less than 60 μm). Units of laminated sediments, massive mud, graded mud, fine sandy mud, fine sand, woody debris and fecal pellets occur in VEC02A04 (Fig. 4.3). In total, 41 % of the sediment core is laminated, 53% is massive, 5% is graded and 1% is missing or disturbed. Laminated intervals range in thickness from 1 cm to 45 cm and are interpreted to be composed of alternating seasonally deposited autochthonous light-coloured diatom-rich layers and allochthonous dark-coloured clay-rich layers (Sancetta 1989; McQuoid and Hobson 1997; Chang et al. 2003; Patterson and Prokoph, in preparation).

4.4.3 Pollen and spores

The pollen and spores of 43 taxa were identified from 116 sediment horizons in the VEC02A04 core (Appendix 4.1). Stratigraphically constrained cluster analysis with square root data transformation (CONISS; Grimm 1987) of pollen percentage data identified 3 pollen zones (FPZ-A, FPZ-B, FPZ-C; Fig. 4.5).

The pollen spectrum of VEC02A04 is dominated by Cupressaceae pollen (core max. 71%, 3723 grains/mm^3; core min 20%, 256 grains/mm^3). *Tsuga heterophylla* pollen is also relatively high (core max. 40%, 1331 grains/mm^3; core min. 6%, 119 grains/mm^3) and *Alnus* pollen maintains a constant presence (core max. 21%, 1096 grains/mm^3; core min. 4%, 93 grains/mm^3). Total pollen and spore concentrations range from a minimum of 1027 grains/mm^3 to a maximum of 6664 grains/mm^3. The high degree of level-to-level variability in the VEC02A04 pollen spectra is a product of the high temporal resolution of this record and suggests that sediments have remained undisturbed since mixing would have resulted in smoother data (Fuller 1998).

4.4.3.1 Zone FPZ-A (1219-744 cm; ca. 3800-2800 ^{14}C yr BP; 4200-3000 cal. yr BP)

This pollen assemblage zone is characterized by Cupressaceae pollen frequencies of 20-64% and concentrations of 1089-1652 grains/mm^3. *Tsuga heterophylla* pollen occurs at frequencies between 7-39% (192-1331 grains/mm^3). *Alnus* pollen is present between 7% (123 grains/mm^3) and 21% (1039 grains/mm^3), *Abies* and *Picea* pollen occur ~3% (~110 grains/mm^3) and *P. menziesii* pollen occurs ~0-2% (~0-33 grains/mm^3). The abundance of Pteropsida (monolete) spores are relatively high in this zone (range 36-8%; 199-1998 grains/mm^3) and *Polypodium vulgare*-type and *Polytrichum*-type spores and Rosaceae pollen occur ~1-2% (~70-110 grains/mm^3). Total pollen and spore concentrations increase from a core minimum of 1027 grains/mm^3 to a zonal maximum of 5519 grains/mm^3, which is reached mid-zone.

4.4.3.2 Zone FPZ-B (744-410 cm; 2800-2100 ^{14}C yr BP; 3000-2100 cal. yr BP)

A decline in Cupressaceae pollen to ~20-44% (302-1032 grains/mm^3) characterizes this pollen assemblage zone. *Tsuga heterophylla* pollen proportions remain comparable to Zone FPZ-A at 9-40% (199-854 grains/mm^3) although a slight increase is observed in the percentage data. Analysis of the concentration of these two taxa in FPZ-B indicates that pollen concentrations of Cupressaceae decline by 50% but there is no corresponding increase in the concentration of *T. heterophylla* pollen (Fig. 4.6). Although the zone boundary based on CONISS occurs at 744 cm, the decline in Cupressaceae pollen proportions does not occur until 650 cm, which corresponds to an age of ca. 2800 cal. yr BP (ca. 2600 ^{14}C yr BP). *Alnus* pollen is present at frequencies of 5-17% (80-266 grains/mm^3), *Abies* pollen occurs ~0-4% (~0-64 grains/mm^3), *Picea* pollen occurs ~0-3% (~0-64 grains/mm^3) and *P. menziesii* pollen is present ~1% (~10 grains/mm^3) in this zone. Pteropsida (monolete) spores occur at frequencies between 9-21% (125-684 grains/mm^3) and *Polypodium vulgare*-type and *Polytrichum*-type spores are also present up to ~3-4% (53-64 grains/mm^3). Total pollen and spore concentrations increase from 1403 grains/mm^3 near the beginning of the zone to peak to 3332 grains/mm^3 mid-zone.

4.4.3.3 Zone FPZ-C (410-0 cm; 2100-0 ^{14}C yr BP; 2100-0 cal. yr BP)

Cupressaceae pollen began to increase in this zone at 330 cm, which corresponds to age of ca. 1900 cal. yr BP (ca. 1900 ^{14}C yr BP), from ~40% (1061 grains/mm^3) to 71% (2577 grains/mm^3) and *T. heterophylla* pollen decreases to ~6-27% (235-545 grains/mm^3). *Alnus* pollen occurs in this zone at frequencies between 4-21% (93-336 grains/mm^3) and *Abies* and *Picea* pollen are present ~2% (~36 grains/mm^3). Pteropsida (monolete) spores occur between 0-23% (0-1253 grains/mm^3), *Polypodium vulgare*-type spores, *Polytrichum*-type spores and Rosaceae pollen occur ~2% (~45, ~64 and ~71 grains/mm^3, respectively). Total pollen and spore concentrations increase from 1602 grains/mm^{3}to a core maximum of 6664 grains/mm^3 near the end of the zone.

4.5 DISCUSSION

4.5.1 Marine palynology

Interpretation of marine palynological records requires the consideration of several factors not generally applicable to lacustrine studies. For instance, long-distance transport of pollen and spores *via* rivers and ocean currents can be common in marine environments and can result in a large "extra-local" or "extra-regional" pollen component in sedimentary deposits (Heusser and Balsam 1977; Heusser 1988; Mudie and McCarthy 1994). Over-representation of certain taxa well adapted to aerial and aquatic transport, such as *Pinus*, and the selective corrosion of certain pollen and spore types in marine environments are additional problems of marine palynology that can result in skewed results (Havinga 1964; Heusser and Balsam 1977). Slower sedimentation rates in marine realms can result in low sedimentary pollen concentrations thus necessitating sub-sampling of large volumes of sediment for analysis, which prevents detailed study of climate and vegetation change (Groot and Groot 1966). Despite these problems, pollen and spores preserved in coastal marine sediments are generally representative of on-shore vegetation and one advantage of marine palynology is that interpretations can often be strengthened by direct comparison with marine chronological standards (e.g., $\partial^{18}O$) and the large suite of marine microfossils often preserved in the same core (Heusser and Florer 1973; Heusser and Balsam 1977; Heusser 1986/1987; Heusser 1988; Mudie and McCarthy 1994; Heusser 1994).

Frederick Sound is an anoxic fjord that provides a unique marine environment in which to study paleoecology and paleoclimate since some of the problems of marine palynology may be considered negligible. This fjord is topographically restricted by a series of sills within the SBIC, which should prevent the incursion of ocean currents and any associated extra-regional pollen component. This may be indicated by the relatively low *Pinus* values in VEC02A04. Selective corrosion of pollen types was not deemed a problem in this study since delicate Pteridophyta pollen is relatively high throughout the core (Havinga 1964; Havinga 1984). Rapid late Holocene sedimentation (0.39 cm/calendar year; 0.48 cm/radiocarbon year) resulted in sufficiently high pollen concentrations per sediment sample and permitted the high-resolution palynological investigation of the VEC02A04 core.

4.5.2 The early late Holocene (FPZ-A; 1219-744 cm; ca. 3800-2800 ^{14}C yr BP; ca. 4200-3000 cal. yr BP)

Cupressaceae pollen, probably attributable to *T. plicata* based on modern biogeography and macrofossil evidence from the Fraser Lowlands and nearby Woods Lake (Fig. 4.1; Wainman and Mathewes 1987; Pojar and MacKinnon 1994; Stolze 2004), dominates the VEC02A04 sediment core. *Thuja plicata* pollen percentages range from 20 to 63% in this section, indicating that this taxon was well established at Frederick Sound by ca. 4200 cal. yr BP (ca. 3800 yr BP; Hebda and Allen 1993). *Thuja plicata* thrives in cool and wet climates today, so its predominance in this section and in correlative levels at Two Frog Lake, Tiny Lake and Woods Lake (Fig. 4.1; Stolze 2004) suggest that cool and wet conditions were regionally established at this time. A cool and wet climate had also developed elsewhere in coastal British Columbia during this interval, correlative with Neoglacial activity in the Canadian Rocky Mountains and the Coast Mountains (Hebda 1983; Ryder and Thompson 1986; Luckman et al. 1993; Hansen and Engstrom 1996; Pellatt and Mathewes 1997; Brown and Hebda 2002a; Turunen and Turunen 2003; Walker and Pellatt 2003; Patterson et al. 2004a, b; Lacourse 2005).

A cool and wet climate in the SBIC at this time may be the result of a dynamic AL. Proxy records of the location and strength of this semi-permanent air mass suggest that it was on average farther eastward and/or more intense than present between 4500-3000 cal. yr BP (Fig. 4.8; Anderson et al. 2005). An eastward positioned and/or stronger AL would produce a climate characterized by cool summers, mild winters and high winter precipitation in coastal British Columbia since cyclonic airflow would deliver mild and moist air from the south and southwest (Cayan and Peterson 1989; Trenberth and Hurrell 1994; Anderson et al. 2005). Additionally, a more intense AL would have affected the direction and intensity of North Pacific storms (Dean and Kemp 2004). A deepened AL would have displaced the polar jet stream and westerlies south of their modern position near the Gulf of Alaska (Klein 1949; Dean and Kemp 2004), which would have resulted in a meridional airflow pattern (i.e., with some north-south flow; "wavy jet") that would have generated strong mid-latitude (30-40° N) winter cyclones (Klein 1949). If a trough of low pressure was centered over the central-eastern Pacific and a ridge of high pressure over the coast of North America, the cyclones would be directed into the northern coast of British Columbia, thus resulting in increased precipitation to this region and providing favorable climate conditions for *T. plicata* (Klein 1949; Krajina 1969; Spooner et al. 2003).

4.5.3 The mid-late Holocene (FPZ-B; 744-410 cm; ca. 2800-2100 ^{14}C yr BP; ca. 3000-2100 cal. yr BP)

Thuja plicata pollen declined beginning at ca. 2800 cal. yr BP (ca. 2600 ^{14}C yr BP) by approximately 10% in relative abundance and by approximately 50% in concentration in zone FPZ-B. The decline in concentration is not accompanied by an increase in *T. heterophylla* pollen concentrations even though a slight increase in the frequency of this pollen type is observed. This decline is not documented at Two Frog Lake or Woods Lake (Fig. 4.1; Stolze 2004) but two late Holocene declines in the relative abundance of Cupressaceae pollen at Tiny Lake are observed (Fig. 4.7). The Two Frog Lake record has a sampling resolution of ~400 years (~300 ^{14}C years), which is too coarse to detect this 900-year event and sampling resolutions were not determined for Tiny Lake or Woods Lake. The fluctuations in *T. plicata* at Tiny Lake may be noise, since they are represented by few data-points, or may be correlative with the *T. plicata* decline at Frederick Sound, but poor chronological control of this sediment core prevents a more detailed comparison at this time.

The *T. plicata* decline at Frederick Sound may represent either death of individuals or decreased pollen production of stressed trees, which could have been caused by a number of factors such as disease, natural or anthropogenic disturbance and/or climate change (Minore 1983; Prentice 1986; Minore 1990; Brown and Hebda 2002a,b; Weber et al. 2003). The decline of *T. plicata* at Frederick Sound did not seem to have an effect on forest composition. Upon removal of a dominant canopy tree, it would be expected that other species would be released from competition and increase in abundance, especially shade intolerant taxa such as *Alnus*, and competitive taxa such as *T. heterophylla* (Allison et al. 1986). However, if the decline of *T. plicata* populations was slow, enough mature trees may have persisted to maintain canopy structure.

No other pollen types in this section decline, suggesting that the variable that was disadvantageous for *T. plicata* was not unfavorable for other taxa. This excludes fire and wind-throw as possible causes of the *T. plicata* decline since *T. heterophylla* would also have been affected, probably to a greater degree than *T. plicata* whose seedlings benefit from low-intensity disturbance (Minore 1990; Packee 1990; Weber et al. 2003). Additionally, there is no increase in disturbance-adapted taxa, such as *Alnus*, *P. menziesii*, *Pteridium* and/or *Polytrichum*, at this time to suggest that fires were frequent (Cwynar 1987; Tolhurst 1990). Selective removal of this tree from forests at Frederick Sound by ancient human populations may be a potential cause of the *T. plicata* decline since humans are known to have inhabited the central mainland coast of British Columbia at this time and because they relied heavily on the rot resistant wood of *T. plicata* for building materials (Clague et al. 1981; Minore 1983; Hebda and Mathewes 1984; Brown and Hebda 2002b). Ancient humans are postulated to have caused the late Holocene (ca. 2000 ^{14}C yr BP) decline of *T. plicata* on southern Vancouver Island because fires were rare and because the climate was favorable for this taxon (Brown and Hebda 2002b). A disease outbreak is another possible cause of the *T. plicata* decline since pathogens can be species specific (Minore 1990). Although *T. plicata* is highly resistant to infection due to the production of thujaplicin, a natural fungicide, a number of bacteria, fungi and insects can harm this tree (Minore 1983). For example, the leaf blight *Didymascella thujina* (Durand) Maire (cedar leaf blight or Keithia disease) can kill up to 97% of 2nd and

3rd year *T. plicata* seedlings when an epidemic occurs (Boyd 1965; Minore 1990). If a pathogen outbreak affected populations of *T. plicata*, it would be expected that the effect would be immediate (e.g., within a decade; Allison et al. 1986) but it appears that *T. plicata* declined over approximately a 100-year period in this record. This does not necessarily exclude the possibility of a pathogen attack as a cause of the *T. plicata* decline because if pathogens only affected certain age classes the decline could have occurred on a multi-decadal scale (Griffin et al. 2003). Climate variability could also have caused the *T. plicata* decline since species respond individualistically to climate change and cold and/or dry conditions would have been restrictive for this taxon but not necessarily for *T. heterophylla* (Krajina 1969; Prentice 1986; Webb 1986; Minore 1990; MacDonald 1993). *Thuja plicata* is currently geographically restricted along the North Pacific coast to regions receiving at least 890 mm (35 in) of annual precipitation and the minimum temperature this tree can withstand in coastal populations is -30 °C (Boyd 1965; Franklin and Dryness 1973; Minore 1990). In contrast, coastal *T. heterophylla* populations can grow in regions receiving less than 380 mm of annual precipitation and withstand minimum temperatures near -39 °C (Packee 1976). These limits provide an estimate of the climate conditions that would have to be approached in order to cause a decline of this tree in the SBIC, but interactions between temperature and precipitation are also important controls on species abundance since trade-offs between two or more climate variables can affect tolerance of extremes (Bartlein et al. 1986; Prentice et al. 1991; Calcote 2003). For example, drier conditions at this time could have resulted in lowered cold tolerance of *T. plicata*, thus resulting in damage or death of individuals during unusually cool periods (Calcote 2003). It is also notable that hydrology is an important control on the distribution of *T. plicata* and *T. heterophylla* in the Pacific Northwest since *T. plicata* often grows on sites within its range that are considered too dry for *T. heterophylla* due to deeper root penetration (Franklin and Dryness 1973; Minore 1983). This suggests that cold temperatures may have been more restrictive for *T. plicata* than drought since exceptionally dry conditions would have affected both *T. plicata* and *T. heterophylla.*

A detailed diatom stratigraphy of the VEC02A04 core shows that Frederick Sound experienced a relatively dry climate (temperatures were not reconstructed) between ca. 2800-2400 cal. yr BP (Wigston 2006). The decline in *T. plicata* also occurred at ca. 2800 cal. yr BP (ca. 2600 ^{14}C yr BP). It would be unusual for vegetation change to be synchronous with an algal response climate change since vegetation usually responds to climate on at least a centennial scale (Fig. 4.8; Prentice et al. 1991; Lacourse 2005; Wigston 2006) but this still suggests that climate change could have been the proximate cause of the *T. plicata* decline at Frederick Sound. Cooling at this time may have also affected glaciers in the Canadian Rocky Mountains and the North Coast Mountains where advances are recorded at ca. 2800 ^{14}C yr BP (Luckman et al. 1993; Clague and Mathewes 1996).

Pathogen attack could have acted synergistically with climate change, which may have stressed and damaged individuals and/or affected pathogens, similar to the mid-Holocene conditions that resulted in the decline of *Tsuga canadensis* (L.) Carr. in eastern North America (Allison et al. 1986; Yu and McAndrews 1995; Fuller 1998; Calcote 2003; Yu 2003; Shuman et al. 2004; Hass and McAndrews 1999). This decline, which occurred ca. 5750 cal. yr BP (ca. 4650 ^{14}C yr BP), was species specific to *T. canadensis* and resulted in approximately a 10% reduction of this taxon in pollen spectra for 1000 to 2000 years, comparable in magnitude, but not duration, to the *T. plicata* decline at Frederick Sound (Fuller 1998; Haas and McAndrews 1999; Bennett and Fuller 2002; Shuman et al. 2004). The hypothesis of a pathogen outbreak as a factor in the *T. plicata* decline at this site may be tested with future high-resolution research by identifying if a synchronous decline occurred elsewhere in the region (Allison et al. 1986; MacDonald 1993; Griffin et al. 2003). Testing the hypothesis of a human impact would be equally intensive since much archaeological work would have to be conducted in the SBIC in order to constrain if humans were present at this time and their population numbers.

A drier and cooler climate in the SBIC at this time may have been caused by a westward shift and/or weakening in the AL, which occurred ca. 2800 cal. yr BP (Fig. 4.8; Klein 1949; Cayan and Peterson 1989; Trenberth and Hurrell 1994; Dean and Kemp 2004; Anderson et al. 2005). Based on instrumental observations, a westward movement of the AL would have been accompanied by a northward shift in the NPH (Klein 1949). A westward displaced and/or weakened AL would have translated less warm and moist maritime air to the coast of northern British Columbia while a more northward positioned NPH would have steered cold northeasterly winds into the region (Klein 1949). Additionally, a westward positioned AL would not have displaced the jet stream and westerlies, which would have allowed a more zonal (i.e., east-west) airflow pattern to predominate (Klein 1949). This type of airflow does not generate the same magnitude of cyclonic storms because strong temperature contrasts are not maintained over relatively short distances, as is the case with meridional airflow (Klein 1949).

Most other proxy reconstructions of climate from coastal British Columbia show no evidence of a mid late-Holocene dry interval or a decline in *T. plicata*, and instead record cool and wet climate conditions at this time, but these studies exhibit centennial (rather than decadal) scale resolution (Mathewes 1973; Hebda 1983; Pellatt and Mathewes 1994, 1997; Patterson et al. 2004a,b; Lacourse 2005). An exception is a very high-resolution sedimentological record from Saanich Inlet, which documents a dry interval between 3250 and 2100 cal. yr BP (Nederbragt and Thurow 2001). It is probable that the relatively low-resolution of previous work failed to capture the brief dry interval documented in the VEC02A04 record. Additional high-resolution records of mid late-Holocene climate are required in order to investigate the distribution of the dry interval, which may have been geographically heterogeneous in coastal British Columbia due to the complexity of atmospheric circulation associated with the AL (Klein 1949; Dean and Kemp 2004).

4.5.4 The late late Holocene (FPZ-C; 410-0 cm; ca. 2100-1200 ^{14}C yr BP; ca. 2100-1000 cal. yr BP)

Thuja plicata pollen began to increase at ca. 1900 cal. yr BP (ca. 1900 ^{14}C yr BP) and reached peak proportions by ca. 1400 cal. yr BP (1510 ± 60 ^{14}C yr BP) in VEC02A04. Relatively high *T. plicata* abundances in this section suggest that a return to the wet climate conditions that previously prevailed at Frederick Sound had occurred by this time (Mathewes 1973; Hebda 1983; Heusser 1983; Brown and Hebda 2002a). The VEC02A04 diatom record shows a return to wetter conditions at ca. 2400 cal. yr BP, which predates the rise of *T. plicata* by ca. 500 years (Fig. 4.8; Wigston 2006). A lag time of several centuries to climate change is reasonable for this long-lived taxon and suggests that a return to wetter conditions in the SBIC at ca. 2400 cal. yr BP were instrumental in the recovery of *T. plicata* (Minore 1983; Prentice et al. 1991; Lacourse 2005). Other records from coastal British Columbia continue to document wet conditions throughout the late Holocene and the varve record from Saanich Inlet shows that a return to wetter conditions occurred ca. 2100 cal. yr BP on southeastern Vancouver Island (Mathewes 1973; Mathewes and Heusser 1981; Hebda 1983; Nederbragt and Thurow 2001; Brown and Hebda 2002; Turunen and Turunen 2003; Lacourse 2005).

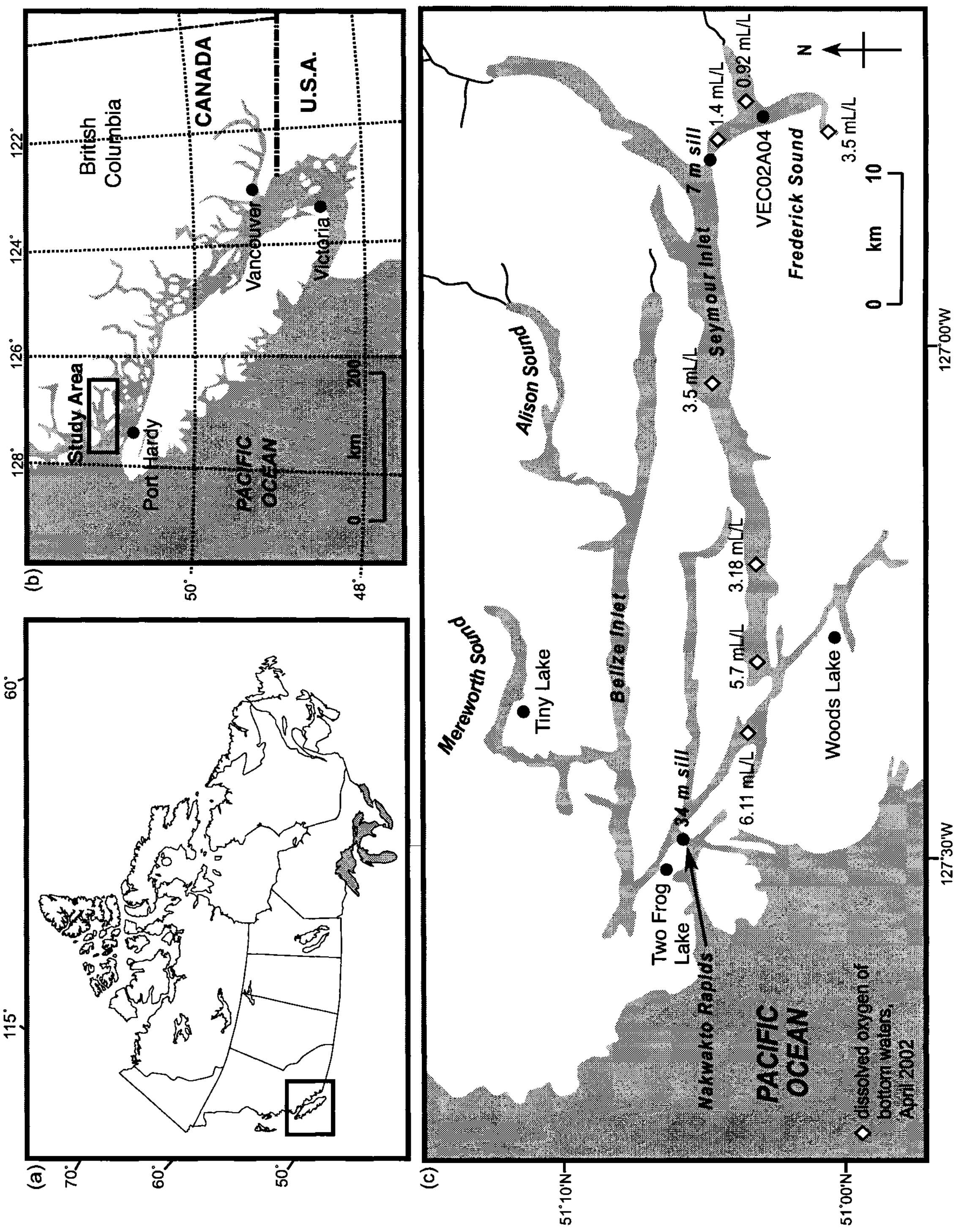
A mechanism for the return to wetter conditions during the late Holocene may be the eastward shift and/or intensification of the AL, which occurred ca. 1200 cal. yr BP (Fig. 4.8; Anderson et al. 2005). Climate change associated with this event was probably not the proximate cause of *T. plicata* recovery at Frederick Sound since the rise of this taxon preceded AL movement by ca. 700 years (Fig. 4.8). Diatom change at Frederick Sound also predates the proposed eastward movement and/or intensification of the AL, which suggests that the return to wetter conditions in this region occurred independently of dynamics associated with the AL. Alternatively, this temporal discordance may represent errors inherent in the age-depth models, which can be up to several hundreds of years (Bennett and Fuller 2002).

If pathogen attack was a factor in the decline of *T. plicata* it is possible that resistance evolved and permitted recovery as it did in populations of *T. canadensis* in eastern North America (Davis 1981; Allison et al. 1996; Shuman et al. 2004). If pathogens mainly affected seedlings, resistant individuals would have had a greater chance of survival past 10 years of age when pollen is first produced and thus gradually re-populated the forest (Minore 1990). Alternatively, the return to a more favorable climate with good growth conditions for *T. plicata* may have strengthened resistance mechanisms already present (Shuman et al. 2004).

4.6 Conclusions

Late Holocene climate dynamics are recorded in fluctuations of Cupressaceaeous pollen preserved in a sediment core retrieved from Frederick Sound, an anoxic fjord within the Seymour-Belize Inlet Complex of the central mainland coast of British Columbia. A decline in *T. plicata* occurred between ca. 2800-1900 cal. yr BP (ca. 2600-1900 ^{14}C yr BP) in response to the development of a drier and cooler climate that punctuated the otherwise wet conditions of the late Holocene. Although climate change was probably the proximate cause of this decline, biotic factors, such as pathogen attack and/or selective felling by humans, may also have been important. The occurrence of the dry interval corresponds to shifts in the AL, suggesting that millennial scale variability of the relative position and/or intensity of this semi-permanent air mass have affected the climate and vegetation of this region throughout most of the late Holocene. Neither a dry climate interval nor a *T. plicata* decline is widely documented in coastal British Columbia at this time, possibly due to the low-resolution quality of previous work. Therefore, this study validates the use of high-resolution palynology in paleoclimate reconstructions and paleoecological research.

Figure 4.1: (a) Map of North America showing the location of the study area (after Vazquez-Riveiros et al. in preparation), (b) map of southwestern British Columbia showing the location of the Seymour-Belize Inlet Complex and (c) map of the Seymour-Belize Inlet Complex showing the location of Frederick Sound, the coring location, the depth and location of important sills and bottom water oxygen data collected in April, 2002 and the location of sites mentioned in the text.


(a)
70°
60°
50°
115°
60°
(b)
50°
48°
128°
126°
124°
122°
British Columbia
CANADA
U.S.A.
Study Area
Port Hardy
Vancouver
Victoria
PACIFIC OCEAN
0 km 200
(c)
51°10'N
51°00'N
127°30'W
127°00'W
Mereworth Sound
Tiny Lake
Belize Inlet
Alison Sound
Seymour Inlet
7 m sill
34 m sill
Nakwakto Rapids
Two Frog Lake
Woods Lake
Frederick Sound
VEC02A04
1.4 mL/L
0.92 mL/L
3.5 mL/L
3.5 mL/L
3.18 mL/L
5.7 mL/L
6.11 mL/L
PACIFIC OCEAN
◇ dissolved oxygen of bottom waters, April 2002
0 km 10
N

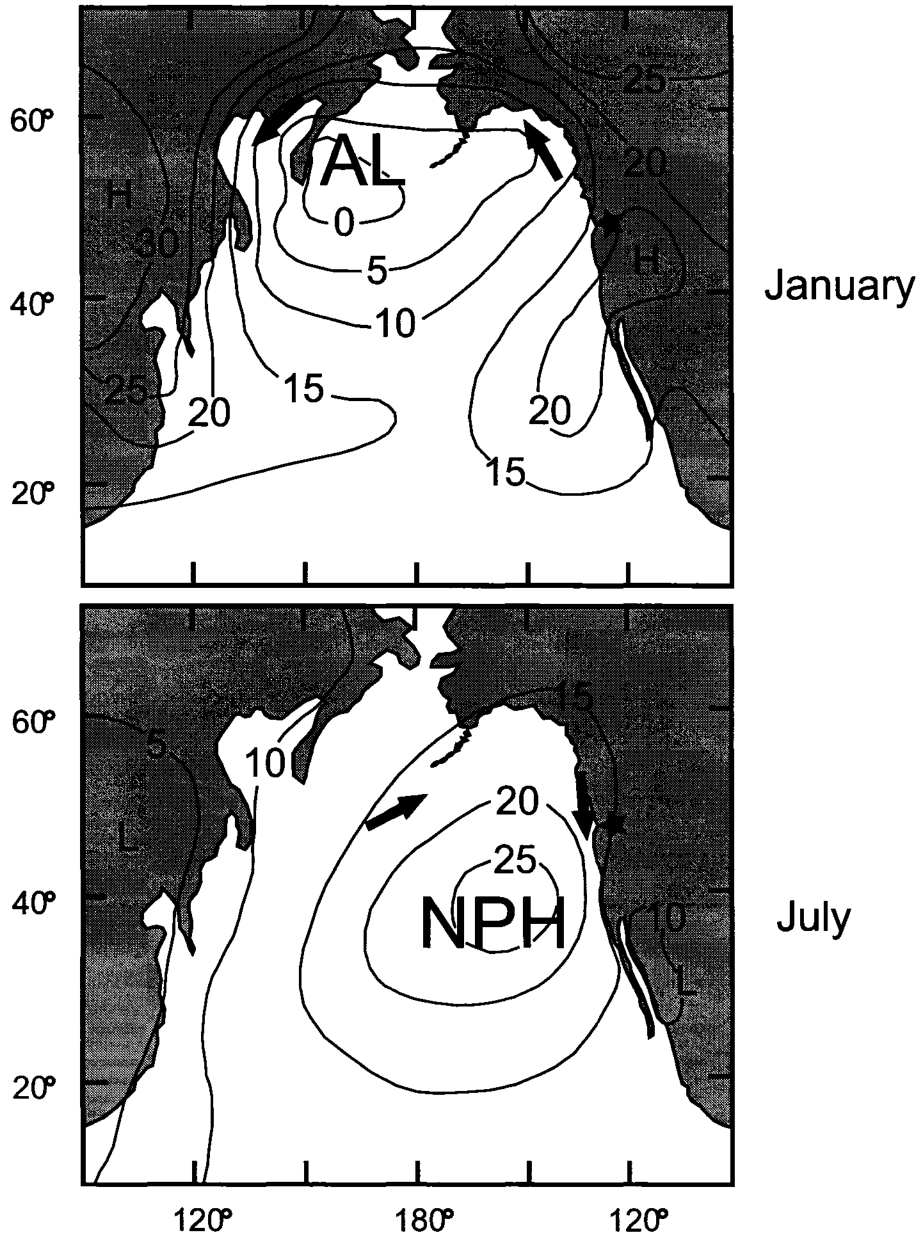
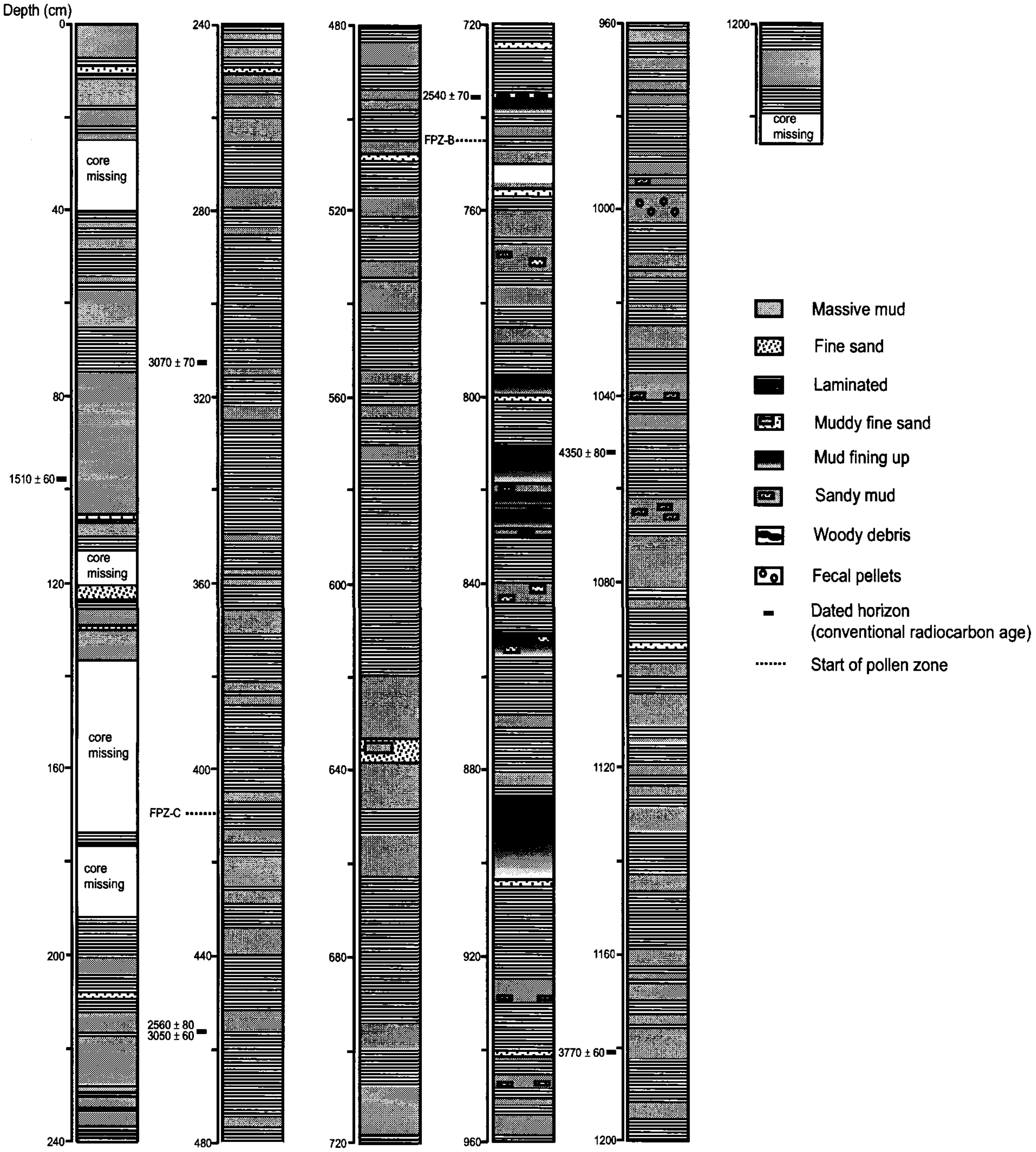


Figure 4.2: The Aleutian Low (AL) and North Pacific High (NPH) atmospheric pressure cells and prevailing wind direction (arrows) during winter (January) and summer (July) from 1951 to 1976. The AL was on average more westward at this time than at present. Star symbol marks the location of the study area. Values + 10,000 divided by 10 gives pressure in millibars. After Favorite et al. (1976).

Figure 4.3: Lithology of the VEC02A04 sediment core. Chronology and pollen zones are noted.


Depth (cm)
0
40
80
1510 ± 60
120
160
200
240
core missing
core missing
core missing
core missing
280
3070 ± 70
320
360
400
FPZ-C
440
2560 ± 80
3050 ± 60
480
520
560
600
640
680
720
2540 ± 70
FPZ-B
760
800
840
880
920
960
1000
1040
4350 ± 80
1080
1120
1160
3770 ± 60
1200
core missing
Massive mud
Fine sand
Laminated
Muddy fine sand
Mud fining up
Sandy mud
Woody debris
Fecal pellets
Dated horizon
(conventional radiocarbon age)
Start of pollen zone

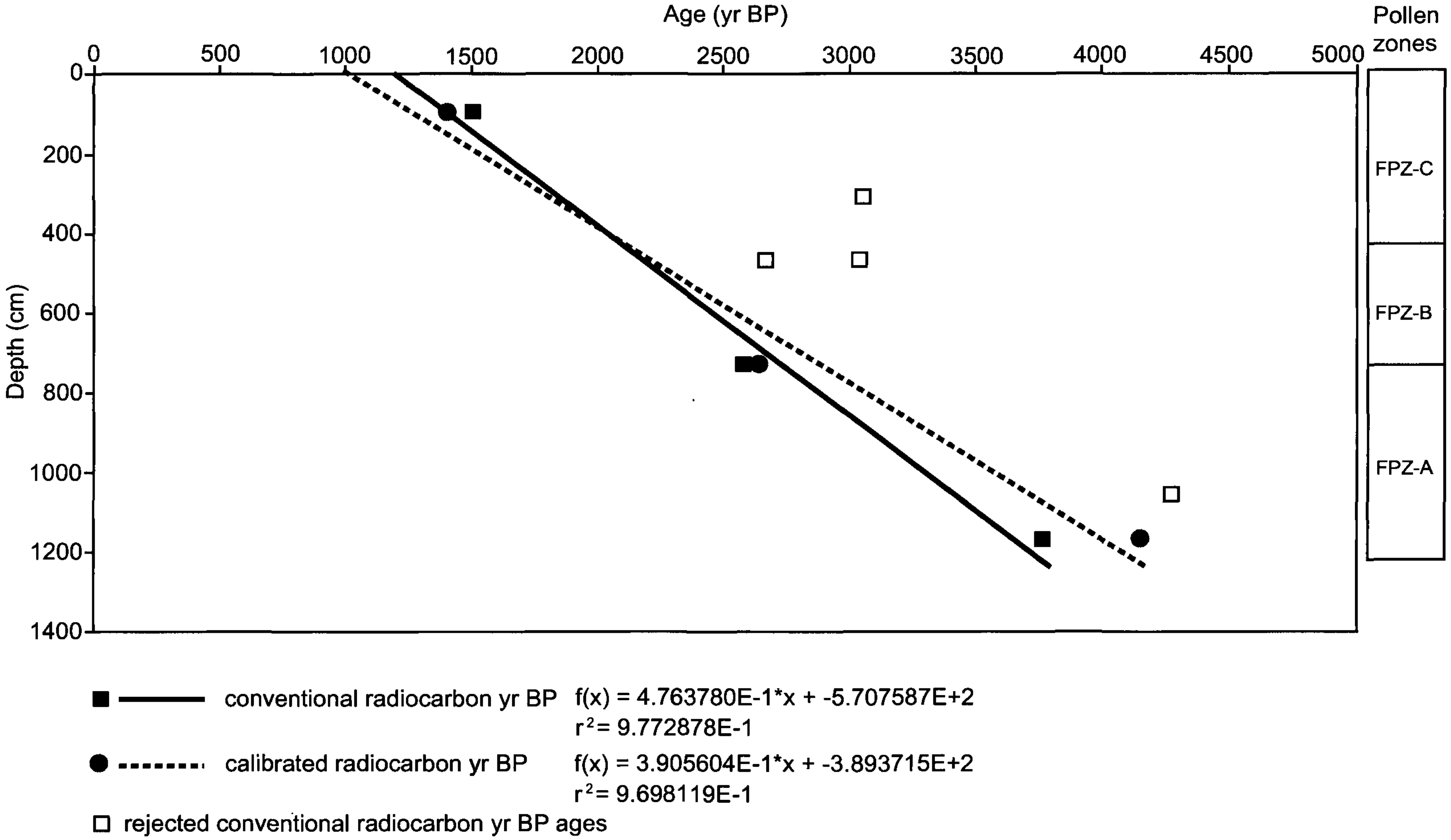
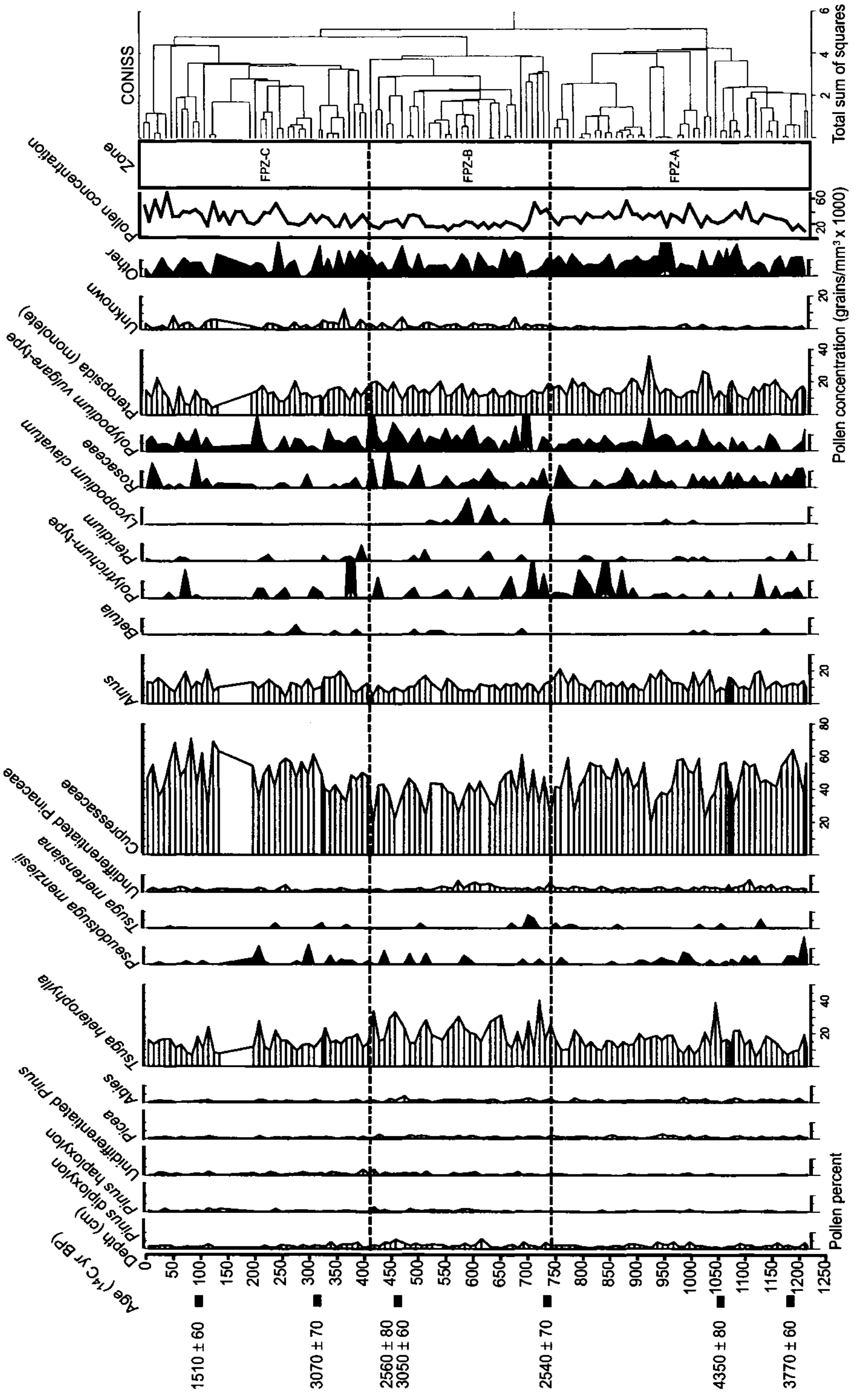


Figure 4.4: Age-depth model for the VEC02A04 sediment core. Pollen zones are shown on the right of the diagram.

Figure 4.5: Summarized pollen percentage diagram for the VEC02A04 sediment core. Chronology is reported on the left side of the diagram. Shaded areas represent a 10% exaggeration.


Age (¹⁴C yr BP)
Depth (cm)
Pinus diploxylon
Pinus haploxylon
Undifferentiated Pinus
Picea
Abies
Tsuga heterophylla
Pseudotsuga menziesii
Tsuga mertensiana
Undifferentiated Pinaceae
Cupressaceae
Alnus
Betula
Polytrichum-type
Pteridium
Lycopodium clavatum
Rosaceae
Polypodium vulgare-type
Pteropsida (monolete)
Unknown
Other
Pollen concentration
Zone
CONISS
FPZ-C
FPZ-B
FPZ-A
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
1200
1250
1510 ± 60
3070 ± 70
2560 ± 80
3050 ± 60
2540 ± 70
4350 ± 80
3770 ± 60
20
40
20
40
60
80
20
20
40
20
20
60
2
4
6
Pollen percent
Pollen concentration (grains/mm³ x 1000)
Total sum of squares

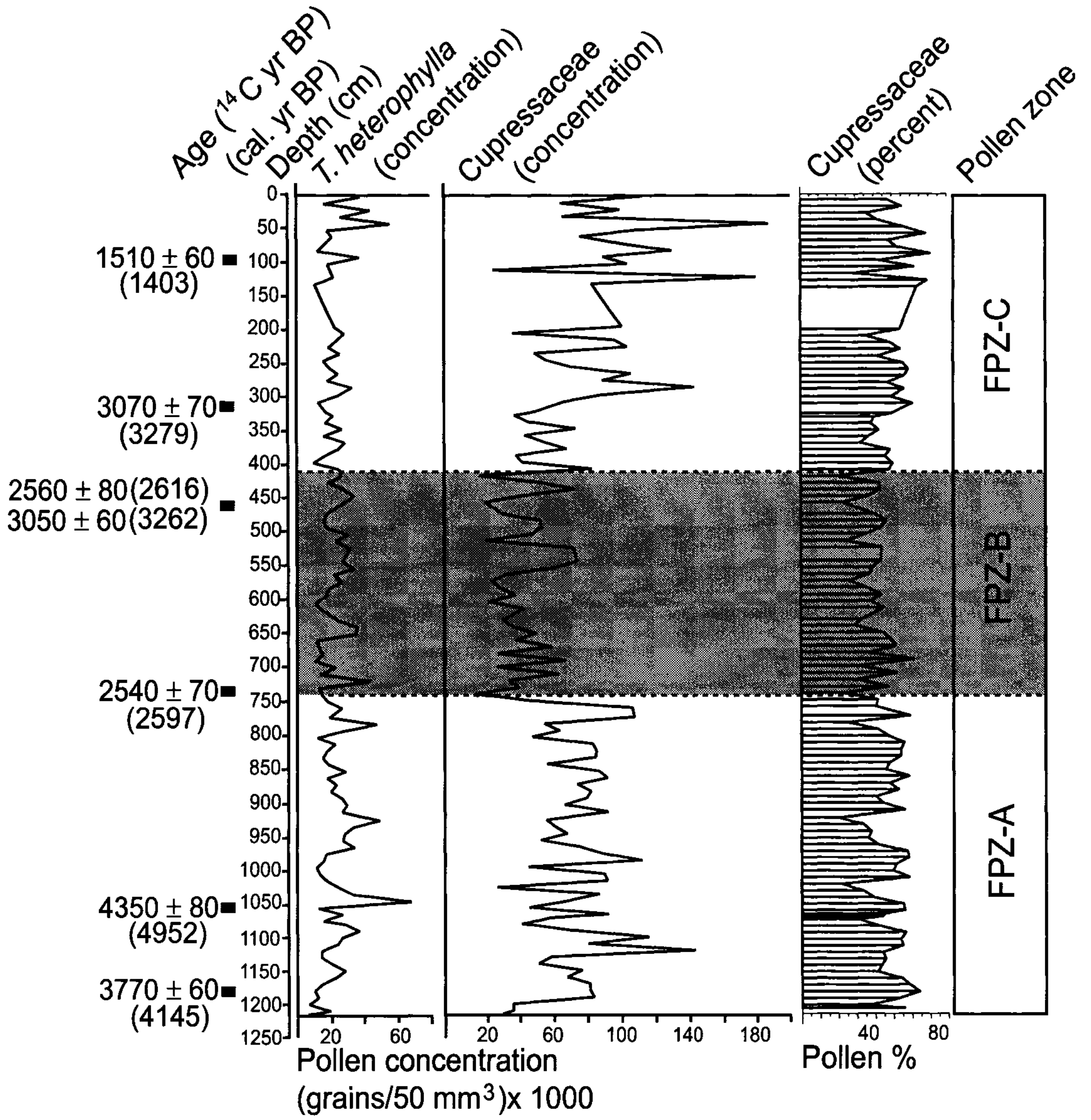


Figure 4.6: Pollen concentration of *T. heterophylla* and *T. plicata* in the Frederick Sound sediment core.

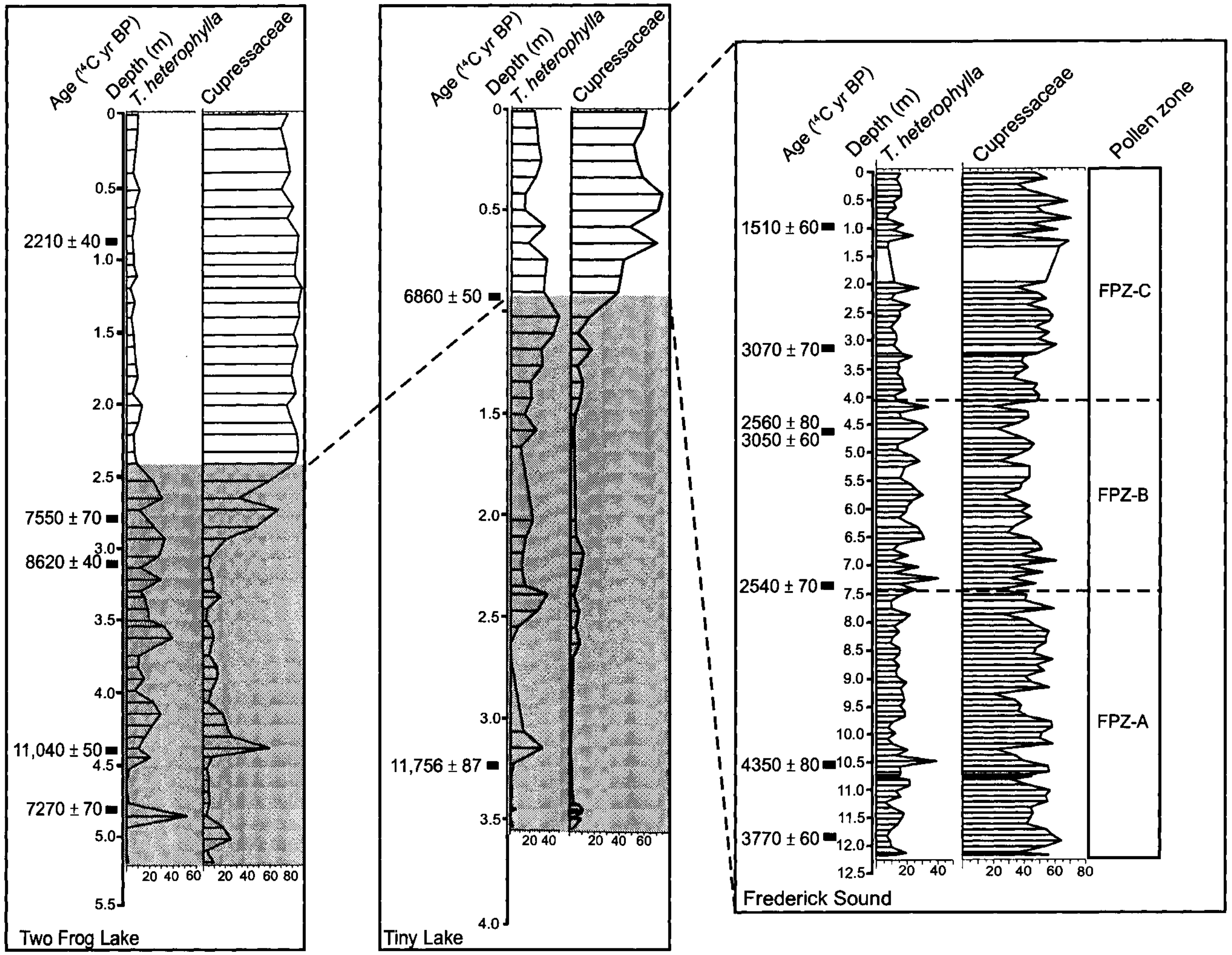
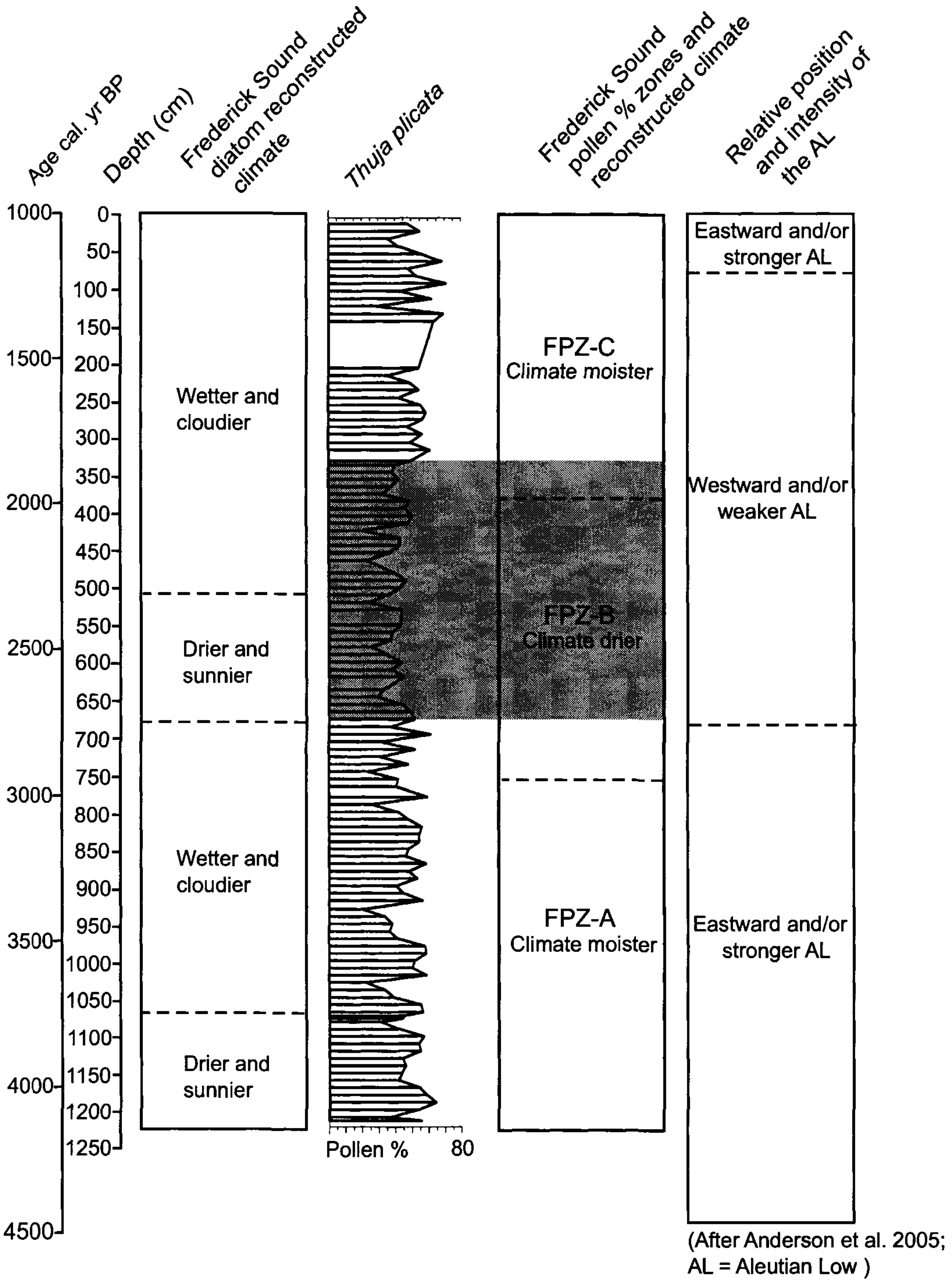


Figure 4.7: Comparison of dominant arboreal pollen types at Two Frog Lake, Tiny Lake and Frederick Sound.



(After Anderson et al. 2005; AL = Aleutian Low)

Figure 4.8: Comparison of VEC02A04 pollen inferred climate, diatom inferred climate and the relative intensity and position of the Aleutian Low pressure system.

Table 4.1: Conventional radiocarbon and calibrated calendar ages of the VEC02A04 sediment core.

Lab no.	Depth (cm)	Lithology	Material dated	Corrected age (^{14}C yr BP)	Calibrated age 95 % C.I. (cal. yr BP)*	Calibrated age 95 % C.I. (cal. yr BP)†*
TO-11083	unknown	unknown	twig	no date		
TO-10788	97	laminated	wood fragment	1510 ± 60	547 AD	1403
TO-11082	313	massive	wood fragment	3070 ± 70	1329 BC	3279
TO-10789	457	laminated	wood fragment	2560 ± 80	666 BC	2616
TO-10790	457	laminated	wood fragment	3050 ± 60	1312 BC	3262
TO-11084	734	woody layer	pine cone	2540 ± 70	647 BC	2597
TO-10791	1051	laminated	twig	4350 ± 80	3002 BC	4952
TO-10793	1182	massive	wood fragment	3770 ± 60	2195 BC	4145

* calibrated using CALIB REV5.0.1 (Stuiver and Reimer 1993) and INTCAL04 data set (Reimer et al. 2004)

† years before 1950

Appendix 4.1: Pollen and spore counts for the VEC02A04 sediment core.

Depth (cm)	*Pinus haploxylon*	*Pinus diploxylon*	Undifferentiated *Pinus*	*Picea*	*Abies*	*Tsuga heterophylla*	*Tsuga mertensiana*	*Pseudotsuga menziesii*	Undifferentiated Pinaceae	Cupressaceae	*Betula*	*Alnus*	*Acer*	*Salix*	*Populus*	*Corylus*	*Impatiens*	Liliaceae	*Agoseris*	*Vitis*	*Cornus*	Rosaceae	Poaceae	Ericaceae	Chenopodiaceae	*Artemisia*	*Ambrosia*	*Eupatorium*	*Ranunculus*	Pteropsida (monolete)	*Polypodium vulgare*-type	*Botrychium*
5	6	10	0	3	1	104	0	0	6	313	0	87	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	100	4	0
15	0	5	1	2	2	43	0	0	8	178	0	40	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	34	3	0
25	3	14	14	6	9	120	0	1	8	276	0	121	0	0	0	0	0	0	0	0	0	6	0	2	0	0	1	0	0	176	3	0
35	9	9	6	6	3	71	0	0	8	181	0	55	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	66	2	0
45	6	18	3	7	8	153	1	0	13	523	0	87	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	100	4	1
55	2	2	5	0	0	49	0	0	10	303	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
65	0	3	1	4	0	57	0	0	13	211	0	58	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	76	5	1
75	5	8	0	1	1	44	0	1	12	279	0	103	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	4	37	3	0
85	4	4	3	1	2	33	0	0	3	362	0	44	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	29	3	0
95	6	7	4	4	5	102	0	0	13	248	0	77	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	87	8	2
105	1	6	2	3	5	50	0	1	4	288	0	51	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	45	1	0
115	8	10	8	6	5	85	0	0	3	103	0	74	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	33	3	0
125	7	5	4	6	2	59	0	0	10	503	0	55	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	2	0
135	7	3	0	1	2	28	0	0	7	229	0	36	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	21	1	0
198	2	5	7	0	2	61	0	2	5	279	0	67	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	68	2	0
208	1	3	1	7	6	97	0	4	9	125	0	33	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	52	8	1
218	2	11	3	2	7	65	0	1	10	266	0	63	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	97	3	0
228	1	4	11	1	1	51	0	0	1	288	1	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	69	0	0
238	7	3	4	3	3	72	1	0	2	139	0	38	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	46	0	0
248	1	9	0	2	1	57	0	0	9	205	0	36	0	0	0	0	0	1	0	0	0	1	2	1	0	0	1	0	0	32	1	0
258	2	7	3	4	4	52	0	0	14	196	0	13	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	28	3	0
268	2	9	3	0	3	66	0	0	3	294	1	65	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	65	0	0
278	5	4	5	2	1	49	0	1	6	247	3	60	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	108	4	0
288	7	16	13	5	4	90	0	0	0	399	1	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	5	0
300	3	5	5	5	2	67	0	6	2	244	0	73	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	65	1	0
310	1	7	3	3	5	35	0	0	4	190	0	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	1	0
325	1	5	4	2	1	55	1	0	5	158	0	33	0	0	1	0	0	0	0	0	0	0	0	2	0	0	1	0	0	38	0	0
330	2	4	1	4	2	72	0	0	3	125	0	50	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	29	0	0
340	2	15	7	3	2	52	0	2	6	140	0	58	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	55	5	1
350	1	5	8	0	0	73	0	0	5	202	1	77	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	77	3	0
360	2	8	3	1	1	43	0	1	8	118	0	63	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	54	2	0

Depth (cm)	*Pinus haploxylon*	*Pinus diploxylon*	Undifferentiated *Pinus*	*Picea*	*Abies*	*Tsuga heterophylla*	*Tsuga mertensiana*	*Pseudotsuga menziesii*	Undifferentiated Pinaceae	Cupressaceae	*Betula*	*Alnus*	*Acer*	*Salix*	*Populus*	*Corylus*	*Impatiens*	Lilaceae	*Agoseris*	*Vitis*	*Cornus*	Rosaceae	Poaceae	Ericaceae	Chenopodiaceae	*Artemisia*	*Ambrosia*	*Eupatorium*	*Ranunculus*	Pteropsida (monolete)	*Polypodium vulgare*-type	*Botrychium*
370	5	12	4	3	1	78	1	1	7	149	0	69	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	64	2	0
380	2	11	0	4	5	67	0	1	3	187	0	30	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	1	33	3	0
390	1	13	3	0	5	64	0	0	3	152	1	24	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	1	53	3	1
400	1	2	11	5	0	36	0	0	5	155	0	31	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	36	1	1
410	2	7	4	0	5	68	0	1	5	229	0	58	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	75	0	0
420	5	4	6	1	2	58	0	0	2	34	0	9	0	0	0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	34	6	0
430	2	5	0	9	1	50	0	0	6	140	0	36	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	67	3	0
440	7	18	8	4	1	77	0	4	3	201	0	39	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	80	2	1
450	1	11	3	4	7	92	0	0	0	113	0	21	0	0	0	0	0	0	0	0	0	7	0	1	0	0	0	0	0	43	2	0
460	1	13	2	2	3	76	0	0	3	52	0	22	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	46	4	0
477	0	10	4	3	12	74	0	0	4	128	0	23	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	1	28	3	0
487	6	6	3	7	3	43	0	2	5	144	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	1	0
497	3	11	5	5	4	47	0	0	5	145	1	34	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	60	3	0
507	2	7	0	7	6	83	1	0	9	130	0	52	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	49	5	0
517	3	7	7	5	4	85	0	2	3	73	0	51	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46	1	0
527	6	12	0	4	0	86	0	0	5	199	1	57	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	58	4	0
547	4	11	0	7	7	74	0	0	16	204	1	35	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	96	3	0
557	4	4	0	4	7	94	0	0	11	165	0	65	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	50	6	0
567	1	7	5	4	6	91	0	0	7	133	0	45	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	43	2	0
577	4	5	2	6	5	95	0	0	21	81	0	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	3	0
587	7	12	4	2	4	85	0	2	8	128	0	28	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	68	2	0
597	5	5	4	6	6	64	0	1	14	138	0	27	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	28	4	0
607	2	5	4	3	2	37	0	0	11	72	0	13	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	30	3	0
634	2	4	1	4	6	95	0	0	18	117	0	37	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	44	3	0
644	2	4	2	6	5	97	0	0	11	97	0	37	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	52	2	0
654	1	2	0	1	0	96	0	0	8	136	0	24	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	34	0	0
664	3	6	2	3	2	44	0	0	7	150	0	36	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	35	2	1
674	0	8	2	2	3	35	1	0	7	163	0	34	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	46	1	0
684	1	1	4	3	2	41	0	0	4	73	0	24	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	24	3	0
694	1	12	0	1	5	28	0	1	5	185	1	24	0	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	34	0	1
704	0	5	2	4	7	70	2	0	6	81	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	11	0

Depth (cm)	Pinus haploxylon	Pinus diploxylon	Undifferentiated Pinus	Picea	Abies	Tsuga heterophylla	Tsuga mertensiana	Pseudotsuga menziesii	Undifferentiated Pinaceae	Cupressaceae	Betula	Alnus	Acer	Salix	Populus	Corylus	Impatiens	Liliaceae	Agoseris	Vitis	Cornus	Rosaceae	Poaceae	Ericaceae	Chenopodiaceae	Artemisia	Ambrosia	Eupatorium	Ranunculus	Pteropsida (monolete)	Polypodium vulgare-type	Botrychium
714	1	6	1	5	5	38	2	0	3	179	0	37	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	51	0	0
724	2	2	0	4	1	124	0	1	9	95	0	18	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	41	0	0
734	0	13	0	0	4	53	0	0	5	166	0	40	0	0	0	0	0	0	0	0	0	4	0	1	0	0	0	1	0	46	3	0
744	1	3	2	4	4	46	0	0	10	42	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	34	1	1
754	0	7	2	5	1	52	1	0	8	139	0	55	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	0	54	0	0
764	3	14	5	8	0	72	0	3	18	296	0	154	0	0	0	0	0	0	0	0	0	10	1	2	0	0	0	0	0	129	3	0
778	1	11	0	4	1	52	1	0	8	299	0	55	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	59	2	0
788	2	13	0	8	15	130	1	0	20	150	0	105	0	0	0	0	0	2	0	0	0	1	0	5	0	0	0	0	0	129	4	0
798	0	5	0	6	5	74	0	0	11	175	0	50	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	0	1	70	3	0
808	0	3	2	6	3	41	0	0	8	165	0	38	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	68	1	0
818	0	2	2	2	1	61	0	0	5	230	0	32	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	63	3	0
828	0	6	1	5	7	47	0	0	6	236	0	58	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	56	2	1
838	5	6	0	1	6	41	0	0	15	235	0	59	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	50	2	0
848	0	3	0	5	0	50	0	0	7	155	0	33	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	51	3	0
858	0	9	0	13	7	78	0	1	4	240	0	65	0	0	0	0	0	0	0	0	0	1	0	0	1	3	0	0	1	83	3	0
868	1	8	0	5	5	48	1	0	7	254	0	43	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	56	1	0
878	2	6	0	5	4	63	0	0	11	204	0	56	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	2	56	2	0
888	1	12	3	3	5	54	0	0	6	227	0	35	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	1	70	2	0
898	6	15	1	4	6	73	0	0	14	220	0	64	0	0	0	0	1	0	0	0	0	4	0	4	0	0	0	0	0	120	3	0
908	1	9	1	1	3	81	0	1	5	183	0	35	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	79	2	0
918	2	6	0	1	5	73	0	1	8	255	0	37	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	52	1	0
930	0	6	3	9	10	140	0	0	12	158	0	143	0	1	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	290	16	0
940	3	20	1	9	7	91	0	1	13	167	0	71	0	0	0	0	0	1	0	0	0	5	1	1	0	0	0	0	0	96	3	0
950	2	13	2	15	4	77	0	2	14	187	0	99	0	0	0	0	0	0	0	0	0	2	0	4	0	0	2	0	0	60	4	0
960	3	9	0	6	5	74	0	1	4	144	0	63	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	3	61	4	0
970	3	20	1	11	6	93	0	1	7	208	0	61	0	0	0	0	0	2	0	0	0	2	2	1	0	0	0	0	1	73	4	0
980	1	6	1	5	5	46	0	0	12	247	0	54	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	46	1	0
990	2	7	5	4	16	42	0	4	6	311	0	61	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	55	2	0
1000	5	13	4	7	4	40	0	2	2	164	0	23	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	42	2	0
1010	2	9	0	1	7	36	0	1	14	249	1	95	0	0	0	0	0	0	0	0	0	4	0	2	0	0	0	0	0	72	1	0
1020	1	8	0	5	5	48	1	0	7	254	0	43	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	56	1	0
1030	0	6	1	9	10	93	0	0	15	98	1	67	1	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	119	6	0

Depth (cm)	*Pinus haploxylon*	*Pinus diploxylon*	Undifferentiated *Pinus*	*Picea*	*Abies*	*Tsuga heterophylla*	*Tsuga mertensiana*	*Pseudotsuga menziesii*	Undifferentiated Pinaceae	Cupressaceae	*Betula*	*Alnus*	*Acer*	*Salix*	*Populus*	*Corylus*	*Impatiens*	Lilaceae	*Agoseris*	*Vitis*	*Cornus*	Rosaceae	Poaceae	Ericaceae	Chenopodiaceae	*Artemisia*	*Ambrosia*	*Eupatorium*	*Ranunculus*	Pteropsida (monolete)	*Polypodium vulgare*-type	*Botrychium*
1040	0	6	7	4	4	91	0	2	17	240	0	146	0	0	0	0	0	0	0	1	0	2	0	2	0	0	0	0	1	177	4	0
1050	0	5	0	4	4	187	0	0	13	187	0	32	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	1	39	1	0
1060	0	1	1	1	0	57	1	0	7	211	0	37	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	0	1	55	2	0
1070	2	6	0	1	5	73	0	1	8	255	0	37	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	52	1	0
1075	0	6	0	2	7	54	0	0	16	160	0	57	0	2	0	0	0	2	0	0	0	3	0	0	0	0	0	0	0	40	0	2
1079	1	5	0	4	5	42	0	1	6	142	0	50	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	58	0	0
1085	2	6	0	7	10	81	0	1	10	116	0	53	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	77	3	0
1094	4	14	0	8	9	101	0	0	15	195	0	42	0	0	0	0	0	0	0	1	0	4	2	1	0	0	0	0	1	56	1	0
1104	3	12	0	2	1	73	0	3	23	323	0	58	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	58	3	0
1114	0	9	0	4	4	65	0	1	30	222	0	33	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	36	0	0
1124	1	5	0	0	2	39	0	4	13	400	0	130	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	121	0	3
1134	0	4	1	6	7	39	2	0	13	161	0	72	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	49	1	0
1144	3	6	0	1	4	56	0	0	7	140	1	25	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	57	0	0
1154	3	8	0	5	9	78	0	0	22	212	0	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	84	5	0
1164	0	16	1	2	3	62	0	0	6	187	0	60	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	95	3	0
1174	0	6	4	7	8	39	0	0	11	225	0	42	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	0	0	64	0	2
1184	1	8	1	3	4	27	0	2	13	225	0	42	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	48	0	0
1194	1	4	0	2	2	33	0	2	6	232	0	44	0	0	0	0	0	0	0	0	0	2	0	2	1	0	0	0	1	28	0	0
1204	0	4	0	7	9	34	0	1	6	184	0	38	2	0	0	0	0	0	0	0	0	4	0	1	0	0	0	0	0	50	1	0
1214	0	13	0	3	1	68	0	6	8	128	0	48	0	0	0	0	0	0	0	0	0	4	1	1	0	0	0	0	0	60	2	1
1219	0	6	2	2	1	35	0	2	5	169	0	29	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	45	4	0

*Unknown I

†Total pollen sum = Main pollen sum + aquatics

Depth (cm)	Osmunda	Huperzia	Lycopodium clavatum	Cheilanthes	Ophioglossum	Pteridium	Cyperaceae	Equisetum	Polytrichum-type spores	Unknown I*	Unknown	Main pollen sum	Exotic Lycopodium	Potamogeton	Typha	Nuphar	Nymphaea	Total pollen sum*
5	0	0	0	0	0	1	0	0	0	0	23	661	30	0	0	0	0	661
15	0	0	0	0	0	0		0	0	0	3	324	30	0	0	0	0	324
25	0	0	0	0	0	0	0	0	0	0	10	770	30	0	0	0	0	770
35	0	2	0	0	0	0	0	0	0	0	10	431	30	0	0	0	0	431
45	0	0	0	0	0	0	0	0	3	0	6	936	30	0	0	0	0	936
55	0	0	0	0	0	0	0	0	0	0	37	443	30	0	0	0	0	443
65	0	1	0	0	0	1	0	1	0	2	5	440	30	0	0	0	0	440
75	0	0	0	0	0	1	0	0	9	0	19	529	30	0	0	0	0	529
85	0	0	0	0	0	0	0	0	0	0	20	512	30	0	0	0	0	512
95	0	0	0	0	0	0	0	0	1	1	3	578	30	2	0	0	0	578
105	0	0	0	0	0	0	0	0	0	0	4	465	30	0	0	0	0	465
115	0	1	0	0	0	0	0	0	0	0	16	357	47	0	0	0	0	357
125	0	0	0	0	0	0	0	0	0	0	44	727	30	0	0	0	0	727
135	0	2	0	0	0	0	0	0	0	1	20	362	30	0	0	0	0	362
198	0	1	0	0	0	0	0	0	0	0	11	514	30	0	0	0	0	514
208	0	0	0	0	0	0	0	0	2	0	4	355	38	0	0	0	0	355
218	0	1	0	0	0	1	0	0	3	1	3	541	30	0	0	0	0	541
228	0	0	0	0	0	2	0	0	0	0	19	528	30	0	0	0	0	528
238	0	0	0	0	0	0	0	0	0	2	9	330	31	0	0	0	0	330
248	0	0	0	0	0	0	0	1	1	0	8	369	40	2	0	0	0	369
258	0	1	0	0	0	0	0	0	2	0	3	333	30	0	0	0	0	333
268	0	0	0	0	0	0	0	0	0	0	7	521	30	0	0	0	0	521
278	0	1	0	0	0	0	0	0	0	0	21	521	30	0	0	0	0	521
288	0	0	0	0	0	0	0	0	0	0	8	706	30	0	0	0	0	706
300	0	0	0	0	0	0	0	0	0	0	13	495	30	0	0	0	0	495
310	0	1	0	0	0	0	0	0	2	0	1	311	31	0	0	0	0	311
325	0	1	0	0	0	0	0	0	1	0	11	320	35	0	0	0	0	320
330	0	0	0	0	0	1	0	0	0	0	17	311	37	0	0	0	0	311
340	0	0	0	0	0	0	0	0	0	0	16	366	34	0	0	0	0	366
350	0	0	0	0	0	0	0	0	0	0	19	473	30	0	0	0	0	473
360	0	1	0	0	0	0	0	0	0	0	11	319	30	0	0	0	0	319

Depth (cm)	Osmunda	Huperzia	Lycopodium clavatum	Cheilanthes	Ophioglossum	Pteridium	Cyperaceae	Equisetum	Polytrichum-type spores	Unknown I*	Unknown	Main pollen sum	Exotic Lycopodium	Potamogeton	Typha	Nuphar	Nymphaea	Total Pollen sum*
370	0	0	0	0	1	1		0	0	0	57	457	30	0	0	0	0	457
380	0	0	0	0	0	4	0	0	25	0	5	384	30	0	0	0	0	384
390	0	0	0	0	0	0	0	0	0	0	3	330	44	0	0	0	0	330
400	0	1	0	0	0	3	0	0	0	0	20	309	41	0	0	0	0	309
410	0	1	0	0	0	0	0	0	0	0	14	474	30	0	0	0	0	474
420	0	0	0	0	0	0	0	0	0	0	5	171	24	0	0	0	0	171
430	0	0	0	0	0	0	0	0	4	0	3	328	30	0	0	0	0	328
440	0	0	0	0	0	0	0	0	0	0	20	466	30	0	0	0	0	466
450	0	0	0	0	0	0	0	0	0	0	5	310	30	0	0	0	0	310
460	0	1	0	0	0	0	0	0	0	0	2	228	30	0	0	0	0	228
477	0	3	0	0	0	0	0	0	0	0	24	320	48	0	0	0	0	320
487	0	0	0	0	0	0	0	1	1	0	7	309	30	0	0	0	0	309
497	0	0	0	0	0	1	0	0	2	0	4	333	30	0	0	0	0	333
507	0	1	0	0	0	3	0	1	0	0	3	364	30	0	0	0	0	364
517	0	0	0	0	0	2	0	0	0	0	11	301	41	0	0	0	0	301
527	0	2	1	0	0	0	0	0	0	0	18	454	30	0	0	0	0	454
547	0	0	0	0	0	1	0	1	1	0	5	468	30	0	0	0	0	468
557	0	0	1	0	0	0	0	1	2	0	12	429	30	0	0	0	0	429
567	0	0	0	0	0	0	0	0	0	0	9	355	46	0	0	0	0	355
577	0	1	1	0	0	0	0	0	0	0	11	312	39	0	0	0	0	312
587	0	0	3	0	0	0	0	0	0	0	6	362	50	0	0	1	0	363
597	0	0	5	0	0	0	0	0	2	0	4	315	41	1	0	0	0	315
607	0	0	0	0	0	0	0	0	0	0	7	190	38	0	0	0	0	190
634	0	0	4	0	0	3	0	0	0	0	10	353	43	0	0	0	0	353
644	0	1	1	0	0	0	0	0	0	0	8	328	30	0	0	0	0	328
654	0	0	0	0	0	0	0	0	0	0	3	307	30	0	0	0	0	307
664	0	2	1	0	0	0	0	0	2	0	6	304	44	0	1	0	0	305
674	0	0	0	0	0	0	0	0	4	1	6	316	30	0	0	0	0	316
684	0	0	0	0	0	0	0	0	0	0	14	197	30	0	0	0	0	197
694	0	0	0	0	0	1	0	0	0	0	0	303	30	0	0	0	0	303
704	0	0	0	0	0	0	0	0	1	0	8	257	34	0	0	0	0	257

Depth (cm)	Osmunda	Huperzia	Lycopodium clavatum	Cheilanthes	Ophioglossum	Pteridium	Cyperaceae	Equisetum	Polytrichum-type spores	Unknown I*	Unknown	Main pollen sum	Exotic Lycopodium	Potamogeton	Typha	Nuphar	Nymphaea	Total pollen sum*
714	0	0	0	0	0	0	0	0	9	0	5	345	31	0	0	0	0	345
724	0	0	0	0	0	0	0	0	0	0	9	307	31	0	0	0	0	307
734	0	0	0	0	0	0	0	0	5	0	8	349	46	0	0	0	0	349
744	0	0	3	0	0	0	0	0	0	0	3	179	35	0	0	0	0	179
754	0	0	0	0	0	0	0		1	0	5	333	32	0	0	0	0	333
764	0	2	0	1	0	0	0	2	2	0	5	730	30	0	0	0	0	730
778	0	2	0	0	0	0	0	0	1	0	5	505	30	0	0	0	0	505
788	0	0	0	0	0	0	0	0	0	0	2	587	30	0	0	0	0	587
798	0	0	0	0	0	0	0	0	7	0	8	418	30	0	0	0	0	418
808	0	0	0	0	0	1	0	0	4	0	5	347	38	0	0	0	0	347
818	2	0	0	0	0	1	0	0	3	0	3	411	30	0	0	0	0	411
828	0	1	0	0	0	0	0	0	0	0	6	435	30	0	0	0	0	435
838	0	0	0	0	0	0	0	0	6	0	3	433	30	0	0	0	0	433
848	0	0	0	0	0	0	0	1	11	0	2	323	30	0	0	0	0	323
858	0	0	0	0	0	2	0	0	4	0	5	520	30	0	0	0	0	520
868	0	0	0	0	0	0	0	0	0	0	3	434	30	0	0	0	0	434
878	0	0	0	0	0	1	0	0	7	0	3	425	30	0	0	0	0	425
888	0	0	0	0	0	2	0	0	0	0	2	429	30	0	0	0	0	429
898	0	0	0	0	0	0	0	0	3	0	5	543	30	0	0	0	0	543
908	0	0	0	0	0	1	0	0	0	0	4	410	30	0	0	0	0	410
918	0	0	0	0	0	1	0	3	0	0	7	454	30	0	0	0	0	454
930	0	3	0	0	0	1	0	0	0	0	6	801	31	0	0	0	0	801
940	0	0	0	0	0	1	0	1	1	0	2	495	30	0	0	0	0	495
950	0	0	0	0	0	0	0	0	1	0	4	492	30	0	0	0	0	492
960	0	2	1	0	0	1	0	3	1	0	6	395	30	0	0	1	0	396
970	0	0	0	0	0	0	0	3	0	0	2	501	30	1	0	0	0	501
980	0	0	0	0	0	1	0	0	0	0	3	429	30	0	0	0	0	429
990	0	1	0	0	0	1	0	0	1	0	12	533	30	0	0	0	0	533
1000	0	0	0	0	0	0	0	0	0	0	9	319	40	0	0	0	0	319
1010	0	1	1	0	0	1	0	0	0	0	1	498	30	0	0	0	0	498
1020	0	0	0	0	0	0	0	0	0	0	3	434	30	0	0	0	0	434
1030	0	1	0	0	0	2	0	0	0	0	14	447	41	0	0	0	0	447

Depth (cm)	*Osmunda*	*Huperzia*	*Lycopodium clavatum*	*Cheilanthes*	*Ophioglossum*	*Pteridium*	Cyperaceae	*Equisetum*	*Polytrichum*-type spores	Unknown I*	Unknown	Main pollen sum	Exotic *Lycopodium*	*Potamogeton*	*Typha*	*Nuphar*	*Nymphaea*	Total pollen sum*
1040	0	0	0	0	0	0	0	0	3	0	5	712	30	0	0	0	0	712
1050	0	1	0	0	0	0	0	0	0	0	1	479	30	0	0	0	0	479
1060	0	0	0	0	0	0	0	0	0	0	3	382	51	0	0	0	0	382
1070	0	0	0	0	0	1	0	3	0	0	7	454	30	0	0	0	0	454
1075	0	0	0	0	0	0	0	0	0	0	4	355	30	0	0	0	0	355
1079	0	0	0	0	0	0	0	0	1	0	2	321	30	0	1	1	0	323
1085	0	0	0	0	0	0	0	0	0	0	5	374	31	0	0	0	0	374
1094	0	0	0	0	0	0	0	4	0	0	1	459	30	0	0	0	0	459
1104	0	0	0	0	0	0	0	3	0	0	4	569	30	0	0	0	0	569
1114	0	0	0	0	0	0	0	1	0	0	7	413	30	0	0	0	0	413
1124	0	0	0	0	0	0	0	0	0	0	4	727	30	1	0	0	0	727
1134	0	0	0	1	0	0	0	0	5	0	2	366	30	0	0	0	0	366
1144	0	0	0	0	0	0	0	0	0	0	3	306	30	0	0	0	0	306
1154	0	0	0	0	0	1	0	0	0	0	6	487	30	0	0	0	0	487
1164	0	0	0	0	0	3	0	0	3	1	4	451	30	0	0	0	0	451
1174	0	0	0	0	0	0	0	1	0	0	3	415	30	0	0	0	0	415
1184	0	0	0	0	0	0	0	0	1	0	6	384	30	0	0	0	0	384
1194	0	0	0	0	0	2	0	0	1	0	0	363	30	0	0	0	0	363
1204	0	0	0	0	0	0	0	0	2	0	4	347	57	0	0	0	0	347
1214	0	0	0	1	0	0	0	0	0	1	4	350	39	0	0	0	0	350
1219	0	0	0	0	0	0	0	0	0	0	0	303	63	0	0	0	0	303

CHAPTER FIVE

SUMMARY OF CONCLUSIONS

Palynological analysis of two lacustrine cores and one marine core retrieved from the Seymour-Belize Inlet Complex (SBIC) on the central mainland coast of British Columbia show that this region has experienced considerable post-glacial climate and vegetation change. The following summarizes the conclusions reached in this thesis.

Chapters 2 and 3:

Two closely spaced lake sites within the SBIC, Two Frog Lake and Tiny Lake, were chosen for study in order to produce a more coherent reconstruction of post-glacial climate change. A major limitation of previous work has been that routinely only one site is investigated within a region and it is commonly assumed that vegetation history of the one site is representative of the region. However, recent work has indicated that this is likely to be an invalid assumption (Brown and Hebda 2002a). By generating a "consensus" on regional vegetation change the effects of site-specific variables, such as edaphic quality and topography, may be recognized and the climate reconstruction from such work will therefore be more robust. However, the results of this study indicate that although the vegetation histories at Two Frog Lake and Tiny Lake have been site-specific to a degree, climate was the proximate cause of change at both sites. Therefore, the assumptions of previous work may be valid, at least across short distances (e.g., 10-20 km) and even in topographically complex regions.

Previous work in coastal British Columbia has mainly been focused on the southern mainland coast and the coastal islands with very little attention paid to the central and northern mainland coastal regions (Turunen and Turunen 2003). Syntheses of this work have indicated that the onset of a cool and moist near modern climate, as indicated by the initial expansion of *T. plicata*, did not begin until after ca. 6600 yr BP (Walker and Pellatt 2003). This study indicates that this event occurred over 1000 years earlier in the SBIC. This finding is important because it indicates that the timing of post-glacial climate transitions was asynchronous in coastal British Columbia and that these events, as well as the expansion of taxa such as *T. plicata*, did not necessarily propagate northward. Therefore, although the climate histories at Two Frog Lake and Tiny Lake were similar, on a broader geographical scale (e.g., over 40 km) extrapolations of regional climate are likely to be unreliable.

General climate and forest history of Two Frog Lake and Tiny Lake:

1. The SBIC was deglaciated prior to 11,040 ± 50 yr BP (13,030 cal. yr BP) and perhaps as early as ca. 12,000 yr BP (ca. 14,900 cal. yr BP). Early Late-Glacial climate (ca. 12,000-11,800 yr BP; ca. 14,900-14,500 cal. yr BP) was cool and dry and permitted the existence of open early successional *Pinus contorta* woodlands. A moistening climate ca. 11,800 yr BP (ca. 14,500 cal. yr BP) resulted in the expansion of *Alnus* and the replacement of open *P. contorta* woodlands by a conifer forest dominated by *Picea* with *Abies*, *P. contorta*, *Tsuga heterophylla*. An increase in *Tsuga mertensiana* and possibly *Chamaecyparis nootkatensis* pollen prior to 11,040 ± 50 (13,030 cal. yr BP) and the persistence of *Alnus* in *Picea* forests at Two Frog Lake may be a response to Younger Dryas-like cooling. A similar climate reversal may have occurred at Tiny Lake where successional trends towards *T. heterophylla* forests were reversed sometime after 11,763

± 87 yr BP (13,815 cal. yr BP). The early Holocene climate of the SBIC was warmer and drier than present and a forest mosaic of *T. heterophylla*, *Picea*, *Pseudotsuga menziesii* and *Alnus* grew at Two Frog Lake. *Pseudotsuga menziesii* was not a component of the early Holocene successional mosaic of *T. heterophylla* and *Alnus* at Tiny Lake because it may have been too moist or because this species did not migrate to this more northerly site. A climate transition to a moister and cooler climate occurred at ca. 8000 yr BP (ca. 9200 cal. yr BP) in the SBIC and permitted the development of late-successional forests of *Thuja plicata* and *T. heterophylla*. *Tsuga heterophylla* was a subordinate species at this time at Two Frog Lake but at Tiny Lake this taxon was the forest dominant. By ca. 6300 yr BP (ca. 7200 cal. yr BP) *T. plicata* had markedly increased at both sites to become the climax species in coastal forests and had nearly replaced *T. heterophylla* at Two Frog Lake.

2. The Two Frog Lake and Tiny Lake records document broadly similar climate intervals to each other and to other sites in coastal British Columbia, suggesting that regional climate has been the proximate control on post-glacial vegetation dynamics in the SBIC. However, the two records differ in detail to each other and to previous work, which indicates that vegetation dynamics can be site-specific, even between closely spaced sites, possibly due to meso to synoptic scale climate heterogeneity and/or localized factors such as edaphic quality or topography.

3. The initial rise of *T. plicata* and the development of a moist and cool climate at ca. 8000 yr BP (ca. 9200 cal. yr BP) in the SBIC predates the event in southern British

Columbia by 1000 years and in Washington by 500 years, but is comparable with onset of moister and cooler conditions at more northerly coastal sites. Atmospheric dynamics associated with the Aleutian Low pressure system may have resulted in climate heterogeneity in the Pacific Northwest during the Holocene.

Chapter 4:

1. The high-resolution (26-year) palynological analysis of the radiocarbon dated sediment core retrieved from Frederick Sound in the SBIC indicates that the late Holocene climate and vegetation of this region has been variable. A decline in *T. plicata* between occurred between ca. 2800-1900 cal. yr BP (ca. 2600-1900 ^{14}C yr BP) when a drier and cooler climate punctuated the otherwise wet conditions of the late Holocene. Climate change is postulated to have been the proximate cause of the *T. plicata* decline at Frederick Sound, although the role of biotic factors cannot be ruled out. Most other paleoclimate records from coastal British Columbia do not document a *T. plicata* decline or a dry interval at this time but this is likely the result of the low-resolution quality of previous work. Further high-resolution research in this study area and elsewhere in coastal British Columbia is required in order to substantiate these hypotheses by constraining the geographical extent of the *T. plicata* decline and dry climate signature.

2. Comparison of the VEC02A04 pollen record with a proxy reconstruction of the Aleutian Low pressure system (Anderson et al. 2005) suggests that millennial scale variability in the relative position and/or intensity of this semi-permanent system have influenced the climate and vegetation of the SBIC throughout most of the Late Holocene.

A de-coupling between the VEC02A04 record and the Aleutian Low record at 1900 cal. yr BP (1900 ^{14}C yr BP) suggests that a return to wetter conditions in the SBIC may not have been driven by movements in the Aleutian Low.

3. The VEC02A04 pollen record validates the use of high-resolution palynology for post-glacial paleoclimate and paleoecological studies because the 900-year decline in *T. plicata* would probably not have been recognized in a lower resolution analysis.

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