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Multi-proxy evidence of postglacial climate and environmental change at Two Frog Lake, central mainland coast of British Columbia, Canada

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Abstract Pollen and diatoms preserved in the radiocarbon dated sediments of Two Frog Lake in the Seymour-Belize Inlet Complex of the central mainland coast of British Columbia document postglacial climate change. Two Frog Lake was isolated from the sea prior to 11,040 ± 50 yr BP (13,030 cal. yr BP) when the climate was cool and dry, and open *Pinus contorta* woodlands covered the landscape. These woodlands were replaced by a mixed conifer forest ca. 10,200 yr BP (ca. 12,300 cal. yr BP) when the climate became moister. A relatively dry and warm early Holocene climate allowed *Pseudotsuga menziesii* to migrate northward to this site where it grew with *Picea*, *Tsuga heterophylla* and *Alnus*. The climate became cooler and moister at ca. 8,000 yr BP (ca. 9,200 cal. yr BP), approximately 500–1,000 years prior to sites located south of Two Frog Lake and on the Queen Charlotte Islands, but contemporary with sites on the northern mainland coast of British Columbia and south coastal Alaska. Climate heterogeneity in central coastal British Columbia appears to have occurred on a synoptic scale, suggesting that atmospheric dynamics linked to a variable Aleutian Low pressure system may have had an important influence on early Holocene climate change in the Seymour-Belize Inlet Complex. The transition to cooler and moister conditions facilitated the expansion of Cupressaceae and the establishment of a modern-type coastal temperate rainforest dominated by Cupressaceae and *T. heterophylla*. This was associated with progressive lake acidification. Diatom changes independent of vegetation change during the late Holocene are correlative with the mid-Neoglacial period, when cooler temperatures altered diatom communities.

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Introduction

The coastal temperate forests of the Pacific Northwest are unique in their coniferous dominance, longevity and productivity, and are important both ecologically and economically (Waring and Franklin 1979; Franklin and Dryness 1973). These forests could be at risk since any future climate change may affect their range and structure

(Hebda 1998). Pollen-based paleoecological studies can provide an important long-term perspective, not available from the instrumental record or modern ecological studies, on the development of forest communities and their response to past climate change, thus providing insight that may be used to predict how these systems may be affected by future variability (Ricklefs 1987; Hebda 1998). Most post-glacial climate reconstructions conducted in coastal British Columbia have been based on terrestrial proxies such as pollen, plant macrofossils and charcoal (e.g. Hebda 1983; Wainman and Mathewes 1987; Pellatt and Mathewes 1997; Brown and Hebda 2002; Lacourse 2005) although aquatic indicators such as diatoms (e.g. Holtham et al. 2004; Doherty 2005) and Chrinomids (e.g. Walker and Mathewes 1989; Barley et al. 2006) have also been used.

As lacustrine ecosystems are also directly affected by climate change, diatom floras from these sediments are excellent indicators of paleoclimate since they respond rapidly to habitat and limnological changes associated with climate. By using both diatoms and pollen in paleoecological research, a more robust and complete reconstruction of postglacial climate change may be formulated. This study uses pollen and diatoms preserved in lake sediments of Two Frog Lake (TFL; informal name), within the Seymour-Belize Inlet Complex (SBIC) of the central mainland coast of British Columbia, to reconstruct a postglacial climate and environmental history of this region (Fig. 1; Meidinger and Pojar 1991; Green and Klinka 1994; Pojar and Mackimmon 1994). The SBIC was chosen as an area of interest because little is known about the Quaternary environmental history of the central mainland coast of British Columbia since the majority of previous work has focused on the southern coast of the province and on the coastal islands (e.g. Mathewes 1973; Mathewes and Heusser 1981; Hebda 1983; Warner 1984; Fedje 1993; Pellatt and Mathewes 1994, 1997; Brown and Hebda 2002, 2003; Lacourse 2005; Lacourse and Mathewes 2005). Understanding the climate history of this region is important because Holocene climate change appears to have been time transgressive in coastal British Columbia and a more thorough understanding of the geographical variability of
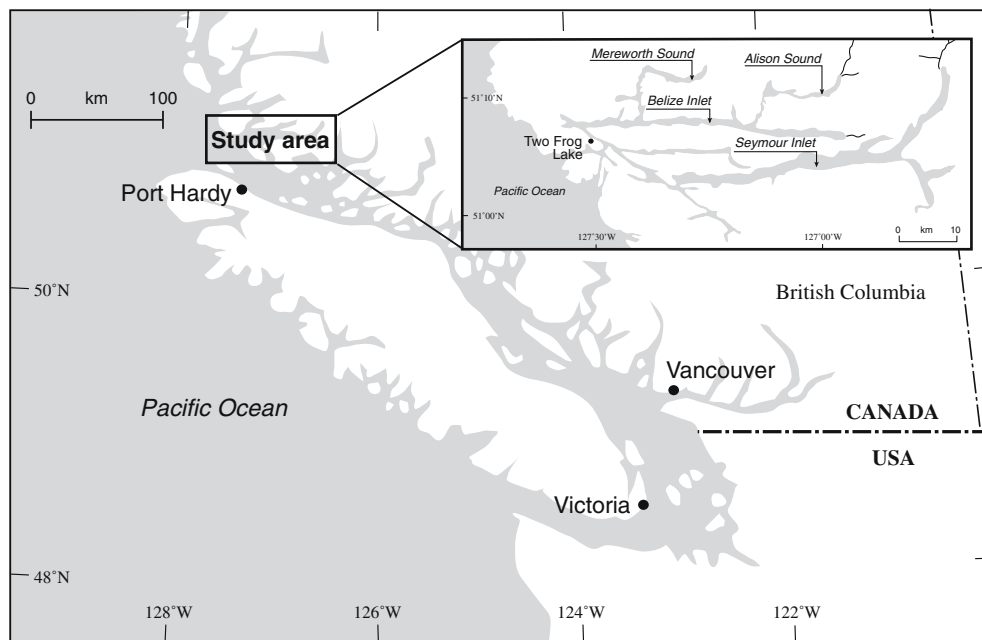

Fig. 1 (**a**) Map of Canada and (**b**) map of British Columbia showing the location of the Seymour-Belize Inlet Complex and (**c**) map of the Seymour-Belize Inlet Complex showing the location of TFL

postglacial climate may provide insight on the drivers and mechanisms of change (Walker and Pellatt 2001, 2003).

Potential target lakes within the SBIC were selected from aerial photographs with accessibility (proximity to the coastline) and elevation (less than 10 m above present sea level) as criteria. Lake elevation was important because the examination of a number of low-lying coastal isolation basins with different sill heights could track postglacial relative sea level movement (Doherty 2005). Several basins were identified for study and this paper presents the results from one site, TFL. Results are compared to previous work in order to place findings into a regional perspective, with particular focus on records from Bear Cove Bog (Hebda 1983) and Misty Lake (Lacourse 2005) on northern Vancouver Island since these are the closest previously studied sites to the SBIC and because they lie within the same biogeoclimatic subzone and variant as TFL (Meidinger and Pojar 1991; Green and Klinka 1994).

Study area

The SBIC is situated on the central coastal mainland of British Columbia, approximately 40 km NE of Port Hardy, Vancouver Island (Fig. 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 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).

TFL is located 3.59 m above sea level and lays 30 m inland from Seymour Inlet (51°06.361′ N, 127°32.082′ W; Fig. 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). A small stream located at the northwestern margin of the basin flows to the
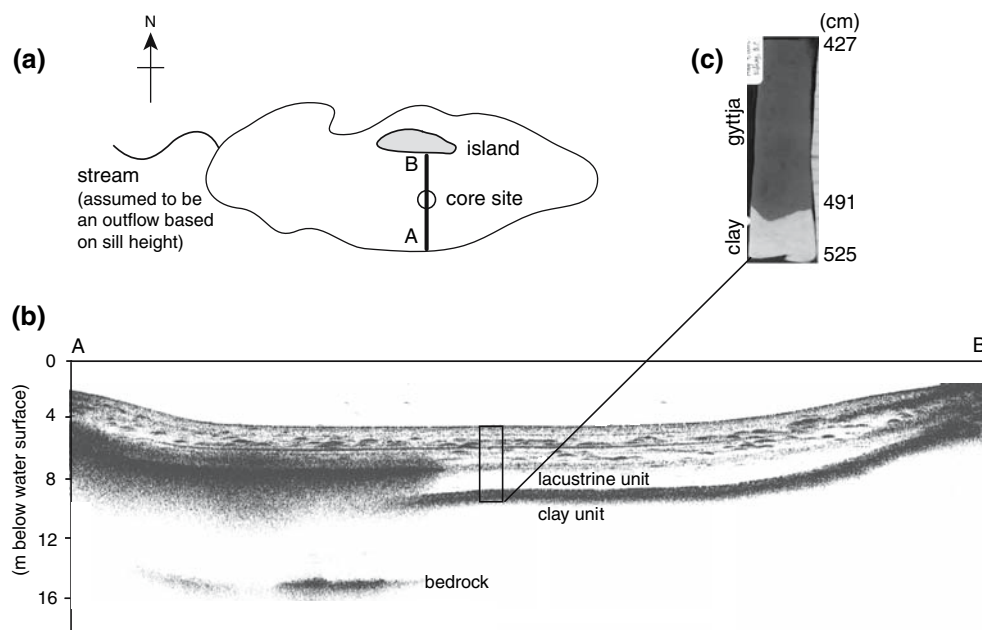

Fig. 2 (a) Schematic of Two Frog Lake showing the core site and transect of the sub-bottom profile (b) and (c) a negative X-ray of the lower Two Frog Lake sediment core showing the contact between basal clay and overlying organic mud

ocean. The lake lies within the Very Wet Hyper-maritime subzone, southern variant (CWHvh1) of the Coastal Western Hemlock biogeoclimatic zone (CWHZ), which 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 (Meidinger and Pojar 1991; Green and Klinka 1994; Pojar and Mackimmon 1994). The climate of this region is characterized by cool summers and mild winters (mean annual temperature of 9.1°C) and is very wet (mean annual precipitation of 3,120 mm) due to the seasonal influences of the Aleutian Low (AL) and North Pacific High (NPH) pressure systems (Green and Klinka 1994; Trenberth and Hurrell 1994). The vegetation of the CWHvh1 is dominated by *T. hetero-phylla* (western hemlock) with *T. plicata* (western redcedar; Meidinger and Pojar 1991). *Picea sitchensis* (Sitka spruce) occupies well-drained sites, such as marine terraces and floodplains, and *Abies amabilis* (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* (mountain hemlock) grows in wet sites with deep organic soils and *Chamaecyparis nootkatensis* (yellow cedar) is common in moist to wet rocky or boggy sites (Pojar and MacKinnon 1994). *Pinus contorta* (lodgepole pine) is common in low elevation dry or boggy sites and *Pinus monticola* (western white pine) grows in dry to moist open sites (Pojar and MacKinnon 1994). *Taxus brevifolia* (western yew) is a common mid-canopy or understory component in mature *Tsuga heterophylla-Thuja plicata* forests (Bolsinger and Jamarillo 1990; Pojar and MacKinnon 1994) and *Acer glabrum* (Douglas maple) grows as a shrub or small tree on open, dry ridges as well as in moist, well-drained sites in this region (Pojar and MacKinnon 1994). Both *Alnus rubra* (red alder) and shrubby *A. sinuata* (Stika alder) are common in the CWHvh1 where they both occupy open disturbed sites. However, *Alnus rubra* is more common in riparian habitats and *A. sinuata* is more common on open dry sites such as avalanche tracks or recently glaciated terrains (Pojar and MacKinnon 1994; Hebda 1997). *Pseudotsuga menziesii* (Douglas-fir) is notably

absent from the CHWvh1 (Allen et al. 1999). An understory of ferns, bryophytes and shrubs, namely *Gaultheria shallon* (salal), form an important ecological component of the forests of the CWHvh1 (Meidinger and Pojar 1991; Klinka et al. 1996; Newmaster et al. 2003).

Methods

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). The profile indicated that the sediments of TFL likely contained two sedimento-logical units: a basal minerogenic clay unit and an overlying organic sediment unit (Fig. 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 raft anchored over the core site (Fig. 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 cling wrap and aluminum foil as an archive. The other half of the sediment core was logged, X-rayed (Fig. 2) and sub-sampled for microfossil and loss-on-ignition (LOI) analysis. The archival core remained at the Pacific Geoscience Centre and the sub-sampled material was shipped to Carleton University, Ottawa, where it was stored in a cold room at 4°C for study. Bulk sediment samples were selected from the sediment sub-samples for radiocarbon dating.

Chronology and sedimentology

Within the 525 cm sediment core, a basal unit (525–491 cm) consists of glaciomarine light gray clay with fine sand that is sharply overlain by a medium brown to black massive lacustrine dy unit (Fig. 2). Dy can be defined as a sticky, gel-like mud that is composed almost entirely of precip-itated humic colloids of terrestrial origin (Faegri and Iversen 1989). Dy is common in oligotrophic

lakes in British Columbia and can be identified by the black to dark brown color of the supernatant liquid following chemical treatment with potassium hydroxide (Faegri and Iversen 1989; Hebda 1997). 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 (Faegri and Iversen 1989).

Since no macrofossils were retrieved from the TFL core, five bulk sediment samples were submitted for AMS radiocarbon dating to Iso-Trace Laboratories, University of Toronto, Toronto, and to Beta-Analytic, Florida (Table 1). The ratios of $^{13}C/^{12}C$ (‰) were not reported from IsoTrace Laboratories and a standard correction factor of –25‰ was applied. Conventional radiocarbon ages were calibrated to calendar years before present using the INTCAL98 database for terrestrial material 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. Late-glacial reservoir effects have 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). No correction was applied to the basal date of 11,040 ± 50 yr BP (13,030 cal. yr BP) at TFL but it is possible that this age may be as much as ~630 years too old (cf. Hutchinson et al. 2004). The other dates obtained from the TFL core have probably not been affected by the incorporation of old carbon because this effect becomes negligible approximately 1,000 years following lake inception as forest and soil development reduce exposure and weathering rates of tills (Engstrom et al. 2000; 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. 3; Telford et al. 2004). The lines were not forced through 0 yr BP at 0 cm. Linear interpolation accounts for potential changes in sedimentation rate better than linear regression and although this model cannot be correct, it is rarely "unacceptably wrong" (Telford et al. 2004). One radiocarbon date (7,270 ± 70 yr BP; 8,603 cal. yr BP) was considered erroneous since it was out of stratigraphic order and was therefore excluded from the age-depth model. Age ranges for pollen zones were estimated from the model (Fig. 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 region of the province (Clague et al. 1995). Trends in organic content of the TFL sediment core were determined by percent loss-on-ignition (Figs. 4, 5; Boyle 2004).
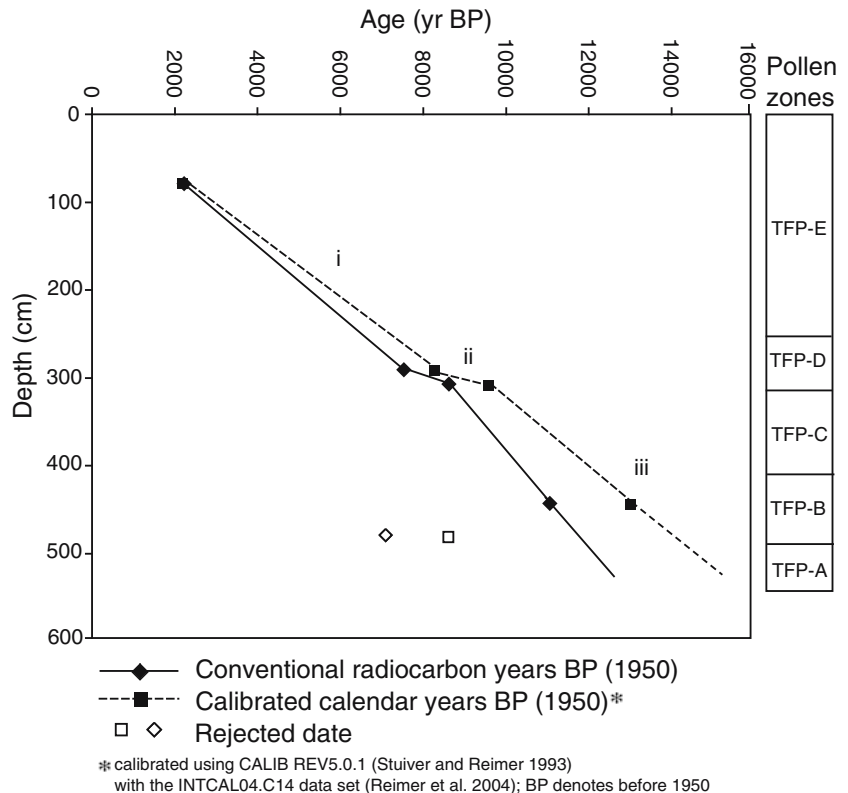
Pollen and spores

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) and Bennett and Willis (2001). 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

Table 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.)[a]
Beta-185142	81	Dy	2,210 ± 40	2,330–2,120 (2,225)
TO-10766	293	Dy	7,550 ± 70	8,425–8,180 (8,303)
Beta-185141	310	Dy	8,620 ± 40	9,660–9,530 (9,595)
Beta-185143	445	Dy	11,040 ± 50	13,170–12,890 (13,030)
TO-10777	489	Dy	7,270 ± 70	8,185–7,940 (8,063)

[a] Calibrated using INTCAL98 (Stuiver et al. 1998); BP denotes before 1950

Fig. 3 Age-depth model for Two Frog Lake based on linear interpolation

Conventional radiocarbon years BP (1950)
Calibrated calendar years BP (1950)✳
Rejected date

✳ calibrated using CALIB REV5.0.1 (Stuiver and Reimer 1993) with the INTCAL04.C14 data set (Reimer et al. 2004); BP denotes before 1950
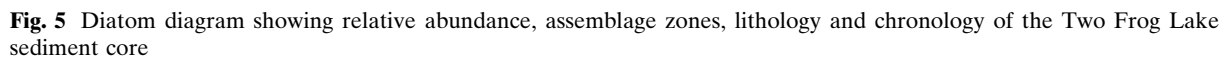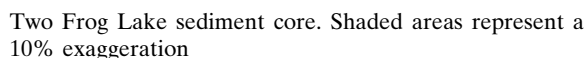
i) sedimentation rate = 0.040 cm/radiocarbon year; 0.035 cm/calendar year
ii) sedimentation rate = 0.016 cm/radiocarbon year; 0.013 cm/calendar year
iii) sedimentation rate = 0.056 cm/radiocarbon year; 0.034 cm/calendar year

because large sedimentary particles were rare and siliceous material did not interfere with pollen identification. 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 2,000 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 concentration (Batch No. 938 934, $n = 10,679 \pm 953$ std. error spores/tablet; Benninghoff 1962; Stockmarr 1971).

All prepared samples were analyzed for pollen and spores, which were enumerated at 400× magnification with an Olympus BX51 transmitted light microscope at intervals of 8 cm or 12 cm from 0 to 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 1,663, 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. (1973), 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). *Pinus* pollen was identified as diploxylon type or haploxylon type (Faegri and Iversen 1989). *Juniperus* (juniper), *Chamaecyparis nootkatensis* (yellow cedar), *Taxus brevifolia* (western yew) and *Thuja plicata* (western redcedar) pollen are grouped together as Cupressaceae since they are difficult to differentiate by light microscopy. *Larix* (larch) and *Pseudotsuga 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,

Fig. 4 Pollen diagram showing the relative abundances of select taxa, total pollen concentration, assemblage zones, lithology, percent loss-on-ignition and chronology of the Two Frog Lake sediment core. Shaded areas represent a 10% exaggeration

Fig. 5 Diatom diagram showing relative abundance, assemblage zones, lithology and chronology of the Two Frog Lake sediment core

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 (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 (older material did not acquire stain as readily). A similar phenomenon was observed for exotic and fossil *Lycopodium 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*; pond lily, *Typha*; cat-tail) frequencies were expressed as a percentage of the total PS. Calculation of pollen concentration followed Stockmarr (1971). Pollen frequency was graphed using Tiliagraph (Grimm 1993) and the CONISS program for stratigraphically constrained cluster analysis with a square root data transformation was applied to aid diagram zonation (Grimm 1987).

Diatoms

Sediment samples (0.5–2.0 g dry sediment) were prepared for diatom analysis following the methods described by Denys (1994) and Battarbee et al. (2001). In brief, samples were heated with 30% hydrogen peroxide and 10% hydrochloric acid to digest organic and calcareous material, centrifuged and any suspended clay material was decanted. Single drops of the residues were mounted on microscope slides with Naphrax®. Diatom counts were carried out using a Nikon Eclipse E200 light microscope under 1,000×

magnification and oil immersion. A minimum of 300 diatom valves were enumerated, except in the basal clay sediments where preservation was poor (minimum count of 200 valves), and identified to the lowest taxonomic level possible using the keys of Van Der Werff and Huls (1957–1974), Patrick and Reimer (1966, 1975), Germain (1981), Hartley (1986), Krammer and Lange-Bertalot (1986, 1988, 1991a, b) and Cumming et al. (1995). Samples were analyzed every 8–20 cm throughout the core and at greater resolution near the contact between clay and overlying organic sediment. Diatom frequencies were expressed as a percentage of the total valves counted and graphed using Tiliagraph (Grimm 1993). The CONISS program for stratigraphically constrained cluster analysis with a square root data transformation was applied to aid diagram zonation (Grimm 1987). Paleoenvironmental interpretation and classification of salinity and life form was based on the methods of Vos and De Wolf (1988, 1993) and Denys (1991–1992, 1994). The diatoms were classified according to the halobian system (Kolbe 1927; Hustedt 1957) that divides species into five categories of salt tolerance: polyhalobous (fully marine), meoshalobous (brackish), oligohalobous halophilous (salt-tolerant freshwater), oligohalobous indifferent (slightly saline) and halophobous (exclusively freshwater).

Results

Twenty-eight pollen and spore taxa were identified from 57 sediment horizons throughout the TFL sediment core. The pollen and spore percentage diagram is divided into five pollen assemblage zones (Fig. 4).

Pollen and spores

Zone TP-1 (525–499 cm)

The sediments of TP-1 consist of light gray homogenous silt that contain fine sand and have low organic content (LOI 1–10%; Fig. 4).

This pollen spectra of this zone is characterized by high relative abundances of *Pinus* diploxylon

pollen, which reach 93% at 515 cm. Cupressaceae pollen fluctuates between <10% and 23%. *Picea*, *Tsuga heterophylla* and *Betula* pollen are present in this zone less than 5%. Non-arboreal pollen (NAP) increases to ~10% by the end of this zone and includes pollen and spores of Rosaceae, Ericaceae, *Polypodium vulgare*-type and Pteropsida (monolete). Pollen and spore concentrations increase from 107 grains/mm^3 to 895 grains/mm^3 at 507 cm.

Zone TP-2 (499–412 cm)

A diffuse transition (*sensu* Schnurrenberger et al. 2003) from the basal marine silt unit to overlying medium brown, grading upward to black, massive dy sediments with higher organic content (LOI 35–60%) occurs at 493 cm. Radiocarbon dates of 7,270 ± 70 yr BP (8,603 cal. yr BP; Table 1) and 11,040 ± 50 yr BP (13,030 cal. yr BP) were obtained from 489 cm and 445 cm, respectively.

Pollen zone TP-2 is characterized by a decline in *Pinus* diploxylon 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 is otherwise present ~2–3%. *Abies* pollen is present ~0–2% and *Acer* pollen occurs ~1% in this zone. NAP reaches ca. 20% at 4.58 m and consists mainly of *Polytrichum*-type, Pteropsida (monolete), *Polypodium vulgare*-type and *Equisetum* spores. Pollen and spore concentrations markedly increase in this zone to 11,847 grains/mm^3.

Zone TP-3 (412–304 cm)

The sediments of TP-3 consist of black dy with relatively high organic content (LOI 40–50%). A radiocarbon date of 8,620 ± 40 yr BP (9,595 cal. yr BP) was obtained from 310 cm.

Pinus diploxylon pollen continues to decline in this zone and is accompanied by an increase in *Tsuga heterophylla* (40%), *Alnus* (47%), *Picea* (20%) and *Pseudotsuga menziesii* pollen (2%). NAP, excluding *Polytrichum*-type spores,

reaches a maximum of ~10% towards the end of the zone. NAP taxa registering greater than 1% in this zone include *Polypodium vulgare*-type, *Equisetum* and Pteropsida (monolete) spores. *Polytrichum*-type spores peak at 312 cm to 55%. Pollen and spore concentrations reach 6,387 grains/mm^3 at 396 cm.

Zone TP-4 (304–252 cm)

The sediments of TP-4 consist of homogenous black dy. Percent LOI values peak to 75% mid-zone and then decrease to 65%. A radiocarbon date of 7,550 ± 70 yr BP (8,303 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% to ~10% throughout the zone and consists mainly of Pteropsida (monolete), *Polypodium vulgare*-type and *Equisetum* spores. A pollen and spore concentration of 5,767 grains/mm^3 occurs towards the end of this zone.

Zone TP-5 (252–0 cm)

The sediments of this zone consist of homogenous black dy and have percent LOI values that fluctuate between ~50–40%. A radiocarbon date of 2,210 ± 40 yr BP (2,225 cal. yr BP) was obtained from 81 cm.

This zone is dominated by Cupressaceae pollen, which peaks to ~90% at 120 cm and maintains a proportion greater than 70% throughout the zone. *Pinus* haploxylon pollen increases to 10% near the end of the zone. *Tsuga heterophylla* pollen occurs at frequencies between 5% and 10% and *Alnus* pollen is present ~3%. NAP peaks to ~7% near the end of the zone and includes *Ophioglossum*, *Lycopodium clavatum* and *Huperzia* spores. Pollen and spore concentrations peak at 11,832 grains/mm^3 in this zone but subsequently decline to 2,563 grains/mm^3.

Diatoms

Zone TD-1 (525–491 cm)

The diatom assemblage of this basal section is characterized by high frequencies of polyhalobous and mesohalobous species. The frequency of polyhalobous species, namely *Coscinodiscus peltoides* and *C. excentricus*, declines throughout the zone and mesohalobous species such as *Nitzschia lanceolata* and *Thalassiosira baltica* fluctuate between 30% and 42%. Oligohalobous-indifferent species, dominated by *Fragilaria pinnata*, increase above 515 cm and attain a peak of 47% at 491 cm.

Zone TD-2 (491–272 cm)

This zone is characterized by a pronounced increase in freshwater diatoms. At 491 cm, frequencies of polyhalobous and mesohalobous taxa fall to trace levels (<1%) and oligohalobous-halophilous species fluctuate between 1% and 5%. The diatom assemblage is dominated by oligohalobous-indifferent species, which consist primarily of *Aulacoseira distans*, *Cyclotella stelligera* and *Fragilaria exigua*. The latter two species decline throughout the zone as *Eunotia tenella* increases in relative abundance. Lower proportions of other oligohalobous-indifferent species, such as *Brachysira brebissoni* and *Fragilaria brevistrata*, are recorded. Halophobous species such as *Pinnularia subcapitca* var. *hilseana* and *Tabellaria flocculosa* are present in low frequencies (<10%), but increase to ~25% as the zone progresses.

Zone TD-3 (272–50 cm)

Oligohalobous-indifferent and halophobous species dominate the diatom assemblage of this zone. The assemblage includes high frequencies of *Frustulia rhomboides* var. *saxonica*, which declines substantially at 100 cm and then increases again to 32% towards to top of the zone. *Aulacoseira distans*, *Eunotia diodon*, *E. tenella*, *Tabellaria fenestrata*, *Fragilaria rhomboides* and *T. flocculosa* are also present in this zone at frequencies ~10%.

Zone TD-4 (50–0 cm)

The diatom assemblage of this zone is dominated by oligohalobous-indifferent species such as *Aulacoseria distans* and *Brachysira brebissonii*, which increase in abundance towards to top of the zone. *Frustulia rhomboides* var. *saxonica* and *Eunotia diodon* remain important components of the flora of the lake at this time even though they are present in lower relative abundances than in the previous zone.

Discussion

The early late-glacial zones
(TP-1, TD-1; ca. 12,000–11,800 yr BP;
ca. 14,900–14,500 cal. yr BP)

The prevalence of marine diatoms such as *Coscinodiscus nodulifer*, *Nitzschia lanceolata* and *Thalassiosira balitica* and the presence of clay sediments with low organic content in the basal zones (zones TP-1 and TD-1) indicate that the TFL basin was open to the sea. A recorded gradual decline in frequencies of polyhalobous and mesohalobous diatom species associated with an increase in the relative abundance of oligohalobous-indifferent species (e.g. *Fragilaria pinnata*) is indicative of declining salinity. This floral change is likely to have been associated with a decline in the penetration of marine waters into the basin as isostatic rebound resulted in land emergence of this site beginning between ca. 12,000 and 11,800 yr BP (ca. 14,900–14,500 cal. yr BP; Clague et al. 1982). The relative sea-level history of the central mainland coast of British Columbia is poorly constrained and has been found to vary regionally (Clague et al. 1982). However, the timing of emergence at the TFL site is correlative to relative sea-level fall associated with isostacy in the Fraser Lowlands (Mathews et al. 1980).

Diploxylon *Pinus* pollen is dominant in this basal zone, but over-representation of *Pinus* is common (Hebda and Allen 1993; Brown and Hebda 2002). The incursion of marine waters into TFL at this time may have contributed to the large abundance of *Pinus* pollen in pollen zone

TP-1 because this taxon is well adapted for aquatic transport and marine sediments can selectively corrode some pollen types (Havinga 1964). 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 *Pinus 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 diploxylon *Pinus* pollen at TFL (Mathewes 1973; Hebda 1983; Wainman and Mathewes 1987; Brown and Hebda 2002, 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), which conforms well to previously reported dates of the *Pinus* biogeochron in coastal British Columbia (Hebda 1983; Hebda and Whitlock 1997; Brown and Hebda 2002; Lacourse 2005).

Low pollen concentrations in this section and the shade intolerant ecology of *Pinus* suggest that the *P. contorta* woodlands at TFL were open, similar to other late-glacial sites along coastal British Columbia (Hebda 1983; Brown and Hebda 2002; 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, *Alnus* and *Picea* can also colonize poorly developed soils but these taxa have higher moisture requirements than *Pinus* (Fonda 1974; Hebda 1983; Harris 1990; Chapin et al. 1994; Fastie 1995). Therefore, the absence of *Alnus* and *Picea* at TFL during this time suggests that the climate was dry. An open and dry landscape with poorly developed soils at TFL during the early late-glacial may have supported shrubby *Juniperus communis* and the haircap mosses *Polytrichum juniperinum* and/or *Polytrichum piliferum*, which are possible sources for the relatively high Cupressaceae pollen and *Polytrichum*-type spores in pollen zone TP-1, respectively (Pojar and MacKinnon 1994).

The early late-glacial geographical distribution of *Pinus contorta* was ubiquitous in coastal British Columbia and the adjacent US states, which indicates that a cool and dry climate prevailed on a regional scale at this time (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 2002; Lacourse 2005). A possible mechanism for a cool and dry climate in northwestern North America during the early late-glacial is the retreating Laurentide Ice Sheet and its effect on atmospheric dynamics. The ice sheet split the jet stream so that North Pacific storms were diverted to the southwestern United States, cooled adjacent air and generated a strong glacial anti-cyclone that delivered cool and dry easterly winds to western coast of North America (Whitlock 1992; Bartlein et al. 1998; COHMAP Members 1988; Brown and Hebda 2002).

The late late-glacial zones
(TP-2, TD-2; ca. 11,800–10,200 yr BP;
ca. 14,500–12,300 cal. yr BP)

At ca. 11,800 yr BP (ca. 14,500 cal. yr BP; 493 cm) a diffuse transition from basal silts to overlying medium brown massive organic muds suggest that the TFL basin was rapidly isolated from the sea and that lacustrine sedimentation predominated once the sill of the basin emerged above high tide level. The final isolation of the basin is marked by the disappearance of polyhalobous and mesohalobous diatom species (e.g. *C. nodulifer*, *N. lanceolata* and *T. balitica*) and an increase in oligohalobous-indifferent taxa (e.g. *F. exigua*, *C. stelligera*, *A. distans*) at 491 cm. An increase in planktic diatoms, namely *Cyclotella stelligera*, in this section of the TFL core (zones TP-2 and TD-2) may indicate that lake levels were higher than during the early late-glacial but may also be evidence for warmer temperatures at this time (Rühland et al. 2003). Climate amelioration could have affected the diatom assemblage by enhancing the stability and duration of thermal stratification which can alter lake water properties such as nutrient content, light availability and pH and favor the growth of *C. stelligera* (Pienitz 1993; Sorvari et al. 2002; Rühland et al. 2003; Harris et al. 2006).

The pollen record indicates that the terrestrial landscape at TFL was also changing at this time.

A decline in *Pinus contorta* pollen is accompanied first by an increase in *Alnus* pollen and then by a rise in *Picea* pollen. Cupressaceae pollen is also present in this section and may be attributable to *Chamaecyparis nootkatensis*, which is thought to have grown on the lowlands of northern Vancouver Island at this time (Lacourse 2005). The rise of *Picea* during the late late-glacial at TFL may be due to edaphic development, succession, a migration lag or climate change. The presence of *Alnus* probably facilitated the expansion of *Picea* during this interval by increasing soil nitrogen availability but *Picea* is capable of growth on nutrient poor substrates so soil development was probably not the proximate cause its increase at TFL (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, and possibly on the Queen Charlotte Islands, suggests that invasion of this site by *Picea* would have been relatively rapid following deglaciation, had climate conditions been favorable (Warner et al. 1982; Fastie 1995; Brubaker et al. 2005). Soil moisture is restrictive for modern *Picea sitchensis* communities, as it is 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 first by *Alnus* and then by a *Picea-Alnus* community (Fonda 1974; Wainman and Mathewes 1987; Brown and Hebda 2002; Brown and Hebda 2003; Lacourse 2005). High pollen concentrations in TP-2 relative to TP-1 suggest that the forest canopy was denser than during the early late-glacial but may also be an artifact of more rapid lacustrine sedimentation since the low shade-tolerant ecology of *Picea* and *Alnus* indicate that the landscape was still relatively open.

A similar *Picea-Alnus* community occurred elsewhere in coastal British Columbia during the late late-glacial indicating that a cool and moist climate was experienced regionally and that climate was an important control on vegetation change at this time (Mathewes 1973; Brown and Hebda 2002, 2003; Lacourse 2005). A moister climate in coastal British Columbia during the

late late-glacial can be attributed to the waning Laurentide Ice Sheet. As the continental ice sheet and associated glacial anti-cyclone receded, moist westerly winds were able to penetrate into this region (Whitlock 1992; Whitlock and Bartlein 1997; Bartlein et al. 1998; COHMAP Members 1988).

Alnus increased in abundance at ca. 11,800 yr BP (ca. 14,500 cal. yr BP) at TFL, broadly coeval with other records from coastal British Columbia (Pellatt et al. 2002; Lacourse 2005). Both *Alnus rubra* and *A. sinuata* are probably represented in this section since they coexisted on northern Vancouver Island during the late late-glacial, and both occur in the SBIC today (Meidinger and Pojar 1991; Lacourse 2005). Although the initial rise was probably a response to the development of a moist climate, the persistence of *Alnus* at TFL throughout pollen zone TP-2 may be indicative of disturbance because *Alnus* is replaced by *Picea sitchensis* within 150–400 years in modern successional sequences in Washington and Alaska (Fonda 1974; Cwynar 1987; Mayle et al. 1993; Fastie 1995; Brown and Hebda 2002). As Two Frog Lake is near the shore of the SBIC ecological disturbance resulting from sea-level fluctuations, for which no local data exists, may in part provide an explanation for the persistence of *Alnus*. It is also possible that cooling associated with a climate reversal at TFL 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 2002). Additional evidence for a cooler climate at this time is the local occurrence of *Tsuga mertensiana*, as indicated by pollen frequencies of 2%, at $11,040 \pm 50$ yr BP (13,030 cal. yr BP) when this tree may have migrated down-slope (Hebda 1983; Dunwiddie 1987; Mathewes 1993; Lacourse 2005). Changes in the diatom community at this time may also be a response to climate cooling. A decline in *Cyclotella stelligera*, a taxon commonly associated with warmer climates and thermal stratification, is accompanied by an increase in small benthic taxa indicative of cool water such as *Fragilaria lata* and *F. exigua* (Pienitz 1993; Pieniz et al. 1995; Laing et al. 1999; Sorvari et al. 2002; Rühland et al.

2003; Saulnier-Talbot et al. 2004; Karst-Riddoch et al. 2005). The timing of cooling at TFL is broadly correlative with the Younger Dryas, which has previously been documented in sedimentological, palynological and foraminiferal records from the west coast of North America between 11,000 and 10,000 yr BP (Engstrom et al. 1990; Mathewes 1993; Mathewes et al. 1993; Patterson et al. 1995; Hansen and Engstrom 1996; Brown and Hebda 2002; Friele and Clague 2002; Pellatt et al. 2002; Lacourse 2005) and may have even been a global event (Peteet 1995).

The rise of *Tsuga heterophylla* following the *Picea-Alnus* phase is consistent with descriptions of modern successional sequences in moist environments where *T. heterophylla* replaces *Picea* over several centuries due to its superior shade tolerance, the main competitive advantage of seedlings of this species, and longevity (Fastie 1995). The prolonged *Alnus* phase at TFL likely facilitated the expansion of *T. heterophylla*, a tree with high nutrient requirements, by increasing soil nitrogen availability in the immature late late-glacial landscape (Crocker and Major 1955; Fonda 1974; Chapin et al. 1994; Fastie 1995; Lacourse 2005).

The early Holocene zones
(TP-3, TD-2; ca. 10,200–8000 yr BP;
ca. 12,300–9,200 cal. yr BP)

At ca. 10,200 yr BP (ca. 12,300 cal. yr BP) the diatom community at TFL underwent marked changes probably related to climate variability. An increase in planktic diatoms, namely *Cyclotella stelligera* and a decrease in benthic species (e.g. *F. exigua*) may be associated with increases in nutrient availability, enhanced thermal stratification and decreased period of ice cover associated with climate warming (Pienitz et al. 1995; Saulnier-Talbot and Pientiz 2001; Karst-Riddoch et al. 2005). The relative abundance of *C. stelligera* appears to "cycle" throughout this zone. Unfortunately, constraint of the timing or duration of these cycles is limited by the chronological control of this record but it is interesting to note that late Holocene cycles of diatoms in Frederick Sound, a marine fjord in the SBIC, were linked to fluctuations in the AL and NPH Pressure systems

(Wigston 2006). During the early Holocene the Aleutian Low was beginning to intensify (COHMAP Members 1988) and it is possible that a reorganization of atmospheric circulation at this time affected the climate of the SBIC and the diatom community of TFL in a cyclic manner.

Changes in the pollen record also document climate change during the early Holocene. *Psuedotsuga menziesii* grew locally at TFL at this time, as indicated by relative abundances of this pollen type near 2% (Tsukada 1982; Hebda 1983). This species, which is competitive in xeric environments, would have migrated northward to TFL in response to the development of a warmer and drier climate at this time (Tsukada 1982; Hebda 1983; Lotan and Critchfield 1990; Brown and Hebda 2002). The occurrence of warm and dry climate during the early Holocene in coastal British Columbia has been well established (Mathewes 1973; Heusser et al. 1980; Mathewes and Heusser 1981; Hebda 1995), but regions with a strong maritime influence such as TFL may have been buffered from extreme temperature and drought by cool and moist Pacific air, thus permitting the co-existence of species with low drought tolerance such as *Tsuga heterophylla*, *Picea* and *Alnus* with *P. menziesii* (Krajina 1969; Cwynar 1987; Packee 1990; Lacourse 2005).

Alnus pollen reaches peak proportions at this time, indicating that the landscape at TFL was relatively open (Fonda 1974). High relative values of *Polytrichum*-type spores in this section are also notable and may be attributable to *Polytrichum juniperinum*, a common moss on open sites in the CHWZ today (Pojar and MacKinnon 1994). Contemporary communities of *Picea*, *Pseudotsuga menziesii*, *Tsuga heterophylla* and *Alnus* occurred on southern Vancouver Island, the Fraser Lowlands and in Washington where fire played an important role in their maintenance (Cwynar 1987; Brown and Hebda 2002; Hallett et al. 2003). It is a possibility that fires were also influential in maintaining an open forest at TFL during the early Holocene when warm and dry conditions would have increased the abundance of dry fuel (Brown and Hebda 2002). A more open forest at TFL is also reflected in the diatom record where high *Aulacoseira* abundances may be attributed to increased watershed

erosion associated with an open landscape since this taxon has high requirements for silica, but are poor competitors, and its relatively heavy cells require turbulent conditions to be maintained in suspension (Wolfe 1996). The warmer and drier conditions of the early Holocene has been attributed to an orbitally controlled solar insolation maximum. The tilt of the earth's axis was greater in the early Holocene (ca. 10,000–8000 yr BP) than today, which caused summers to be warmer and winters to be cooler than present and indirectly resulted in a more persistent North Pacific High pressure system that delivered 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).

The early Holocene to mid-Holocene
(TP-4, TD-2; ca. 8,000–6,300 yr BP;
ca. 9,200–6,300 cal. yr BP)

Cupressaceae pollen began to increase ca. 8,000 yr BP (ca. 9,200 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 probably attributable to *Thuja plicata* since macrofossil evidence places this species in the Puget Lowlands as early as 7,460 yr BP (QL-1435; Barnosky 1981). *Thuja plicata* is capable of survival and growth on a wide range of soil conditions but low moisture is especially restrictive for coastal populations of this taxon (Minore 1990). It is possible that a higher water table, 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 that shore lines were lower than present until sometime in the late Holocene (Clague et al. 1982). The expansion of *T. plicata* may therefore be indicative of the onset of Holocene climate moistening, and possibly cooling, at ca. 8,000 yr BP (ca. 9,200 cal. yr BP) at TFL. A moister and cooler climate would have permitted the expansion of this species, thus permitting canopy closure and the exclusion of shade intolerant taxa such as *Picea* and *Alnus* from forests at TFL (Fonda 1974; Minore 1990).

Vegetation change may have affected the diatom assemblage in TFL at this time. The disappearance of *Cyclotella stelligera* at ca. 8,000 yr BP (ca. 9,200 cal. yr BP), which exhibits a strong relationship with pH, and the subsequent increase in acidophilous taxa such as *Brachysira brebissonii* and *Fragilaria lata*, may be associated with natural lake acidification, a common feature of lake development on poorly buffered terrain (Whitehead et al. 1989). Usually this process is related to the eventual depletion of base cations as they are leached from developing soils and increased terrestrial cation storage as vegetation cover becomes progressively dense (Whitehead et al. 1989; Pienitz et al. 1999; Ponader et al. 2002). Lake acidification at this time could also have been influenced by the development of a cooler climate since temperature can modify in-lake dissolved inorganic carbon metabolism (Psenner and Schmidt 1992; Sommaruga-Wögrath et al. 1997; Wolfe 2002).

The onset of a moister and cooler climate occurred earlier at TFL than at more southern sites in coastal British Columbia and Washington where the cooler and wetter conditions that permitted *T. plicata* expansion did not develop until after ca. 6,600 yr BP and ca. 7,500 yr BP, respectively (Mathewes 1973; Barnosky 1981; Leopold et al. 1982; Hebda and Mathewes 1984; Wainman and Mathewes 1987; McLachlan and Brubaker 1995; Hebda 1995; Pellatt et al. 2001; Brown and Hebda 2002). It is notable that change at TFL also preceded climate and vegetation change at Misty Lake and Bear Cove Bog, which are located less than 40 km south of this site on northern Vancouver Island and also lie within the CWHvh1, as well as sites on the Queen Charlotte Islands (Hebda 1983; Warner 1984; Fedje 1993; Pellatt and Mathewes 1994, 1997; Lacourse 2005; Lacourse and Mathewes 2005). The timing of this climate transition at TFL is coincident instead with mainland coastal sites to the north; Diana Lake Bog on the northern mainland coast of British Columbia and Little Swift Lake in southwestern Alaska (Turunen and Turunen 2003; Axford and Kaufman 2004). The AL pressure system intensified at this time in response to an orbitally induced decrease in solar insolation (COHMAP Members 1988) and this would have

resulted in the development of a moister climate in central and north coastal British Columbia. A more intense AL would have generated stronger mid-latitude cyclones and steered them into northern British Columbia and Alaska, which would have resulted in high precipitation in the SBIC relative to more southerly locations and may not have had as much of an impact on the leeward lowlands of the Queen Charlotte Islands where paleoecological studies within the CWHZ have concentrated (Klein 1949; Warner 1984; Heusser et al. 1985; Fedje 1993; Mantua and Hare 2002; Dean and Kemp 2004; Lacourse and Mathewes 2005).

The mid to late Holocene
(TP-5; TD-3, TD-4; ca. 6,300 yr BP–present;
ca. 7,200 cal. yr BP-present)

Cupressaceae, probably *Thuja plicata* based on macrofossil evidence from the Fraser Lowlands (Wainman and Mathewes 1987), was an important taxon at TFL in the mid to late Holocene, with relative pollen abundances of >70% sustained throughout this interval. The predominance of Cupressaceae pollen in this zone (TP-5) could be an artifact of over-representation but it is likely that *T. plicata* was an important part of the forest at TFL at this time since this pollen type is generally well represented in lake sediments (Hebda and Allen 1993). The expansion of Cupressaceae (*T. plicata*) at TFL by ca. 6,300 yr BP (ca. 7,200 cal. yr BP) was probably in response to the development of a modern cool and moist climate (Krajina 1969; Hebda 1983; Minore 1990). The development of modern conditions at TLF predate the onset of a similar climate in the Fraser Lowlands, on Vancouver Island and on the Queen Charlotte Islands, which did not occur until after 3,500 yr BP, correlative with Neoglacial activity in the Canadian Rocky Mountains and Coast Mountains (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 2002; Lacourse 2005). The relatively early transition to a modern climate at TFL may again be associated with dynamics in the Aleutian Low pressure system and the diversion of synoptic scale North Pacific storms into the north coast of British Columbia, with the SBIC falling at their southern limit.

An increase in the diversity of acidophilous diatom species (e.g. *E. tenella*, *F. rhomboides*, *F. rhomboides* var. *saxonica*) and the low relative abundance of planktic taxa (e.g. *A. distans*, *C. stelligera*), which are rare or absent at low pH values, indicate that lake acidification continued throughout the mid and late Holocene (cf. Flower and Battarbee 1983; Charles 1985; Pienitz et al. 1995). Lake acidification throughout the late Holocene may have been associated with continued climate cooling during the Neoglacial interval in British Columbia (Porter and Denton 1967; Psenner and Schmidt 1992; Sommaruga-Wögrath et al. 1997; Wolfe 2002) or a more dense coniferous forest canopy, indicated by relatively high pollen concentrations in this section, that would have increased the input of dissolved organic carbon into the basin (Whitehead et al. 1989; Pienitz et al. 1999; Ponader et al. 2002). At 50 cm (ca. 1400 yr BP; ca. 1,300 cal. yr BP) a shift in the diatom community is observed with no accompanying change in vegetation. Climate cooling associated with Neoglacial advances at ca. 1,400 yr BP may have briefly lowered water pH, permitting the expansion of acidophilous taxa such as *Frustulia rhomboides* var. *saxonica* (Psenner and Schmidt 1992; Sommaruga-Wögrath et al. 1997; Wolfe 2002). Continued climate cooling may have destabilized the diatom community through the disruption of habitat availability and nutrient input, thus reducing competition and permitted the subsequent expansion of *Aulacoseira distans* (Wolfe 2003). Diatoms appear to be a more sensitive indicator than pollen of climate change at this time, perhaps due to the brevity of late Holocene climate fluctuations, and illustrate the benefits of employing a multi-proxy approach to paleoecological reconstruction.

Conclusions

Pollen and diatom records from Two Frog Lake describe postglacial environmental and climate changes of the Seymour-Belize Inlet region of the

central mainland coast of British Columbia. Open *Pinus contorta* parklands had covered the landscape by at least ca. 12,000 yr BP (ca. 14,900 cal. yr BP) when relative sea level was lower than present and the climate was cool and dry. At ca. 11,800 yr BP (ca. 14,500 cal. yr BP) the basin became isolated from the sea and a *Picea-Alnus* community developed when the climate became moister. A cold reversal correlative with the Younger Dryas in coastal British Columbia is recorded at 11,040 ± 50 yr BP (13,030 cal. yr BP) when *Tsuga mertensiana* migrated down-slope to grow locally at TFL and planktic diatom assemblages were disrupted. Early Holocene warming at ca. 10,200 yr BP (12,300 cal. yr BP) resulted in the northward migration of *Pseudotsuga menziesii* and the maintenance of parkland conditions, which affected the diatom community of TFL by promoting *Aulocoseira* species. Climate cooling and moistening began at ca. 8,000 yr BP (ca. 9,200 cal. yr BP) and influenced the vegetation at TFL by permitting the development of a closed forest of Cupressaceae (*Thuja plicata*) and *Tsuga heterophylla*. Planktic diatom communities declined in the basin at this time perhaps due to lake acidification associated with the changing environment and cooler temperatures. The consideration of this record in a regional context reveals that the early Holocene climate cooling and moistening is remarkable in central coastal British Columbia. It is possible that a dynamic Aleutian Low pressure system was an important control on the early Holocene climate of this region, with the Seymour-Belize Inlet Complex at the southern extent of immediate influence. Late Holocene climate variability associated with the Neoglacial interval is not documented in the pollen record but may be indicated by the diatom communities in TFL. This result illustrates the usefulness of employing a multi-proxy approach to paleoclimate reconstructions since the brevity or subtlety of the Neoglacial signal in this maritime region may have precluded registration in the pollen record.

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