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A record of Lateglacial and Holocene vegetation and climate change from Woods Lake, Seymour Inlet, coastal British Columbia, Canada

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Abstract

The Lateglacial and Holocene vegetation and environmental history recorded in a small coastal lake in the Seymour Inlet area, British Columbia, is described. *Pinus*-dominated vegetation and a cool and moist climate prevailed in the early phase of the Lateglacial. Later stages of the Lateglacial were characterised by a mixed coniferous forest with *Tsuga* species, *Picea* and *Abies* and slightly warmer conditions and increased moisture. *Alnus, Picea* and *Pteridium aquilinum* dominated the vegetation of the early Holocene. Warmer and drier conditions prevailed during this phase. Increased moisture and decreased temperatures characterised the mid-Holocene as indicated by the dominance of Cupressaceae, *Tsuga heterophylla*, *Alnus* and *Picea* in the forest around the study site. This represented a transitional stage to the late-Holocene Cupressaceae–*T. heterophylla* phase, when the modern climate regime characterised by temperate and wet conditions became established. The vegetation succession identified correlates well with Lateglacial and Holocene records from other sites in the Coastal Western Hemlock biogeoclimatic zone of British Columbia. Sedimentological and microfossil records from the examined sediment core indicate that saltwater intrusions into the lake basin occurred during the early Lateglacial and the middle to late Holocene resulting from changes in relative sea level.

Keywords: pollen analysis; Lateglacial and Holocene; vegetation history; palaeoclimate; Coastal Western Hemlock biogeoclimatic zone; British Columbia

1. Introduction

Large areas of coastal British Columbia are influenced by a temperate and wet climate that favours the formation of coniferous forest communities dominated by western hemlock and western redcedar. Previous research on the Lateglacial and Holocene vegetation history in this region (Fig. 1), referred to as the Coastal Western Hemlock (CWH) biogeoclimatic zone, has mainly concentrated on areas of Vancouver Island (Hansen, 1950; Hebda, 1983; Brown and Hebda, 2002; Lacourse et al., 2003; Lacourse, 2005), the Queen Charlotte Islands and the adjacent mainland coast (Banner et al., 1983; Warner, 1984; Quickfall, 1987; Lacourse et al., 2003, 2005) and the southern mainland coast (Hansen, 1940; Mathewes, 1973; Mathewes and Rouse, 1975; Pellatt et al., 2002). These studies indicate that climate has varied considerably throughout the Lateglacial and Holocene. However, regional interpre-

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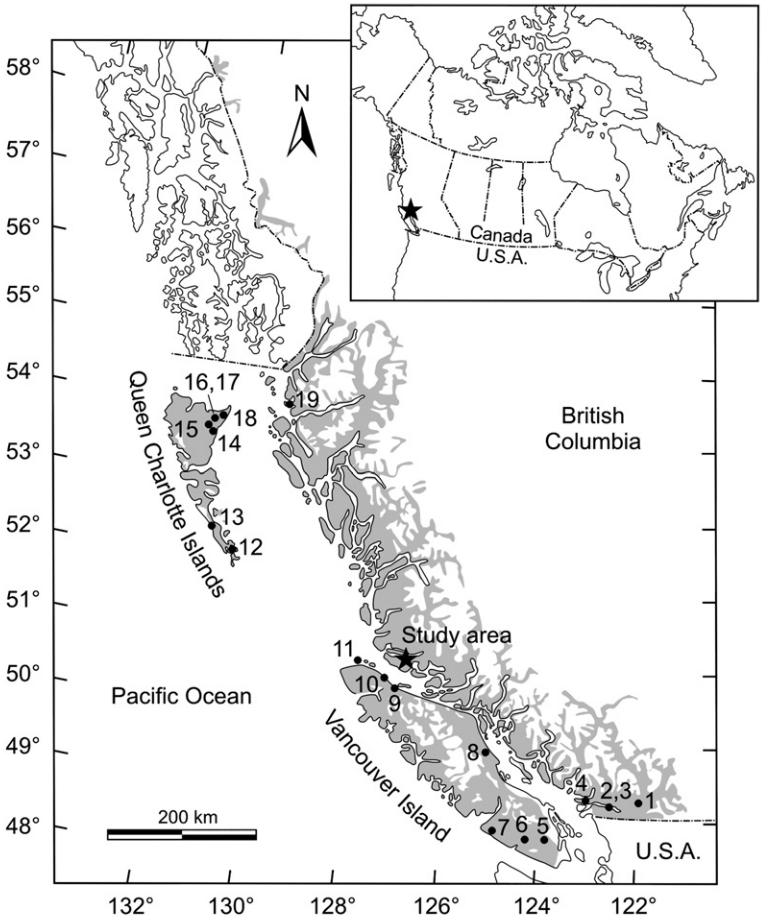

Fig. 1. Map of British Columbia, Canada, showing the distribution of the Coastal Western Hemlock biogeoclimatic zone (grey) and the locations of the Woods Lake study site and other palynologically investigated sites within this zone: (1) Mathewes and Rouse (1975); (2) Mathewes (1973); (3) Pellatt et al. (2002); (4) Hansen (1940); (5–7) Brown and Hebda (2002); (8) Hansen (1950); (9) Lacourse (2005); (10) Hebda (1983); (11) Lacourse et al. (2003); (12) Quickfall (1987); (13) Lacourse et al. (2005); (14–15) Warner (1984); (16–17) Quickfall (1987); (18) Warner (1984); (19) Banner et al. (1983).

tation is currently hampered by the limited data constraining vegetation and climate history of the central mainland coast of British Columbia.

This study focuses on a lake basin in the Seymour Inlet area, a remote part of the central mainland coast located northeast of Vancouver Island. Palaeoenvironmental research in this area allows a more detailed reconstruction of vegetational and climatic changes in the CWH biogeoclimatic zone. Based on sedimentological and microfossil analyses, the local variation in vegetation and climate at the investigated site are constrained and compared to changes that occurred elsewhere in the region during the Lateglacial and Holocene.

2. Study area

The Seymour Inlet, a large marine inlet complex that extends ca. 50 km inland (Fig. 2), comprises a network of islands and glacially scoured, steep-sided fjords in mountainous terrain, which are characteristic of the mainland coast north of Vancouver Island (Pojar and MacKinnon, 1994). The Seymour Inlet area lies within the CWH zone (Fig. 1), which occurs at low to middle elevations along the coast of British Columbia, mostly west of the Coast Mountains. The CWH zone is characterised by a cool mesothermal to temperate and wet climate with cool summers and mild winters. These conditions are primarily the result of variation in atmospheric and oceanic circulation in the northeast Pacific, which are governed by the Aleutian Low, the North Pacific High, the Jet Stream and the equatorial El Niño/La Niña cycle (Patterson et al., 2004).

Characteristic soils in the CWH zone are podzols with mors as the prevailing humus form (Pojar et al., 1991). Dominant trees include western hemlock (*Tsuga*

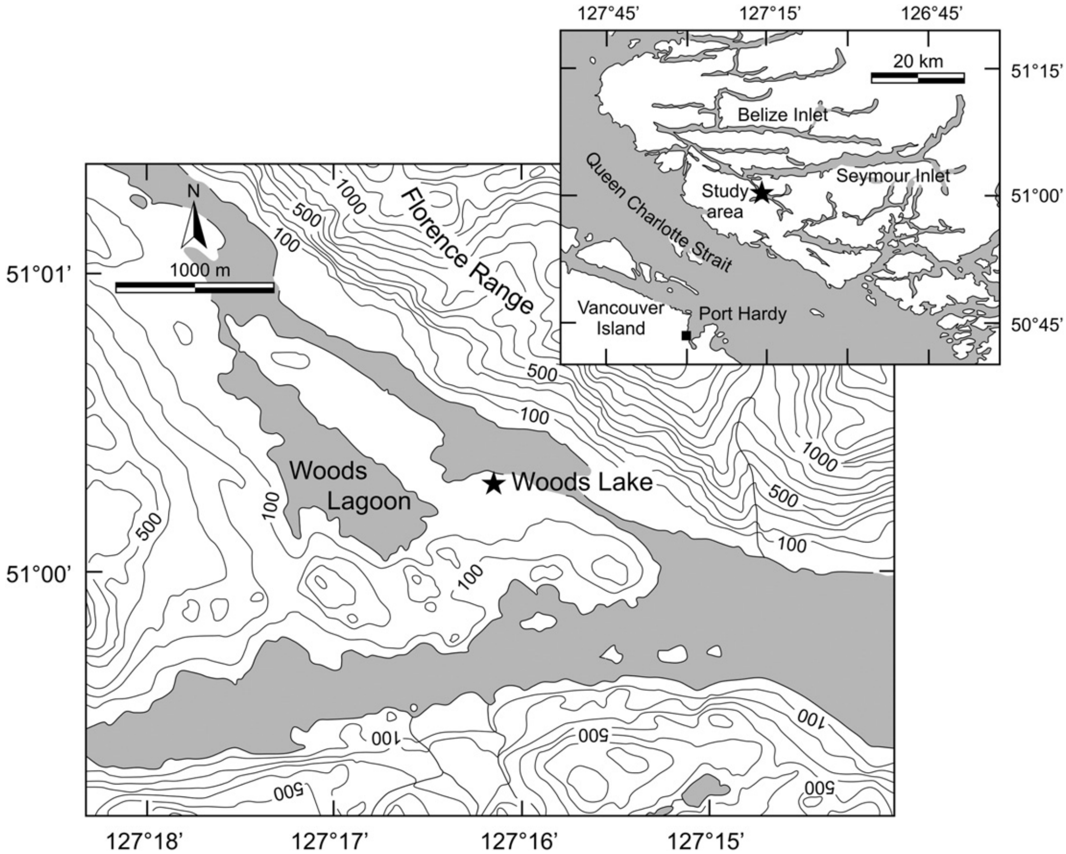

Fig. 2. Location of the Woods Lake study site (51°00′16.0″ N; 127°16′7.6″ W). Note that the sill separating the lake basin from Seymour Inlet has an elevation of approximately 2 m above mean sea level.

heterophylla) and western redcedar (*Thuja plicata*). Drier parts of the zone are characterised by Douglas-fir (*Pseudotsuga menziesii*), whereas Pacific silver fir (*Abies amabilis*) and yellow cedar (*Chamaecyparis nootkatensis*) are found in moister areas. Other widespread species are red alder (*Alnus rubra*) and Sitka spruce (*Picea sitchensis*). A sparse herb layer and the predominance of mosses are characteristic of the CWH zone (Pojar et al., 1991). In some coastal areas, the ericaceous shrub salal (*Gaultheria shallon*) forms impenetrable thickets in the understorey of the coniferous forests (Pojar and MacKinnon, 1994).

Woods Lake (informal name) is located in the western section of the Seymour Inlet area, ca. 40 km northeast of Port Hardy, Vancouver Island (Fig. 2). The study site is a small (0.21 ha), oval freshwater lake that lies approximately 30 m from the southern shoreline of Seymour Inlet. The sill of the lake basin, which is composed of granodiorite, has an elevation of approximately 2 m above mean sea level (Doherty, 2005). The lake has a maximum measured water depth of 5 m and drains into Seymour Inlet through an outlet to the northwest. The temperate rain forest vegetation surrounding Woods Lake is consistent with the general CWH biogeoclimatic zone distribution, consisting primarily of *Tsuga heterophylla*, *Picea sitchensis* and *Thuja plicata* along with *Gaultheria shallon* in the understorey. Grasses (Poaceae), sedges (Cyperaceae) and salal are common around the lakeshore, whilst Labrador tea (*Ledum groenlandicum*) and mosses occur intermittently. Climate data recorded at a nearby weather station at Egg Island indicate a mean annual temperature of ca. 8.5 °C and a mean annual precipitation of ca. 2500 mm for this area (Environment Canada, unpubl. data).

3. Methods

3.1. Lake selection and sampling

Proximity to the coastline and accessibility were important criteria in the selection of the Woods Lake study site, as the rough terrain and the density of the understorey made overland access to the lake difficult. A lake elevation of less than 10 m above present mean sea level was chosen to document the influence of the changes in

Table 1
Stratigraphy of the Woods Lake core

Depth (cm)	Sediment description
44–0	Black to very dark brown gyttja
71–44	Very dark brown to dark greyish brown gyttja; bands of silt to fine sand at 68–66 and 50–48 cm
91–71	Olive brown gyttja with layers of silt and fine to middle sand
127.5–91	Olive gyttja with middle to coarse sand and occasional wood fragments
139–127.5	Olive sandy gyttja; layer of disturbed sediment with coarse sand and small pebbles at 139–130 cm
155.5–139	Dark olive sandy gyttja with occasional plant fragments
169–155.5	Olive grey gyttja; layers of silt to coarse sand above 165 cm
199–169	Black gyttja
220–199	Dark brown organic gyttja with occasional small plant fragments; silt layers at 220–217, 213–211.5 and 205–200 cm
223–220	Dark brown gyttja containing a noticeable silt component
228–223	Dark brown gyttja
251–228	Very dark brown gyttja with rare small plant fragments
267–251	Dark grey brown gyttja with layers of silt and fine sand
272–267	Dark grey brown gyttja containing low amounts of silt
276–272	Transition zone from marine silt to dark grey brown gyttja
284–276	Olive grey marine silt with scattered shell fragments; layer of brown silty gyttja at 280.5–279.5 cm

relative sea level on the coastal forest vegetation. A sediment core of 284 cm in length was obtained with a Livingstone corer from the deepest part of the lake, where the sediment infill was determined by sub-bottom seismic profiles to attain maximum thickness. Basal marine silt and an overlying limnic gyttja were identified as the two main sediment units (Table 1).

3.2. Radiocarbon dating

Four samples were collected from the sediment core for AMS radiocarbon dating (Table 2). One sample was taken above the marine silt–limnic gyttja transition zone (276–272 cm) in the lower part of the core. Two samples were obtained from immediately below and above a disturbed sediment layer (139–130 cm) in the central portion of the Woods Lake core. One additional sample was collected from the uppermost section of the core to determine the onset of the late-Holocene establishment of freshwater conditions in the lake basin as indicated by the disappearance of marine/brackish microfossils at 21 cm (Doherty, 2005; this study).

For the calibration of the conventional ^{14}C ages, the software OxCal v3.9 (Bronk Ramsey, 1995, 2001) was used to generate the probability distribution functions of the calibrated dates, using a cubic spline interpolation of the INTCAL98 calibration curve (Stuiver et al., 1998). The experimental standard deviations of the conventional data were multiplied by a laboratory multiplier of two (cf. International Study Group, 1982). Calibrated age ranges refer to 2σ (95.4% confidence interval). The weighted averages of the probability distribution functions were used as central-point estimates (Telford et al., 2004).

3.3. Pollen preparation and counting

Fifty-two subsamples of known volume were taken for pollen analysis. Tablets of *Lycopodium clavatum* spores were added to each sample to facilitate the

Table 2
Radiocarbon dates for the Woods Lake sediment core

Sample (Laboratory No.)	Depth (cm)	Radiocarbon age[a] (yr BP±σ)	Calibrated age range[b] (cal yr BP)	Central-point estimate[c] (cal yr BP)	Material
W4(SUERC-3092[d])	20–19	1604±36	1331–1631 (0.95) 1667–1692 (0.04) 1649–1662 (0.01)	1496	Gyttja
W3(SUERC-4705[d])	110	3758±29	3965–4296 (0.97) 3929–3947 (0.02) 4333–4348 (0.01)	4122	Gyttja
W2(SUERC-3091[d])	144–143	7176±44	7820–8173 (0.98) 7791–7809 (0.02)	7988	Gyttja
W1(TO-10780[e])	269–268	11,820±90	13,420–14,299 (0.79) 14,712–15,254 (0.21)	13,950	Plant debris

Note: Two additional samples were collected at 133–132 and 51–50 cm, but yield inconsistent radiocarbon ages. The samples were rejected because of the influence of younger and older carbon, respectively (Doherty, 2005).

[a] ^{14}C dates normalised to $\delta^{13}C_{PDB} = -25‰$.

[b] At 2σ probability (95.4% confidence interval). A laboratory factor of $k=2$ was used (International Study Group, 1982).

[c] Using weighted average method.

[d] NERC Radiocarbon Laboratory and SUERC AMS Facility, 2004, 2005.

[e] ISO Trace Laboratory, University of Toronto, 2003.

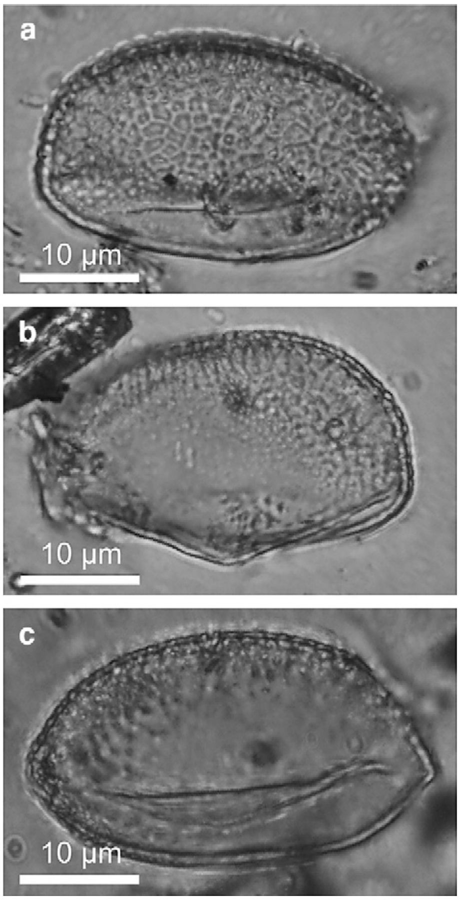

Fig. 3. Pollen of *Lysichiton americanum* found in the sediment sample of the Woods Lake core at 170 cm: (a) Polar view (slightly oblique) showing the well-developed reticulation. (b) Side view illustrating the disappearance of the reticulum towards the aperture. (c) Polar view (slightly oblique) showing the aperture.

calculation of pollen concentrations (Stockmarr, 1971). Pollen sample preparation followed standard techniques (Faegri et al., 1989). The pollen residues were mounted in silicone oil. Counting was carried out at 400× magnification. Pollen grains and fern spores attributable to terrestrial plant taxa were included in the total pollen and spore sum (ca. 1000 pollen grains per sample), whereas pollen of aquatics such as submerged and floating macrophytes were excluded from the sum.

3.4. Microfossil identification and nomenclature

Most pollen and spore types were identified following Richard (1970), McAndrews et al. (1973), Faegri et al. (1989), Moore et al. (1991) and Kapp et al. (2000) and with the aid of the modern pollen and spore reference collection of the Canadian Museum of Nature, Ottawa. The '*Pinus* undiff.' pollen includes *Pinus haploxylon* type and *Pinus diploxylon* type (Faegri et al., 1989), which were not counted separately because distinguishable features were not always visible. Grains of the 'Cupressaceae' pollen (Kapp et al., 2000) were ascribed to *Thuja plicata* and *Chamaecyparis nootkatensis*, since both species are the most common Cupressaceae taxa in the CWH zone today (Pojar et al., 1991). Pollen grains derived from skunk cabbage (*Lysichiton americanum*) were frequently found in samples from the Woods Lake sediment core. The single grains of '*Lysichiton americanum*' pollen, ranging from 30 to 35 µm in size, are characterised by an elongated latitudinal aperture (Halbritter et al., 2007) and a reticulate ornamentation diminishing towards the aperture (Fig. 3).

Non-pollen palynomorphs such as algal remains were identified after Van Geel et al. (1989), Kapp et al. (2000) and Komárek and Jankovská (2001). The identification of 'hystrichospheres' and 'microforaminifera' followed Evitt (1969) and Kapp et al. (2000), respectively. 'Nymphaeaceae hairs' and conifer stomata were identified after Pals et al. (1980) and MacDonald (2001).

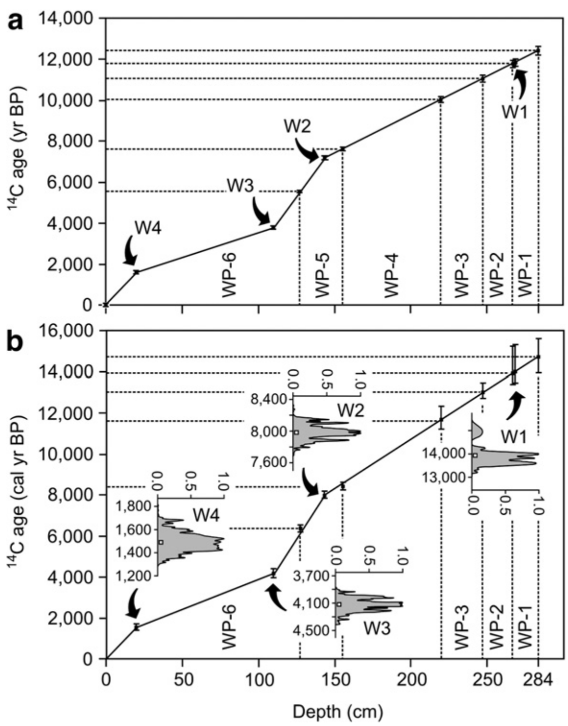

Fig. 4. Age-depth model (linear interpolation) for the Woods Lake sediment core: (a) Plot of the uncalibrated ^{14}C dates. The error bars are based on 2σ. (b) Plot of the calibrated ^{14}C dates. The insets show the probability distribution functions of the calibrated ages. Line segments join corresponding ages and depths of pollen zone boundaries.

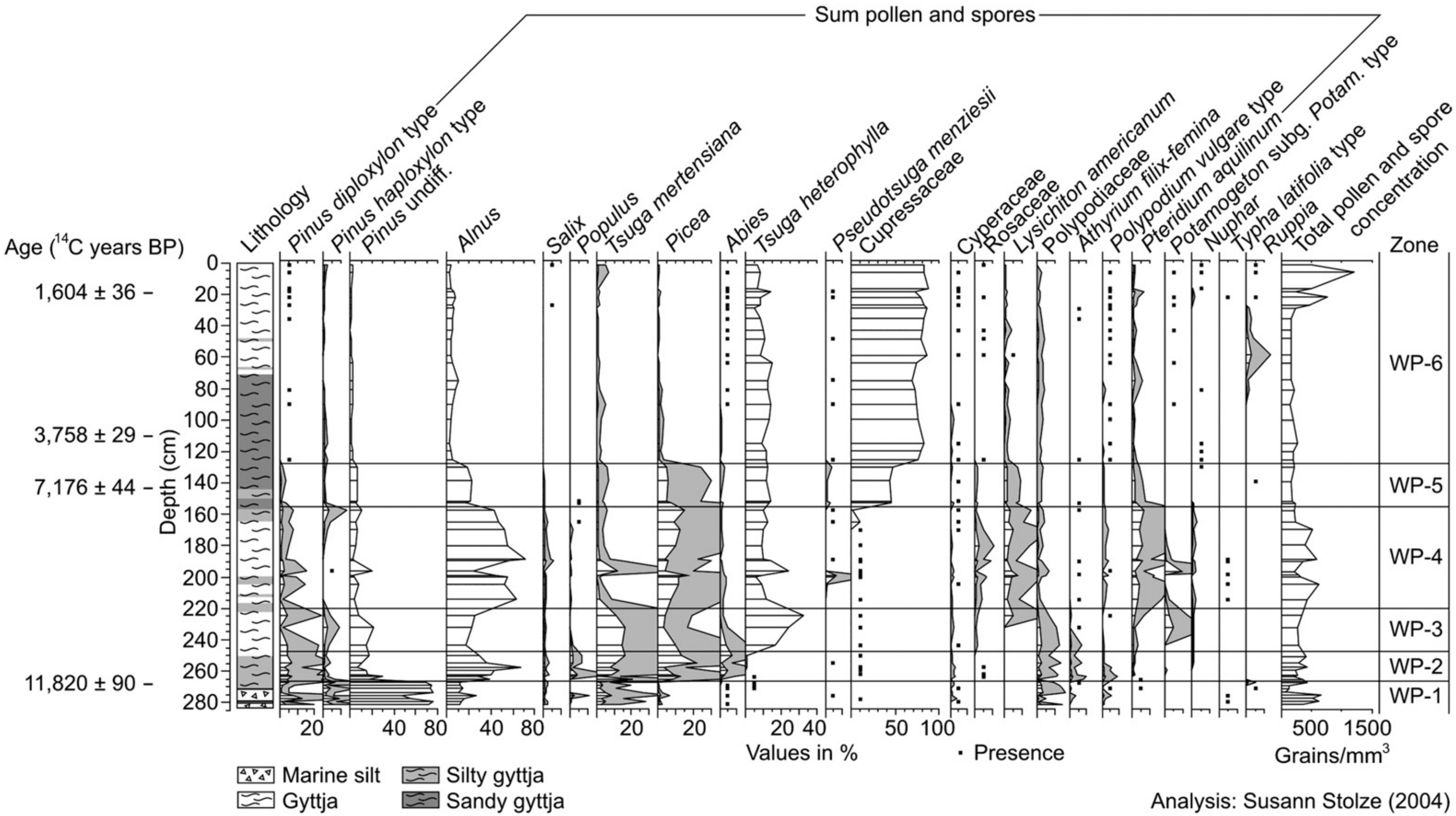

Fig. 5. Woods Lake — Summarised percentage diagram of pollen and spores included in the terrestrial pollen and spore sum and pollen attributable to aquatic plants. Percentages are represented as open curve with depth bars; an additional fivefold exaggeration is applied for low percentages. Very low frequencies are represented by closed squares.

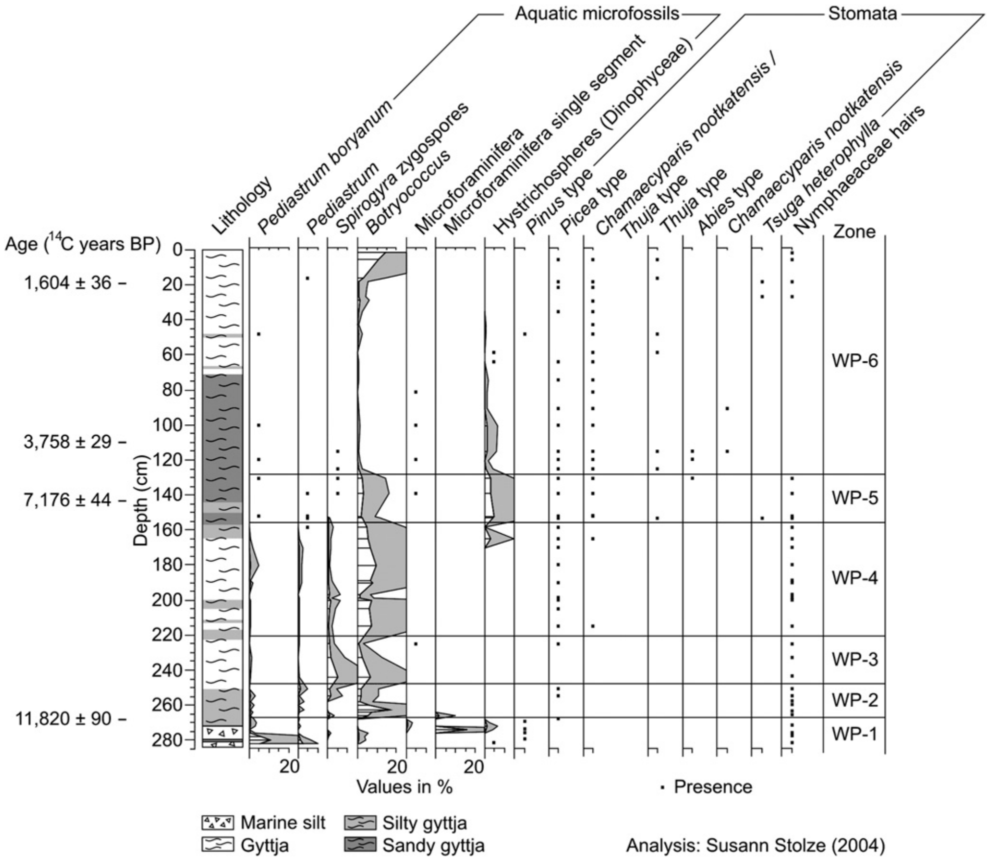

Fig. 6. Woods Lake — Non-pollen palynomorphs. Percentages are represented as open curve with depth bars; an additional fivefold exaggeration is applied for low percentages. Very low frequencies are represented by closed squares. Stomata and trichomes are also displayed as closed squares if present. Pollen zones are applied to this diagram.

3.5. Data presentation

Percentage diagrams were constructed for the pollen and non-pollen palynomorphs using the software packages TILIA 2.0.b.4 and TILIA-GRAPH 2.0.b.5 (Grimm, 1991, 1993) and subdivided into pollen zones by cluster analysis using CONISS (Grimm, 1987). Aquatics were not included in the pollen and spore sum because the present study focuses on upland vegetation (cf. Grimm, 1987). Pollen values of aquatics were expressed as a percentage of the terrestrial pollen and spore sum plus the aquatics. Non-pollen palynomorphs were tallied following the same method as the aquatics or were reported when present.

4. Results

4.1. Radiocarbon dates and age-depth modelling

Based on the uncalibrated radiocarbon dates (Table 2), an age-depth model was developed using linear interpolation. The radiocarbon age of the surface sample was set at 0±50 yr BP and the base of the sediment core was determined to have a radiocarbon age of 12,396±191 yr BP. The developed age-depth model was employed to calculate the ages and respective errors for the onset and termination of each pollen zone (Fig. 4a). The calibrated age ranges derived from the measured radiocarbon dates are given in Table 2. The corresponding probability distribution functions are shown in Fig. 4b. Calculation of the central-point estimate for the sample from 269–268 cm provided an age of 13,950 cal yr BP. The three samples at 144–143 cm, 110 cm and 20–19 cm yielded central-point estimates of 7988, 4122 and 1496 cal yr BP, respectively. Central-point estimates of the onset and termination of the different pollen zones are given below.

4.2. Pollen zones and distribution of non-pollen palynomorphs

The pollen diagram was subdivided into six pollen zones on the basis of cluster analysis (Fig. 5). The palynologically defined zones were also used to determine whether significant changes in the non-pollen palynomorphs occurred simultaneously with changes in the sum pollen and spore spectra (Fig. 6).

Zone WP-1 (Pinus–Alnus–Tsuga mertensiana; 284–267 cm): *Pinus* undiff. pollen is abundant (up to 75%) throughout the zone with *Pinus diploxylon* type and *Pinus haploxylon* type pollen occurring at frequencies of 2–12% and 8%, respectively. *Alnus* and *Tsuga mertensiana* pollen are present at 13% and 7%, while *Picea* pollen occurs at low values (ca. 1%). Spores of Polypodiaceae reach values up to 3%. *Ruppia* pollen is present in the uppermost samples (up to 1%). The total pollen and spore concentration shows high values of about 600 grains/mm^3 in the first half of this zone, which sharply decreases at 274 cm to 75 grains/mm^3.

Pinus type stomata are continuously present throughout the zone, and *Picea* type stomata appear in the uppermost sample. *Pediastrum boryanum* (10%) and *Botryococcus* (<1%) occur in the lower half of the zone, whereas microforaminifera and hystrichospheres appear abundantly between 274 and 270 cm.

Zone WP-2 (Alnus–Tsuga mertensiana–Pinus; 267–247.5 cm): The zone is distinguished from WP-1 by lower proportions of all *Pinus* pollen types, accompanied by higher values of *Tsuga mertensiana* (17%), *Picea* (22%) and *Abies* (8%). The lower part of this zone is marked by a sharp increase in *Alnus* pollen values that reach frequencies up to 70%. *Populus* pollen occurs at frequencies of 5%. Fern spores (e.g., *Athyrium filix-femina*, *Polypodium vulgare* type) are present at higher values than in WP-1. *Nuphar* pollen is first recorded at 258 cm and present at low continuous frequencies (<1%). The total pollen and spore concentration shows increased values of about 400 grains/mm^3.

Microforaminifera occur in the lowermost sample. Algal remains (e.g., *Botryococcus*, *Pediastrum*, *Spirogyra* zygospores) are abundant throughout this zone. Nymphaeaceae hairs are present and stomata of the *Picea* type occur occasionally.

Zone WP-3 (Tsuga heterophylla–Tsuga mertensiana–Alnus; 247.5–220 cm): WP-3 is characterised by a significant increase in *Tsuga heterophylla* pollen, which attains peak frequencies of 34% in the uppermost sample (225 cm). *Tsuga mertensiana* pollen remains at 15% and *Pinus* undiff. at 20%. *Alnus* (20%), *Picea* (5%) and *Abies* pollen (<5%) are less abundant than in WP-2. Fern spores are present at lower frequencies than in the preceding zone. Pollen of *Lysichiton americanum* occurs for the first time in the uppermost sample at ca. 5% abundance. *Potamogeton* subg. *Potamogeton* type pollen is abundant at ca. 5% and *Nuphar* pollen occurs. The total pollen and spore concentration shows values of approximately 300 grains/mm^3.

Algal remains are abundant in this zone, where *Spirogyra* zygospores reach values of 6%. Nymphaeaceae hairs are present throughout WP-3. *Picea* type stomata occur in the uppermost sample.

Zone WP-4 (Alnus–Picea–Pteridium aquilinum; 220–155.5 cm): The zone is defined by another sharp increase in *Alnus* pollen (73%). *Picea* pollen attains higher values (up to 15%) than in WP-3, while *Abies* (<1%), *Tsuga mertensiana* (1%) and *Tsuga heterophylla* (ca. 10%) pollen are generally present at lower values. *Pseudotsuga menziesii* pollen occurs at frequencies of ca. 7% in two samples in the middle part of the zone (200 and 199 cm). At 197 cm, *Tsuga heterophylla* and *Tsuga mertensiana* pollen show frequency peaks of 24% and 12%, respectively, whilst *Picea* pollen declines in abundance (5%). Pollen of Cupressaceae reaches 10 % at the top of the zone. Non-arboreal pollen (mainly Rosaceae, *Lysichiton americanum*) and spores (e.g., *Pteridium aquilinum*, *Polypodium vulgare* type) are present at higher frequencies than in WP-3. In the middle of this zone at 197 cm, pollen of *Potamogeton*subg. *Potamogeton* type reaches high values (9%). *Nuphar* pollen is present at higher abundances than in WP-3. *Typha latifolia* type pollen occurs at low values (<1%) in the lower half of the zone. The total pollen and spore concentration is higher than in WP-3 reaching up to 600 grains/mm^3, but decreases in the uppermost samples to ca. 200 grains/mm^3.

Botryococcus, Pediastrum and *Spirogyra* zygospores are present throughout WP-4. Hystrichospheres appear at the end of the zone and peak at 165 cm. Nymphaeaceae hairs and *Picea* type stomata occur continuously. *Chamaecyparis nootkatensis/Thuja* type stomata are found at 215 cm and 165 cm.

Zone WP-5 (Cupressaceae–Alnus–Tsuga heterophylla–Picea; 155.5–127.5 cm): Zone WP-5 is distinguished from the previous zone by a sharp increase in the frequency of Cupressaceae pollen (ca. 40%). *Tsuga heterophylla* pollen is continuously present (up to 15%). *Abies*, *Picea* and *Alnus* pollen, non-arboreal pollen (e.g., Rosaceae, *Lysichiton americanum*) and fern spores (e.g., *Pteridium aquilinum*) occur at lower frequencies than in WP-4. *Ruppia* pollen is present at 139 cm, whereas *Nuphar* pollen occurs in the lower- and uppermost samples. The total pollen and spore concentration values remain at ca. 200 grains/mm^3.

Algal remains occur at lower values than in WP-4. Hystrichospheres are abundant throughout the zone (up to 5%) and microforaminifera occur at 139 cm. Nymphaeaceae hairs as well as *Picea* type stomata and *Chamaecyparis nootkatensis/Thuja* type stomata

Table 3
Summary of Lateglacial and Holocene vegetation, climate and lake condition at the Woods Lake study site. Climatic stages are displayed in comparison to previous and modern climatic conditions, respectively

Zone	Vegetation phase	Vegetation composition	Climate compared to previous conditions		Period	Lake conditions
WP-6	Cupressaceae–*Tsuga heterophylla*	Closed forest dominated by cedar and western hemlock	Cooler Moister	Modern (temperate and wet)	Late Holocene	Fresh Saltwater influenced
WP-5	Cupressaceae–*Alnus–Tsuga heterophylla–Picea*	Mixed coniferous forest dominated by cedar, western hemlock with alder and spruce	Cooler Moister	Temperate Moist	Mid-Holocene	Saltwater dominated
WP-4	*Alnus–Picea–Pteridium aquilinum*	Open forest composed of shade-intolerant taxa (e.g., alder, herbaceous taxa) and shade-tolerant taxa (e.g., spruce, western hemlock)	Warmer Drier	Warm Dry	Early Holocene	Saltwater influenced Fresh
WP-3	*Tsuga heterophylla–Tsuga mertensiana–Alnus*	Mixed coniferous forest dominated by western and mountain hemlock with alder	Warmer Moister	Cool Moist	Lateglacial	Fresh
WP-2	*Alnus–Tsuga mertensiana–Pinus*	Mixed coniferous forest of shade-tolerant taxa (e.g., mountain hemlock, pine, spruce, fir) with alder	Warmer? Moister	Cool Moist	Lateglacial	Fresh Saltwater influenced
WP-1	*Pinus–Alnus–Tsuga mertensiana*	Pine-dominated vegetation with alder, mountain hemlock and spruce	Cool Moist/Dry?	Cold Moist/Dry?	Lateglacial	Saltwater dominated

are present. Stomata of the *Thuja* type and *Tsuga heterophylla* were recognised in the lowermost sample (153 cm), whereas stomata of the *Abies* type are present in the uppermost sample (130 cm).

Zone WP-6 (Cupressaceae–Tsuga heterophylla; 127.5–0 cm): The zone is characterised by another increase in the frequency of Cupressaceae pollen (80%) and lower abundances of *Alnus*, *Abies* and *Picea* pollen, non-arboreal pollen (e.g., *Lysichiton americanum*) and spores (e.g., *Pteridium aquilinum*). Pollen of *Tsuga heterophylla* is found at similar frequencies as in WP-5. *Nuphar* pollen is present at low values in the lower and upper part of WP-6, whereas *Ruppia* pollen is abundant in the middle of the zone (ca. 2% at 58.55 cm). The total pollen concentration remains stable throughout WP-6 and shows a fivefold increase at 5.32 cm.

Botryococcus is less abundant (<1%) than in WP-5 but shows a steep increase in abundance (up to 15%) at the top of the zone (5.32–1 cm). Hystrichospheres and microforaminifera occur in the first half of WP-6. Stomata of several taxa (e.g., *Picea* type, *Thuja* type) are present throughout the zone. Nymphaeaceae hairs are not present throughout most of the zone but re-appear at 26.61 cm.

5. Discussion

5.1. Vegetation and environmental history at Woods Lake

A summary of the Lateglacial and Holocene changes in vegetation, climate and lake conditions at the Woods Lake study site is presented in Table 3.

5.1.1. Pinus–Alnus–Tsuga mertensiana Phase (Zone WP-1; 284–267 cm; 12,396 (± 191)–11,764 (± 179) yr BP, 14,696–13,871 cal yr BP)

Pine, alder and mountain hemlock dominated the forest vegetation around the study site during this phase. The lake basin was subject to saltwater inundation with an intermittent period of freshwater dominated conditions. The saltwater influence ceased towards the end of this vegetation phase.

The very high frequencies of *Pinus* undiff. pollen imply that pine was growing near the lake (cf. Hebda and Allen, 1993), which is supported by the presence of *Pinus* type stomata in the sediments (cf. MacDonald, 2001). However, it must be taken into account that pine pollen is often overrepresented, particularly in samples representing recently deglaciated or sparsely vegetated landscapes where the overall pollen production is low (Faegri et al., 1989; Hebda and Allen, 1993; Pellatt et al., 1997). Thus, the dominance of *Pinus* pollen in the pollen assemblages is not necessarily indicative for a pine forest (Faegri et al., 1989).

In the Woods Lake record, pollen of both the *Pinus diploxylon* type and *Pinus haploxylon* type are present suggesting that *Pinus contorta* and *Pinus monticola* (and possibly *Pinus albicaulis*) may have occurred near the lake. Following Lacourse et al. (2003), *Pinus contorta* (lodgepole pine) was probably the dominant species. The pollen record and the occurrence of clumps of *Alnus* pollen (Stolze, 2004) indicate that alder was also significant in the vegetation around the lake. The *Alnus* pollen was probably derived from *Alnus crispa*

(Sitka alder), as this species grows under cooler climatic conditions than *Alnus rubra* (Uchytil, 1989). The ability of *Pinus* and *Alnus* to grow in early successional stages on immature soils enabled these two shade-intolerant taxa to colonise recently deglaciated areas under the cold climatic conditions that prevailed in the Lateglacial.

Coniferous taxa with a higher ecological demand on growing conditions (e.g., soil, light) than *Pinus* were also present, suggesting an advanced stage in the Lateglacial vegetational succession. Following the suggestion of Mathewes (1993) and Pellatt et al. (1997) the recorded frequencies of *Tsuga mertensiana* pollen indicate that mountain hemlock grew close to the lake. The low abundance of *Picea* pollen suggests a regional occurrence of spruce (cf. Hebda and Allen, 1993). However, *Picea* type stomata were found in the uppermost sample of zone WP-1, reflecting its close occurrence to the basin towards the end of this phase. Ferns may have represented a significant part of the Lateglacial vegetation (cf. Lacourse et al., 2003). However, the increased frequency of fern spores in the Woods Lake record might also be the result of an input from marine sources as fern spores can be overrepresented due to their resistance to breakdown (Havinga, 1984).

The sediment record and the aquatic pollen and non-pollen palynomorph assemblages indicate that saltwater influenced conditions prevailed in the lake basin throughout most of this Lateglacial period. The high total pollen and spore concentration observed may be related to a relatively large pollen source area as pollen may have been introduced into the basin through marine transport. A short period of freshwater dominated conditions occurred in the early stage of this phase, as indicated by the abundance of freshwater algae such as *Pediastrum boryanum* and *Botryococcus* in the microfossil record. The transition from the silt containing marine shell fragments to dark grey brown gyttja at 276 to 272 cm indicates that the lake basin became more sheltered from the sea towards the end of this phase. The reduction in the total pollen and spore concentration suggests that the marine pollen input may have declined. However, the occurrence of *Ruppia* pollen, microforaminifera and hystrichospheres indicates that saltwater influenced conditions persisted, perhaps due to occasional flooding of the basin at high tides or during storm events.

Radiocarbon dating of plant debris from immediately above the marine–limnic transition (Table 2) suggests that the isolation of the Woods Lake basin from Seymour Inlet was essentially completed by 11,820± 90 yr BP. The inferred timing of the fall in relative sea level in the Seymour Inlet area is consistent with the results of previous studies establishing that the glacio–isostatic emergence of southern coastal British Columbia was rapid in the millennium after deglaciation, reaching present day datum at about 11,500 yr BP (Mathews et al., 1970; Clague et al., 1982; Hutchinson et al., 2004).

5.1.2. Alnus–Tsuga mertensiana–Pinus Phase (Zone WP-2; 267–247.5 cm; 11,764 (± 179)–11,040 (± 165) yr BP; 13,871–13,062 cal yr BP)

This vegetation phase is marked by a significant decline in pine, an increase in alder and an expansion of more shade-tolerant coniferous trees (e.g., mountain hemlock, spruce, fir). The aquatic pollen and microfossil records indicate that freshwater conditions prevailed in the lake, suggesting the isolation of the basin from Seymour Inlet.

Pine was still present around the lake at this time, even though percentage and concentration values of *Pinus* undiff. pollen are significantly lower than in WP-1 (Stolze, 2004). This decrease may reflect a change in the pollen source area associated with the isolation of the basin from the sea or may indicate a successional change as pine was replaced by other more shade-tolerant coniferous trees such as spruce and mountain hemlock. The spread of *Picea* may have been promoted by the emergence of low-lying coastal land in the vicinity of the basin as relative sea level fell. The presence of *Picea* type stomata provides evidence that spruce was growing close to the lake shore (cf. MacDonald, 2001). On the northwest Pacific coast, *Picea sitchensis* is known to be an early pioneer on immature soils recently exposed by glacial retreat or isostatic uplift. It is also common on sites affected by ocean spray and brackish water, where other tree taxa are less successful (Burns and Honkala, 1990).

The relatively high values of *Tsuga mertensiana* pollen imply that mountain hemlock expanded significantly near the lake, becoming a dominant or co-dominant element of the forest. This subalpine taxon is an indicator of a cool and humid climate and snowy winters (Burns and Honkala, 1990). Shade-tolerant *Abies* also spread around the lake. Despite the relatively low pollen values, this taxon probably became an important element of the forest vegetation (cf. Heinrichs et al., 2002).

The abrupt increase and high abundance of *Alnus* during this phase may be evidence of a rise in soil moisture (cf. Klinka et al., 1989) or an increase in available habitat due to falling relative sea level. A similar rise in the abundance of *Alnus* pollen has also been noted in other Lateglacial records including those from the Fraser Lowland (Pellatt et al., 2002) and northern Vancouver Island (Lacourse, 2005). In these Lateglacial assemblages an increase in *Alnus viridis* type and *Alnus crispa* type pollen was recorded, implying that shrub alder rather than red alder (*Alnus rubra*) prevailed. *Populus* was also present during this phase, presumably growing on moist sites near the lake (cf. Pojar and MacKinnon, 1994). Ferns (e.g., *Athyrium filix-femina*) formed a significant portion of the understorey of the Lateglacial forest.

The elevated minerogenic content of the gyttja and the presence of microforaminifera suggest that saltwater intrusions into the basin still occurred during the early stages of this phase. Subsequently, freshwater conditions became established in the lake, as indicated by the observed remains of freshwater taxa (e.g., *Spirogyra*, *Botryococcus*, *Nuphar* pollen, Nymphaeaceae hairs). The change from dark grey brown to very dark brown gyttja containing occasional plant fragments implies an increase in biomass production associated with the development of quiet, freshwater conditions. Despite the diminishing marine pollen influx, relatively high total pollen and spore concentration values were observed. This may be a result of a slower sedimentation rate and an increased influx of pollen and spores from the increasingly dense vegetation cover surrounding the lake.

5.1.3. *Tsuga heterophylla–Tsuga mertensiana–Alnus* Phase (Zone WP-3; 247.5–220 cm; 11,040 (± 165)–10,018 (± 144) yr BP; 13,062–11,615 cal yr BP)

This interval is marked by a sudden expansion of western hemlock in the forest and a concomitant decline in other coniferous taxa and alder in the vegetation around the study site. Freshwater conditions prevailed in the lake throughout this vegetation phase.

The pollen record indicates the expansion and establishment of western hemlock as a major component of the vegetation. A sharp rise in *Tsuga heterophylla* pollen also occurs in Lateglacial pollen records from other coastal sites of British Columbia and has been interpreted to reflect wetter climatic conditions (e.g., Pellatt et al., 2002). The pollen record and concentration values as recorded by Stolze (2004) show that *Tsuga mertensiana* continued to be important in the forest around Woods Lake, indicating cool and moist conditions with a relative high snowpack during the winter. Spruce still grew near the lake, as suggested by the presence of *Picea* type stomata. Thus, a mixed forest of western hemlock, mountain hemlock, spruce and pine with ferns in the understorey can be assumed to have existed through this interval. However, the portion of pine in the vegetation declined towards the end of this phase, probably being replaced by seral taxa with higher demands on soil conditions including *Tsuga heterophylla* and *Picea*.

The end of this Lateglacial interval was also characterised by a conspicuous expansion of Skunk cabbage (*Lysichiton americanum*). This species is characteristic of swamps, standing water and nutrient-rich seepage areas (Pojar and MacKinnon, 1994) and probably grew on the lake fringe or on wet sites in the adjacent forest. The wet climatic conditions, the ceased marine influence and a concurrent increase in available habitat may have facilitated the expansion of this taxon.

The aquatic record indicates that the environmental conditions and vegetation composition within the lake were similar to those attained during the previous *Alnus–Tsuga mertensiana–Pinus* phase. In addition, *Potamogeton*, which commonly inhabits shallow to moderately deep (1–3 m) bodies of usually standing water (Pojar and MacKinnon, 1994), expanded in the lake.

5.1.4. *Alnus–Picea–Pteridium aquilinum* Phase (Zone WP-4; 220–155.5 cm; 10,018 (± 144)–7622 (± 97) yr BP; 11,615–8412 cal yr BP)

This phase was characterised by an increase in alder, spruce and herbaceous taxa, whereas western and mountain hemlock declined considerably. A freshwater environment prevailed in the lake. The end of this interval was marked by a marine intrusion into the basin.

The pollen record provides evidence for a major expansion of *Alnus* during this phase. Palynological studies from the Fraser Lowland and Vancouver Island have shown that *Alnus rubra* was the prevailing alder species for a similar vegetation phase (Pellatt et al., 2002; Lacourse, 2005). The increasing importance of alder and other shade-intolerant taxa (e.g., *Lysichiton americanum*, Rosaceae, *Pteridium aquilinum*) and the decline in shade-tolerant coniferous trees such as *Abies* and *Tsuga* species around the lake suggests that the forest canopy became more open. The decline of especially *Tsuga mertensiana* indicates a warming and possibly drying climate during this early-Holocene interval. Despite the notable decline of *Tsuga heterophylla*, the Woods Lake pollen record shows that this taxon still played an important role in the forest vegetation. The decrease of these shade-tolerant taxa was accompanied by an expansion of *Picea*, which became a significant component of the forest community surrounding the lake.

Palynological studies from other sites in the CWH zone indicate that the early-Holocene changes in vegetational pattern described above are typically accompanied by an increase in the occurrence of *Pseudotsuga menziesii* (e.g., Mathewes, 1973; Hebda, 1983; Lacourse, 2005). These authors related the expansion of Douglas-fir to the establishment of conditions that were drier and warmer than those which exist today. In contrast to these studies, Douglas-fir was only present as an important constituent of the tree layer around Woods Lake during a relatively short interval of the early Holocene. The subsequent sharp decline of this species is followed by a brief increase in shade-tolerant mountain hemlock and western hemlock and a decline in spruce. This change may be the result of a short interval of cooler and wetter climatic conditions during the middle of this vegetation phase.

The end of this early-Holocene phase is marked by a minor expansion of Cupressaceae. The presence of *Chamaecyparis nootkatensis/Thuja* type stomata indicates that *C. nootkatensis* or *Thuja plicata* grew in close vicinity to the lake. Their expansion may suggest a climatic cooling and/or wetter conditions due to increased precipitation or development of a higher water table (Klinka et al., 1989; Pellatt and Mathewes, 1997).

Aquatic taxa characteristic of a freshwater environment (e.g., *Nuphar*, *Typha*, *Botryococcus*, *Spirogyra*) were abundant in the lake throughout this phase. The inferred cooler and moister interval in the middle of this vegetation phase was accompanied by an expansion of *Potamogeton*. The observed dark brown and black organic gyttja indicates that sedimentation took place in shallow water and that eutrophic conditions prevailed. High total pollen and spore concentration values are indicative of a slow sedimentation and a high pollen and spore influx. The occurrence of sand in the olive grey gyttja in the upper section of the sediment and the appearance of hystrichospheres by the end of this phase suggest that the lake basin was subject to renewed saltwater influence. This is supported by decreased total pollen and spore concentration values and the presence of marine and brackish water diatoms (Doherty, 2005).

5.1.5. Cupressaceae–Alnus–Tsuga heterophylla–Picea Phase (Zone WP-5; 155.5–127.5 cm; 7622 (± 97)–5544 (± 74) yr BP; 8412–6337 cal yr BP)

This vegetation phase was characterised by a significant expansion of Cupressaceae taxa in the forest, whereas spruce and alder declined considerably. Marine intrusions into the lake basin occurred throughout this interval, increasing towards the end of this phase.

The pollen and stomata records indicate that cedar occurred near the lake. Presumably western redcedar (*Thuja plicata*) rather than yellow cedar (*Chamaecyparis nootkatensis*) predominated in the vegetation, which is suggested by the occasional presence of *Thuja* type stomata. The relatively high values of *Tsuga heterophylla* pollen and particularly the presence of stomata show that western hemlock occurred together with western redcedar. The decline in pollen frequencies of *Picea* and *Alnus* in the Woods Lake record suggests a decreasing importance of both taxa in the vegetation around the lake, presumably due to the development of a denser canopy of the mixed coniferous forest. However, spruce still grew near the basin throughout this phase, as indicated by the presence of *Picea* type stomata, and alder probably persisted on wetter sites close to the lake or on sites where the forest canopy was not yet fully closed. The low values of *Abies* pollen may suggest a regional presence of fir (Janssen, 1984) or the scattered occurrence of this taxon around the lake, which is supported by the presence of *Abies* type stomata in the Woods Lake record. The inferred closing of the forest canopy during this phase is also supported by the decline of more shade-intolerant taxa (e.g., Rosaceae, *Lysichiton americanum*, *Pteridium aquilinum*) in the vegetation. The decline in *Lysichiton americanum* may also be a result of saltwater intrusions into the pond, as available habitat decreased.

The establishment of a mixed coniferous forest dominated by western hemlock, cedar (*Thuja plicata/Chamaecyparis nootkatensis*) and spruce has also been described for sites on Vancouver Island and ascribed to the mid-Holocene (Hebda, 1983; Brown and Hebda, 2002; Lacourse, 2005). The increasing abundance of Cupressaceae taxa in the vegetation is interpreted to reflect decreasing temperature and/or increasing precipitation during this period (Pellatt and Mathewes, 1997).

The increased abundance of hystrichospheres and the presence of microforaminifera and *Ruppia* pollen imply that saltwater penetration into the basin took place throughout this interval. Enhanced sedimentation rates during the inundation events may explain the low values of the total pollen and spore concentration observed in the Woods Lake record. However, the occurrence of microfossils indicating freshwater conditions (*Nuphar* pollen, *Spirogyra*, *Botryococcus*, Nymphaeaceae hairs) suggests that the basin was not continuously under marine influence. The observed change in gyttja colouration from dark olive to olive along with an increased content of fine to coarse sand imply that saltwater penetration into the lake basin was most pronounced towards the end of the phase.

Based on radiocarbon dating, the inferred marine influence commenced prior to 7176±44 yr BP and persisted to at least 3758±29 yr BP (Table 2), covering the mid-Holocene vegetation phase. Destructive erosion of the sediments during marine incursion may explain the observed abrupt changes in pollen frequencies marking the lower and upper boundaries of pollen zone WP-5. The occurrence of a layer of disturbed sediment at 139–130 cm and the shape of the radiocarbon age-depth model (Fig. 4) corroborate the assumption of a hiatus in the sediment record. Marine intrusion into the lake basin during this period corresponds well with a regional high-stand in relative sea level during the mid-Holocene (Clague et al., 1982; Hutchinson et al., 2004).

5.1.6. *Cupressaceae–Tsuga heterophylla Phase (Zone WP-6; 127.5–0 cm; 5544 (± 74) yr BP–present; 6337 cal yr BP–present)*

This phase is characterised by a further major expansion of cedar and the establishment of a cedar and western hemlock dominated forest. Saltwater influenced conditions prevailed in the lake during most of this interval. However, freshwater conditions were established in the basin during the late stages of this vegetation phase.

The recorded high values of Cupressaceae pollen as well as the presence of stomata indicate that *Chamaecyparis nootkatensis* and *Thuja plicata* grew near the lake throughout the phase, with *Thuja plicata* being the more abundant species. The renewed expansion of cedar indicates a further increase in precipitation and decrease in temperature leading to the establishment of modern climatic conditions during this phase. *Abies* grew around the lake at least during the early stages of this phase. The proportion of less shade-tolerant tree taxa (e.g., *Alnus*, *Picea*) and herbaceous plants (e.g., *Lysichiton americanum*, *Pteridium aquilinum*) continued to decline in response to a further closure of the forest canopy.

Picea type stomata were recorded in the sediments corresponding to this phase but only low frequencies of *Picea* pollen were encountered. This apparent discrepancy may possibly be explained by the introduction of stomata from proximal marine sources, as the lake basin continued to be occasionally open to marginal saltwater penetration. Alternatively, the continued presence of *Picea* type stomata may be attributed to the run-off input from the steep slopes surrounding the lake. At present, spruce grows immediately adjacent to the lake. The low frequencies of *Picea* pollen in the modern Woods Lake sediments, however, do not reflect the nearby presence of this taxon (cf. Hebda, 1983). Spruce trees growing at the study site are small, indicating unfavourable growing conditions that are probably related to the damp, poorly drained soils. These conditions may result in low pollen production and consequently the observed low pollen values.

In addition to the sediment record, evidence of marine inundation of the lake basin during most of this interval is provided by the presence of hystrichospheres, sporadically occurring microforaminifera, the abundance of *Ruppia* pollen and the periodic occurrence of brackish/marine diatoms (Doherty, 2005). The disappearance of marine proxies and re-occurrence of freshwater microfossils (e.g., *Nuphar* pollen, Nymphaeaceae hairs, *Botryococcus*) indicate a decline in salinity and a return to freshwater conditions during the late stages of this phase. The cessation of the marine influence was characterised by an increase in the total pollen and spore concentration values and a decrease in the deposition of allochthonous minerogenic material. Radiocarbon dating suggests that the onset of the establishment of present-day freshwater conditions occurred shortly before 1604±36 yr BP (Table 2).

5.2. *Regional synthesis*

Comparison of the Woods Lake record with palynological records from other sites within the CWH zone (Fig. 1) indicates that similar vegetation patterns occurred across this region during the Lateglacial and Holocene.

5.2.1. *Lateglacial*

The pollen records from Woods Lake and other sites in the CWH zone covering the Lateglacial period show that *Pinus*, probably *Pinus contorta*, dominated the plant communities (Hansen, 1940, 1950; Mathewes, 1973; Mathewes and Rouse, 1975; Hebda, 1983; Warner, 1984; Brown and Hebda, 2002; Pellatt et al., 2002; Lacourse, 2005), which have been interpreted by most authors to reflect a cold and probably dry climate. A few authors, however, suggested a cool and moist climate for this period (Hansen, 1940; Mathewes and Rouse, 1975). At the Woods Lake site, this pine-dominated vegetation was replaced by a mixed coniferous forest with *Picea*, *Tsuga mertensiana*, *Abies*, *Pinus* and *Tsuga heterophylla*. Forests of similar composition were widespread during the Lateglacial in areas today ascribed to the CWH zone, where increased conifer diversity and abundance suggest cool and moist climatic conditions (Hansen, 1940; Mathewes, 1973; Hebda, 1983; Brown and Hebda, 2002; Pellatt et al., 2002; Lacourse, 2005). The Woods Lake record indicates that the beginning of this Lateglacial interval was also characterised by a significant increase in *Alnus*, followed by a rise in *Tsuga heterophylla*. Similar successions have been reported from sites within the CWH zone on the Queen Charlotte Islands, Vancouver Island and southwestern British Columbia (Mathewes, 1973; Hebda, 1983; Warner, 1984; Brown and Hebda, 2002; Pellatt et al., 2002; Lacourse, 2005). Relatively high values of *Tsuga mertensiana* pollen (>10%) have been recorded for Lateglacial coniferous forests at Woods Lake and other sites within the CWH zone on northern Vancouver Island (Hebda, 1983; Lacourse, 2005) and Graham Island (Warner, 1984). Records from sites on southern Vancouver Island (Brown and Hebda, 2002) and southwestern British Columbia (Mathewes, 1973; Pellatt et al., 2002) show only very small frequencies of this pollen type, providing evidence that the warmer and less humid conditions present in this region prevented mountain hemlock from spreading.

5.2.2. Early Holocene

The increased portion of more shade-intolerant taxa (e.g., *Alnus*, *Pseudotsuga menziesii*, *Pteridium aquilinum*) concomitant with a decline in shade-tolerant trees (*Tsuga mertensiana*, *Abies*) in the vegetation reflect warmer and drier climatic conditions that became established during the early Holocene (Mathewes, 1973; Mathewes and Rouse, 1975; Banner et al., 1983; Hebda, 1983; Warner, 1984; Quickfall, 1987; Brown and Hebda, 2002; Pellatt et al., 2002; Lacourse, 2005). These conditions are attributed to higher solar insolation levels, which resulted in increased summer temperatures (COHMAP, 1988). During the early Holocene, *Pseudotsuga menziesii* played an important role in the CWH zone along the mid- to southern coast of British Columbia. The proportion of this taxon generally increased from sites located close to the shore (Brown and Hebda, 2002; Lacourse, 2005; this study) to sites further inland (Mathewes, 1973; Pellatt et al., 2002), suggesting that a gradient in moisture developed in the early Holocene that was similar to present day patterns (cf. Brown and Hebda, 2002; Brown et al., 2006). *Picea*, usually growing under conditions of abundant moisture, decreased in importance from CWH sites close to the shore (Hebda, 1983; Brown and Hebda, 2002; Lacourse, 2005; this study) to those further inland (Mathewes, 1973; Mathewes and Rouse, 1975; Brown and Hebda, 2002; Pellatt et al., 2002), confirming the above conclusion.

5.2.3. Mid-Holocene

The expansion of *Tsuga heterophylla* and the, often subsequent, spread of Cupressaceae taxa and their establishment as dominant or co-dominant trees in the forest vegetation marked the mid-Holocene interval at most CWH sites (Hansen, 1940; Mathewes, 1973; Mathewes and Rouse, 1975; Banner et al., 1983; Warner, 1984; Quickfall, 1987; Brown and Hebda, 2002; Lacourse, 2005). Unlike these sites where the pollen frequencies of cupressaceous taxa increase gradually, indicating a continuous expansion of these conifers, the Woods Lake record is characterised by a sharp increase in the relative abundance of Cupressaceae pollen. This significant change in the pollen record correlates well with the inferred mid-Holocene hiatus in the sediments and, therefore, does not necessarily reflect a sudden spread of cedar in the study area at this time. An overall decline in shade-intolerant taxa such as *Alnus* and partly *Pseudotsuga menziesii* occurred at most CWH sites. The portion of Douglas-fir decreased significantly in parts of the CWH zone where conditions are presently wetter (Hebda, 1983; Lacourse, 2005; this study). At sites today located near the transition from the moist CWH to the drier Coastal Douglas-fir biogeoclimatic zone, *P. menziesii* maintained or increased its portion in the forests to form a co-dominant or dominant component (Mathewes, 1973; Mathewes and Rouse, 1975; Brown and Hebda, 2002). The distribution of Douglas-fir suggests that a gradient in moisture must have prevailed in the mid-Holocene that limited the expansion of this species. The overall increase in shade-tolerant taxa and the decline in shade-intolerant species are interpreted to reflect the establishment of moister and somewhat cooler climatic conditions than in the preceding early-Holocene interval (Mathewes, 1973; Mathewes and Rouse, 1975; Banner et al., 1983; Warner, 1984; Quickfall, 1987; Brown and Hebda, 2002; Lacourse, 2005; this study).

5.2.4. Late Holocene

Another increase in Cupressaceae taxa characterised the onset of the late Holocene interval at Woods Lake and other CWH sites (Mathewes, 1973; Mathewes and Rouse, 1975; Banner et al., 1983; Hebda, 1983; Warner, 1984; Quickfall, 1987; Brown and Hebda, 2002; Lacourse, 2005), which has been attributed to the development of moister and cooler climatic conditions. At most sites, cedar and western hemlock dominated forests with varying portions of other tree taxa became established under these modern conditions. *Alnus* and *Pseudotsuga menziesii* remained important constituents of the vegetation at presently drier sites of the CWH zone (Mathewes, 1973; Brown and Hebda, 2002). The Woods Lake record is almost exclusively dominated by pollen of Cupressaceae that reaches frequencies above

80% of the pollen and spore sum, representing the highest Cupressaceae pollen values of all palynological records from CWH sites. This may indicate that the prevalence of cupressaceous taxa around Woods Lake was likely due to favourable edaphic conditions and the suppression of other shade-tolerant trees such as *Tsuga heterophylla*.

Palynological records from other biogeoclimatic zones along the coast of British Columbia show similar climatic trends during the Lateglacial and Holocene (e.g., Hebda and Mathewes, 1984; Mathewes and King, 1989; Pellatt and Mathewes, 1997; Hallett et al., 2003), suggesting that a larger scale climate prevails along the northwest Pacific coast.

6. Conclusions

The Woods Lake microfossil record represents an important link in Lateglacial and Holocene vegetation history and climate change between previously investigated palynological sites in the CWH biogeoclimatic zone. The vegetational and climatic changes derived from the Woods Lake record are consistent with those inferred from other palynological sites in the CWH zone, suggesting that a coherent vegetation and climate history occurred at a regional level. Comparison of palynological data from different sites suggests that the gradient in moisture that presently occurs within this region must have prevailed since the Lateglacial or early Holocene. The study demonstrates that the reconstruction of vegetation history can be refined by the combination of pollen and conifer stomata analyses. Low pollen frequencies of coniferous trees may be interpreted to reflect regional presence of the taxa, but the occurrence of their stomata provides evidence that these trees grew in close proximity to the study site. In addition to the reconstruction of the vegetation and climate history, the Woods Lake record provides evidence for variations in the lake environment associated with changes in relative sea level. The lake basin was inundated during the Lateglacial, but became isolated from Seymour Inlet in response to the glacio-isostatic emergence of coastal British Columbia. A renewed phase of prolonged seawater incursion is indicated for the mid-to late Holocene.

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