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POSTGLACIAL VEGETATION, CLIMATE HISTORY AND LAND-SEA INTERACTION AT ISLAND LAKE, BAIE DES CHALEURS, NEW BRUNSWICK, AS DOCUMENTED BY PALYNOLOGICAL ANALYSIS*

Robert J. MOTT**, Hélène JETTÉ***, Joël GUIOT and André CLOUTIER: first and fourth author: Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8; third author, CEREGE CNRS/Université Paul Cézanne UMR 6635, B 80, F-13545 Aix-en-Provence, France.

ABSTRACT This study demonstrates that lakes located near the coast, close to large bodies of water, can document sea-level fluctuations and the subtle sea-land interaction that governs coastal areas. At Island Lake, located close to the head of Baie des Chaleurs, northern New Brunswick, the postglacial marine transgression corresponds with a reversal from a cold and dry herb and shrub tundra environment to open pioneer forest that was warmer and wetter. Successive incursions of poplar/aspen and spruce were succeeded by boreal forest dominated by spruce, alder and birch. A forest dominated by alder and fir, indicators of wetter and even colder local conditions followed. Paleoclimatic reconstruction inferred from pollen stratigraphy indicates that an early warming period culminating *ca.* 9450 BP, was followed by a period when temperatures remained cool. At the same time, the annual precipitation rose sharply, suggesting increased availability of moisture in this area. This is interpreted as a cooling effect due to the proximity to a large body of water to the study site and is attributed to the marine transgression into Baie des Chaleurs following the discharge of glacial lakes Agassiz and Barlow-Ojibway into the Great Lakes and Goldthwait Sea and the isostatic adjustment of the landmass. The cooling effect was recorded by a vegetation change from *ca.* 9450 to 8100 BP. Within that period, from *ca.* 8500 to *ca.* 8400 BP, the vegetation did not record the effect of the proximity to the sea. This period is postulated to be a period of low water levels in the Baie. Recovery to the regional climate norm occurred after 8100 BP when the climate was warmer than today. Since then the climate gradually cooled.

RÉSUMÉ *Histoire de la végétation postglaciaire, du climat et de l'interaction terre-mer au lac Island, baie des Chaleurs, Nouveau-Brunswick, établie à l'aide d'analyses polliniques*. Cette étude démontre que des lacs situés à proximité de vastes étendues d'eau peuvent fournir des informations sur les variations antérieures du niveau marin et les subtiles interactions terre-mer qui régissent les régions côtières. Au lac Island, à l'amont de la baie des Chaleurs, dans le nord du Nouveau-Brunswick, pendant que se produisait la transgression marine postglaciaire, la toundra froide et sèche à herbes et arbustes a été remplacée par une forêt pionnière plus chaude et plus humide. Après des incursions successives de peupliers/trembles et d'épinettes, une forêt boréale dominée par l'épinette, l'aulne et le bouleau s'est établie. Par la suite, une forêt où dominaient l'aulne et le sapin, indices de conditions locales plus humides et froides, s'est installée. Les reconstructions paléoclimatiques basées sur la stratigraphie pollinique mettent en lumière l'existence d'une période de réchauffement hâtive culminant vers 9450 BP, suivie d'une période pendant laquelle la température s'est refroidie. Parallèlement, les précipitations annuelles ont rapidement augmenté, ce qui suggère un accroissement de l'humidité régionale. Le refroidissement découlerait de la présence d'une vaste étendue d'eau à proximité du site d'étude ; celui-ci aurait été causé par une transgression marine dans la baie des Chaleurs survenue à la suite de la décharge des lacs Agassiz et Barlow-Ojibway dans les Grands Lacs et la mer de Goldthwait due au redressement isostatique du continent. Des changements dans la composition végétale reflètent ce refroidissement entre 9450 et 8100 BP, sauf vers 8500 à 8400 BP, période durant laquelle la baie présentait probablement un bas niveau d'eau. Un retour aux conditions climatiques régionales normales s'est produit après 8100 BP, époque à laquelle la température était plus chaude qu'aujourd'hui. Depuis cette période, le climat se refroidit graduellement.

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*Geological Survey of Canada Contribution 2004096
**E-mail address: rjmott@gsc.nrcan.gc.ca
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INTRODUCTION

Palynologic and paleoclimatic investigations at Island Lake, near Baie des Chaleurs, New Brunswick, were undertaken with three purposes: 1) fill an important gap in knowledge of the paleoenvironmental history of New Brunswick since no complete palynological investigation has been published for the northern part of the province; 2) test the effect on the regional climate of the discharge of glacial lakes Agassiz and Barlow-Ojibway via the Great Lakes into the Goldthwait Sea, from about 9600 to 8300 BP (Anderson and Lewis, 1992; Anderson, personal communication, 1993); 3) determine if terrestrial environments can record sea-level fluctuations and document the low water stage reported by Syvitsky (1992) for the Baie des Chaleurs following ice retreat and isostatic adjustment of the landmass, *ca.* 9000 BP; and 4) develop and refine transfer functions to document climate changes that affected the area and, *ipso facto,* develop a sophisticated tool capable of documenting the interaction of water masses with the terrestrial domain.

Anderson and Lewis (1992) proposed a theory, based on previous work (Lewis *et al.,* 1988; Lewis and Anderson, 1989), that drainage of cold water from glacial lakes Agassiz and Barlow-Ojibway into the Great Lakes and Goldthwait Sea would have induced cold climates that had the effect of delaying seasonal warming, reducing the growing season and modifying the vegetation succession in the surrounding land. They examined pollen records from around the Gulf of St. Lawrence and found pollen anomalies that suggested a vegetation response to a cold meltwater-capped Goldthwait Sea at 10 000-8000 BP, namely an anomaly in *Alnus* cf. *crispa* (green alder) in the Lower St. Lawrence-Gaspé Peninsula and Baie des Chaleurs regions.

Previously, Richard and Labelle (1989) had proposed that increased *Alnus* cf. *crispa* between 9500 and 7000 BP at a site in Gaspésie was caused by a dry and/or stormy summer climate that favoured frequent wild fires. Such conditions resulted from more prevalent catabatic winds from the Laurentide Ice Sheet situated just north of the St. Lawrence estuary. Richard *et al.* (1992) presented evidence of *Alnus* cf. *crispa*-dominated zones at other Lower St. Lawrence River sites and favoured an interpretation of cold and dry conditions related to the proximity of the Laurentide Ice Sheet, rather than to cold meltwater drainage (Anderson and Lewis, 1992). By contrast, Jetté and Richard (1992) proposed that the *Alnus* cf. *crispa* zones at sites along the north side of Baie des Chaleurs indicated that vegetation migration was delayed by a cool and wet rather than cool and dry climate attributable to the proximity of the Laurentide Ice Sheet.

Island Lake, near the head of the Baie, is ideally located to register and document the effect of a cold water body on vegetation and climate. Transfer functions, developed using a multivariate analysis method (Guiot, 1990), provide quantitative climate values that allow us to document the amplitude of this interaction and monitor the effect.

The site can also provide information on the sea-level history of the Baie des Chaleurs since deglaciation. Syvitsky (1992) suggested an early Holocene low sea level, possibly 90 m below present-day limits in Baie des Chaleurs. This event occurred about 9000 years ago, following deglaciation and isostatic adjustment of the landmass and is based on the interpolation of the rebound rates presented by Rampton *et al.* (1984) and Gray (1987), and on terrestrial evidence. Sediment changes and palynological investigations at Island Lake provide information on sea-level fluctuations and contribute to a better understanding of the postglacial history of Baie des Chaleurs.

This integrated study combines results from different environmental components: vegetation history, sea-level fluctuations and climatic reconstruction. Such integrated studies are essential in the development of new methodologies needed to document the subtle interactions between land and sea and the dynamism of environmental changes throughout the Holocene.

STUDY AREA

LOCATION

Island Lake (47° 49' 30" N, 66° 11' 00" W; NTS 21 O/16) is located near the head of Baie des Chaleurs, about 40 km southeast of Campbellton, northern New Brunswick, at an elevation of 290 m. The lake occupies a small (3 ha) kettle in an area of hummocky, stagnant ice terrain, situated in the Appalachian Mountain region between the Gaspésie Plateau and the Matapedia Plateau (Fig. 1). The deepest water (9 m) at the centre of the lake is south west of a gravel ridge protruding from the shore. The lake is situated in a transitional zone between two mixed forest types: one characterized by sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), spruce (*Picea glauca*) and balsam fir (*Abies balsamea*); and the other by sugar maple, yellow birch, white pine (*Pinus strobus*) or beech (*Fagus grandifolia*) (Loucks, 1961; Rowe, 1972). Such sites, in transitional position, can register vegetation movements and document climatic fluctuations through time.

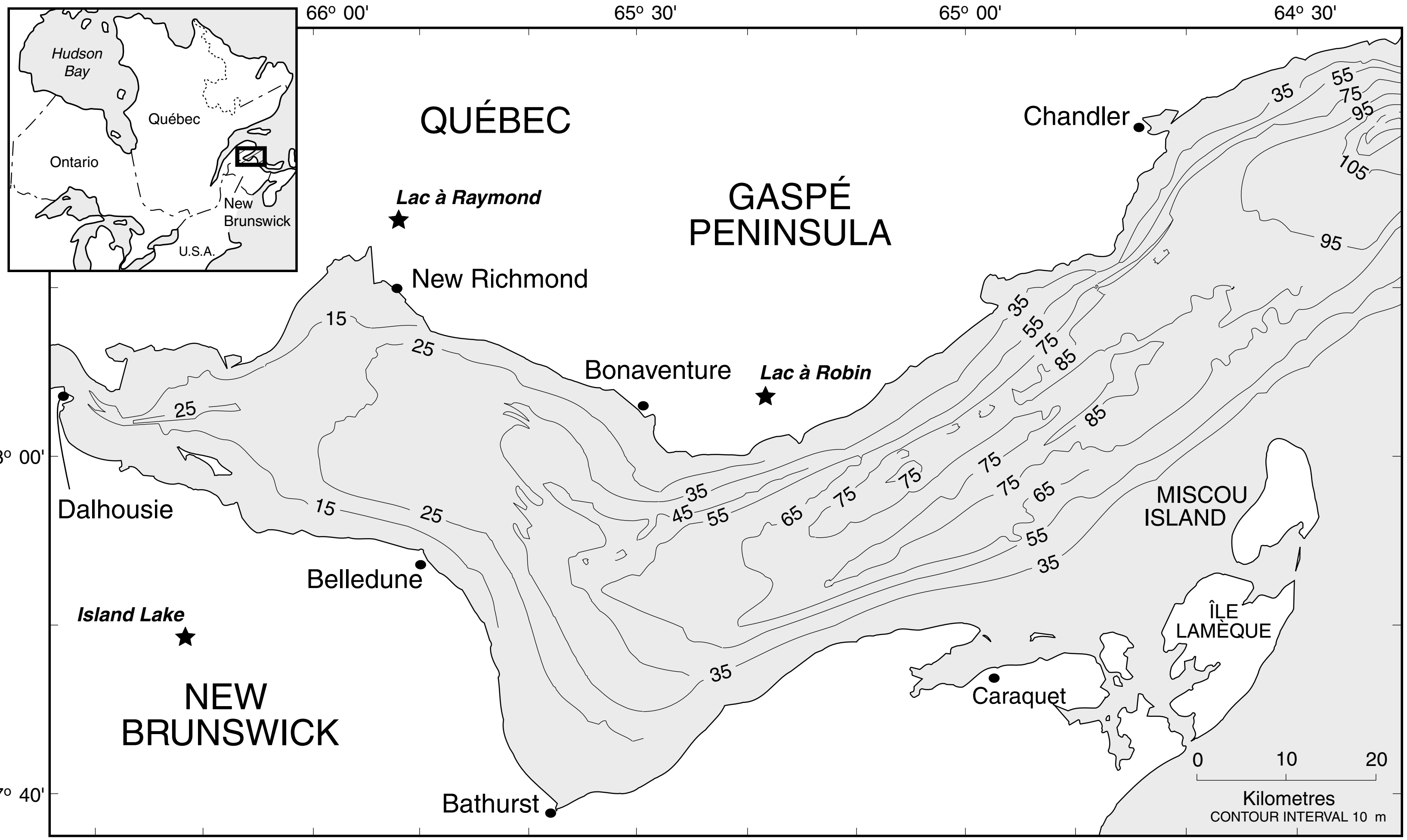
Baie des Chaleurs today is a broad, shallow basin characterized by inner and outer sills, which are at water depths of 22 and 90 m, respectively. The inner basin (Restigouche Channel) is 33 m deep at its deepest point, and the outer basin reaches 135 m. The bathymetry of the baie is illustrated in Figure 1 (after Syvitsky, 1992).

CLIMATE

Today's climate in this area is mild and influenced by the presence of Baie des Chaleurs. Mean July and mean January temperatures are 17.1 °C and -13.7 °C, respectively. Annual precipitation reaches 1 080 mm per year (Environment Canada, 2002).

POSTGLACIAL HISTORY

The postglacial history of the Baie des Chaleurs is complex. Some researchers are in agreement with some phases of this history, whereas other phases await consensus because their interpretation is based on circumstantial



Bathymetry after J.P.M. Syvitski (1992)

Figure 1. Location map for the Baie des Chaleurs region.

Carte de localisation de la région de la baie des Chaleurs.

evidence and not on direct measurement. There seems to be a consensus on the ice sheet retreat phase. According to Schafer (1977), Late Wisconsinan ice retreated *ca.* 14 000 BP, and, according to Rampton *et al.* (1984), was completed by 12 100 BP. Josenhans and Lehman (1999) suggested that by 12 200 BP ice-proximal sedimentation had ceased in the outer part of the baie. Glaciers had retreated into shallow water or behind fiord sills. Richard *et al.* (1997) revised the deglacial chronology of the Gaspé Peninsula based on AMS dates of terrestrial plant matter in lake sediments throughout the area. They postulated that a significant amount of ice covered the Peninsula until after 10 000 BP with final deglaciation occurring between 9500 and 9000 BP. This raises the possibility that late ice persisted in the New Brunswick Highlands well after the age of 12 100 BP reported by Rampton *et al.* (1984). An organic layer buried by what was interpreted as glacial till and dating to 11 500 BP was reported in the southern part of the Highlands (Lamothe, 1987; McNeely and McCuaig, 1991, p. 32) indicating the presence of late ice in the area. As well, a lake reported by Mayle *et al.* (1993) in the southern Highlands with a basal AMS date of 11 100 BP and a record of the Younger Dryas cold interval indicates that glaciers may have occurred in that area just prior to that time. Studies by Stea and Mott (1989, 1998) led them to postulate that glacial ice covered some areas of the Maritimes during the Younger Dryas cold interval (10 800-10 200 BP). This raises the possibility that late ice also remained in parts of northern New Brunswick until after 10 000 BP as well.

Because sea level was eustatically depressed as the ice sheet retreated, a low salinity lake is postulated to have occupied Baie des Chaleurs *ca.* 12 700 BP (Rampton *et al.*, 1984). Shortly after this phase, marine incursion occurred between 12 700 and 12 000 BP (Pronk *et al.,* 1989). Marine regression followed as a result of isostatic adjustment of the landmass and despite eustatic sea-level rise, although timing awaits a consensus. According to Schafer (1977), marine regression would have occurred about 10 000 to 8000 years ago. Bail (1983) concluded that relative sea level fell to -10 m in the early Holocene. On the other hand, Rampton *et al.* (1984) and Syvitsky (1992) are more specific, suggesting 10 000 and 9000 BP, respectively, for this event. The latter author bases his interpretation on the depth of the outer sill (-90 m), on the presence of fluvial channels in glaciomarine sediments to this depth, and on the interpolation of the terrestrially determined rebound rates of Gray (1987) to a water depth of -90 m. Dyke and Peltier (2000) treat this figure with caution as it is excessive when related to other shorelines around the Gaspésie region. They suggest that the shoreline was below sea level but by less than 20 m and certainly by less than 40 m. A more recent bathymetry survey revealed that the channels are not fluvial, but are parallel flutes probably formed by tidal currents (Shaw *et al.*, 2002). A submarine moraine with a bevelled surface at -45 m, and undisturbed glacial morphology below this depth (Syvitsky, 1992), suggests that this is the regression depth for the bay (Shaw *et al.*, 2002).

Early and middle Holocene marine transgression brought the sea to its modern level (Syvitsky, 1992).

METHODOLOGY

PALYNOLOGICAL ANALYSIS

In August 1978, Mott obtained a 7.5-m core from below 9 m of water in Island Lake using a modified Livingstone sampler (Livingstone, 1955; Wright *et al.*, 1965). The sediments were subsampled at 20 cm intervals and, after the first round of analysis, some subsampling was done at intermediate levels. The subsamples were treated using a modified Erdtman method: 10 % hydrochloric acid (HCl), 10 % potassium hydroxyde (KOH), 48 % hydrofluoric acid (HF), 50 % HCl, 10 % KOH and acetolysis (sulphuric acid and acetic anhydride) (Faegri *et al.*, 1989). The residues were mounted and counted in silicone oil. Pollen percentages were calculated on a sum excluding hydrophylous taxa and Pteridophyta (Berglund and Ralska-Jasiewiczowa, 1986). As seen in the pollen profile, the pollen sum used for percentage calculations approached or exceeded 500 grains except in the lower less organic sediments where the sum ranged between 200 and 300 grains. In the lowest sample in laminated clay, less than 100 grains were counted. Determination of pollen concentrations followed the method developed by Benninghoff (1962), using the pollen of *Eucalyptus globulus.*

Preparations were counted at a magnification of 400X and increased to 640X to help with difficult identifications. Results of pollen analysis were recorded using the TILIA spreadsheet and the pollen diagram was created using TILIA*GRAPH (E.C. Grimm, Illinois State Museum, Springfield, Illinois).

To simplify the pollen diagram, small counts of various taxa were grouped as “Other thermophilous trees”, “Other shrubs” and “Other herbs”. The Lycopodiaceae column combines various *Lycopodium* species; Pteridophyta includes all fern taxa except *Sphagnum*, and the aquatics column combines all hydrophylous taxa. Lithology is based on visual appearance and properties of the sediments.

PALEOCLIMATIC RECONSTRUCTION

Paleoclimatic reconstruction was derived using a multivariate analysis method. This method, fully described by Guiot (1990), provides a climatic reconstruction using the best modern analogs closest to fossil values.

The method has been adapted to the Canadian context by integrating information from more than 1 100 Canadian modern surface samples and 1 200 meteorological stations. Meteorological data used to link modern vegetation to climate are mean July and mean January temperatures and total annual precipitation, as average values compiled for the last 35 years. In order to offer all possible scenarios for the reconstruction, the complete Canadian dataset was used to provide modern analogs representative of a broad range of climatic domains: wet cold, wet warm, humid cold and humid warm. Forty different taxa covering all vegetation domains were used. Total annual precipitation provides a record of the availability of moisture in the system. It is indirectly linked with fluctuations in the groundwater level.

RESULTS

SEDIMENTS

The sequence is described as follows: algal gyttja from the surface to a depth of 400 cm; finely laminated dark gyttja from 400 to 508 cm; light calcareous laminated gyttja from 508 to 531 cm; finely laminated dark gyttja from 531 to 642 cm; organic silty clay from 642 to 660 cm; and grey laminated clay from 660 to 750 cm.

RADIOCARBON DATING

Dating was done by conventional methodology at the Geological Survey of Canada and accelerator mass spectrometry (AMS) at Beta Analytic (Florida). The dates are listed in Table I. There is a discrepancy between two dates from the base of Island Lake. One dates the maximum in willow *(Salix)* (9920 ± 60 BP; Beta-70672 on willow twigs at 650 cm), and the other dates the maximum of poplar/aspen *(Populus)* (GSC-2748; 12 300 ± 210 BP on lake sediment from 633 to 638 cm). At Lac à Raymond (Table I), on the north shore of Baie des Chaleurs, a maximum in willow *(Salix)* pollen at the base of the sequence was dated at 12 000 ± 240 BP by conventional dating on gyttja (GSC-4922) (Jetté and Richard, 1992). It was also dated at 10 150 BP (TO-1613) by the AMS methodology on willow twigs. The discrepancy between the AMS date on terrestrial remains and the conventional date on gyttja was attributed, at that lake, to "hard-water effect" common in recently deglaciated terrain.

The date of the willow *(Salix)* maximum at Island Lake (9920 ± 60 BP; Beta-70672) is in agreement with the date of the willow maximum at Lac à Raymond (10 150 ± 220 BP; TO-1613). This is to be expected for two lakes located on the south and north shores of the same bay because willow has light fluffy seeds that are easily dispersed.

The date of 12 300 ± 210 BP (GSC-2748) for the poplar-aspen *(Populus)* maximum at the base of Island Lake is considered to be anomalous and a discrepancy of more than 2300 years can be attributed to hard-water error.

The date of 8650 ± 100 BP at level 495 to 505 cm of Island Lake could also be too old. Presence of carbonate-bearing sediment has been detected at 465 cm, above the level dated. This date was not used for the determination of sedimentation rates for the base of the sequence.

The chronology of events is calculated by applying a linear sedimentation rate of 0.078 cm/yr determined between the date of 5940 BP (340 cm) and the date of 9920 BP (650 cm) and 0.057 cm/yr for the last 5940 years.

PALYNOLOGICAL ANALYSIS

Results from the pollen analysis are presented as a pollen diagram (Fig. 2). The pollen sequence has been divided visually into 8 pollen zones. Zone 1 (735 to 657.5 cm), zone 2 (657.5 to 637.5 cm), zone 3 (637.5 to 627.5 cm), zone 4 (627.5 to 610 cm), zone 5 (610 to 580 cm), zone 6 (580 to 470 cm), zone 7 (470 to 150 cm) and zone 8 (150 cm to the present). Zone 6 has been divided into 3 subzones to illustrate brief but important changes in vegetation succession. Some of the zones are short-lived indicating high rates of change, especially for the basal part of the sequence. The zones are well-defined and represent specific stages in the vegetation succession of the area.

Zone 1 (735 to 657.5 cm; before 10 150 BP). Herb pollen zone. Brownish grey clay and laminated clay.

High levels of *Oxyria digyna*, *Artemisia* (sage) and Cyperaceae (sedges) characterize this interval. Other herbs such as Caryophyllaceae, Chenopodiaceae, Tubuliflorae and

TABLE 1

Radiocarbon dates

Depth (cm)	Material	Laboratory number	Delta ^{13}C	Corrected date (BP)
Island Lake, south shore of Baie des Chaleurs				
337-343	Lake sediment	GSC-5620	-29.9	5940 ± 110
495-505	Lake sediment	GSC-3492	-27.5	8650 ± 100[1]
633-638	Lake sediment	GSC-2748	-33.5	12 300 ± 210[1]
650	Salix remains	Beta-70672[2]	-28.5	9920 ± 60
Lac à Raymond, north shore of Baie des Chaleurs				
1030-1032	Salix sp.	TO-1613[2]	-29.4	10 150 ± 220
1026-1032	Lake sediment	GSC-4922		12 000 ± 240[1]

[1] Dates suspected to be anomalous
[2] AMS dates

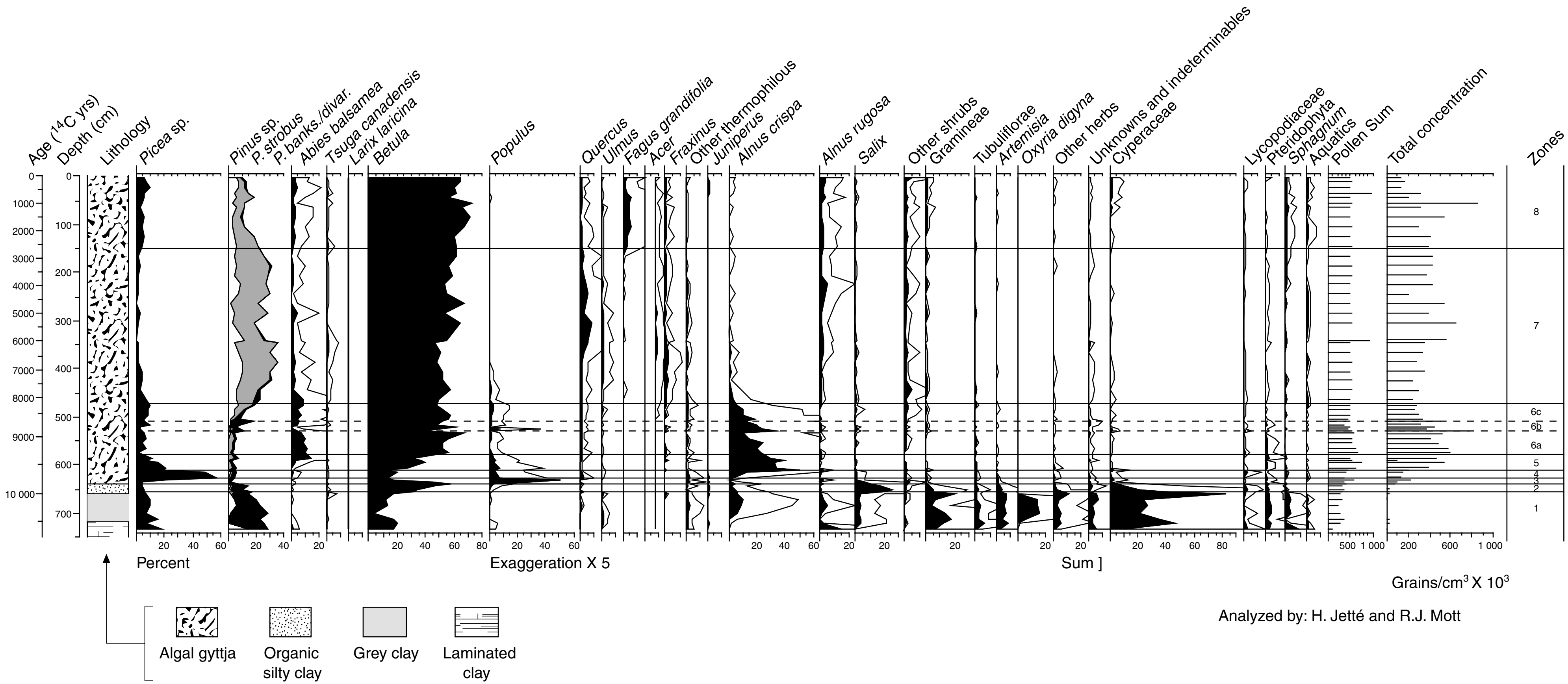


Figure 2. Island Lake, New Brunswick pollen diagram.

Diagramme pollinique, lac Island, Nouveau-Brunswick.

grasses are present with some shrubs such as willow *(Salix)* and alder *(Alnus).* Pollen concentrations are low, less than 20 000 grains/cm^3.

Tree pollen of *Picea* and *Pinus* (spruce and pine) present in the basal part of the zone are attributed to long-distance transport. Higher in the sequence, the representation of herbs and shrubs increases and the long-distance transport component becomes gradually less important.

The assemblage is characteristic of arctic-alpine environments. The best modern analogs for this type of assemblage are found today in the herb tundra assemblages of Victoria and Banks Islands in the Canadian Arctic. The inferred mean July temperatures are between 7 to 9 °C and the inferred mean January temperature is -23.8 and -32 °C. Dry conditions (precipitation of about 150 to 266 mm/yr) prevailed. The climate was dry and cold. The values for the basal sample are too anomalous to be considered.

Zone 2 (657.5 to 637.5 cm; *ca*. 10 150 to 9920 ± 60 BP) Shrub pollen zone. Dark grey organic silty clay.

The *Betula* (birch), *Salix* (willow) and Cyperaceae pollen assemblage zone is a well defined level rich in shrubs such as *Salix*, *Betula* and *Alnus* (alder). Herbs (sedges, grasses and *Artemisia*) are still present. *Rumex, Thalictrum,* Urticaceae and other herbs reach their maximum values in this zone. Pollen concentration is low at 655 cm (35 000 grains/cm^3) but rises gradually to 90 000 grains/cm^3.

Zone 2 is interpreted as a shrub tundra assemblage with a well defined peak of *Salix* at 650 cm. Modern analogs for these assemblages are found in the shrub tundra of the Yukon and northern Québec. Mean July temperatures of 9 to 11.5 °C and mean January temperature of -23.7 to -30.6 °C are inferred for this zone. Precipitation is still low but slightly higher (185 to 450 mm/yr) than for the previous zone.

Zone 3 (637.5 to 627.5 cm; *ca*. 9920 to 9820 BP) *Populus* (poplar/aspen) pollen assemblage zone (Pioneer forest). Dark brown to black gyttja.

Zone 3 is characterized by the sudden disappearance of herbs and shrubs and by high values (more than 50 %) of *Populus*. Some *Betula* (birch), *Picea* (spruce) and *Juniperus* (juniper) pollen grains are also present. Pollen concentrations double between 635 cm (90 000 grains/cm^3) and 630 cm (220 000 grains/cm^3), during the *Populus* maximum.

This assemblage characterizes an open pioneer forest of poplar/aspen. Poplar and aspen produce seeds that are easily disseminated by wind or water and these species can spread rapidly in the absence of competition. The poplar/aspen stage was probably very short-lived. No close modern analog exists for this type of forest; the best modern analogs found are from northern Québec (Poste-de-la-Baleine in 1964, but now Kuujjarapik/Whapmagoostui) and from the Yukon Territory. The mean July temperatures inferred vary from 12 to 15 °C and the mean January temperatures vary from -22 to -26 °C while the inferred annual precipitation varies from 300 to 800 mm/yr. The reconstruction suggests cold wet (Québec, close to James Bay) and cold dry (Yukon) assemblages. Because the general trend of the precipitation curve is rising, the cold and wet reconstruction is favoured.

Zone 4 (627.5 to 610 cm; *ca*. 9820 to 9700 BP). *Picea* (spruce) pollen assemblage zone (Pioneer forest). Dark grey to black gyttja.

Dramatic diminution of *Populus* (Poplar/aspen) and replacement by *Picea* pollen (55 %) characterizes this zone. Some birch *(Betula)* and alder *(Alnus)* were present in the landscape. Pollen concentration reaches 130 000 grains/cm^3.

Due probably to interspecific competition, an open forest of spruce rapidly replaced the pioneer forest of poplar/aspen. The open spruce forest also contains some birch and alder. Poplar/aspen was still present, suggesting open or disturbed forest. Modern analogs for this type of forest are found in the open spruce forest around Lac Delorme area, Nouveau-Québec, and in eastern Labrador.

Inferred mean July temperatures are 13.5 and 14.6 °C while mean January temperature is -20 °C for Island Lake at that time. Inferred mean annual precipitation is 800 and 1 015 mm/yr.

Zone 5 (610 to 580 cm; *ca*. 9700 to 9450 BP). Picea (spruce), *Betula* (birch) and *Alnus* (alder) pollen assemblage zone. (Open northern boreal forest). Black, finely laminated algal gyttja.

Alnus crispa (33 %), *Betula* (30 %), some *Picea* (20 %) and *Abies* (fir) (2 %) characterize this interval. Pollen concentration reaches 550 000 grains/cm^3. Alder, birch, spruce and fir dominated a boreal forest at this time. The high pollen concentrations found at this level indicate a more closed forest but with open areas of green alder. The best modern analogs found for the fossil assemblage are reported in the Sept-Îles area, north shore of St. Lawrence River, Québec, and in the Norman Wells area, Northwest Territories.

The inferred mean July temperatures are 15.7 and 16.9 °C, the mean January temperatures are -21 and -13 °C, and the mean annual precipitation rises from 832 to 1 125 mm/yr.

Zone 6 (580 to 470 cm; *ca*. 9450 to 8100 BP). *Betula* (birch), *Alnus* (alder) and *Abies* (fir) pollen assemblage zone (boreal forest).

High levels of *Alnus crispa, Abies* and *Betula* pollen dominate Zone 6. *Populus* is still present. Pollen concentrations oscillate between 400 000 and 500 000 grains/cm^3. Three subzones (6a, 6b and 6c) have been defined within the zone to highlight three different vegetation successions at the site.

Subzone 6a (580 to 531 cm; ca. *9450 to* ca. *8500 BP).* Betula*,* Alnus*, and* Abies *assemblages (boreal forest). Soft, black gyttja.* The representation of *Alnus* and *Abies* increases dramatically while *Picea* and *Populus* decline. Pollen concentrations vary from 400 000 to 500 000 grains/cm^3. This mixed forest assemblage indicates a cold and humid boreal forest of fir, birch and alder. The best modern analogs found are from northern Québec.

Climatically, this subzone is characterized by a marked decline of the mean July temperature from the previous level (16.9 °C) to as low as 14.6 °C. Mean January temperature also declines suddenly from -12 °C to -16.8 °C while the annual precipitation increases dramatically to 1 370 mm/yr.

Subzone 6b (531 to 508 cm; from ca. *8500 to* ca. *8400 BP).* Alnus *and* Betula *assemblages with increased amounts of* Betula, Alnus, Populus *and* Pinus *(pine).* A short-lived reversal to drier conditions is noted. This is seen as a decline of fir and an increase in alder, poplar/aspen and jack pine *(Pinus banksiana/divaricata).* A sediment change from dark gyttja to light laminated gyttja between 508 and 531 cm parallels this change. According to sedimentation rates, this interval lasted only a century, and the drier conditions and sediment change may have lowered water levels in the lake.

Climate was warmer and drier and, for the first time in the sequence, the best modern analog is found in New Brunswick. During that time *(ca.* 8400 to *ca.* 8100 BP), mean July and mean January temperatures rose to 18 and -11.8 °C, respectively, warmer than the present in this area, while annual precipitation declined to as low as 1 048 mm/yr.

Subzone 6c (508 to 470 cm; from ca. *8400 to* ca. *8100 BP).* Alnus, Abies *and* Betula *assemblages. Soft, black gyttja*. *Pinus* and *Populus* diminish while *Alnus* and *Abies* increase. *Betula* is still an important component. This assemblage indicates a cold and humid boreal forest of fir, birch and alder. The best modern analogs are from Québec. This is a reversal to conditions similar to those in place during subzone 6a.

Climatically, this subzone is characterized by a decline of the mean July temperature from the previous subzone (18 °C) to between 16.4 and 17.4 °C. Mean January temperatures also decline from -12.3 °C to -14.9 °C while the annual precipitation increases slightly (between 1 036 and 1 147 mm/yr).

Zone 7 (470 to 150 cm; ca. 8100 to ca. 2800 BP). *Pinus*, *Betula* and thermophilous taxa pollen assemblage zone (mixed coniferous-deciduous forest).

Black to dark brown, soft, algal gyttja of this zone is characterized by relatively high values of *Pinus* (pine), mainly *Pinus strobus* (white pine type), *Betula* (birch) and various thermophilous species such as *Tsuga* (hemlock), *Quercus* (oak), *Ulmus* (elm) and a variety of *Acer* (maple) taxa. Some *Alnus* (alder) is still present. Pollen concentrations vary between 200 000 and 600 000 grains/cm^3.

These assemblages can be found today in mixed coniferous-deciduous forests of New Brunswick and southern Québec. Early in the zone, the presence of white pine and other thermophilous taxa indicate conditions that were warmer than the present in the area. The gradual decline of these thermophilous taxa, from the base to the top of this zone, is indicative of a cooling trend.

At the base of the zone, the inferred climate shows a maximum in the mean July temperature of 18.2 °C and a minimum in the mean January temperature of -11.5 °C. These values gradually decline with time. The mean January temperature decline of 2.2 °C is more pronounced than the mean July temperature decline of 0.8 °C for that length of time. This period is also characterized by the lowest values in annual precipitation with minimal lows at 5940 BP and *ca.* 3000 years ago.

Zone 8 (150 cm to 0 cm; from ca. 2800 BP to the present). *Betula* (birch) and *Fagus* (beech) pollen assemblage zone (Mixed deciduous-coniferous forest).

Dark brown algal gyttja with some plant detritus characterizes this zone. High values of *Betula* (birch), some *Abies* (fir), some *Picea* (spruce) and *Fagus* (beech) characterize this zone. *Pinus* representation continues to decline while *Picea* and *Abies* increase regularly. This trend is also highlighted by the decline of various thermophilous taxa such as *Quercus*, *Ulmus*, *Fraxinus* and *Tsuga*. The arrival of beech in the area reflects the slow migration rate of this species.

The general trend for this zone is a gradual cooling but variable. There is in excess of a 1 °C variation for mean January temperature and a variability of more than 1.0 °C cooling for the mean July temperature from the beginning to the end of the zone.

PALEOCLIMATIC RECONSTRUCTION

Table II presents the results of the paleoclimatic reconstruction with information on the modern pollen analogs used as reference data. Figures 3A and 3B present the climatic curves (mean July temperature, mean January temperature and annual precipitation) inferred from transfer functions using the link between pollen assemblages and climate. The curves are presented in relation to pollen zonation, regional chronology and vegetation reconstruction.

The column Dmin in Table II reports the mathematical distance compiled between the modern analog and the fossil spectrum. Distances less than 50 are considered satisfactory while distances greater than 50 must be interpreted cautiously. All reconstructions below 630 cm (Zones 1-3) show a Dmin greater than 50, indicating a large mathematical distance between the fossil spectra and the modern analogs. This is typical of postglacial fossil assemblages for which no modern pollen analog exists today. Species, at that time, were migrating north following ice retreat, each species migrating at its own rate and, due to these different rates of migration, reached northern New Brunswick at different times. Therefore, there was a time lag between ice retreat and the time when all the species were present in the landscape. In northern New Brunswick, this lag would cover from deglaciation to approximately 9500 BP. From that time to the present, the main vegetation components were in place and pollen assemblages can be used to reconstruct the main elements of climate. This corresponds with the interval having Dmin values less than 50. The analogs are found either in New Brunswick, in Gaspésie, or elsewhere in Québec, giving a stable climate close to the

TABLE II

Paleoclimate reconstruction with climate data for modern pollen analogs

Depth (cm)	Tjal (°C)	Tjan (°C)	Tjau (°C)	Tjul (°C)	Tjul-1 (°C)	Tjuu (°C)	Ptol (mm)	Ptot (mm)	Ptou (mm)	Dmin	ANLG	Long. (°W)	Lat. (°N)	Code	Name	Location
3	-14.87	-13.68	-13.47	16.54	17.14	17.30	1 061.80	1 079.20	1 254.82	33	C526	-66.18	47.83	MS-78-12	Island L.	Northern NB
13	-15.90	-14.21	-14.06	16.59	16.80	17.24	1 072.38	1 086.34	1 271.30	34	C107	-67.26	48.44	-	Lavoie 1	Gaspé, QC
23	-13.94	-12.40	-11.11	16.94	17.69	18.34	1 044.95	1 059.03	1 086.42	36	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
35	-13.22	-12.46	-11.11	17.36	17.70	18.34	1 036.29	1 055.40	1 077.81	35	C526	-66.18	47.83	MS-78-12	Island L.	Northern NB
45	-12.73	-11.34	-11.04	17.58	18.22	18.33	1 039.48	1 043.40	1 057.25	24	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
55	-13.51	-13.23	-10.14	17.05	17.27	17.34	1 060.09	1 102.65	1 279.20	36	C526	-66.18	47.83	MS-78-12	Island L.	Northern NB
65	-15.28	-14.59	-13.22	16.45	16.75	17.31	1 089.00	1 185.04	1 262.89	39	C111	-71.42	47.08	MARC	Marcotte L.	Gaspé, QC
85	-14.43	-13.16	-12.89	17.13	17.74	17.84	1 064.09	1 076.69	1 195.85	47	C536	-66.60	47.92	MS-77-9	Sharp L.	Northern NB
105	-13.97	-13.43	-13.17	17.31	17.36	17.90	1 032.52	1 061.11	1 064.48	37	C526	-66.18	47.83	MS-78-12	Island L.	Northern NB
125	-14.03	-13.57	-13.21	17.27	17.35	17.46	1 024.20	1 052.93	1 076.09	37	C526	-66.18	47.83	MS-78-12	Island L.	Northern NB
145	-13.78	-11.63	-11.01	17.39	18.15	18.32	1 035.76	1 040.37	1 095.53	27	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
165	-13.92	-13.73	-11.39	17.48	17.56	18.12	930.88	961.71	1 045.85	43	C077	-78.50	46.54	–	CGC-41	Outaoutais, QC
185	-13.96	-13.79	-11.47	17.45	17.50	18.29	890.84	1 010.41	1 033.31	32	C115	-68.94	47.54	–	Ouel L.	Gaspé, QC
205	-13.91	-13.84	-12.86	17.46	17.49	17.97	1 007.67	1 033.98	1 185.18	40	C115	-68.94	47.54	–	Ouel L.	Gaspé, QC
225	-14.01	-13.96	-13.67	17.13	17.42	17.52	982.89	1 031.47	1 023.23	42	C077	-78.50	46.54	–	CGC-41	Rimouski, QC
245	-13.97	-13.70	-11.13	17.43	17.51	18.32	941.50	1 013.91	1 035.03	49	C116	-68.94	47.54	–	Ouel, L.	Gaspé, QC
265	-13.80	-13.56	-12.82	17.31	17.38	17.54	915.24	1 037.45	1 042.47	48	C526	-66.18	47.83	MS-78-12	Island L.	Northern NB
285	-13.99	-13.85	-12.38	17.24	17.46	17.60	936.71	971.44	1 092.16	48	C077	-78.50	46.54	–	CGC-41	Outaouais, QC
305	-13.61	-13.20	-9.57	17.03	17.32	17.36	1 027.26	1 064.50	1 351.11	67	C526	-66.18	47.83	MS-78-12	Island L.	Northern NB
340	-14.00	-13.84	-12.95	17.49	17.52	18.00	953.79	974.34	1 109.57	40	C077	-78.50	46.54	–	CGC-41	Outaouais, QC
345	-13.86	-13.43	-13.20	17.53	18.02	18.28	957.80	964.37	1 012.90	31	C708	-79.47	46.45	–	Frair L.	Northeastern ON
365	-13.99	-13.73	-13.19	17.47	17.73	18.01	952.67	965.24	1 120.18	46	C077	-78.50	46.54	–	CGC-41	Outaouais, QC
385	-13.74	-12.27	-10.92	17.56	18.03	18.34	971.02	1 014.03	1 039.89	49	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
405	-13.96	-13.45	-11.92	17.35	17.65	18.10	992.74	1 024.77	1 029.63	33	C116	-68.94	47.54	–	Ouel L.	Gaspé, QC
425	-13.62	-12.16	-10.98	17.45	17.97	18.32	1 025.91	1 033.96	1 043.19	36	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
445	-13.73	-11.69	-11.38	17.76	18.14	18.37	923.53	1 032.66	1 040.24	44	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
465	-13.61	-11.52	-11.17	17.39	18.18	18.31	1 044.71	1 063.76	1 198.21	48	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
475	-17.10	-14.93	-11.46	16.75	17.35	18.24	1 037.90	1 047.07	1 068.73	48	C092	-71.22	48.23	–	Flevy L.	L. St. Jean, QC
485	-17.54	-14.64	-14.24	16.59	17.22	17.27	1 031.08	1 036.46	1 056.04	46	C090	-70.62	47.61	–	Espoir L.	Rimouski, QC
495	-14.42	-14.26	-12.67	16.80	17.22	17.33	1 045.70	1 144.83	1 232.73	41	C851	-71.42	47.07	–	–	Northern QC
505	-14.26	-12.34	-10.84	15.64	16.44	17.27	1 058.88	1 089.42	1 219.31	46	C416	-57.57	49.37	–	–	Nfld
515	-13.91	-11.76	-11.32	16.70	17.66	18.34	978.58	1 105.75	1 115.27	50	C528	-67.63	46.58	MS-77-18	Mouse L.	NB
525	-13.91	-11.38	-11.19	17.29	18.17	18.34	1 042.34	1 048.41	1 117.87	51	C539	-65.77	47.50	MS-77-12	Papineau L.	Northern NB
530	-19.70	-16.03	-11.83	14.38	15.87	17.80	1 046.65	1 167.16	1 264.05	71	C867	-71.25	47.55	–	–	QC
535	-14.47	-13.23	-10.75	15.38	17.11	17.30	1 022.52	1 041.91	1 273.11	42	C897	-67.47	48.45	–	–	Gaspé, QC
545	-13.79	-12.03	-9.93	15.54	16.35	16.97	1 053.17	1 067.12	1 155.20	44	C416	-57.57	49.37	–	–	Nfld
555	-17.25	-15.21	-11.63	14.15	15.06	16.23	1 055.32	1 245.39	1 395.40	61	C855	-71.20	47.25	–	–	Northern QC
565	-17.92	-16.63	-14.38	14.47	14.68	16.35	1 068.54	1 313.86	1 337.39	39	C855	-71.20	47.25	–	–	Northern QC
575	-17.30	-16.78	-10.98	14.33	14.56	17.03	1 274.00	1 371.37	1 404.40	61	C855	-71.20	47.25	–	–	Northern QC
585	-14.40	-8.67	-7.68	15.40	15.68	17.13	1 038.37	1 124.59	1 138.01	49	C418	-57.60	50.22	–	–	Nfld
595	-13.39	-12.13	-7.60	15.89	16.97	17.14	995.11	1 066.57	1 247.90	40	C266	-67.12	50.13	Sept Iles	LD L.	Sept-Îles, QC
605	-25.91	-20.74	-16.98	15.12	16.19	17.31	397.23	832.42	1 061.85	48	C941	-68.82	50.37	–	–	Northern QC
615	-24.81	-20.03	-18.87	12.98	13.49	17.35	365.30	804.47	938.46	44	C435	-57.97	52.57	–	–	NL
625	-20.95	-19.62	-19.55	13.61	14.59	14.71	854.40	1 014.97	1 026.07	46	C203	-69.92	54.42	Delorme	L. Delorme II	Northern QC
630	-25.89	-22.41	-21.78	11.54	12.15	16.82	480.41	790.73	841.52	83	C176	-77.70	55.30	–	PBO6	James Bay, QC
635	-26.21	-25.90	-24.10	14.71	14.85	15.32	302.76	306.32	343.29	104	C314	-135.68	62.72	PL-92-182	–	YT
640	-27.56	-23.82	-23.27	7.76	8.50	11.36	273.32	304.33	613.63	90	C153	-74.95	59.16	–	LTO3	Northern QC
645	-27.38	-23.70	-23.31	8.24	10.12	11.02	254.42	450.27	601.98	111	C149	-75.25	58.58	–	LRO1	Northern QC
650	-27.93	-26.43	-23.27	10.42	11.52	12.32	198.31	285.48	527.06	133	C335	-132.07	69.58	PL-93-22	–	YT
655	-31.10	-30.65	-27.02	9.68	9.86	11.89	175.12	184.61	279.93	93	VC369	-107.85	69.05	PL-93-74	–	Victoria Is., NU
660	-32.15	-31.95	-30.76	8.83	8.93	9.86	168.63	169.18	191.15	92	C373	-106.35	70.53	PL-93-80	–	Victoria Is., NU
670	-29.50	-29.16	-28.05	7.05	7.15	8.42	147.21	162.97	166.78	117	C383	-117.55	73.03	MS-74-13	–	Banks Is., NT
685	-29.30	-23.78	-20.00	7.12	7.68	8.37	164.23	266.20	372.07	200	C080	-73.68	61.29	–	CNQ	Northern QC
700	-29.17	-28.64	-21.01	7.02	7.20	8.35	164.31	174.13	299.06	142	C383	-117.55	73.03	MS-74-13	–	Banks Is., NT
712	-31.13	-29.44	-29.13	7.01	7.78	10.58	152.66	156.64	213.20	147	C365	-124.27	71.75	MS-74-11	–	Banks Is., NT
720	-31.10	-29.50	-28.83	7.27	7.46	9.68	150.88	152.69	174.06	159	C365	-124.27	71.75	MS-74-11	–	Banks Is., NT
735	-24.65	-22.32	-22.25	12.76	13.07	14.82	261.93	788.97	837.85	98	C194	-67.40	55.25	Boundary	Boundary L.	Northern QC

Depth – Depth in cm of Island Lake core; Tjal - January lower temperature; Tjan – Average January temperature; Tjau – January upper temperature; Tjul – July lower temperature; Tjul-1 – Average July temperature; Tjuu – July upper temperature; Ptol – Annual precipitation lower value; Ptot – Total average annual precipitation; Annual precipitation upper value; Ptou – Annual precipitation upper value; Dmin – Calculated mathematical distance; ANLG – Analog site from data base; Long. – Longitude of analog site; Lat. – Latitude of analog site; Code – Field reference number if any; Name – Name of the analog site if any; Location – General location of the analog site (NB: New Brunswick; Nfld: Newfoundland; NL: Newfoundland and Labrador; ON: Ontario; QC: Québec; NT: Northwest Territories; NU: Nunavut; YT: Yukon Territory).

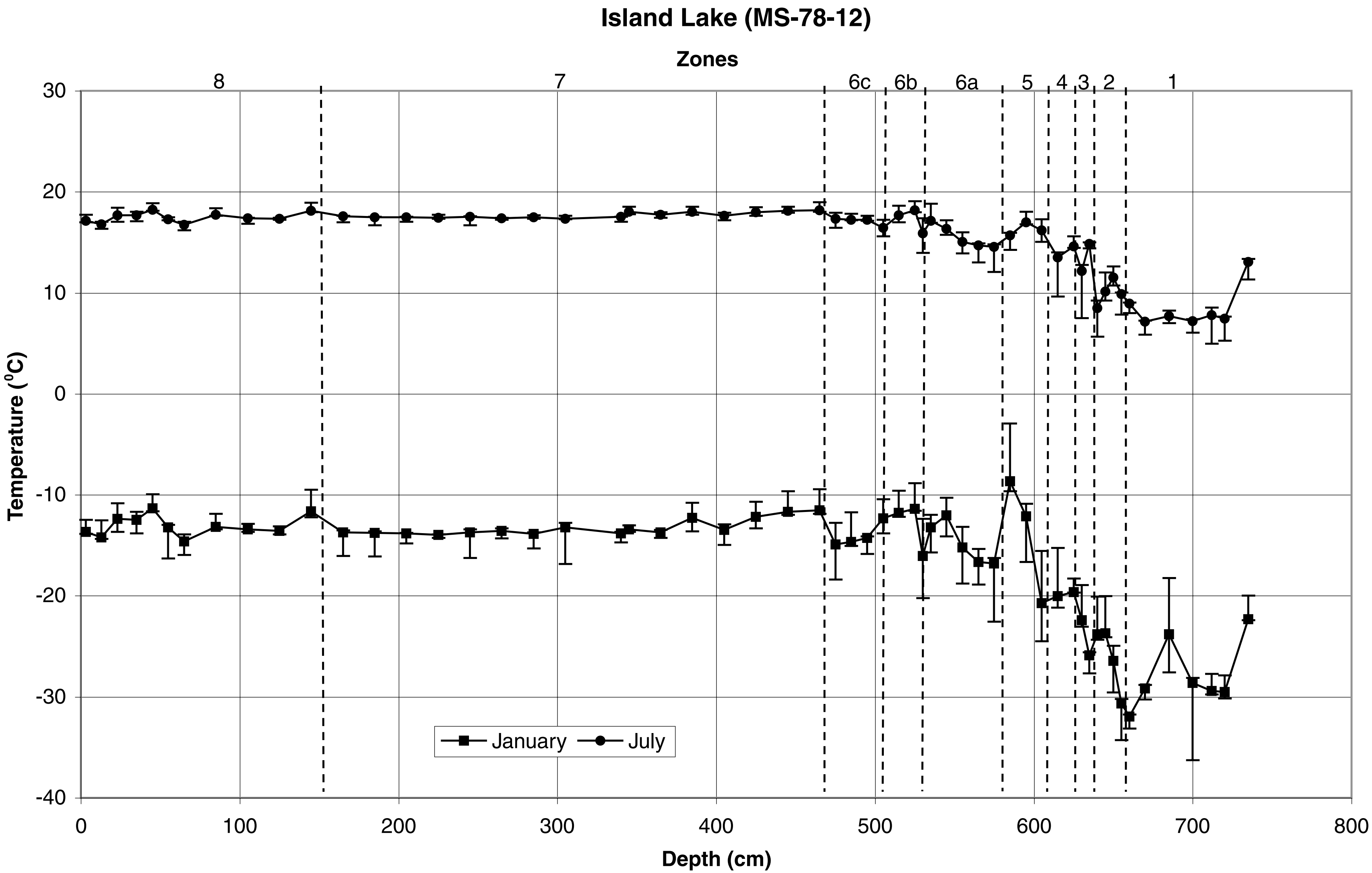


Figure 3A. Island Lake core temperature reconstruction.

Reconstitution du profil des températures au lac Island, Nouveau-Brunswick.

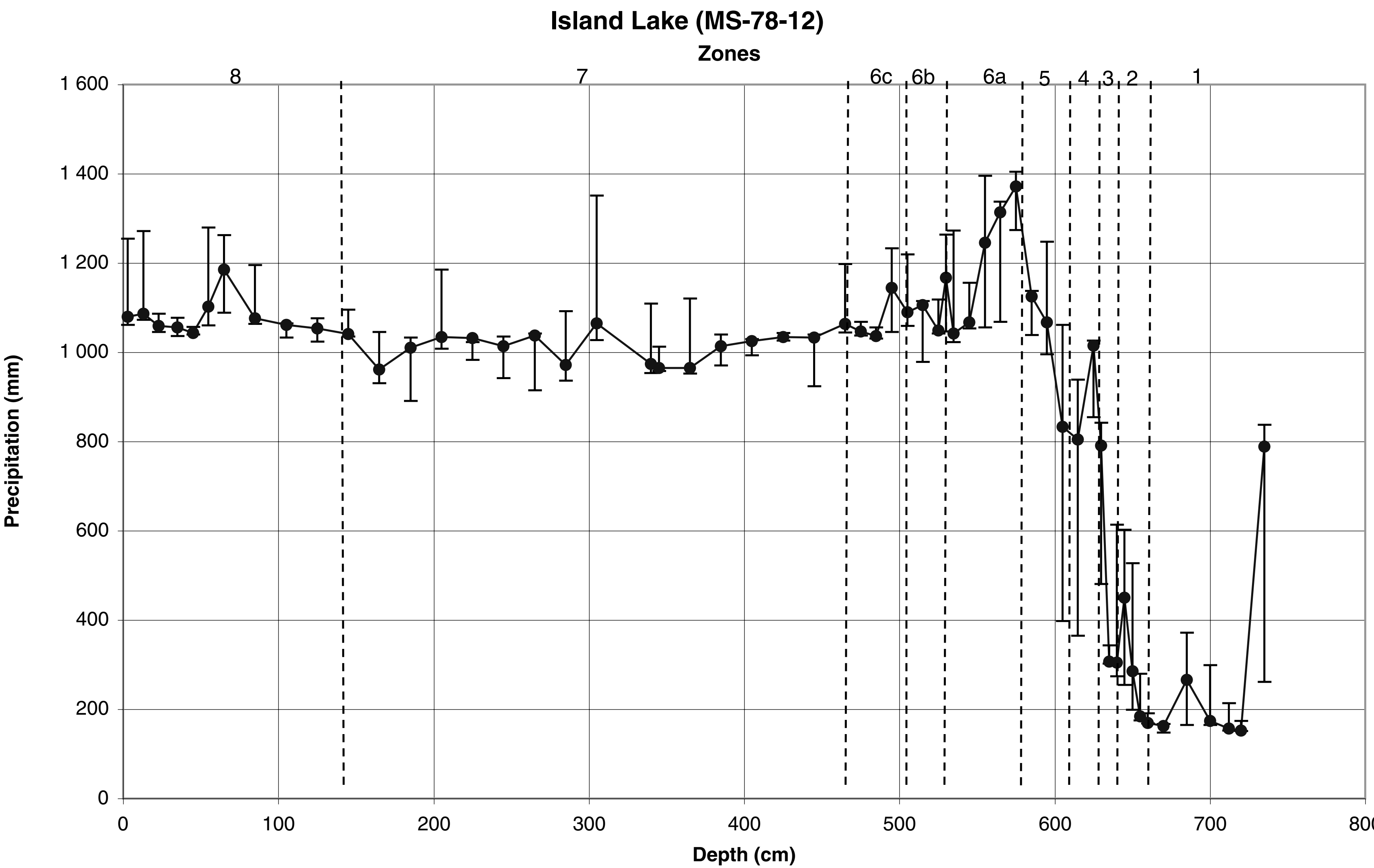


Figure 3B. Island Lake precipitation reconstruction.

Reconstitution du profil des précipitations au lac Island, Nouveau-Brunswick.

modern one. The exception is zone 6 (between 9500 and 8100 BP) where for some levels of this zone (515-530, 555, 575-585 cm), the distance is often close to 50 and sometimes larger. This lack of good analogs could be responsible for the variability of precipitation and temperature for January, July remaining more stable. Levels 245-305 cm in zone 7 are also characterized by large distances, but their climate estimates are not significantly different from the previous and following levels, making them more realistic.

DISCUSSION

Following deglaciation, herb tundra colonized the area surrounding Island Lake. No reliable basal date has been obtained for this event. However, lake sites located in west central New Brunswick record a warm interval dating about 11 100 BP succeeded by a cold interval between approximately 11 000 and 10 000 BP (Mott *et al.,* 1986; Mayle *et al.*, 1993; Mayle and Cwynar, 1995) that is not seen at Island Lake. This would suggest that the onset of organic sedimentation at this lake started just prior to 10 000 BP. The climate was cold and dry. Sedges (Cyperaceae), grasses (Poaceae) and herbaceous plants were characteristic of the area. By 9920 ± 60 BP, shrub tundra dominated by willow (*Salix*) and birch (*Betula*), probably shrub birch, colonized the area when the climate was still cold and dry.

From about 9900 to 9800 BP poplar/aspen (*Populus*) colonized the area as a pioneer species. Temperature and precipitation rose gradually. Around 9700 BP, spruce (*Picea*) replaced poplar/aspen as the dominant tree type, probably as a result of interspecific competition. Poplar/aspen needs open space with maximum exposure to light and does not tolerate competition.

From 9700 to 9450 BP, a boreal forest of spruce, alder (*Alnus*), fir (*Abies*) and birch (*Betula*) occupied the landscape. The climatic reconstruction shows a gradual rise in mean July and January temperatures up to values of 16.9 and -8.7 °C, respectively. During this period, the mean January temperature switched suddenly from -20.7 to -8.7 °C. This is tentatively associated with the final disappearance of regional ice on the plateau of northern New Brunswick and on the Gaspé Peninsula (Richard *et al.,* 1992, 1997).

At 9450 BP, there was an abrupt local climatic deterioration. The vegetation cover changed from a boreal forest of alder, fir, birch and spruce to a forest of fir and alder. Mean July and mean January temperatures dropped significantly and the annual precipitation curve records a dramatic increase. The timing of this event can be linked with the discharge, into the Great Lakes and Goldthwait Sea, of cold water from glacial Lakes Agassiz and Barlow-Ojibway into the Gulf of St. Lawrence (Anderson and Lewis, 1992). Although cold water conditions are reported in the Gulf of St. Lawrence during the Younger Dryas cold event, there is little evidence of cold water influx from glacial lake after 10 000 BP (de Vernal *et al.*, 1993). However, close examination of the inferred temperature at one site in Cabot Strait reported by de Vernal *et al.* (1993) does show a slight cooling coincident with the time of glacial lake water influx reported by Anderson and Lewis (1992). The proximity to a large and colder body of water in the southern Gulf and Baie des Chaleurs, was probably sufficient to change the vegetation composition of the area surrounding Island Lake, and to induce a lowering of the temperature of the warmer and the colder months by 2 and 3 °C, respectively. Sea level was probably closer to the study site than at present because the land was still isostatically depressed. The proximity of cold water with warm air created foggy conditions that favoured alder and fir. This is detected and translated by the multivariate analysis as an increase in annual precipitation.

This perturbation is well defined in the earlier part of the discharge, from about 9450 to 8500 BP and ceases for a century, from about 8500 to about 8400 BP. During this period, the vegetation composition reversed in response to warmer and drier conditions. Climatic reconstruction indicates high values of 18 °C and -11.8 °C for mean July and January temperatures, respectively, and lower values for annual precipitation. Possibly the cooling effect of cold water in the Baie des Chaleurs ceased during a period that seems to have lasted about 100 years (according to rates of sedimentation determined by the local chronology). A sedimentological change from soft black gyttja to dense brown gyttja seems to indicate that the groundwater level was lower than before at the site during that period. For this short interval in the order of 100 years, cold water may not have reached Baie des Chaleurs, and the baie was at a low stand due to the interplay between isostatic rebound and eustatic sea-level rise.

According to Syvitsky (1992), sea level was at a low stand of -90 m in Baie des Chaleurs. Based on the interpolation of the isostatic-rebound rates of Gray (1987), Shaw *et al.* (2002) estimated that the low stand occurred at about 9000 BP. According to this study, the low sea-level stand in Baie des Chaleurs occurred about 8500-8400 BP. However, this is an interpolated age. Because of the lack of precise chronology, the length of this interval is speculative. Four sites from the Gaspé Peninsula just north of the Baie des Chaleurs reported by Jetté and Richard (1992) show similar sequences of events following the basal assemblages dominated by herbaceous taxa. Successive peaks in *Salix* (willow), *Betula* (birch) and *Picea* (spruce) pollen are followed by an interval dominated by *Alnus crispa* (green alder) pollen. Unfortunately, the lack of sufficient detail in the pollen profiles and imprecise chronology preclude identifying the equivalent of Zone 6b in these profiles.

By 8400 BP, the vegetation surrounding Island Lake reflected the cooling effect of a large body of cold water in Baie des Chaleurs that lasted until 8100 BP. The study site was closer to the sea than today and the vegetation record indicates that the climate was more humid possibly as a result of widespread foggy conditions around the bay.

This demonstrates the close interaction between the land and large bodies of water and the strong effect of the presence of cold water on the vegetation. This is more apparent in the mean January temperature profile (2 °C lower) than the mean July temperature profile (1 °C lower).

From 8100 BP to the present, the vegetation responded to changes in regional climate. Temperature decreased gradually with time with a possible recess *ca.* 1200 years ago when a slight warming is recorded for both the mean July and January temperatures (18.1 °C and -13.1 °C), as compared with present values.

The total precipitation curve for this site demonstrates that the mid-Holocene, from about 8100 to 2800 BP, was characterized by the driest conditions for the last 10 000 years. This condition, culminating *ca.* 6000 BP could also be interpreted as an indication that the sea was still rising in this area or that the land was still oscillating due to isostatic rebound.

CONCLUSION

Results from sedimentological observations, palynological investigations and climatic reconstruction made at Island Lake, located near the head of Baie des Chaleurs, northern New Brunswick, indicate that this lake recorded a suite of well defined events spanning the last 10 000 years. The interpretation of these events contributes significantly to the postglacial history of eastern Canada and provides information that leads to a better understanding of the subtle interaction between the land and the sea in this area.

It is demonstrated that the vegetation surrounding Island Lake, located close to the head of Baie des Chaleurs, and quite far from the entrance of the baie and from the main Atlantic water masses, was highly sensitive to the variation of water in Baie des Chaleurs. This information has been translated into a suite of climatic variables monitoring the effect of cold water on climate, moisture and vegetation.

The study area was also highly sensitive to water level fluctuations in Baie des Chaleurs associated with isostatic adjustment of the landmass and eustatic sea-level rise. A regional chronology is presented. A short period of about 100 years between about 8500 and 8400 BP when the regional groundwater table may have been lowered as a result of lower sea level in Baie des Chaleurs is suggested. A date of about 8400 BP is proposed for this possible low sea-level stand.

This study is a first step in developing new methodologies needed to quantify the amplitude of past environmental changes and to better understand and quantify the subtle interaction that exists between climate, biota and the behaviour of large bodies of water.

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REFERENCES

Anderson, T.W. and Lewis, C.F.M., 1992. Climatic influences of deglacial drainage in southern Canada at 10 to 8 ka suggested by pollen evidence. Géographie physique et Quaternaire, 46: 255-272.

Bail, P., 1983. Problèmes géomorphologique de l'englacement et de la transgression marine pléistocène sud-orientale. Thèse de doctorat, Université McGill, 148 p.

Benninghoff, W.S., 1962. Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities. Pollen et Spores, 4: 232-233.

Berglund, B.E. and Ralska-Jasiewiczowa, M., 1986. Pollen analysis and pollen diagrams, p. 455-484. *In* B.E. Berglund, ed., Handbook of Holocene Palaeoecology and Palaeohydrology. Wiley, Chichester, 869 p.

de Vernal, A, Guiot, J. and Turon, J.-L., 1993. Late and postglacial paleoenvironments of the Gulf of St. Lawrence: Marine and terrestrial palynological evidence. Géographie physique et Quaternaire, 47: 167-180.

Dyke, A.S. and Peltier, W.R., 2000. Forms, response times and variability of relative sea-level curves, glaciated North America. Geomorphology, 32: 315-333.

Environment Canada, 2002. Canadian Climate Normals or Averages 1971-2000, Website: <http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html>. Last accessed December 1, 2005.

Faegri, K., Kaland, P.E. and Kzrywinski, K., 1989. Textbook of Pollen Analysis. 4th ed. Wiley, Chichester, 328 p.

Gray, J.T., 1987. Quaternary processes and paleoenvironments in the Gaspé Peninsula and the Lower St. Lawrence Valley. International Union for Quaternary Research XIIth Congress, Excursion Guidebook C-4, Ottawa, 84 p.

Guiot, J., 1990. Methodology of the last climatic cycle reconstruction in France from pollen data. Paleogeography, Paleoclimatology and Paleoecology, 80: 49-69.

Jetté, H. and Richard, P.J.H., 1992. Contribution à l'histoire postglaciaire de la végétation en Gaspésie méridionale, Québec. Géographie physique et Quaternaire, 46: 273-284.

Josenhans, H. and Lehman, S., 1999. Late glacial stratigraphy and history of the Gulf of St. Lawrence, Canada. Canadian Journal of Earth Sciences, 36: 1327-1345.

Lamothe, M., 1987. Stratigraphy, lithology and geochemistry of till in the vicinity of tin-bearing granites, central New Brunswick, Canada, p. 206. *In* Programme and Abstracts: International Union for Quaternary Research, XIIth Congress (Ottawa, July 31 to August 9, 1987), Ottawa, 311 p.

Lewis, C.F.M. and Anderson, T.W., 1989. Oscillations of levels and cool phases of the Laurentian Great Lakes caused by inflows from glacial Lakes Agassiz and Barlow-Ojibway. Journal of Paleolimnology, 2: 99-146.

Lewis, C.F.M., Anderson, T.W. and Miller, A.A.L., 1988. Lake, ocean and climate response to meltwater discharge, Great Lakes and western Atlantic Ocean, p. 81. *In* Program and Abstracts: 10th Biennial Meeting of the American Quaternary Association (University of Massachusetts, June 6-8), Amherst.

Livingstone, D.A., 1955. A lightweight piston sampler for lake deposits. Ecology, 56: 137-139.

Loucks, O.L., 1961. A forest classification for the Maritime Provinces, p. 85-167. *In* Proceedings of the Nova Scotia Institute of Science. Halifax, Vol. 25, Part 2 (1959-60), 167 p.

Mayle, F.E. and Cwynar, L.C., 1995. Impact of the Younger Dryas cooling event upon lowland vegetation in Maritime Canada. Ecological Monographs, 65: 129-154.

Mayle, F.E., Levesque, A.J. and Cwynar, L.C., 1993. Accelerator-mass- spectrometer ages for the Younger Dryas event in Atlantic Canada. Quaternary Research, 39: 355-360.

McNeely, R. and McCuaig, S., 1991. Geological Survey of Canada Radiocarbon Dates XXIX. Geological Survey of Canada, Ottawa, Paper 89-7, 134 p.

Mott, R.J., Grant, D.R., Stea, R. and Occhietti, S., 1986. Late-glacial climatic oscillation in Atlantic Canada equivalent to the Allerod-younger Dryas event. Nature, 323: 247-250.

Pronk, A.G., Bobrowsky, P.T. and Parkhill, M.A., 1989. An interpretation of late Quaternary glacial flow indicators in the Baie des Chaleurs region, northern New Brunswick. Géographie physique et Quaternaire, 43: 179-190.

Rampton, V.N., Gauthier, R.C., Thibault, J. and Seaman, A.A., 1984. Quaternary Geology of New Brunswick. Geological Survey of Canada, Ottawa, Memoir 416, 77 p.

Richard, P.J.H. and Labelle, C., 1989. Histoire postglaciaire de la végetation au Lac du Diable, mont Albert, Gaspésie, Québec. Géographie physique et Quaternaire, 43: 337-354.

Richard, P.J.H., Larouche, A.C. and Lortie, G., 1992. Paléophytogéographie et paléoclimats postglaciaires dans l'ouest du Bas-Saint-Laurent, Québec. Géographie physique et Quaternaire, 46: 151-172.

Richard, P.J.H., Veillette, J.J., Larouche, A.C., Hétu, B., Gray, J.T. and Gangloff, P., 1997. Chronologie de la déglaciation en Gaspésie : nouvelles données et implications. Géographie physique et Quaternaire, 51: 163-184.

Rowe, J.S., 1972. Forest Regions of Canada. Department of the Environment, Canadian Forestry Service, Ottawa, Publication 1300, 172 p.

Schafer, C.T., 1977. Distribution and depositional history of sediments in Baie des Chaleurs, Gulf of St. Lawrence. Canadian Journal of Earth Sciences, 14: 593-605.

Shaw, J., Gareau, P. and Courtney, R.C., 2002. Paleography of Atlantic Canada 13-0 kyr. Quaternary Science Reviews, 21: 1861-1878.

Stea, R.R. and Mott, R.J., 1989. Deglaciation environments and evidence for glaciers of Younger Dryas age in Nova Scotia, Canada. Boreas, 18: 169-187.

_____ 1998. Deglaciation of Nova Scotia: Stratigraphy and chronology of lake sediments and buried organic sections. Géographie physique et Quaternaire, 52: 3-21.

Syvitsky, J.P.M., 1992. Marine geology of Baie des Chaleurs. Géographie physique et Quaternaire, 46: 331-348.

Wright, H.E., Jr., Livingstone, D.A. and Cushing, E.J., 1965. Coring devices for lake sediments, p. 494-520. *In* B. Kummel and D.M. Raup, eds., Handbook of Paleontological Techniques. W.H. Freeman, San Francisco, 852 p.