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# Reconstitution du climat de l'île de Terre-Neuve à 6 ka BP fondée sur la synthèse des données polliniques tirées des sédiments lacustres holocènes

# Eine Rekonstruktion des Klimas auf der Insel Neufundland um 6 ka v.u.Z., gestützt auf die Synthese von Pollen-Belegen aus Holozän-Sedimenten

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# A 6 KA BP RECONSTRUCTION FOR THE ISLAND OF NEWFOUNDLAND FROM A SYNTHESIS OF HOLOCENE LAKE-SEDIMENT POLLEN RECORDS

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ABSTRACT A 6 ka reconstruction for the island of Newfoundland is presented in the context of a synthesis of Holocene pollen records for twelve sites within or at the margin of the boreal forest, five of which are new. Climatic reconstruction is based primarily on representation of the major boreal taxa: balsam fir, spruce, birch and pine, with charcoal data for some sites. The period of greatest Holocene warmth began at 6 ka. Although temperatures at inland sites were at or close to modern values as early as 8.5-8.0 ka, it was not until 6 ka on the Avalon Peninsula, in the southeast, and 5.5 ka in the north, that coastal sites registered expansion of more thermophilous taxa. Thus oceanic warming lagged terrestrial warming. Temperatures during the period of greatest warmth were no more than 1.0°C higher than modern, based on fluctuations of the upper forest limit and post-Hypsithermal contraction of the range of indicator taxa. Fire importance increased after 6 ka as pine expanded, but moisture availability also increased. The first indications of cooling occurred on the coast at 4.5-4.0 ka, but at different times after 4.0 ka inland; thus oceanic cooling led terrestrial cooling. The latest Holocene has been cool, moist and relatively free from fire.

RÉSUMÉ *Reconstitution du climat de l'île de Terre-Neuve à 6 ka BP fondée sur la synthèse des données polliniques tirées des sédiments lacustres holocènes.* La reconstitution a été faite à partir des données polliniques holocènes tirées de 12 sites (dont 5 nouveaux) situés à l'intérieur de la forêt boréale ou à sa marge. La reconstitution climatique est d'abord fondée sur la représentation des principaux taxons boréaux : le sapin baumier, l'épinette, le bouleau et de pin, avec données sur charbon à certains sites. La période la plus chaude de l'Holocène a commencé à 6 ka. Si les températures atteignaient les valeurs modernes ou en étaient près dès 8,5-8,0 ka à l'intérieur de l'île, ce n'était pas avant 6 ka dans la péninsule d'Avalon, au sud-ouest, et à 5,5 ka au nord que les sites côtiers ont enregistré l'expansion des taxons plus thermophiles. Ainsi, le réchauffement océanique a suivi le réchauffement terrestre. Les températures au cours de la période la plus chaude étaient plus élevés d'à peine 1°C que maintenant, évaluées sur la base des fluctuations de la limite altitudinale de la forêt et la réduction post-hypsithermale de la gamme des taxons indicateurs. L'importance des feux s'est accrue après 6 ka avec l'expansion du pin, mais l'humidité a aussi augmenté. Les premières indications d'un refroidissement se sont manifestées sur la côte vers 4,5-4,0 ka, et à différentes périodes après 4 ka à l'intérieur. Ainsi, le refroidissement océanique a entraîné le refroidissement terrestre. L'Holocène le plus récent a été frais, humide et relativement exempt de feux de forêts.

ZUSAMMENFASSUNG *Eine Rekonstruktion des Klimas auf der Insel Neufundland um 6 ka v.u.Z., gestützt auf die Synthese von Pollen-Belegen aus Holozän-Sedimenten.* Die Rekonstruktion wird im Kontext der Synthese von Holozän-Pollenbelegen von zwölf Plätzen innerhalb oder am Rand des nördlichen Nadelwaldgürtels vorgestellt, von denen fünf neu sind. Die Klima-Rekonstruktion stützt sich vor allem auf das Vorkommen der hauptsächlichen borealen Taxa: Balsam-tanne, Fichte, Birke und Kiefer, mit Kohledaten für manche Plätze. Die wärmste Periode im Holozän begann um 6 ka. Wenn auch die Temperaturen an Inlandplätzen bei oder nahe bei modernen Werten zu einer so frühen Zeit wie 8.5 -8.0 ka lagen, geschah es auf der Avalon-Halbinsel nicht vor 6 ka im Südwesten und 5.5 ka im Norden, daß die Küstenplätze die Ausbreitung von thermophileren Taxa registrierten. So folgte die Ozean-Erwärmung auf die Erd-Erwärmung. Während der Periode der höchsten Wärme waren die Temperaturen nicht mehr als 1.0°C höher als heute, bestimmt aufgrund der Fluktuationen der oberen Waldgrenze und der post-hypsithermalen Schrumpfung der Serie von Beleg-Taxa. Mit der Ausbreitung der Kiefer nach 6 ka hat die Bedeutung der Feuer zugenommen, aber der Feuchtigkeits-Vorrat nahm auch zu. Die ersten Zeichen einer Abkühlung traten an der Küste um 4.5-4.0 ka auf, jedoch im Inland zu verschiedenen Zeiten nach 4.0 ka; so führte die Abkühlung des Ozeans zu einer Abkühlung des Festlands. Das jüngste Holozän war kalt, feucht und relativ feuerfrei.

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## INTRODUCTION

The boreal zone of Canada attains its southernmost limit on the island of Newfoundland: St. John's (47°34'N) is more distant from the north pole than Victoria, BC (48°25'N). The boreal character of Newfoundland's climate is determined primarily by the cold water of the Labrador Current, which surrounds the island and brings ice to northern coasts for at least four months each year. Growing seasons are consequently cool and short, especially near the coast, nowhere more distant than 100 km. Vigorous frontal disturbances moving along the Polar and Arctic fronts produce abundant precipitation. A summer soil moisture deficit is recorded only in the northeast, downwind of the prevailing west- to southwesterlies. Natural fire is rare except in this northeastern area, where it is associated with relatively dry summer conditions resulting from a northward extension of the Bermuda High, and with summer convection (Banfield, 1981, 1983).

Only in sheltered inlets does the boreal forest meet the ocean; headlands, and plateau surfaces above the altitudinal treeline (rarely exceeding 350 m asl), support tuckamore (krummholz), barrens (heathland) and bog. Even on the south coast arctic-alpine species occur close to sea-level. Nevertheless, rare species more common in the temperate deciduous forest are to be found in sheltered western and southern valleys, where the length of the growing season is greatest. These species presumably crossed the Cabot Strait from Cape Breton Island, following the path of earlier boreal migrants.

Damman (1976, 1983) relates modern plant distributions and forest composition to differences in climatic conditions; his system of ecoregions is adopted in this paper. Sites have been selected to represent Damman's major forest ecoregions. However, not all of his subregions are represented, and no complete postglacial record is available from the south coast of the island, attempts to obtain lake sediment cores spanning the Holocene from non-forested sites having met with limited success. Where an ecoregion is represented by more than one site it is possible to compare pollen sequences at a more local scale and to examine local environmental influences. Such comparisons may yield useful climatic information, not only because of the island's accidented relief and low altitudinal treeline but also because of the strong oceanic influence at coastal locations.

Although the number of available sites is greater than that used in earlier syntheses (Macpherson, 1981, 1985), only seven of the twelve selected sites have been published in full or are in press (Dyer, 1986; Henningsmoen, 1977; Macpherson, 1982; McCarthy, under review; Terasmae, 1966). Since much of the material to be presented is new, and since the vegetation at 6 ka can only be understood in terms of its history, and can only be interpreted climatically by reference to its subsequent development, this review presents a summary of the course of vegetational development throughout the Holocene, with emphasis on the middle Holocene (~8.0-4.0 ka). Summary interpretations for the individual sites are presented in the Appendix, together with notes on the respective ecoregions.

### MODERN VEGETATION

The locations of the sites to be discussed are shown in Figure 1, which also shows the modern ecoregions of Damman (1983) with certain of the subregions. Table I presents forest inventory data from the provincial Forest Management Districts and earlier Forest Inventory Regions (Newfoundland, Department of Forestry and Agriculture, 1974, 1990) grouped in such a way as to be comparable with the Damman ecoregions. Because of climatic (Fig. 2; Banfield, 1983), topographic and edaphic constraints only one third of the island is classified as productive forest. Proportions under productive forest range from >60% in the combined North Shore ecoregion and Northcentral subregion, which is generally below 200 m asl and experiences a relatively "continental" climate, to <6% in the South Coast Barrens Subregion, a wet, foggy plateau rising above 300 m, with forest confined to sheltered valleys. Regions with intermediate values may have extensive areas rising above the altitudinal treeline, for example in the Long Range Mountains of the Northern Peninsula (rising to 500-800 m), or may be a mosaic of productive forest on mesic sites with lakes, bogs and fens in depressions, and rock barrens on summits, exposed coasts and areas with thin surficial deposits.

Based on proportions of merchantable lumber (Table I) balsam fir (*Abies balsamea)* is the dominant tree overall (48% of the productive forest); where it is regionally dominant, in Western Newfoundland and on the Northern and Avalon Peninsulas, humidity is greatest and fire infrequent or rare. Black spruce (*Picea mariana*) dominates in the "continental" Northcentral and North Shore regions where fire is most common, and where summers, though short, are warm and relatively dry. White birch (*Betula papyrifera*), mountain white birch (*B. papyrifera* v. *cordifolia* (Regel)), white spruce (*Picea glauca*), larch (*Larix laricina*) and balsam poplar (*Populus balsamifera*) are also widespread, although larch tends to be confined to poorer sites and balsam poplar to rich valley bottoms (Ryan, 1978). Although birch occurs in the fire succession where fire is frequent, it is also abundant in the Western ecoregion where fire is extremely rare. Other trees are restricted to certain regions of the island by summer temperatures or the length of the growing season (Damman, 1976). Trembling aspen *(Populus tremuloides*) is most abundant (>2%) in the Northcentral subregion where root sucker development is favoured by summer warmth and where stands may be of fire origin (Page, 1972). White pine (*Pinus strobus)* does not occur on the Northern Peninsula where summers are cool and short. Red pine (*Pinus resinosa*) is largely confined to xeric sites in central Newfoundland where mean annual maximum temperatures are in excess of 30°C (Damman, 1976; Roberts, 1985); regeneration on more mesic sites is fire-dependent (Mallik and Roberts, 1994). Yellow birch (*Betula lutea*) is confined to areas with long growing seasons: the Western region below 250-300 m elevation and sheltered valleys on the south coast

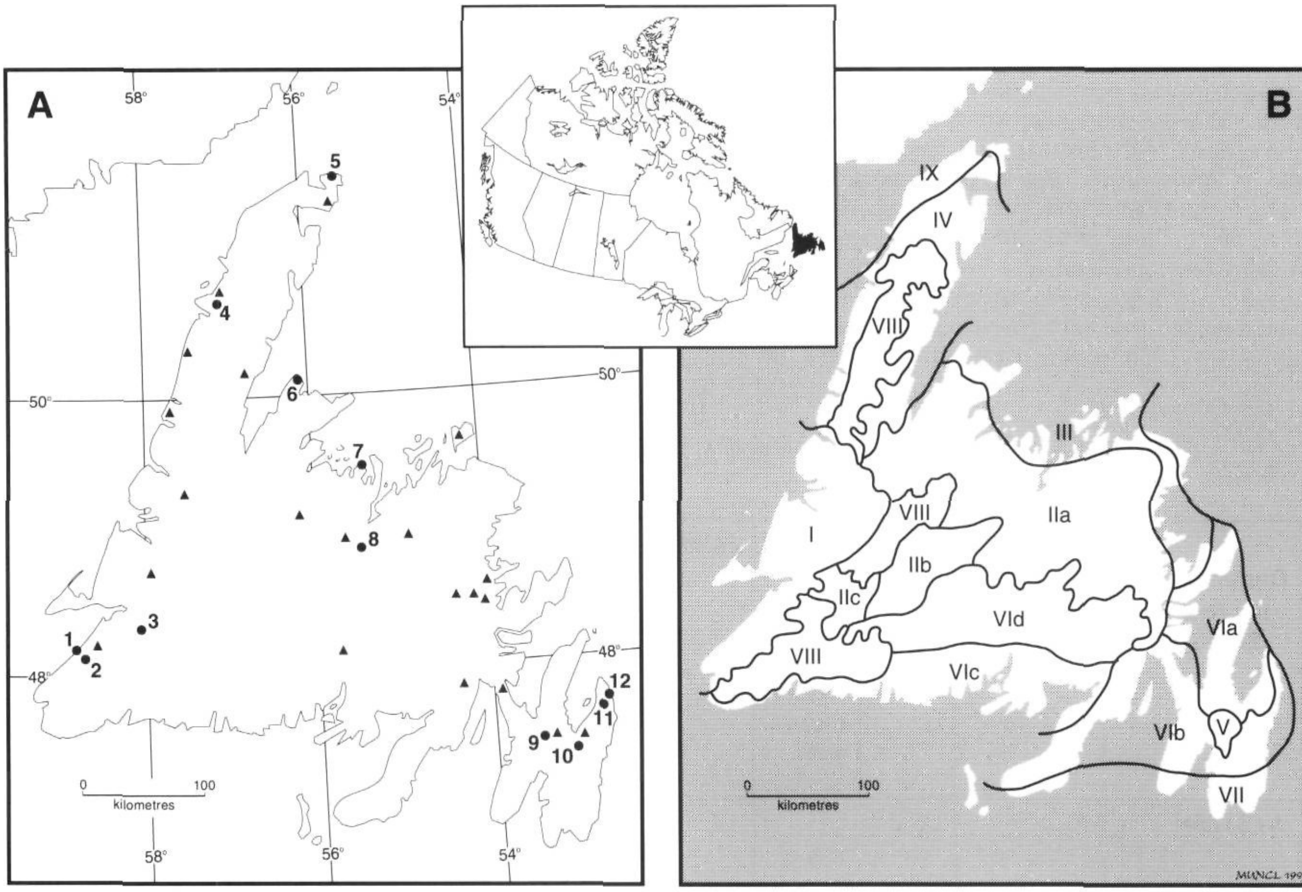



FIGURE 1. A. Locations of lake sediment sites (numbered) and of surface pollen samples. B: Ecoregions and subregions of the island of Newfoundland (after Meades and Moores, 1989; after Damman, 1983; reproduced with permission of Forestry Canada, Newfoundland and Labrador region).
Ecoregions: I: Western Newfoundland; II: Central Newfoundland (Subregions: IIa: Northcentral; IIb, IIc: Southwestern); III: North Shore; IV: Northern Peninsula; V: Avalon Forest; VI: Maritime Barrens (Subregions: VIa: Northeastern; VIb: Southeastern; VIc: South Coast; VId: Central); VII: Eastern Hyper-Oceanic Barrens; VIII: Long Range Barrens; IX: Strait of Belle Isle.

*Localisation des sites de sédiments lacustres (numérotés) et des échantillons polliniques de surface. B. Écorégions et sous-régions de l'île de Terre-Neuve (à partir de Meades et Moores, 1989; à partir de Damman,1983 ; reproduit avec la permission de Forêts Canada, région de Terre-Neuve et du Labrador).*
*Écoregions: I: Ouest de Terre-Neuve; II: Centre de Terre-Neuve (sous-régions: IIa: Centre-nord; IIb, IIc: Sud-ouest); III: Côte nord; IV: Péninsule nord; V: Forêt d'Avalon; VI: Landes maritimes (sous-régions: VIa: Nord-est; VIb: Sud-est; VIc: Côte sud; VId Centre); VII: Landes hyper-océaniques de l'est ; VIII: Landes du Long Range; IX: Détroit de Belle-Isle.*

including the Avalon Peninsula (Damman, 1976). Black ash (*Fraxinus nigra*), which occurs only as a shrub, is even more restricted, growing only in sheltered southwestern valleys and at a single site near the north coast (Damman, 1976; Ryan, 1978).

The two species of alder, mountain alder (*Alnus crispa*) and speckled alder (*Alnus rugosa*), also differ in their distributions. The former is found in all regions, while the latter is absent or rare where summer temperatures are low: the Northern Peninsula, the southeast including the Avalon Peninsula and southern coastal plateaux.

It will be noted that all the species mentioned above have light, winged or hairy seeds which are easily dispersed. Thus their dispersal to and within the island raises few problems. Further, a disjunct modern population within the island does not necessarily indicate that the distribution of the species was formerly continuous. The ease of dissemination of the seeds of the dominant plants makes it reasonable to assume some measure of vegetation-climate equilibrium. The barrier of the Cabot Strait does not appear to have delayed the response to initial Holocene warming.

## MODERN POLLEN

Table I lists mean percentages of pollen of the principal taxa for surface lake-sediment samples from the ecoregions and subregions, permitting comparison of the tree and pollen abundances. Locations of modern pollen sites are shown in Figure 1. In addition to the sites for which pollen diagrams are presented, modern pollen data were obtained from Railton (1973), McAndrews and Davis (1978), D.L. Butler (in progress) and from other of the author's unpublished sites.

*Abies balsamea* is greatly under-represented by its pollen and modern lake-sediment samples rarely contain more than 10% *Abies* pollen. Lowest balsam fir values indicate more "continental" conditions and are recorded in the fire-prone Northcentral subregion and the North Shore ecoregion. *Picea* pollen percentages (normally >15% and up to 48%) are more representative of the proportion of spruce trees (40% overall), and tend to be inversely related to *Abies* values. *Betula*, by contrast, although comprising only 12% of the modern forest, is registered by pollen percentages of 20-50%, with values up to 60% in Western Newfoundland and in the small Avalon Forest ecoregion. Although these regions have long growing seasons favouring tree birch, birch pollen values can also be high where shrub birch is included in the total, as on the Northern Peninsula. *Pinus* comprises less than 0.2% of the forest yet contributes up to 12% of the modern pollen rain in the Northcentral region. High pine values on the Northern Peninsula indicate wind dispersal, probably from areas west of the Gulf of St. Lawrence. Exposed coastal and upland sites record up to 49% *Alnus* from alder scrub. Such sites can also record up to 7% Ericales. *Larix* appears so rarely in pollen profiles that it is not considered in this study, and data on modern *Populus* pollen are also inadequate.

Conifers and some hardwoods in marginal locations may be reduced to krummholz or even prostrate form while

TABLE I

*Damman Ecoregions: productive forest, principal trees and modern pollen percentages from lake sediments*

| Damman Ecoregion/ Subregion | Productive forest: % area | ***Abies balsamea*** % | | ***Picea*** % | | ***Pinus strobus*** % | | ***Betula*** % | | ***Alnus*** % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | tree | pollen mean range | tree | Σ pollen mean range | tree | Σ pollen mean range | tree | Σ pollen mean range | pollen mean range |
| WESTERN | 41.4 | 66.2 | 5.5<br>2.0-10.5 | 17.1 | 16.5<br>4.0-26.3 | 0.2 | 3.9<br>2.0-5.7 | 10.4 | 41.0<br>20.0-59.5 | 12.3<br>4.5-31.0 |
| NORTHERN PENINSULA/ STRAIT of BELLE ISLE | 33.8 | 64.9 | 5.2<br>1.5-10.8 | 27.5 | 20.5<br>15.5-26.8 | 0 | 4.1<br>2.1- 7.6 | 6.9 | 33.0<br>21.5- 35.5 | 17.8<br>4.0-49.0 |
| N. CENTRAL/ N. SHORE | 63.3 | 24.2 | 3.8<br>1.2-6.6 | 61.1 | 32.0<br>19.3-44.1 | 0.1 | 4.0<br>1.0-10.2 | 10.2 | 27.7<br>21.3-32.0 | 19.8<br>6.5-37.4 |
| CENTRAL:SW | 35.6 | 37.5 | | 45.7 | | 0.1 | | 12.9 | | |
| MARITIME BARRENS: Central, S.Coast | 42.1 | 48.4 | 6.0<br>0.4-14.6 | 37.2 | 39.3<br>33.4-48.2 | 1.0 | 7.9<br>3.2-12.2 | 11.5 | 20.0<br>10.0-29.1 | 11.6<br>6.0-17.5 |
| MARITIME BARRENS: Avalon Pen. | 32.9 | 76.8 | 5.6<br>1.6-10.4 | 14.8 | 19.9<br>7.5-38.5 | 0 | 1.6<br>0.4-2.4 | 4.6 | 32.7<br>20.9-55.6 | 16.5<br>1.7-37.7 |

Data for the Long Range Barrens Ecoregion (VIII) are included with Western and Northern Peninsula Ecoregions. The Northeastern and Southeastern Maritimes Barrens Subregions (VIa, VIb) are represented by data for the Avalon Peninsula.

Σ Pollen: all species in the genus are included (*i.e. Betula* includes shrub birch, etc.)

(Butler, in progress; Damman, 1983; Dyer, 1986; Macpherson, 1982; McAndrews and Davis, 1978; McCarthy *et al.*, in press; Newfoundland, Department of Forestry and Agriculture, 1974, 1990; Railton, 1973) continuing to produce pollen; thus the presence of a taxon in the pollen record need not indicate the presence of the taxon in tree form (Davis, 1980).

Discrimination between pollen grains of *Picea glauca* and *P. mariana* and between *Pinus strobus* and *P. resinosa* has been undertaken for some cores. Measurements of *Betula* grain diameters permit a degree of discrimination between tree and shrub taxa at some sites, but the size range 20-25 µm includes grains of both shrub species and the tree species *B. cordifolia* (mountain white birch) (Dyer, 1986). Thus the category "shrub birch" includes only grains <20 µm in diameter. There have been few attempts to discriminate between *Alnus crispa* and *A. rugosa.*

## CHARCOAL AND FIRE

Information on microscopic charcoal counts is included with the pollen data where available. Charcoal fragments were counted rather than measured; charcoal areas on a batch of duplicate slides from Kennys Pond (site 11) were measured at the Laboratoire Jacques-Rousseau, Université de Montréal, and trends were determined to be very similar (P.J.H. Richard, pers. comm., 1993). Newfoundland lacks numerical analyses of natural fire rotation comparable to those available for southeastern Labrador ( Foster, 1983), the Maritime Provinces (Wein and Moore, 1977, 1979) or northern Québec (Payette *et al.*, 1989). Documentary evidence indicates that during the European period fire of anthropogenic origin has been common adjacent to settlements and, in the twentieth century, to the railway (Wilton and Evans, 1974), but charcoal profiles in general fail to show increased surface values. In part this results from the strategy of site selection but may also be related to changing near-surface rates of sediment accumulation or failure of the sampler to collect the topmost sediment. Thus near-surface charcoal concentrations are normally taken to represent immediately pre-European values.

The pre-European fire rotation in black spruce stands in central Newfoundland is estimated on ecological grounds to have been about 150 years (M.G. Weber, pers. comm., 1994), compared with the 100-year rotation calculated for the continental northern boreal forest of Québec (Payette *et al.*, 1989), and the 500-year rotation calculated by Foster (1983) for southeastern Labrador, where summers are cooler and moister. Red pine stands in Newfoundland are subject to a short (15-30 year) modern wildfire cycle, non-lethal to mature trees, which may facilitate the expansion of black spruce at the expense of red pine (Roberts and Mallik, 1994). The length of the natural red pine fire rotation in Newfoundland is estimated at 300-400 years (M.G. Weber, pers. comm., 1994), as compared with a cycle of less than 200 years in the North American continental interior

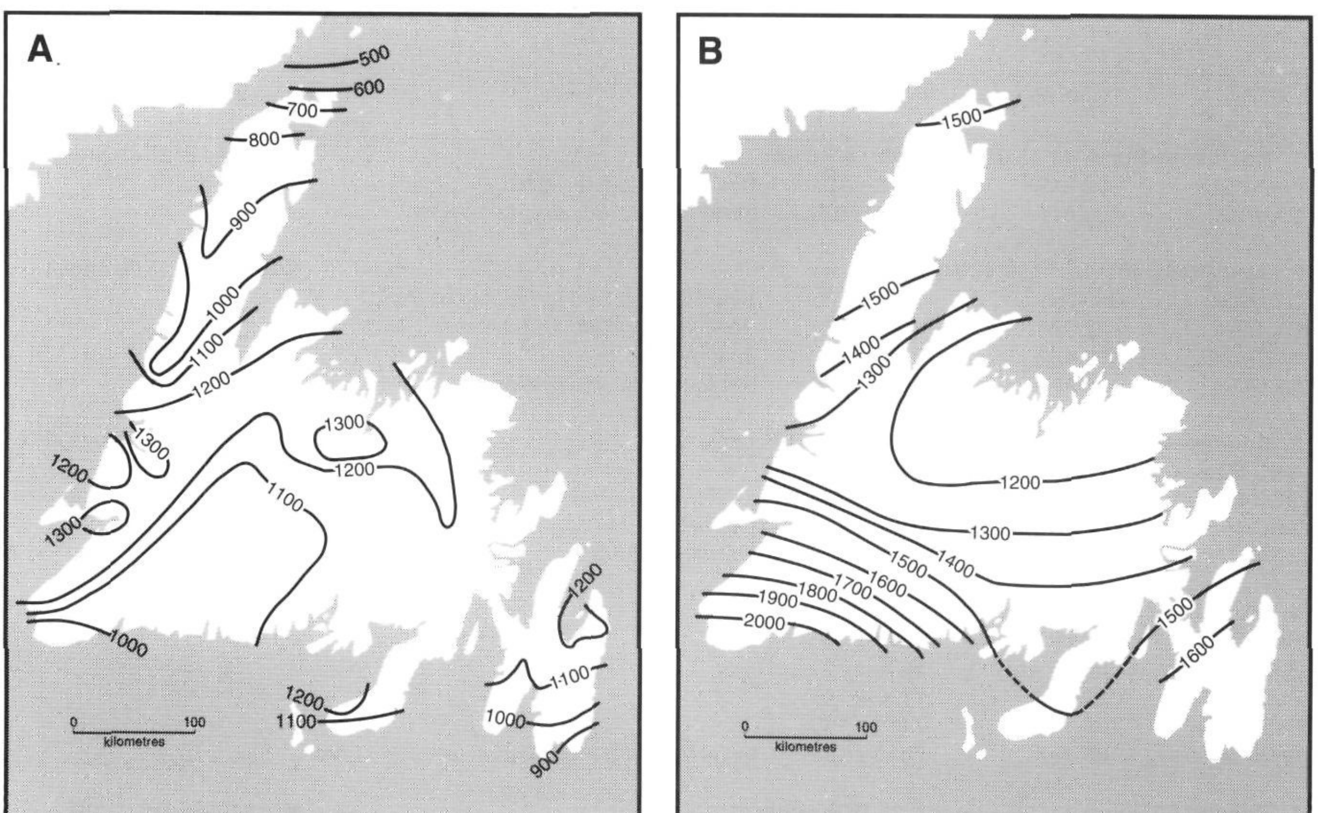



FIGURE 2. A) Average annual number of degree-days above 5°C (from Banfield, 1983). B: Mean annual total precipitation (mm), adjusted to be consistent with observed runoff (from Banfield, 1983; after Den Hartog and Ferguson, 1975). (Both maps reproduced with permission of Kluwer Publishers.)

*A) Nombre annuel moyen de degrés-jours au-dessus de 5°C (de Banfield, 1983). B) Précipitations annuelles moyennes totales (mm), compensées en fonction du ruissellement observé (selon Banfield, 1983; à partir de Den Hartog et Ferguson, 1975). Les deux cartes sont reproduites avec la permission de Kluwer Publishers.*

(Heinselman, 1981). The sampling intervals in the cores to be discussed in this paper are too coarse to permit the regular identification of individual fires. Intervals of increased charcoal concentration do, however, indicate periods of increased regional "fire importance" (Clark, 1988; MacDonald *et al.*, 1991), whether of fire extent or frequency, which may be attributable to a combination of greater continentality, with occasional summer droughts and increased atmospheric convection, and the presence of readily combustible conifers, especially pines (Heinselman, 1981).

## DATING CONTROL

Six sites have bulk-sediment radiocarbon dates bracketing or close to 6 ka (Table II), but only one date (GSC-4086: Leading Tickles) coincides with 6 ka. The quality of the interpolated dates used in the following discussion depends upon the number of dated levels and upon the accuracy of the dates, all of which are on bulk organic sediment. The data set is biassed toward the lateglacial and early Holocene, as many dates were originally obtained to control the chronology of deglaciation and lateglacial events (*e.g.* Anderson, 1983; Macpherson and Anderson, 1985; Anderson and Macpherson, 1994). Unfortunately these dates are the most subject to error. However, regional consistency of dates lends support to the later Holocene chronology.

Basal or near-basal dates may be too old, especially in areas of limestone bedrock (as in western Newfoundland) or where the dated sediment contains much autochthonous organic material as indicated by high *Pediastrum* values (but not necessarily by enriched $\delta^{13}C$). These anomalies are of two types: a) basal dates >10 ka on sediment attributable to the early Holocene both from sites lacking evidence of the Younger Dryas oscillation and from sites which registered the oscillation (Anderson and Macpherson, 1994). Following recognition of Younger Dryas glacial readvance into the sea along the northeast coast (Liverman *et al.*, 1991; Munro, 1994) as well as on the Northern Peninsula (Grant, 1989) it is considered that sites which failed to register the oscillation remained ice-covered until the onset of the oscillation or later. Mayle *et al.* (1993) date the termination of the Younger Dryas at about 10 ka in New Brunswick and Nova Scotia on the basis of AMS dating of terrestrial macrofossils. The basal dates from sites 1, 3, 6, 7, and 8 fall into this category (Table II); b) dates >10 ka on sediment with evidence of the arrival of spruce, which appears to have arrived in southwestern Newfoundland no earlier than 10 ka (Anderson and Lewis,

TABLE II

*Bulk sediment radiocarbon dates from representative sites, with additional information*

| Lab no. | Depth (cm) | $^{14}C$ age | Comments | Reference(s) |
|---|---|---|---|---|
| **1. Robinsons Pond:** 48°15.5'N, 58°48'W; 40 m asl | | | | McCarthy *et al.* (in press) |
| WAT-1929 | 303-313 | 5090 ± 70 | *Alnus* rise: date rejected | |
| GX-9965 | 408-417 | 11300 ± 620 | basal organic; adjusted to 10.5 ka | |
| **2. Joes Pond:** *48°14.5'N, 58°46'W; 42.5 m asl* | | | | *McCarthy et al. (in press)* |
| GX-9962 | 289-291 | 3300 ± 235 | *Alnus* rise: applied to Robinsons Pond | |
| GX-9963 | 422-425 | 9445 ± 380 | *Abies* rise; applied to Robinsons Pond | |
| WAT-1923 | 450-452 | 10950 ± 80 | date rejected | |
| GX-9964 | 490-495 | 10130 ± 375 | basal organic: early Holocene | |
| **3. Southwest Brook Lake:** 48°28'N, 57°59'W; 145 m asl | | | | Anderson and Lewis (1992) |
| GSC-5628 | 219-225 | 4150 ± 70 | | Anderson, p.c. (1994) |
| GSC-5041 | 314-320 | 8550 ± 220 | | |
| GSC-4631 | 383-386 | 11100 ± 120 | Lateglacial - Holocene transition: adjusted to 10.5 ka | |
| **4. Stove Pond:** 50°40.4'N, 57°12.2'W; 55 m asl | | | | this study |
| Beta-36435 | 50-60 | 4400 ± 90 | | |
| Beta-32595 | 90-95 | 5420 ± 70 | | |
| Beta-32596 | 120-127.5 | 7180 ± 140 | | |
| Beta-32597 | 139-146 | 7410 ± 130 | | |
| Beta-32598 | 180-187 | 7810 ± 130 | basal organic, isolation from Goldthwait Sea | |
| **5. Saddle Hill Pond:** 51°35.32'N, 55°31.18'W; 32 m asl | | | | McAndrews, p.c. (1994) |
| WAT-686 | 55-65 | 2680 ± 90 | | |
| GX-6032 | 65-75 | 2965 ± 140 | loss-on-ignition decrease | |
| WAT-685 | 200-210 | 5210 ± 100 | *Alnus* increase, *Betula* decrease | |
| GX-6033 | 345-355 | 9430 ± 255 | *Salix*, herb decrease, *Betula* increase | |

| Lab no. | Depth (cm) | $^{14}$C age | Comments | Reference(s) |
|---|---|---|---|---|
| **West Saddle Hill Pond** (bog): (same site as 5) | | | | Henningsmoen (1977) |
| T-501 | 358-368 | 7500 ± 130 | precedes *Picea* increase | |
| **6. Compass Pond**: 50°02.05'N, 56°11.78'W; 236 m asl | | | | Dyer (1986) |
| GSC-3910 | 95-100 | 2050 ± 90 | | |
| GSC-3906 | 195-200 | 3050 ± 140 | | |
| GSC-3903 | 295-300 | 4690 ± 160 | | |
| GSC-3902 | 395-400 | 6280 ± 120 | | |
| GSC-3992 | 435-440 | 8310 ± 140 | | |
| GSC-3898 | 495-500 | 9950 ± 150 | initial *Picea* increase; adjusted to 9.5 ka | |
| GSC-3891 | 540-545 | 11700 ± 180 | basal organic; initial Holocene; adjusted to 10.5 ka BP | |
| **Small Scrape Pond:** 49°56.98'N, 56°05.28'W; 122 m asl | | | | Dyer (1986) |
| GSC-3937 | 315-320 | 9470 ± 160 | initial *Picea* increase; applied to Compass Pond | |
| **7. Leading Tickles:** 49°28.28'N, 55°28.38'W; 105 m asl | | | | this study |
| GSC-4107 | 210-215 | 4200 ± 110 | | |
| GSC-4086 | 265-270 | 5960 ± 120 | | |
| GSC-4183 | 380-385 | 9600 ± 230 | initial *Picea* increase | |
| *GSC-3610* | *405-415* | *10500 ± 140* | *initial Holocene* | |
| **8. Bishops Falls**: 48°56.17'N, 55°30.33'W; 75 m asl | | | | this study |
| GSC-4148 | 225-230 | 6340 ± 70 | | |
| GSC-4131 | 290-295 | 10800 ± 140 | initial *Picea* increase; adjusted to 9.5 ka | |
| GSC-3647 | 314-319 | 11800 ± 200 | basal organic; initial Holocene; adjusted to 10.5 ka | |
| **9. Whitbourne Bog:** 47°25.5'N, 53°32'W; 60 m asl | | | | Terasmae (1963) |
| I(GSC)-4 | 490-500 | 8420 ± 300 | basal organic | |
| **10. Hawke Hills:** 47°19.33'N, 53°08'W; 220 m asl. | | | | Macpherson (1982) |
| Dal-289 | 118-128 | 3169 ± 85 | | |
| Dal-290 | 218-228 | 4660 ± 85 | | |
| Dal-323 | 285-295 | 7290 ± 150 | | |
| **Golden Eye Pond:** 47°23.17'N, 53°03.25'W; 208 m asl | | | | this study |
| GSC-4015 | 310-315 | 8370 ± 130 | *Picea* increase; applied to Hawke Hills | |
| GSC-3136 | 419-424 | 10100 ± 250 | basal organic; initial Holocene; applied to Hawke Hills | |
| **11. Kennys Pond:** 47°35.42'N, 52°42.83'W; 70 m asl | | | | this study |
| GSC-4016 | 192-197 | 3760 ± 80 | | |
| Beta-32594 | 225-232 | 5830 ± 100 | | |
| GSC-3618 | 293-298 | 8570 ± 90 | basal organic | |
| **12. Sugarloaf Pond:** 47°37'N, 52°40'W; 100 m asl | | | | Macpherson (1982) |
| Dal-295 | 450-460 | 7270 ± 200 | | |
| GSC-2601 | 571-576 | 9270 ± 150 | basal organic | |
| **Pool's Cove:** 47°38'N, 55°30.83'W; 150 m asl | | | | Vardy (1991) |
| GSC-5028 | 210-215 | 8300 ± 120 | main *Picea* increase | |
| GSC-4945 | 245-250 | 9710 ± 120 | basal organic; initial *Picea* increase | |
| **Millertown:** 48°44'N, 56°36'W; 250 m asl | | | | McNeely and McCuaig (1991) |
| GSC-4231 | 167-172 | 9340 ± 140 | basal organic; *Picea* increase | |
| **Cat Arm River**: 50°2.80'N, 56°49.30'W; 387 m asl | | | | McNeely and McCuaig (1991) |
| GSC-4192 | 153-155 | 8380 ± 100 | basal organic; *Picea* increase | |

1992), or dates on this horizon younger than 10 ka but which are significantly older than other regional dates. The dates on the spruce rise from sites 6 and 8 fall into this category.

Minimal adjustments have been made to these dates, as follows: dates with anomalies of type (a) were adjusted to 10.5 ka (rather than to 10 ka) where the date was older than 10.5 ka (sites 1, 3, 6, 8). Dates with anomalies of type (b) were adjusted to the (younger) date of the spruce increase at a site within the same or adjacent ecoregion, provided that other sites in the region confirmed the chronology (sites 6, 8). These adjustments affect the

TABLE III

*Summary of Holocene climatic indicators for representative sites*

| | WESTERN | | | NORTHERN PENINSULA | NORTH SHORE | | NORTH CENTRAL | MARITIME BARRENS (AVALON PENINSULA) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ka BP | Robinsons Pond (coast) | Joes Pond (inland) | SW Brook Lake (interior) | Stove Pond | Compass Pond | Leading Tickles | Bishops Falls | Hawke Hills (upland) | Kennys Pond (inland) | Sugarloaf Pond (coast) |
| 0 | | | | | | | | | | |
| 0.5 | | | | | | | | | | |
| 1.0 | | | | | | | *Pinus* | | | |
| 1.5 | | | | | | | X | | | |
| 2.0 | | | | | ■ *Abies* ⇑ | | X *Picea* ⇑ | | | *Abies* ⇑ |
| 2.5 | *Abies* ⇑ | *Abies* ⇑ | | | | *Picea* ⇑ *Betula* ⇓ | X *Abies* ⇓ *Betula* ⇓ | shrubs ⇑ | *Abies* ⇑ | |
| 3.0 | wetland ⇑ | wetland ⇑ | end of record | wetland ⇑ | ■ *Fraxinus* ⇓ | | *Pinus* | *Abies* ⇓ ■*Betula* ⇓ | X | |
| 3.5 | □ *Alnus* ⇑ *Betula* ⇓ | ■ *Alnus* ⇑ | *Pinus* ⇓ | X | *Picea* ⇑ *Betula* ⇓ | *Abies* ⇓ | X | X | X | |
| 4.0 | | *Pinus* ⇓ | ■ | | | ■ *Pinus* ⇓ | | X | ■X *Picea* ⇑ | |
| 4.5 | | | | ■X *Picea* ⇑ | ■ | | X | ■ | | |
| 5.0 | | | *Pinus* ⇑ wetland ⇑ | *Betula* ⇓ | | | X | X | wetland ⇑ X *Betula* ⇓ | |
| 5.5 | | | | ■ | *Fraxinus* ⇑ | | X | X | X | |
| 6.0 | | | | wetland ⇑ | | ■ *Pinus* ⇑ | X *Abies* ⇑ | X Abies ⇑ | ■X | *Abies* ⇑ |
| 6.5 | | *Pinus* ⇑ | | | ■ | | ■X *Pinus* ⇑ *Betula* ⇓ | | | |
| 7.0 | | | *Fraxinus* ⇑ | ■ | | | X | | | |
| 7.5 | | | | ■ *Picea* ⇓ X *Betula* ⇑ *Picea* ⇑ | *Betula* ⇑ | *Betula* ⇑ *Picea* ⇓ | X | ■ XBetula ⇑ | | ■ |
| 8.0 | | | *Betula* ⇑ | ■ emergence | | | X *Betula* ⇑ | **Abies* ⇑ | *Betula* ⇑ *Abies* ⇑ | *Betula* ⇑ *Abies* ⇑ |
| 8.5 | | | ■ *Picea* ⇑ | | ■ *Picea* ⇑ | *Picea* ⇑ | *Picea* ⇑ | □ * *Picea* ⇑ | ■ *Picea* ⇑ | □ *Picea* ⇑ |
| 9.0 | *Betula* ⇑ *Abies* ⇑ | *Betula* ⇑ *Abies* ⇑ | | | *Abies* ⇑ | *Abies* ⇑ | *Abies* ⇑ | | | |
| 9.5 | □ *Picea* ⇑ | ■ *Picea* ⇑ | *Abies* ⇑ *Picea* ⇑ | | □ *Picea* ⇑ | ■ *Picea* ⇑ | □ *Picea* ⇑ | | | ■ |
| 10.0 | | ■ | | | | | | □ | | |

■ $^{14}C$ date
□ $^{14}C$ date: nearby site
X high charcoal
⇑⇓ increase, decrease
* data from nearby site
**intensity of shading indicates relative warming and cooling trends for individual sites**

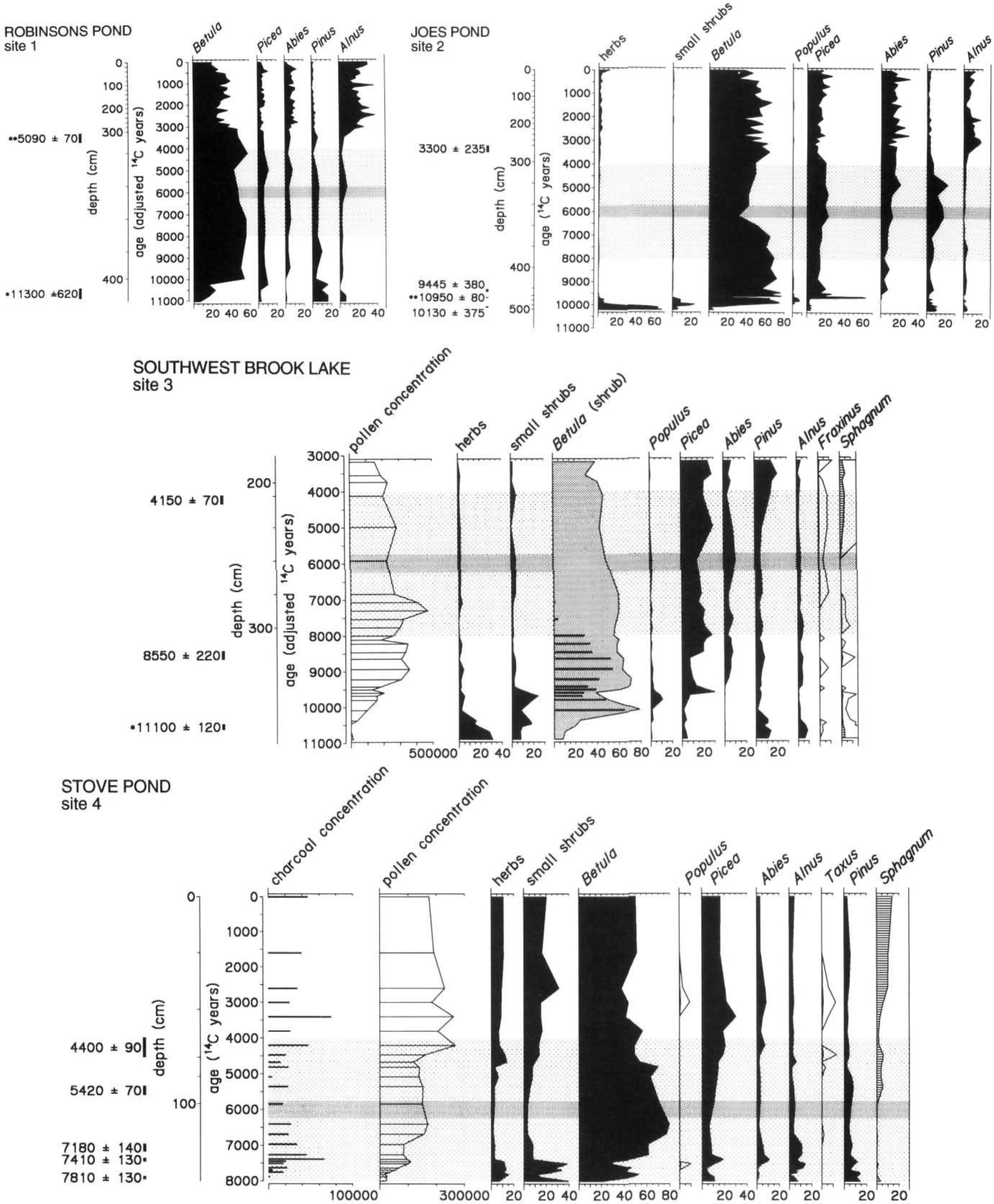
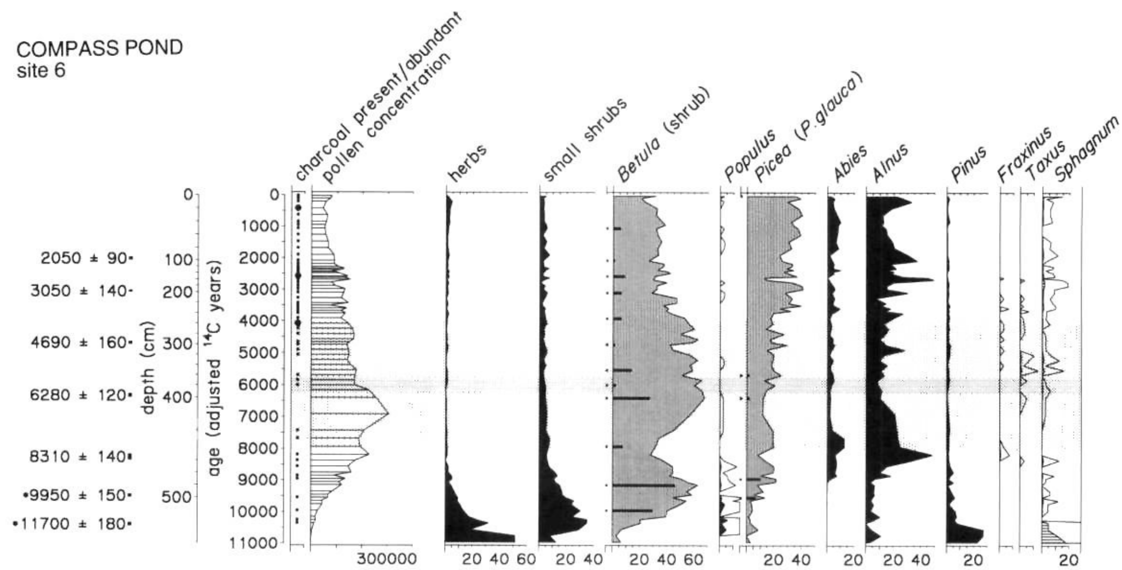
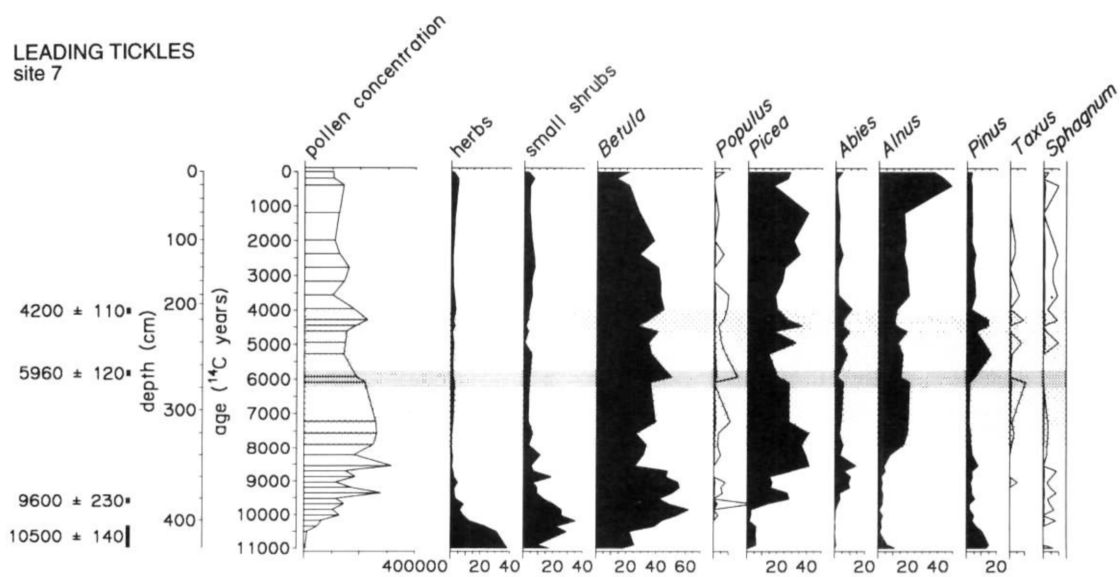
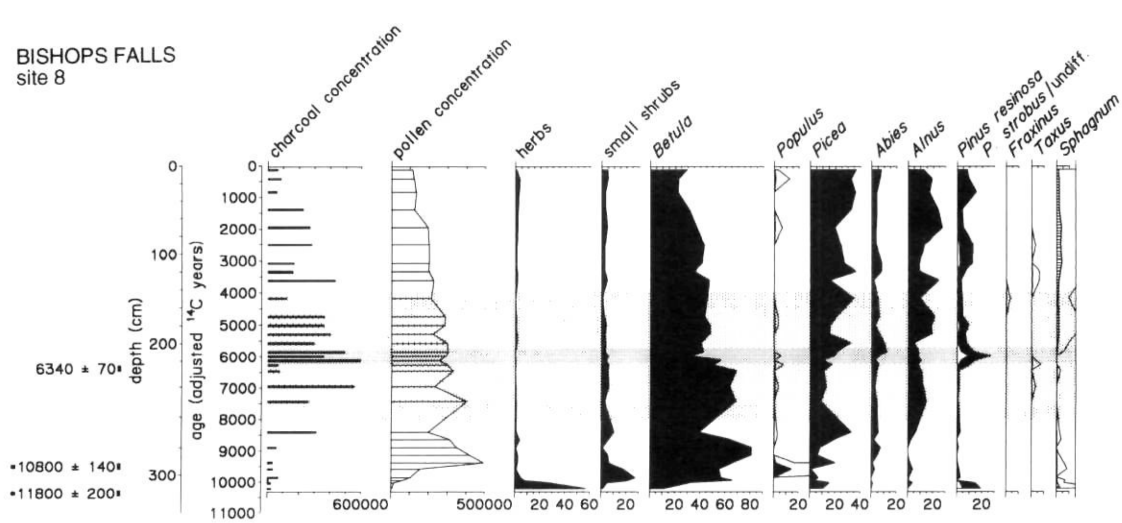



FIGURE 3. Summary pollen diagrams from representative sites. Reference numbers as in Figure 1A. Asterisked dates have been adjusted and double-asterisked dates are rejected (see Table II). Superimposed histograms: on *Betula* curve: shrub birch (where determined); on *Picea* curve: *P. glauca* (where determined). Exaggeration is x 10.

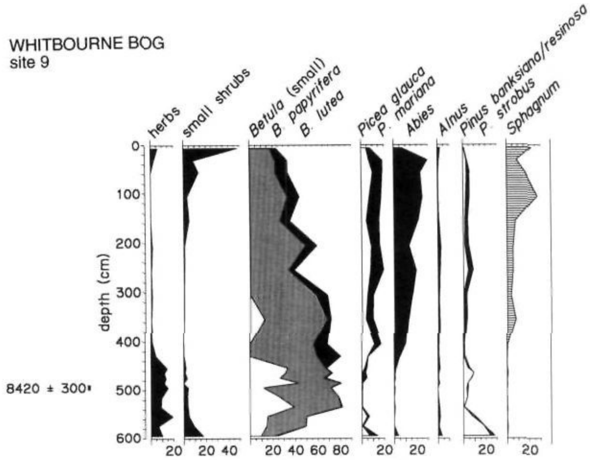
*Diagrammes polliniques abrégés de sites représentatifs. Les numéros de référence sont les mêmes qu'à la figure 1A. Les dates avec un astérisque ont été compensées et les dates avec double astérisque ont été rejetées (voir le tabl. II). Histogrammes surimposés : sur la courbe de* Betula *(le bouleau nain là où il a été défini) ; sur la courbe de* Picea *(l'épinette blanche là où elle a été définie). Exagération de 10 x.*


COMPASS POND
site 6
charcoal present/abundant
pollen concentration
herbs
small shrubs
Betula (shrub)
Populus
Picea (P.glauca)
Abies
Alnus
Pinus
Fraxinus
Taxus
Sphagnum
2050 ± 90
3050 ± 140
4690 ± 160
6280 ± 120
8310 ± 140
9950 ± 150
11700 ± 180
depth (cm)
age (adjusted ¹⁴C years)
300000

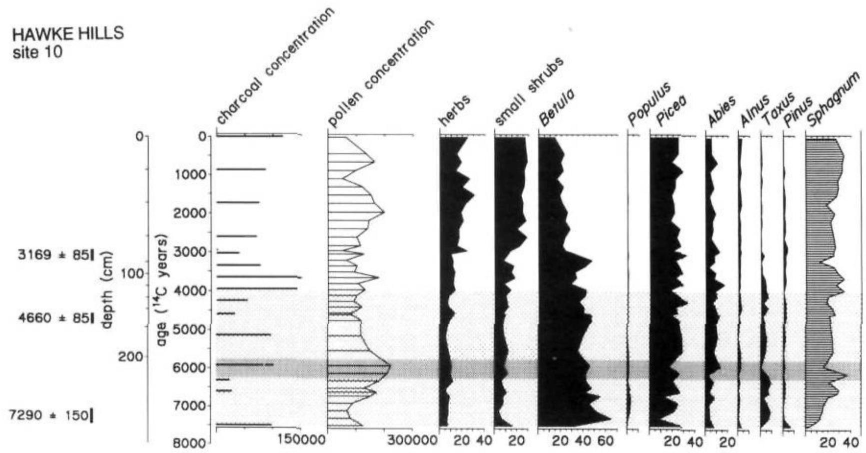


LEADING TICKLES
site 7
pollen concentration
herbs
small shrubs
Betula
Populus
Picea
Abies
Alnus
Pinus
Taxus
Sphagnum
4200 ± 110
5960 ± 120
9600 ± 230
10500 ± 140
depth (cm)
age (¹⁴C years)
400000



BISHOPS FALLS
site 8
charcoal concentration
pollen concentration
herbs
small shrubs
Betula
Populus
Picea
Abies
Alnus
Pinus resinosa
P. strobus/undiff.
Fraxinus
Taxus
Sphagnum
6340 ± 70
10800 ± 140
11800 ± 200
depth (cm)
age (adjusted ¹⁴C years)
600000
500000

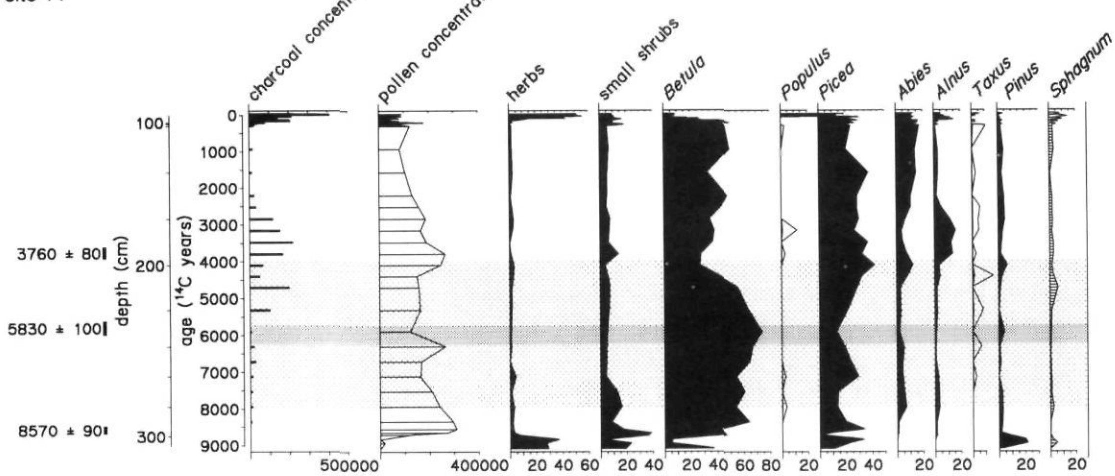
WHITBOURNE BOG
site 9



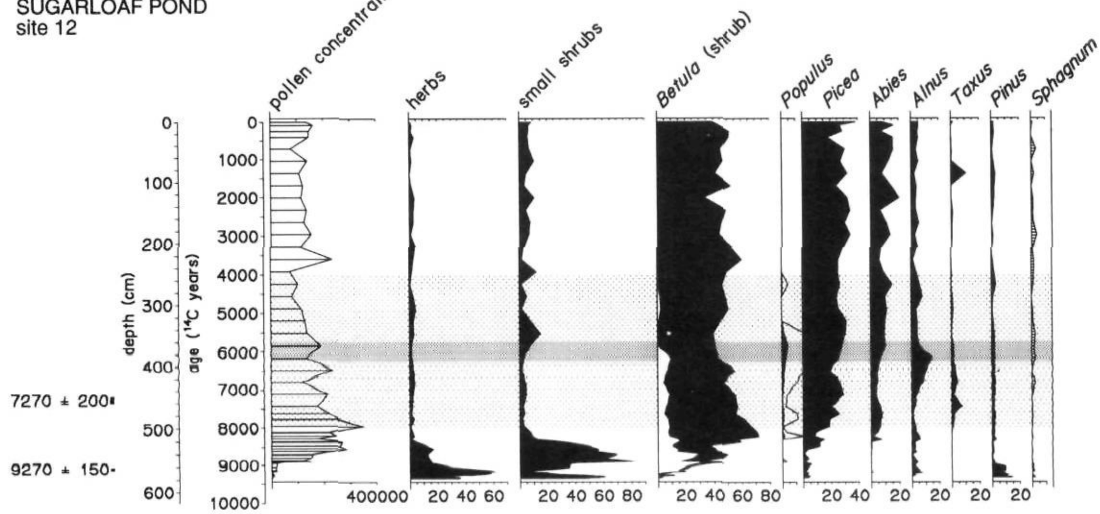

HAWKE HILLS
site 10




KENNYS POND
site 11




SUGARLOAF POND
site 12



chronologies of sites 3 and 6 only until ~8.5 ka, of site 8 until 6.3 ka. Conflicts between the chronologies of sites 1 and 2 were arbitrarily resolved by applying the chronology of site 2 to site 1. The age scales of the pollen diagrams (Fig. 3) are interpolated from adjusted dates, but radiocarbon dates are shown at the correct depths. Interpolated dates are used in the discussion unless otherwise indicated, and should be considered as only approximate.

## VEGETATION AND CLIMATE RECONSTRUCTION

Trends for major and indicator taxa are plotted for ten of the representative sites in Table III, together with levels of greater fire importance where charcoal was counted. Intervals of greater interpreted warmth for the individual sites are indicated by shading; the table cannot be used to compare absolute temperatures between sites. Summary pollen diagrams are presented in Figure 3; the category herbs includes Cyperaceae, the category small shrubs comprises Ericales, *Juniperus, Myrica gale, Salix* and (rare) *Shepherdia canadensis.*

### EARLIEST HOLOCENE TO 8.0 KA

Basal lake sediment dates ≤10.2 ka on the Avalon Peninsula and on the uplands of Central Newfoundland mark the locations of ice centres which persisted until the end of the Younger Dryas oscillation (Anderson and Macpherson, 1994; Macpherson, 1982); similar evidence suggests the persistence of ice on Long Range summits until after 8 ka (J.H. McAndrews, pers. comm., 1994). Nevertheless, trees spread rapidly along the south and southwest coasts and through the central lowlands. *Populus* and possibly also *Betula papyrifera* and *B. cordifolia* preceded *Picea* in invading the early Holocene shrub birch heath which replaced the pioneer herb-dwarf shrub tundra. However, the earliest records of tree birch (defined as grains >20 µm in diameter) may have resulted from long-distance transport (Marcoux and Richard, 1993) and may include shrub grains because of overlapping size ranges.

*Picea* was the first conifer to arrive at an interpolated date of 10 ka in the southwest of the island (Anderson and Lewis, 1992). It appears to have spread rapidly along the south coast (9.7 ka [$^{14}$C] at Pools Cove, Fortune Bay; Vardy, 1991) and across the west and centre of the island, the area with warmest summers today, arriving in the North Shore and Central Newfoundland ecoregions by about 9.5 ka (9.6 ka [$^{14}$C] at Leading Tickles (7); 9.3 ka [$^{14}$C] at Millertown). The initial expansion of spruce was invariably followed within a few centuries by the arrival (>1%) and expansion of balsam fir, an indication of priseral succession.

Where *Picea* species were identified, *P. glauca* expanded before *P. mariana.* Two spruce pollen percentage peaks normally occur, the second as much as 1000 years later than the first, the first dominated by white spruce, the second by black spruce (Vardy, 1991; D.L. Butler, in progress). In southwestern Newfoundland the very rapid decline from the initial peak of *Picea* (undifferentiated) is ascribed to a temperature reversal (Anderson and Lewis, 1992). Birch commonly peaks between the two spruce maxima, and on the main part of the island where the grains have been measured this is largely or partly due to an increase in shrub birch (Anderson and Lewis, 1992; Vardy, 1991). This study interprets the shrub birch expansion as an indication of slow climatic amelioration and the expansion of shrub-birch heath into more exposed areas, away from the sheltered lake sites where spruce was first established.

Where the timing of the second spruce rise on the main part of the island is most closely constrained it began ~8.5 ka, coinciding with the arrival and expansion of spruce at all Avalon Peninsula sites. Significant and widespread warming is indicated, permitting the expansion of spruce on the main part of the island, the dispersal of seeds to the Avalon Peninsula and the establishment of spruce trees there.

At three sites, Southwest Brook Lake (3), Leading Tickles (7) and a site in the eastern Northcentral subregion (D.L. Butler, in progress), there is some evidence for the presence of pine at ~8.5 ka (increased pine pollen percentages, high total pollen concentration), suggesting that summer temperatures may have already reached or surpassed modern levels at locations remote from windward coasts.

The climate signal contained in pollen records for the 10-8 ka interval can be summarised:

1. By ~9.5 ka temperatures in sheltered inland locations were favourable for spruce and balsam fir.
2. After 9.5 ka the trend of increasing temperature slowed, or may have been reversed; higher and more exposed areas were colonised by shrub birch.
3. Growing season duration and temperatures increased markedly at ~8.5 ka, permitting the rapid expansion of boreal forest trees. Pine may have been locally present at this time. This warming is attributed by Anderson and Lewis (1992) to diversion of glacial lake drainage from the Gulf of St. Lawrence to Hudson Bay.

### 8.0 - 6.5 KA

By 8.0 ka the major components of the present vegetation were present throughout most of the island. Payette (1993), following Lamb (1980) and Engstrom and Hansen (1985), interprets the pollen record of southeastern Labrador to indicate the arrival of *Picea* and *Abies* from Newfoundland by 7.9 ka. These trees were already present in a shrub-tundra at Cat Arm River, >350 m asl on the more sheltered eastern side of the Northern Peninsula at 8.4 ka (McNeely and McCuaig, 1991). The delayed arrival of conifers (7.4 ka) at Stove Pond (4) west of the Long Range is attributed to priseral succession following isolation of the lake from the Goldthwait Sea at 7.9 ka. At Saddle Hill Pond (5), at the northeastern end of the Strait of Belle Isle, conifers did not expand until ~7.2 ka (Henningsmoen, 1977).

An expansion of *Betula* >20 µm, taken to represent tree birch, was under way at several sites before 8.0 ka. Tree birch expansion, however, began later (8.0-7.5 ka) at upland and northern sites, where shrub birch representation continued or even expanded (interpreted as a result of upslope migration) during the 8.0-6.5 ka interval. Shrub birch presence also continued at the coastal site of Sugarloaf Pond (12) on the Avalon Peninsula. At Whitbourne Bog (9) on the Avalon Peninsula the arrival of *Betula lutea* after 8.0 ka coincided with a rapid decline in shrub birch.

At several sites the expansion of tree birch can be associated with evidence of fire; this is particularly evident at Stove Pond (4) on the Northern Peninsula where birch expansion at the expense of both conifers and heathland plants followed peak input of charcoal. While fire incidence can be related to fuel accumulation as tree density increases, this does not seem to have been the case at Stove Pond. At Bishops Falls (8) charcoal concentrations were higher than today's from 8.5 ka to 7.0 ka; birch and alder pollen percentages increased while spruce declined. This also appears to be an example of fire succession. At Southwest Brook Lake (3), on the other hand, there is no evidence to suggest that controls on the expansion of tree birch were anything but climatic. Modern birch populations in the Western Newfoundland ecoregion reflect the warm summers and long growing season, and fire is seldom a factor (Damman, 1976, 1983).

The continuous representation of *Fraxinus* at Southwest Brook Lake after 7 ka is taken to indicate its local presence. Since black ash is at its modern northern limit in Newfoundland its arrival is further evidence of a growing season, in suitable locations, as least as warm and as long as today's (Damman, 1976).

At Joes Pond (2), an expansion of *Pinus* after ~7.0 ka is evidence of warming near the southwest coast; the estimated date is poorly constrained but is at least 1000 years later than the initial date suggested for pine expansion at Southwest Brook Lake (3) in the interior. At Robinsons Pond (1), only 4 km distant and on the coastal cliff, the pine signal is absent.

The climate signal contained in pollen records for the 8.0-6.5 ka interval can be summarised:

1. In the interior of the southwest of the island increasing summer warmth and growing season length to modern levels and above is indicated by expansion of tree birch and by the arrival at 7 ka of black ash. On the Avalon Peninsula upland, tree *Betula* and *Taxus* percentages above present give the same signal.

2. Later arrival (<7.0 ka) of pine near the southwest coast than in the interior, where it may have been present by 8.5 ka, and its absence at the coast, indicate that ocean temperatures remained low. Continuing representation of shrub birch at northern and eastern coastal sites gives the same signal.

3. In central Newfoundland, on the Northern Peninsula, and to a lesser extent on the Avalon Peninsula, elevated charcoal concentrations may indicate a greater frequency of warm, dry summer weather than today. In addition, where pine was present it may have contributed to greater inflammability of the forest (*cf.* Anderson *et al.*, 1986).

6.5 - 4.0 KA

This interval began with a reduction of fire importance at all sites, and saw the spread of pine to its present limits. Pine, both *P. resinosa* and *P. strobus*, began to expand at Bishops Falls (8) in the Central ecoregion at 6.3 ka [$^{14}$C] and at Leading Tickles (7) on the coast to the north at 6.0 ka [$^{14}$C]. At these sites maximum pine percentage values exceeded those from modern lake sediment samples in the vicinity of red and white pine trees (D.L. Butler, in progress) and pine was certainly present. Pine increased at Southwest Brook Lake (3) after 5 ka. On the Avalon Peninsula, at Kennys Pond (11) (and probably also at Whitbourne Bog, 9) steady low pine values occur only after a minor peak at 4 ka and indicate scattered local *Pinus strobus*. A very minor and irregular increase in pine was recorded at Compass Pond (6) between ~6.0 and 3.7 ka, but this is interpreted as representing a regional rather than a local source (Dyer, 1986). The diachronous expansion of pine is ascribed to control by its rate of migration through the existing forest, rather than by climate; Green (1982) discusses the migration of a number of tree taxa within Nova Scotia in similar terms. Thus the presence of pine can only indicate that the limiting climatic threshold had been passed prior to its arrival. This characteristic of the record for pine, the most thermophilous tree taxon of any abundance, creates difficulties for the descriptive interpretation used in this paper. Numerical interpretations based on transfer functions that are weighted toward pine (*e.g.* Bartlein and Webb, 1985) may well yield questionable results.

*Fraxinus* may have extended its range beyond the modern limit in the 6.5-4.0 ka interval; it is recorded intermittently at low values between ~5.5 and 3.0 ka at Compass Pond (6), and this may indicate the local presence of the plant (Dyer, 1986), suggesting a longer growing season. This interpretation is supported by a decline in shrub birch at this site to very low values between 6.0 and 4.5 ka, to the benefit of both tree birch and spruce. This suggests a gradual increase in surface ocean temperature off the northeast coast, permitting the spread of forest to the higher areas of the basin. A similar, but more rapid, oceanic warming is indicated at Sugarloaf Pond (12) on the Avalon Peninsula where shrub birch declined at 6.0 ka, while spruce and balsam fir increased. Climatic amelioration is also evident at the Hawke Hills site (10) on the Avalon interior upland, where balsam fir values were elevated between ~6.0 and 3.7 ka. This period coincides with the deposition of sediment with increased organic content (Macpherson, 1982).

The 6.5-4.0 ka period was one of generally much greater fire importance than present in the central and eastern regions, with short intervals of reduced fire activity. One such interval of reduced fire activity introduced the period, another can be recognised at its close, at ~4.5-4.0 ka on the Northern Peninsula (4), in central Newfoundland (8) and on the Avalon Peninsula (10, 11) and may have been controlled by climate.

The period of maximum fire importance at Bishops Falls (8) was not one of reduced moisture, for balsam fir values were intermittently high and *Sphagnum* increased. Rather, it appears to be related to the presence of pine. It is of interest in this regard that Bergeron and Brisson (1994) find an association of high modern rates of red pine recruitment with increased precipitation near the species limit in northern Québec. That high charcoal inputs were recorded on the Avalon Peninsula uplands, 300 km downwind, at the same time indicates that fires, and by inference pine, were widespread in central Newfoundland ~6-5 ka.

Like Bishops Falls, most sites reveal an increase in *Sphagnum* at ~6 ka. Basal radiocarbon dates on bog peat from widespread coastal locations cluster at 6.3-5.0 ka (Davis, 1984; Irwin, 1994), indicating the island-wide onset of paludification, and supporting the interpretation of an increase in moisture.

What, then, are the climate signals in the pollen record for the 6.5-4.0 ka interval? They are:

1. An increase in ocean surface temperatures indicated by decreasing shrub birch and increasing tree pollen, rapid at 6 ka off the Avalon Peninsula, more gradual from 6.0-4.5 ka to the north.

2. A lengthening of the growing season in the northeast as indicated by the expansion of black ash at Compass Pond (6) after ~5.5 ka.

3. Increasing warmth as indicated by the increase in forest and change in sediment composition at Hawke Hills (10) ~6 ka. Temperatures were <1°C higher than present (Macpherson, 1982).

4. Possibly increased winter temperatures after 6 ka, recorded by elevated balsam fir values at Southwest Brook Lake (3), Leading Tickles (7) and Bishops Falls (8) (but not at Compass Pond or on the Avalon Peninsula) (Anderson *et al.*, 1991).

5. Increased moisture as indicated by increases in *Sphagnum* at sites in all regions, by other evidence of paludification, by increases in *Abies* in the North Shore and North Central regions, together with a rapid increase in *Pinus*, including *P. resinosa*.

6. A possible increase in summer convective activity contributing to greater importance of fire ~6.0-4.5 ka.

7. A reduction in fire importance, perhaps climatically controlled, during the warming at 6.5-6.0 ka, and again at ~4.5-4.0 ka.

8. A reduction in pine at the near-coastal sites of Joes Pond (2) and Leading Tickles ~4.5-4.0 ka, suggesting a reduction in ocean surface temperatures.

### 4.0 KA TO THE PRESENT

By 4.5 ka at Bishops Falls (8) and 4.2 ka [$^{14}$C] at Leading Tickles (7) pine percentages had fallen to levels perhaps indicative of scattered local populations or individuals rather than the more extensive patches of white pine — red pine forest suggested by the earlier pine peaks. The sharp decline of pine at Leading Tickles at 4.2 ka, like that at Joes Pond (2) at ~4.5 ka, is significant in that pine values never again fully recovered. Bishops Falls is still within the range of both red and white pine, but Leading Tickles, although within the range of white pine, is 10 km seaward of surviving red pine stands (Roberts, 1989). Damman (1976) suggests that red pine is limited by a mean annual maximum temperature of 30°C. This isoline is now 15 km inland of Leading Tickles (Environment Canada, Atmospheric Environment Service, unpublished data). In light of the steep coastward temperature gradient (Damman, 1976) and the location of the nearest red pine stands there has been a decline of 1.0-1.5°C in the mean annual maximum temperature at Leading Tickles since the pine maximum.

A subsequent interval of elevated pine percentages at Bishops Falls (~3.3-2.5 ka) coincides with increases in *Abies* and *Sphagnum*, with reduced charcoal input, and with a further, island-wide, cluster of basal bog dates (Davis, 1984). A further pine peak at 0.8 ka at Bishops Falls is associated with a sharp reduction in charcoal to pre-European values. The ~3.0 ka pine peak appears to have been related to increased moisture; the evidence for the 0.8 ka peak is less clear. Spruce expanded at the expense of birch after 1.5 ka, despite the reduction in fire activity, suggesting a reduction in the length of the growing season. A similar change is apparent at Leading Tickles and at Compass Pond; at the latter site it occurred quite rapidly after 4.0 ka.

At Compass Pond (6) shrub birch increased after 4.5 ka, perhaps indicating retreat of forest from the highest parts of the catchment. The subsequent expansion of spruce and fir at the expense of birch may indicate cooling at intermediate elevations, and the decline and disappearance of black ash after 3.0 ka suggest that by that time the growing season was reduced in length even at lower elevations. The end of the *Fraxinus* and *Taxus* records is associated with evidence of a major fire. A further increase in *Abies* after 2.0 ka points to increased moisture availability.

At Stove Pond (4), on the Northern Peninsula, increases in herbs and small shrubs ~4.5 ka are probably related to paludification; a coincident increase in spruce at the expense of birch may indicate cooling. Until ~3.5 ka the trends of the records for birch, spruce and fir are similar to those from Compass Pond, and a subsequent decline in the conifers and increase in *Sphagnum* indicate further paludification, echoing the record from Saddle Hill Pond (5) at the northern extremity of the peninsula (Davis *et al.*, 1988). A decline in *Sphagnum* 4.2-3.5 ka suggests drier conditions; charcoal values were somewhat higher in this interval.

On the Avalon Peninsula pine, presumably white pine, did not arrive until 4.0 ka, and it may be significant that there followed a period of local fires which caused marked changes in the vegetation. However, by ~2.5 ka fire importance was reduced to pre-European levels and Kennys Pond (11) and Sugarloaf Pond (12) recorded increases in balsam fir, perhaps indicating greater relative moisture. Increasing charcoal concentrations at Hawke Hills (10) on the Avalon Peninsula upland after ~2.5 ka may indicate increasing openness of the site and input of charcoal from distant sources; the forest limit withdrew from above the site by 3.5 ka. A decrease in birch at ~3.0 ka at this site may reflect decreasing birch input from the Avalon Forest in the lowland to the west (Whitbourne Bog, 9).

The climatic record for the period from 4.0 ka to the present is one of decreasing summer warmth, decreasing length of the growing season, decreasing importance of fire, and indications of greater but fluctuating relative moisture. Different temperature thresholds were crossed at different times in different regions and even at the same site, but comparison of the pine records at Joes Pond (2) near the west coast and Southwest Brook Lake (3) in the interior indicates that cooling was led by a change in ocean surface temperatures.

## CONCLUSIONS

The 6 ka time-horizon marks the beginning of the period of greatest Holocene warmth on the island of Newfoundland. Differences in growing-season temperatures between 6 ka and today are at most 1.5°C. Although the reconstructed vegetation at inland sites indicates that temperatures may have been at or close to modern values as early as 8.5-8.0 ka, it was not until 6 ka on the Avalon Peninsula and after 5.5 ka on the northeast coast that coastal sites registered the final reduction of cold-tolerant taxa and arrival or increase of thermophilous taxa. Thus oceanic warming lagged terrestrial warming, but the influence of the cold ocean in the middle Holocene was much less extensive than it had been before 8.5 ka (Anderson and Lewis, 1992). Although charcoal input was high in central Newfoundland between 6.0 ka and 4.5 ka, fires were related to the widespread presence of pine rather than to increased drought; most sites, in fact, provide evidence of increased moisture compared with the earlier Holocene. Available moisture remained generally high after 6 ka, but some fluctuations are apparent in the north and northeast, where the interval following 3.5 ka was again markedly moist.

The first clear indication of post-Hypsithermal cooling occurred in the interval 4.5-4.0 ka at northeastern and western near-coastal sites, in the form of a decline of pine or tree birch, depending on the location. Evidence of cooling at interior sites occurred after 4.0 ka. Thus oceanic cooling led terrestrial cooling. In the southeast of the island, however, evidence of cooling was delayed until after 3.7 ka at Avalon Peninsula sites. Fire activity at these sites was reduced to pre-European levels after 3.0 ka, but in central Newfoundland fire importance declined to pre-European levels only after 1.5 ka. Evidence of greater moisture at most sites in the later Holocene may have resulted from a reduction in evapotranspiration, rather than from an increase in precipitation.

The 6.5-6.0 ka and 4.5-4.0 ka intervals were marked by temporarily reduced fire importance. The climatic implications of synchronous warming or cooling and reduced fire activity in these intervals are unclear.

The timing and trend of inferred temperature changes at coastal sites are in broad agreement with the Holocene sequences of bottom water temperatures in Notre Dame Channel, off the northeast coast of Newfoundland, and of surface water temperatures in Canso Basin, southwest of the island (Scott *et al.*, 1984). Evidence from Notre Dame Channel indicates that during most of the Holocene the Outer Labrador Current water mass dominated, with bottom water temperatures rising to a maximum of 2-4°C in the interval ~6.0-2.5 ka. Since ~2.5 ka the colder Inner Labrador Current water mass has dominated with bottom water temperatures of 0-3°C, colder than any experienced since the immediate post-glacial. In Canso Basin, southwest (and, in the growing season, upwind) of Newfoundland, surface water temperatures were higher than present from before 6 ka to ~4.8 ka.

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# APPENDIX

## THE SITES

Information on the ecoregions (Fig. 1B) is drawn largely from Damman (1983) and Banfield (1983; Fig. 2). Site locations are shown in Figure 1A. Radiocarbon dates and geographic coordinates are given in Table II. Summary pollen diagrams are presented in Figure 3.

### WESTERN NEWFOUNDLAND ECOREGION

Uplands rise to 800 m, but in inland valleys the growing season is warm and long (growing degree-days >1200); precipitation is abundant and fire is rare. *Abies balsamea* is the dominant conifer. Some (rare) deciduous forest species are confined to this region.

1. Robinsons Pond (J. McAndrews, pers. comm. 1987; McCarthy *et al.*, in press)

The site is a kettle ~40 m asl immediately behind the coastal cliff in an area of pasture and alder scrub.

2. Joes Pond (Anderson and Lewis, 1992; J. McAndrews, pers. comm., 1987; McCarthy *et al.*, under review)

The site is at 42.5 m asl in a valley on the coastal plain 4 km inland from the shore of St. Georges Bay; the site is surrounded by boreal forest.

These sites are conveniently discussed together. The presence of up to 10% calcium carbonate in the sediment may account for the confusing chronology; the problem has been simplified by applying the Joes Pond dates to the corresponding horizons at Robinsons Pond. The present chronological interpretation differs from that of McCarthy *et al.*

The early record of boreal trees at Joes Pond is of an initial and shortlived *Picea* expansion (~9.7 ka) followed by an increase in *Abies* (9.4 ka [$^{14}$C]) and *Betula*. The early spruce expansion at Robinsons Pond is much less marked, reflecting the exposed coastal location, but the birch expansion is comparable, suggesting the possibility of an expansion of shrub birch into a dwarf-shrub tundra along the coast as well as of tree birch inland. At Joes Pond *Pinus* expanded after 7.0 ka and declined rapidly ~4.5 ka and more slowly to modern values by 3.3 ka, but this signal is missing at Robinsons Pond. At 3.3 ka [$^{14}$C] a massive expansion of *Alnus* indicates the development of alder scrub as a consequence of coastal cooling or increased soil moisture.

This record indicates that the temperature threshold for spruce and fir was crossed early in the Holocene at Joes Pond, and for pine by 7.0 ka. It is possible that pine was never present at Robinsons Pond on the coast. Rapid cooling at ~4.5 ka was followed by further cooling and increased moisture (increased wetland taxa).

This climatic interpretation is supported by reconstructed mean July temperatures 1°C higher than present (McCarthy *et al.*, under review) during the period of high pine values at Joes Pond (~6.5-3.7 ka). The original interpretation of McCarthy *et al.* places the climatic optimum at Joes Pond between ~7.0 and ~5.5 ka, ending well before the better-dated pine decline on the northeast coast at Leading Tickles (exposed to the influence of the Labrador Current) or even before clear evidence of cooling at Stove Pond, on the Northern Peninsula.

3. "Southwest Brook Lake" (informal name) (Anderson and Lewis, 1992; T.W. Anderson, pers. comm., 1994)

At the boundary between the Western, Central and Long Range Barrens ecoregions. The lake is in a valley at 145 m asl in a plateau rising to >600 m; treeline is at 300-360 m. This is a key site in the hypothesis of an early Holocene climatic reversal (Anderson and Lewis, 1992).

The date of 11.1 ka marks renewed organic sedimentation following the end of the Younger Dryas (earliest Holocene); it has been adjusted to 10.5 ka. *Populus* was the first tree to migrate into tundra or heath with small shrubs and shrub *Betula*. An increase of *Picea* to a sharp peak at 9.7 ka was accompanied by a decrease in shrub birch. Spruce immediately declined, being replaced by *Betula* (including grains <20 µm), *Alnus* and *Abies balsamea*. *Picea* increased again at 8.4 ka, as shrub birch again declined and larger birch grains increased. *Fraxinus* was continuously present after 7.0 ka. A minor pine peak at ~8.5 ka may reflect the arrival of pine trees in the Maritime Provinces (Anderson, 1985) or may indicate that pine was present regionally (see also sites 1 and 2). Pine increased slowly after 5.0 ka; a possible decline is apparent before the record ends at ~3 ka.

This record suggests that the temperature threshold for spruce and fir was crossed early in the Holocene, and that there was slow amelioration of summer temperatures until 8.5 ka, possibly interrupted by a cold oscillation after 9.7 ka (see also site 2) (Anderson and Lewis, 1992). At 8.5 ka rapid warming permitted the expansion of spruce and tree birch on the slopes above the lake. Possible further warming after 5 ka permitted expansion of pine; a pine decline after 3.3 ka may indicate cooling. An increase in *Sphagnum* after 5.5 ka indicates increased moisture.

## NORTHERN PENINSULA FOREST ECOREGION

This region consists of the western and eastern margins of the Northern Peninsula. Summers are cool and short (900-1100 growing degree days) especially on the coast, and fire is infrequent. *Abies balsamea* is the principal conifer.

4. Stove Pond

The site is at 55 m asl, 8 km inland on the coastal lowland west of the Long Range Mountains of the Northern Peninsula. The lake lies within an extensive area of bog, with poor forest on higher areas of till and raised strandlines and along streams. The basal date (7.8 ka) marks isolation of the lake on emergence from the Goldthwait Sea.

Boreal forest (*Picea, Abies, Alnus*) began to develop ~7.4 ka following emergence. Within 200 years, following fire, the conifers were replaced in part by *Betula* (grains >20 µm); high tree birch percentages suggest a similarity to the modern forest in southwestern Newfoundland where mean growing-season temperatures are 1-2°C warmer (Damman, 1976). An increase in *Sphagnum* at 6 ka marks the onset of paludification, accompanied by a decline in tree birch and an increase in *Picea*; birch declined more rapidly after 5.0 ka. *Sphagnum* declined in the interval 4.2-3.5 ka when charcoal input was high; *Abies* peaked at the beginning and end of this interval. The progress of paludification during the past 3000 years is indicated by increasing *Sphagnum*, herbs and small shrubs, and decreasing *Picea* and *Abies*.

The record indicates that summer temperatures at this inland site were warmer than present by 7 ka. Cooling was evident at the site after 5 ka. Paludification began at this time, regressed 4.2-3.5 ka and has continued to the present.

## STRAIT OF BELLE ISLE ECOREGION

Despite the low elevation (<60 m asl) summers are cold and short (<900 growing degree-days). Tree species are stunted, seldom >6 m tall and frequently form krummholz (tuckamore) <3 m high.

5. Saddle Hill Pond (Henningsmoen, 1977; McAndrews and Davis, 1978; Davis, 1984; Davis *et al.*, 1988; J. McAndrews, pers. comm., 1994)

The site is at 32 m asl, 1 km inland from the north coast of the Northern Peninsula. The lake is surrounded by bog; mixed tuckamore occurs in sheltered locations among the surrounding heathland, and poor forest occurs 10 km inland. Davis *et al.* (1988) ascribe the local absence of trees to climatic constraints, paludification, and modern cutting. The basal date (9.4 ka) is minimal for isolation of the site on emergence from the Daly Sea (Grant, 1992).

*Picea* and *Abies balsamea* expanded at ~7.2 ka (Henningsmoen, 1977). An increase in *Sphagnum* at 5.2 ka marks the onset of paludification. More extensive *Sphagnum* peat development associated with decreasing conifer percentages and pollen influx is evident after ~3.0 ka in peat monoliths taken from the nearby L'Anse aux Meadows Norse site (Davis, 1984; Davis *et al.* 1988). These changes are interpreted as responses to climatic cooling. This site was always colder than Stove Pond (Site 4) and an "optimum" cannot be identified.

## NORTH SHORE ECOREGION

This highly irregular coastal zone is drier and experiences warmer, but shorter, summers than southwestern coastal areas (1100-1300 growing degree-days); fire is a regular occurrence. *Picea mariana* is the predominant tree. The quality of the forest deteriorates with coastal exposure.

6. Compass Pond (Dyer, 1986)

The site is a rock basin lake on a plateau 236 m asl and 3 km inland from the northern coast of the Baie Verte Peninsula. The catchment rises to >300 m; the lower slopes are forested but the summits support barrens. The basal date of 11.7 ka marks the inception of organic sedimentation; it is adjusted to 10.5 ka. The date of 9.9 ka marks the arrival of *Picea*; it is adjusted to 9.5 ka.

*Populus* (probably *P. tremuloides*) was the first tree to invade the early low shrub-herb tundra, where shrub birch was also expanding. Increasing *Picea glauca* pollen probably marks the approach of the tree which reached the site ~9.5 ka. *Abies balsamea* and *Alnus* expanded ~8.9 ka, followed by further expansion of *Picea* which by 8.0 ka consisted entirely of *P. mariana*. High APF and increased organic content of the sediment at 8.3 ka [$^{14}$C] mark closure of the forest at the site. *Betula* <20 µm expanded after 8.0 ka until ~6.0 ka while *Alnus* values remained high; these shrubs may have been colonising upper slopes in the catchment and vicinity. Shrub birch declined after 6 ka. *Betula* >20 µm increased after 8.0 ka at the expense of *Picea* and *Abies*; the input of large birch grains remained high until 4.0 ka. The presence of *Fraxinus nigra* during this period suggests expansion of its range. *Pinus* values were higher than present in the interval 6.0-3.5 ka, but probably not high enough to indicate the local presence of pine trees. After 6 ka charcoal was frequent; oscillating values for *Betula*, *Picea, Abies*, *Alnus* and small shrubs and the sporadic presence of *Populus* suggest the influence of fire. Declining values for *Betula* after 4.0 ka are associated with increasing *Picea*, *Abies* and *Sphagnum*, suggesting decreasing summer warmth and increased moisture availability. A major fire at ~2.5 ka, signalled by abundant charcoal, decreases in spruce, fir and tree birch, and increases in alder and shrub birch, marks the end of the *Fraxinus* and *Taxus* records. Increased herbs, *Alnus* and charcoal in the topmost samples are ascribed to modern disturbance of the catchment.

The record resembles that from Stove Pond (4) in the increased middle Holocene values for *Betula*, and indicates gradual summer warming from the early Holocene to 6 ka; a temperature decline is evident after 4 ka.

7. Leading Tickles (Macpherson and Anderson, 1985)

The site occupies a rock basin 105 m asl 1 km from the shore of an arm of Notre Dame Bay. The surrounding hills rise to 190 m. The forest has been subject to cutting, which may account for increased *Alnus* in the most recent sediment. The basal sediment includes evidence of the Younger Dryas oscillation (Macpherson and Anderson, 1985; Anderson and Macpherson, 1994).

Although *Betula* grains were not measured, and no attempt was made to discriminate between *Picea glauca* and *P. mariana*, the early Holocene sequence is sufficiently similar to that from Compass Pond for the same general interpretation to apply. The one exception is the later rise and smaller peak of *Alnus*. Between 8.0 ka and 4.0 ka *Betula* values were lower while *Picea* and *Populus* values were higher than at Compass Pond, suggesting a response to fire.

At 6.0 ka [$^{14}$C] *Pinus*, including much *P. resinosa*, increased markedly, and values remained high until 4.2 ka [$^{14}$C]. This is the period when charcoal concentrations at Bishops Falls (8, below) were maximal, and red pine may have taken advantage of openings created by fire. After 4.2 ka pine values were maintained at a higher level than before 6 ka, indicating the presence of scattered *P. strobus*; the site is beyond the present range of red pine. Despite the evidence for fire succession while pine values were high (6.0-4.2 ka), there is evidence to suggest, nevertheless, that this was not a period of reduced precipitation: *Abies* increased sporadically, *Taxus* was more abundant than today and *Sphagnum* increased. This accords with the finding of Bergeron and Brisson (1994) that modern rates of recruitment of red pine near its limit in northwestern Québec are correlated with precipitation.

The *Abies* decline at 3.5 ka may indicate a change to drier conditions more similar to those prevailing today on this leeward coast. The subsequent decline in *Betula* and increase in *Picea* resemble those at Compass Pond (6) and are attributed to cooling.

CENTRAL NEWFOUNDLAND ECOREGION: NORTHCENTRAL SUBREGION

This is the most "continental" area of the island, with rolling or hilly topography <200 m asl. Summers are warm (1200-1300 growing degree-days) with mean annual maximum temperatures >30°C in much of the subregion, but are shorter than in the Western Newfoundland ecoregion. Precipitation is <1200 mm; occasional prolonged dry spells occur and fire frequency is the highest on the island. *Picea mariana* is the predominant tree and *Populus tremuloides* is widespread (Page, 1972). *Pinus resinosa* is restricted to this subregion (Damman, 1976; Roberts, 1985).

8. BISHOPS FALLS

The site is a kettle at 75 m asl in an area of till and glaciofluvial sediment with low relief. The basal date of 11.8 ka marks the inception of organic sedimentation; it is adjusted to 10.5 ka. The date of 10.8 ka marks the early *Picea* rise; it is adjusted to 9.5 ka.

The pollen record in the early Holocene is sufficiently similar to that from Leading Tickles for the same general interpretation to apply. Charcoal values were high in the interval 8.8-7.0 ka, and fire may have maintained *Betula* populations at a higher level than at Leading Tickles. Charcoal concentrations were reduced ~6.4 ka, but were followed before 6.0 ka by very high concentrations which were associated with a sharp reduction in *Betula* and a very sharp increase in *Pinus*, including more identifiable *P. resinosa* than *P. strobus*. Further peaks in pine at 5.3 ka, 3.0-2.5 ka and 0.8 ka all follow or are associated with increased charcoal concentrations. Each pine peak includes successively smaller proportions of *P. resinosa* and relatively greater proportions of *P. strobus*. Bergeron and Gagnon (1987) suggest that red pine populations can be maintained by a shifting mosaic of populations taking advantage of new openings created by fire. The evidence from this site suggests that if this process operated competition from other species gradually reduced red pine numbers after its initial arrival; it is confined today to xeric sites on glacial outwash or bedrock. Thus the pine record may not contain a specific climatic signal. However, the 3.0-2.5 ka pine peak is accompanied by increased *Abies* and *Sphagnum*, indicating moist conditions, and suggesting variability of precipitation levels after the middle Holocene. After 2.0 ka *Picea* increased at the expense of *Betula* and fire activity decreased.

AVALON FOREST ECOREGION

This is a small (~500 km$^2$) relatively low-lying region much of which is underlain by ribbed moraine with countless small lakes and bogs. The southwestern exposure leads to a climate which is foggy and humid with cool but relatively long summers (<1200 growing degree-days) and mild winters (Banfield, 1983; 1994). *Abies balsamea* is the dominant conifer; *Betula lutea* is present.

9. Whitbourne Bog (Terasmae, 1963)

The site occupies an infilled lake at 60 m asl. The basal 160 cm of the core consists of lacustrine sediment, the remainder is peat. The diagram was drawn from data supplied from the Geological Survey of Canada's pollen data base (H. Jetté, pers. comm., 1993) and with reference to Terasmae's original diagram. The diagram is of particular value because of the discrimination of *Betula, Picea* and *Pinus*. *Populus* and *Taxus* were not recorded.

The single date (8.4 ka) immediately precedes the expansion of *Picea glauca* and the decline of herbs, small shrubs and small (shrub?) *Betula*. An expansion of *Abies* followed, accompanied by expansions of both *Betula papyrifera* and *B. lutea*. Shortly thereafter *Picea mariana* began to expand and, with *Abies balsamea*, continued this trend to the topmost (anthropogenically influenced) level while *Betula* declined. The pine curve indicates that most of the early inblown pine pollen was of the *Pinus banksiana/resinosa* type. A middle Holocene pine peak is largely of the same type, and is probably also of distant origin, but steady low values of *P. strobus* above this level probably indicate a local population of white pine, which is now severely depleted by cutting. Pre-modern *Abies* values were exceptionally high. Interpolation of dates is not attempted.

MARITIME BARRENS ECOREGION: SOUTHEASTERN AND NORTHEASTERN SUBREGIONS (AVALON PENINSULA)

The area is a plateau at 150-300 m; productive forest (~30% of area) is limited to sheltered interior valleys and areas distant from the south coast. Summers are cool (1100-1200 growing degree-days) and precipitation is abundant. Winter snow cover may be discontinuous. *Abies balsamea* is the dominant conifer.

10. Hawke Hills (Macpherson, 1982, 1994)

The site is a kettle at treeline (~220 m asl) in an area of disintegration moraine on the western flank of the Hawke Hills (>300 m), overlooking the lowland of the Avalon Forest. The basal date (7.2 ka) postdates the arrival of *Picea* on the upland (8.4 ka [$^{14}$C] at Golden Eye Pond, 208 m, 9 km to the NE); deglaciation of the upland occurred shortly before 10 ka.

Because of the site's aspect and open vegetation (representation of herbs and low shrubs) it is open to receive pollen and charcoal fragments from the forest to the west and from the main part of the island. The increase in *Betula* at the base follows a charcoal peak. The increase in *Abies* at ~6.0 ka is interpreted as reflecting an increase of fir near the site and coincides with the beginning of more organic sediment accumulation which continued until 3.7 ka, when fir declined. A sharp decline of *Betula* at ~3.0 ka may in part reflect a birch decline in the Avalon Forest. However, it is accompanied by relative increases in herbs and low shrubs and reductions in the rate of sediment accumulation and pollen influx. Together with a reduction in *Taxus* these changes suggest a withdrawal of the local treeline. An additional factor to be considered in the later Holocene record is the increased input of nonarboreal pollen from the developing marginal bog, but removal of wetland taxa from the pollen sum does not affect the interpretation (Macpherson, 1982).

High charcoal input at 5-6 ka correlates with central Newfoundland (Bishops Falls, 8), but the high input at 3-4 ka can be correlated with Kennys Pond (11), and probably relates to regional fires on the Avalon Peninsula.

This site recorded greatest summer warmth between 6.0 and 3.7-3.0 ka, when the upper forest margin rose above the site. Forest did not extend to cover summits 100 m higher than the site where arctic-alpine elements persist in the flora. Given lapse rates similar to the present this limits warming to <1°C (Macpherson, 1982).

11. Kennys Pond

The site lies at 70 m asl in a kettle 3.5 km from the Atlantic Coast; it is sheltered by the coastal hills in which Sugarloaf Pond (12, below) lies; catchment relief is only 10 m. The surrounding area of till was cleared for agriculture before incorporation into the City of St. John's; it is reasonable to assume that the original forest was richer than that in the Sugarloaf Pond catchment. The basal date (8.6 ka) is minimal for deglaciation and indicates late decay of ice; it marks the local expansion of *Picea*.

Tree birch values were high at ~6.0 ka; a slight rise in charcoal may indicate fire succession. Charcoal values were high ~5.3-4.7 ka and ~4.0-2.5 ka; anthropogenic fire accounts for high charcoal values 0.3-0 ka. High charcoal values centred on 5.0 ka were associated with a reduction in birch and an increase in spruce. Subsequent reduced charcoal input until ~4.0 ka was accompanied by an increase in fir and a further increase in spruce. The subsequent period of high fire incidence followed the arrival of pine, present at low values after 4.0 ka, and had major effects on the vegetation; peak values of *Alnus* and *Populus* were recorded, indicating fire succession, and *Abies* values were greatly reduced. The subsequent period of low charcoal concentrations saw increases of birch and fir. *Sphagnum* increased after 5.0 ka.

High birch values by 8.5 ka suggest summer temperatures warmer than present. Birch peaked at 6 ka and declined rapidly after 5 ka in favour of spruce and fir. This vegetation change was associated with evidence of fire and was not controlled initially by climate; there is no evidence of corresponding change at the more exposed Sugarloaf Pond site until after 3.5 ka.

12. Sugarloaf Pond (Macpherson, 1982)

The site is a rock-basin lake 1 km from the Atlantic coast, at 100 m asl in a steep-sided col in a range of coastal hills rising to 170 m. The forest cover thins on slopes above and seaward of the site. The basal date (9.3 ka) on basal organic sediment is minimal for deglaciation and indicates late deglaciation.

*Picea* was the first tree to expand in the initial herb — small shrub — shrub birch tundra. There is no evidence of early arrival of *Populus*. Expansions of *Abies balsamea*, tree *Betula* and a further expansion of *Picea* followed by 8.0 ka. *Alnus* was not clearly present until 7.0 ka, increasing until 6.2 ka, when it declined along with shrub birch while balsam fir expanded. This sequence is interpreted as representing the development of forest near the site, while shrub birch grew on the upper slopes. At 6.2 ka balsam fir extended its vertical range, possibly preceded by *Alnus* and *Populus*. *Taxus* values were high ~7.5-6.5 ka; by analogy with the Hawke Hills record this suggests a forest margin environment. Tree birch peaked at 3.5 ka, to be replaced in part by spruce, and at 2.0 ka by balsam fir.

Summer temperatures near the site were similar to today's by 7.5 ka. Expansion of forest to higher parts of the catchment by 6.2 ka indicates further warming, probably related to higher ocean surface temperatures. The tree birch peak at 3.5 ka may indicate maximum summer warmth; it is associated with a decline in balsam fir and coincides with clear evidence of fire at Kennys Pond. Charcoal fragments were not counted but were more abundant than present from 8.5 ka to 3.0 ka. Balsam fir increased ~2.0 ka, indicating increased moisture, but the *Sphagnum* record does not indicate significant paludification.