Holocene vegetation and climatic history of Prince Edward Island, Canada

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The vegetation and climate of the Holocene of Prince Edward Island are reconstructed from pollen analysis of four Sphagnum peat bogs, Portage and East Bideford Bogs in the west and Mermaid and East Baltic Bogs in the east. The discussion is based largely on percentage data supported by pollen influx estimates.

The earliest recognizable vegetation was tundra-like with nonarboreal birch, willow, Artemisia, and upland grasses and sedges. The vegetation changed remarkably within a short period, from tundra at 10 000 years BP, to forest-tundra (spruce - nonarboreal birch association) between 10 000 and 8000 years ago, to pine at or shortly after 8000 years ago. Hemlock arrived 7000 years ago and dominated along with white pine from about 6500–4500 years BP. Beech came in about 3400 years ago and formed part of a hemlock–beech–birch association up until modern times. Sharp increases in weeds and grasses and declines in hemlock, birch, and beech denote European settlement approximately 100–150 years ago.

A gradual warming trend is inferred for the period prior to about 8000 years BP, but rapid climatic improvement took place shortly after 8000 years ago corresponding with the pollen transition from spruce to pine. Maximum temperatures (close to 8.5°C) were reached approximately 4000 years ago when the mean annual temperature may have been almost 2.5°C warmer than present. Deterioration of the climate occurred at approximately 3000 and 1500 years ago, coinciding with increases in spruce, Ericaceae, and Sphagnum, and a decrease in pine.

On reconstruit l'histoire de la végétation et du climat au cours de l'Holocène dans l'île du Prince-Édouard à partir de l'analyse du pollen provenant de quatre tourbières à Sphagnum, les marais de Portage et d'East Bideford à l'ouest, et de Mermaid et d'East Baltic à l'est. On base la discussion surtout sur les données en pourcentages appuyées par des estimations d'influx de pollen.

La végétation la plus précoce qu'on reconnaît était de type toundra avec des bouleaux et des saules non arboreens, la présence d'Artemisia, et des herbes et laîches de plateaux. La végétation a changé de façon remarquable durant une courte période de temps de la toundra, il y a 10 000 ans, à la toundra-foret (association épinette – bouleau non aboreen) entre 8000 et 10 000 ans, et à la forêt de pin vers 8000 ans ou un peu après. La pruche est arrivée il y a 7000 ans et a dominé avec le pin blanc d'environ 6500–4500 ans avant le présent. Le hêtre est arrivé il y a environ 3400 ans et forme une partie de l'association pruche–hêtre–bouleau qui persiste encore aujourd'hui. Des augmentations nettes dans le pollen herbacé et des diminutions de la pruche, du bouleau et du hêtre marquent l'arrivée des Européens il y a environ 100–150 ans.

On reconnaît une tendance graduelle au réchauffement pour la période antérieure à environ 8000 ans avant le présent, mais une amélioration climatique rapide s'est produite peu après 8000 ans correspondant à la transition de l'épinette au pin. Les températures maximales (près de 8,5°C) ont été atteintes il y a environ 4000 ans alors que la température moyenne annuelle pouvait être environ 2,5°C plus chaude qu'actuellement. La détérioration du climat s'est produite approximativement entre 3000 et 1500 ans avant le présent, ce qui coïncide avec l'augmentation dans la population d'épinettes, d'Ericacées et de Sphagnum et la diminution du pin.

Introduction

Even though Prince Edward Island is only about 5600 km² in surface area, there are, nevertheless, several suitable sites to study the succession of vegetation and the climatic cycle of the Holocene, herein defined as the time interval since 10 000 years BP. Most of these sites are peat bogs and up to 25 such potential deposits exist throughout the island (Graham and Associates Ltd. 1972, 1974). On the other hand, the freshwater lakes and ponds only occur in the north-central and eastern parts of the island. Only peat bog sites were analyzed in this study.

This study traces the history of vegetation and climate of Prince Edward Island since the retreat of Wisconsinan ice from the Maritime Provinces. To test whether this history was consistent throughout the island as a whole, four sites were studied, Portage and East Bideford Bogs in the west and Mer-
Fig. 1. Map of Prince Edward Island showing location of sampling sites. The unspecified dots represent locations of other peat bog and lake sites under study. The dashed line approximates the westward extent of freshwater ponds and lakes and associated glaciofluvial and glaciolacustrine deposits.

maid and East Baltic Bogs in the east (Fig. 1). Pollen profiles of the Portage, Mermaid, and East Baltic Bogs comprised an earlier unpublished study (Anderson 1967), and an additional paper incorporating data from several other sites is planned.

The initial stimulus for such a study partly stemmed from comments made by Erskine (1961) that "the vegetational history of the Island is, at best, hypothetical until analyses may be made of peat and lake-sediment samples for fossil pollen." Also, such a pollen stratigraphic undertaking complements studies carried out by Livingstone and Livingstone (1958), Livingstone (1968), Railton (1975), and Hadden (1975) in Nova Scotia and by Terasmae (1973) and Mott (1975) in New Brunswick, resulting in a better understanding of late Quaternary regional vegetation migration patterns in eastern Canada. With the exception of a single peat bog – intertidal peat study by Terasmae (in Frankel and Crowl 1961), there had been no detailed pollen analysis of Prince Edward Island lake or bog sediments.

General Physical and Floristic Features

Physiography

Prince Edward Island forms part of the Maritime Plain physiographic unit (Bostock 1970) which includes northeastern and central New Brunswick and northeastern Nova Scotia. The topography of the island is largely bedrock controlled (Crowl 1960b; Prest 1972). The bedrock consists mainly of red sandstone, mudstone, and conglomerate and is thought to be Late Pennsylvanian and Early Permian in age (Barss et al. 1963; Langston 1963). Rock outcrops are prevalent along the much indented coastline; inland the bedrock is mantled by up to a maximum 3–4.5 m of glacial drift (Prest 1973).

The island is often described as a gently rolling lowland because much of the surface undulates at elevations of less than 60 m above sea level. Two distinctly hilly regions occur in the centre and in the southeast, but nowhere does elevation exceed 146 m. In the west, the terrain is less undulating and the surface is relatively low and flat with elevations ranging from sea level to as high as 53 m in the extreme northwest.

Many small streams and brooks drain the island; these flow from drainage divides running east–west up the centre and north–south in the eastern part of the province. Where drainage is impeded, extensive swamps, bogs, and poorly drained soils prevail; these are particularly common in the east and west but rare in the central hilly region.

Glacial History

The surficial deposits were mapped by Owen (1949), Crowl (1960a,b, 1969), Frankel (1960, 1966), Crowl and Frankel (1970), and Prest (1962, 1964, 1972). Prest (1973) compiled the data from these various studies into an overall surficial deposits map of Prince Edward Island, with descriptive notes on the distribution and nature of the glacial and postglacial deposits and events. The evidence of glaciation, general ice-flow patterns,
and retreat of Wisconsinan ice are succinctly discussed in Prest and Grant (1969) and in Prest (1970).

Prince Edward Island was influenced largely by a massive ice dome located just north of the island and centred over the Gulf of St. Lawrence. Late Wisconsinan ice flowed out from this dome across western Prince Edward Island and curved to the southwest and then westward along Northumberland Strait (V. K. Prest, personal communication, 1979). It is uncertain yet how much, if any, of this ice extended throughout the eastern part of the island. The widespread abundance of glaciofluvial and glaciolacustrine deposits throughout the east-central and eastern parts of the island possibly relates to this advance or to an earlier Wisconsinan advance (V. K. Prest, personal communication, 1979). Grant (1977) speculated that the eastern part of the island, east of the dashed line shown in Fig. 1, may not have been covered by the last advance of Wisconsinan ice on the basis of dissimilarities in the ice-flow features and nature of the glacial deposits and soils in the area. Palynological and radiocarbon-dating evidence from this study, however, do not support such an inference. Radiocarbon dates from the base of the two eastern sites, Mermaid and East Baltic Bogs, have shown that these sites, in fact, are slightly younger than those in the western part of the island. The reverse situation would be expected if Grant’s concept is valid.

Glacial recession apparently started as early as 14 000 – 15 000 years ago in the Gulf of St. Lawrence and subsequently in the eastern and western extremities of Northumberland Strait (Prest 1969). By 12 500 years ago the sea had encroached onto the western end of the island; shells, which Prest (1970) related to a high sea level stand, were found at the western end and were radiocarbon dated at 12 400 ± 170 and 12 670 ± 340 years BP (GSC-101, GSC-160; Dyck and Fyles 1963, 1964).

Compact basal till, distinguishable in three phases as sand, clay-sand, and clay, covers most of the island (Prest 1973). Ablation till and glaciofluvial and glaciolacustrine deposits, which reflect ice stagnation during the final stages of deglaciation, are especially common throughout the east-central and eastern parts of the island east of the dashed line shown in Fig. 1. For further details on the nature and distribution of unconsolidated deposits the reader is referred to Prest (1973).

Climate

Putnam (1940) maintained Prince Edward Island is influenced more by the continental winds, air masses, and weather systems moving eastward than by maritime systems, even though no part of the island is more than 16 km from the sea. Frontal storms and generally westerly winds bring cold air masses from central Canada in winter, but southerly winds bring warm, humid air from the south and southwest in summer. The sea apparently acts as a moderating effect as the mean annual and monthly temperatures are uniform throughout the island and do not vary more than 1°C. Average January and July temperatures are −6.5 and 19.1°C, respectively, while the mean annual temperature averages about 6.0°C (Wernstedt 1972). The climate is considered moist, as precipitation averages just over 100 cm per annum, snowfall about 203 cm per annum, and the mean annual relative humidity 83%. The frost-free period amounts to about 140 days, giving a growing season of approximately 180 days. In spring, however, northwesterly winds delay the growing season, especially if heavy ice conditions persist in the Gulf of St. Lawrence.

Vegetation

Prince Edward Island is situated within the Acadian Forest Region of Rowe (1977) and the Maritime Lowlands Ecoregion of Loucks (1962). The natural climax vegetation is a mixed forest in which white and red spruce (Picea glauca and P. rubens), fir (Abies balsamea), sugar and red maple (Acer saccharum and A. rubrum), beech (Fagus grandifolia), yellow birch (Betula lutea), white pine (Pinus strobus), and hemlock (Tsuga canadensis) predominate. Extensive stands of individual species are rare although pure stands of beech dominated the hilltops of the central and southeastern uplands in the past (Erskine 1961).

Northern hardwood elements, i.e., beech, sugar maple, and yellow birch, and the conifers red spruce, hemlock, and white pine, are typical present-day colonizers of the well drained upland areas. White spruce and black spruce (Picea mariana), fir, eastern white cedar (Thuja occidentalis), and tamarack (Larix laricina) dominate the poorly drained soils, swamps, and bogs. Red and white spruce are conspicuous along streams, fence rows, and on abandoned farmlands. Red sandy loams of the better drained areas, and burned-over areas have encouraged jack pine (Pinus banksiana) growth, but white pine is more widespread on the coarser textured soils. The most adaptable and best growing coastal trees seem to be white spruce, balsam fir, and yellow birch.

Extensive surveys of the vegetation of Prince Edward Island were carried out by Hurst (1940), Gaudet and Profitt (1958), and Erskine (1961). Erskine has discussed the vegetation in terms of five major communities: forest, freshwater, bog,
Characteristics of the Sampling Sites

The peat bogs are open raised Sphagnum bogs, except the Mermaid site which is a heavily wooded lowland site adjacent to Mermaid Pond. The open areas of the bogs are dominated mostly by ericaceous plants (i.e., Chamaedaphne calyculata, Azalea canadensis, species of Vaccinium), cloudberry (Rubus chamaemorus), cotton grass (Eriophorum angustifolium), and Sphagnum interspersed with islands of stunted black spruce and tamarack. The margins of the bogs are wooded with dense stands of white and black spruce, tamarack, eastern white cedar, wire birch (Betula populifolia), red maple, and alder (Alnus sp.).

The sediments generally consist of poorly decomposed Sphagnum peat near the surface grading downward to well decomposed peat. All the sites were originally lakes, as fine algal gyttja underlies peat. Coarse sand is present at the base; at Mermaid and East Baltic Bogs sand overlies reddish brown till.

Portage Bog (46°40'25"N, 64°04'30"W) comprises 1.3 ha and is 6.6 m deep at the centre. It is surrounded by shallow, fine-grained marine deposits and fine sandy to clayey loams of the Armadale complex and the Egmont and Haliburton Soil Series (Whiteside 1965). In the bog area, the island is only about 3.5 km wide, and the topography is flat and low (just under 8.0 m above sea level (asl)).

East Bideford Bog (46°38'N, 63°54'W) occupies 6.5 ha of open area and is 6.5 m deep at the centre. The glacial deposits in the area are clayey sand till to the south and west and glaciomarine beach gravels to the north and east. The soils are fine, sandy loams of the Kildare, O'Leary, and Albeny Soil Series (Whiteside 1965). The bog surface is about 8.0 m asl.

Mermaid Bog (46°15'N, 63°01'30"W) borders a small shallow pond 4 km in diameter. The bog averages less than 3 m in depth at the margin of the pond and becomes shallower away from the pond. A sandy clayey till comprises the glacial deposits of the area (Prest 1964), and the local soil is the Alber- ry–Charlottetown fine, sandy loam (Whiteside 1965). The bog surface is about 15 m asl.

East Baltic Bog (46°24'30"N, 62°9'W) encompasses 1.25 ha and is almost 6 m deep at its centre. The local surficial deposits consist of a reddish-brown, clay-sand till with outwash and glacifluvial sediments nearby (Crowl 1960b). The soils are fine sandy clayey loams of the Armadale complex and Charlottetown Series (Whiteside 1965). Local elevation is just over 45 m asl.

Methods

Samples for pollen analysis were obtained with a Hiller peat sampler (Faegri and Iversen 1975) after a series of probes to determine the deepest point at each site. Pollen samples were extracted at 5 cm intervals and closer where rapid sediment changes were apparent. Core increments for radiocarbon dating were recovered with a 30 cm long piston corer (Mott 1966).

Samples of peat, gyttja, and silty clay were prepared for pollen analysis using the standard KOH procedure for peat and gyttja and HCl and HF digestion for silty clay followed by acetylation (Faegri and Iversen 1975). Counts of at least 200 arboreal pollen were made for each sample. Relative percentages were calculated on the basis of a pollen sum of arboreal, shrub, and herb taxa excluding aquatics, spores, and indeterminable grains. The diagrams were zoned on the basis of diagnostic pollen assemblages.

Absolute frequency determinations (pollen influx) were carried out at the East Bideford site only. A known quantity of exotic (Eucalyptus) pollen was added to a known volume of peat (determined by water displacement) prior to chemical processing. Concentrations of fossil pollen (grains/cm²) were multiplied by the rate of peat accumulation (cm/year) to obtain pollen influx (grains/cm²/year).

Radiocarbon dates were obtained on the lowermost organics at each site, for specific pollen horizons, such as the rise in hemlock and rise in beech, and at various levels in East Bideford Bog (Table 1). The radiocarbon dates at East Bideford Bog were combined with dates on the hemlock and beech pollen rises (obtained at East Baltic and Portage Bogs respectively) to derive peat accumulation rates and pollen influx estimates at East Bideford Bog.

Pollen Zonation and Inferred Vegetation

The pollen diagrams, Figs. 2–6, are in abbreviated form with only the major pollen taxa necessary for pollen zonation present. The diagrams are divided into recognizable pollen assemblage zones on the basis of changes in the frequencies of one or more diagnostic taxa. Because the assemblage zones are consistent from site to site, the pollen zonation and inferred vegetation will be discussed as a whole, beginning with the
TABLE 1. Radiocarbon dates

<table>
<thead>
<tr>
<th>Bog site</th>
<th>Core interval (cm)</th>
<th>Laboratory dating No.</th>
<th>Uncorrected age (14C years BP)</th>
<th>δ13C (‰)</th>
<th>Corrected age (14C years BP)</th>
<th>Pollen horizon</th>
</tr>
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<tbody>
<tr>
<td>Portage</td>
<td>77–82</td>
<td>GSC-2626</td>
<td>530± 60</td>
<td>-27.4</td>
<td>490± 60</td>
<td>Beech rise</td>
</tr>
<tr>
<td>Portage</td>
<td>417–423</td>
<td>GSC-2629</td>
<td>3460± 70</td>
<td>-27.0</td>
<td>3430± 70</td>
<td>Decline in Artemisia</td>
</tr>
<tr>
<td>Portage</td>
<td>623–628</td>
<td>GSC-773</td>
<td>9880±150</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Bideford</td>
<td>82–88</td>
<td>GSC-2662</td>
<td>390± 80</td>
<td>-25.0</td>
<td>390± 80</td>
<td></td>
</tr>
<tr>
<td>East Bideford</td>
<td>210–215</td>
<td>GSC-2659</td>
<td>1150± 80</td>
<td>-26.2</td>
<td>1130± 80</td>
<td></td>
</tr>
<tr>
<td>East Bideford</td>
<td>300–305</td>
<td>GSC-2655</td>
<td>1960±120</td>
<td>-24.8</td>
<td>1960±120</td>
<td></td>
</tr>
<tr>
<td>East Bideford</td>
<td>328–333</td>
<td>GSC-2649</td>
<td>2180±60</td>
<td>-27.3</td>
<td>2140±60</td>
<td></td>
</tr>
<tr>
<td>East Bideford</td>
<td>628–631</td>
<td>GSC-2647</td>
<td>8180± 80</td>
<td>-31.8</td>
<td>8070± 80</td>
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<tr>
<td>East Bideford</td>
<td>328–333</td>
<td>GSC-2649</td>
<td>8000±140</td>
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<tr>
<td>Mermaid</td>
<td>276–280</td>
<td>GSC-793</td>
<td>8630±180</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>East Baltic</td>
<td>335–340</td>
<td>GSC-2509</td>
<td>4050± 60</td>
<td>-27.4</td>
<td>4020± 60</td>
<td>Hemlock minimum</td>
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<tr>
<td>East Baltic</td>
<td>495–500</td>
<td>GSC-2473</td>
<td>7040± 70</td>
<td>-27.3</td>
<td>7000± 70</td>
<td>Hemlock rise</td>
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<td>East Baltic</td>
<td>574–578</td>
<td>GSC-775</td>
<td>8430±150</td>
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</tr>
</tbody>
</table>

Fig. 2. Relative pollen diagram of Portage Bog. Artemisia is designated by pattern inside Upland Herbs profile.

oldest zones first. Complete diagrams showing all taxa will appear in a separate report.

**Pollen Assemblage Zone 7**

This zone is characterized by high percentages of birch (presumably nonarboreal birch as the grains are commonly less than 25 μm), willow, and uplands herbs, most notably Artemisia, grasses and sedges in Portage Bog (Fig. 2), Mermaid Bog (Fig. 5), and East Baltic Bog (Fig. 6). Pollen influx estimates are unavailable for this zone; interpretations, therefore, rest entirely on the percentage data.

The initial vegetation following retreat of Wisconsinan ice was very much tundra-like on the
Fig. 3. Relative pollen diagram of East Bideford Bog. The time scale (in thousands of years before present) was determined from six radiocarbon dates plus two dates for the rises in hemlock and beech pollen (obtained at East Baltic and Portage Bogs respectively).

### Pollen Assemblage Zone 6

The pollen records of the Portage, Mermaid, and East Baltic Bogs are supported by percentage, and more importantly, by absolute frequency data from the East Bideford Bog beginning in this zone (Figs. 3, 4). Total pollen influx increases from about 2700 grains/cm²/year at the base of the zone to more than 65,000 grains/cm²/year maximum. Mott (1975) obtained only about 6500–7000 grains/cm²/year maximum in the equivalent pollen zone at Basswood Road Lake, New Brunswick. Figure 4 shows that the rate of peat accumulation at East Bideford Bog is basically linear, i.e., it decreases with increase in depth of sediment, and is more than likely not constant in the basal part of the peat. The distorted influx values of this zone are believed to be due to the anomalous high sedimentation rate used for the lowermost 15 cm of peat where age assignments are imprecise. Closer radiocarbon control, on the other hand, would undoubtedly show the basal part of the peat to be characterized by extremely low sedimentation rates. This is supported by the compressed nature of the pollen profiles in this zone in both the percentage and influx diagrams.

This zone is distinguished by an initial sharp peak in nonarboreal birch (amounting to a maximum of 55% at East Baltic Bog) succeeded by spruce (close to 42% maximum at Portage Bog). Spruce, however, is not as high in the Mermaid and East Baltic diagrams as it is in the Portage and East Bideford.
sites. Spruce either played a less prominent role in the vegetation of the eastern part of the island than in the western part at this time, or the spruce zone is severely compressed and (or) truncated due to the very low rates of sedimentation at the base of the eastern sites.

The replacement of the tundra elements, notably willow, nonarboreal birch, grass, and sedge by a birch–spruce association at all four sites implies a tundra–forest transition vegetation in this zone. This is consistent with the conclusions of Davis and Webb (1975). The transition occurred at approxi-
Pollen Assemblage Zone 5

The high percentages and influx estimates of birch and spruce in the preceding zone give way to rising percentages and a marked peak in influx of pine pollen (mainly white pine, Pinus strobus) in this zone. White pine, thus, replaced the birch-spruce association as the dominant vegetation of the uplands. The replacement of nonarboreal birch by arboreal birch (grains generally greater than 25 μm) near the base of this zone and the almost complete absence of other tundra indicators such as willow, Artemisia, and grass pollen indicate tundra conditions were far removed by this time.

Pollen Assemblage Zone 4

The high pine values of the preceding zone are replaced by increasing percentages and influx rates of hemlock pollen in this zone. Influx of spruce, pine, and arboreal birch remain relatively constant throughout. Total pollen influx, which reflects the trends of pine and birch, averages close to 5000 grains/cm²/year.

The hemlock profile first starts to rise near the top of zone 5, but in this zone it increases sharply to maximum values (close to 30% in all the relative diagrams and to about 1500 grains/cm²/year in the influx diagram of East Bideford Bog). This sharp increase represents the arrival of hemlock on the island and it is radiocarbon dated at 7000 ± 70 years BP (GSC-2473) in East Baltic Bog.

Even though hemlock, pine, and birch reach maximum values of about 1500 grains/cm²/year, hemlock is considered to have been the more dominant tree species throughout this zone. Movement of hemlock into a pine association is often regarded as a basic successional pattern for this genus (Walker and Hartman 1960). In contrast to pine, once the shade tolerant hemlock has become established under dense forest stands, it can slowly advance to a dominant position without benefit of a major disturbance, thus behaving as a climax species (Hough 1960). The maximum percentages and influx estimates of hemlock between approximately 6500 and 4500 years ago represent its proba-
ble dominance of a hemlock – white pine forest at this time.

Pollen Assemblage Zone 3

Hemlock decreases sharply at the top of the preceding zone and reaches minimum values of only about 5% and 50 grains/cm²/year in this zone. This mid-Holocene decline of hemlock is radiocarbon dated at 4020 ± 60 years BP (GSC-2509) in East Baltic Bog.

White pine and arboreal birch increase at this time and birch becomes progressively more abundant eastward reaching values as high as 70% at East Baltic Bog. Total pollen influx increases to a minor peak of 8500 grains/cm²/year (Fig. 4) which reflects the resurgence of pine and birch. The inferred vegetation probably resembled a mixed conifer-hardwood forest with white pine and most likely white and yellow birch the dominant taxa.

Zone 3 is also distinguished by increasing percentages and influx rates of beech pollen, representing the arrival of beech which is radiocarbon dated at 3430 ± 70 years BP (GSC-2629) in Portage Bog. According to Hough and Forbes (1943) "... beech is able to build up an understory beneath mature hemlock, white pine, ... under conditions unfavourable to these conifers and to many of the hardwoods." Thus the tolerant beech possibly created openings in the conifer canopy which may have benefited some of the more intolerant hardwoods, i.e., elm, ash, hickory, and basswood, which make their first appearance in this zone.

Pollen Assemblage Zone 2

This zone is characterized by a second peak in the percentages and influx estimates of hemlock. However, both percentage and influx values never reach the peak levels achieved in the earlier hemlock maximum of zone 4.

Percentage and influx of birch and beech pollen are also high in this birch zone. Birch increases from an average of 30–40% at Portage and East Bideford Bogs to as high as 60% at East Baltic Bog. Beech also increases eastward from an average maximum of about 7% in the western sites to as high as 20% at East Baltic Bog. Hemlock, on the other hand, decreases from about 10–20% at Portage and East Bideford Bogs to only about 5% at East Baltic Bog. A hemlock–birch–beech forest association is thus inferred for this zone in the western part of the island, and a birch–beech association is inferred for the eastern part.

Total pollen influx (Fig. 4) increases to a maximum of 13 000 grains/cm²/year between 3000 and 2000 years ago, after which it remains at less than 5000 grains/cm²/year, with the exception of a minor increase at approximately 400 years ago. Davis (1977) also recorded a similar influx reduction within the past 2000 years in his New England sites.

Three radiocarbon dates, 2140 ± 60 (GSC-2649), 1960 ± 120 (GSC-2655), and 1130 ± 80 years BP (GSC-2659), fall within this zone at East Bideford Bog. The youngest dates on this zone are 490 ± 60 years BP (GSC-2626) for near-recent declines of hemlock and hardwood pollen in Portage Bog and 390 ± 80 years BP (GSC-2662) at East Bideford Bog.

Pollen Assemblage Zone 1

This uppermost zone is marked by a slight increase and then a decrease in total pollen influx to a modern-day value of 3200 grains/cm²/year and by sudden increases in percentage and influx of ragweed (Ambrosia) and grass pollen. Also, there are noticeable declines in tree pollen, particularly hemlock and beech. The zone 2/1 boundary represents the initiation of forest clearing and agriculture as a result of peak European immigrations and colonial establishments between 1830 and 1880 AD (Raymond et al. 1963).

The modern-day total pollen influx estimates are equivalent to those from Basswood Lake, New Brunswick (Mott 1975), where 2927 grains/cm²/year were obtained in the surface sample. A recent resurgence of spruce is apparent in the percentage diagrams at all four sites, and spruce along with pine make up the majority of the total pollen influx at East Bideford Bog. The high spruce values more than likely represent secondary growth of red spruce (Picea rubens), which is apt to colonize the partial openings of the upland hardwood forest, while jack pine (Pinus banksiana) has recently become abundant near East Bideford Bog because of past fires in the area (Erskine 1961).

Holocene Climatic Interpretation

Because the pollen stratigraphies are more or less consistent from site to site, several inferences can be made with respect to the climatic history of the island during the Holocene. Figure 7 shows profiles of selected pollen taxa which best reflect the overall climatic changes characterizing the Portage Bog area and Prince Edward Island in general since approximately 10 000 years ago.

Recent compilations of modern pollen taxa in a transect from the tundra to the deciduous forest of eastern and central North America by Davis and Webb (1975) and Webb and McAndrews (1976) have demonstrated that good correlation exists between modern pollen distribution and vegetation distribution. These compilations make it feasible to
Fig. 7. Portage Bog pollen diagram showing the pollen profiles which best reflect the approximate temperature and relative, minimum precipitation changes for the past 10,000 years. Points on the paleotemperature curve represent mean annual, present-day temperatures for the following fossil pollen–modern pollen analogue locations, versus time in thousands of years before present: (49.5°N, 77.5°W) = 9000–8000 years; (47°N, 78°W) = 7500 years; (44°45'N, 75°50'W) = 6000 years; (42°00'N, 72°45'W) = 4000 years; (43°50'N, 74°45'W) = 1500 years; (44°50'N, 69°10'W) = 1000 years.

Relate fossil pollen data to modern-day vegetation and thus interpret the fossil pollen assemblages in terms of past climatic changes. Figure 7 also shows a speculative paleotemperature curve based on an analogy between the average percentage of dominant fossil pollen in Portage Bog and the modern pollen data of Davis and Webb (1975). Points on the paleotemperature curve refer to site locations which are best defined by this analogy and where the present-day mean annual temperatures are known (Wernstedt 1972; Houde 1978).

Because pollen assemblage zone 7 appears to have no modern-day analogue, mainly on account of the high percentages of Artemisia, it is not possible to derive paleotemperature estimates for the period prior to about 10,000 years BP. Besides, there is a good possibility that the climate at that time was unlike any climate known today (Birks 1976).

Climatic conditions started to improve noticeably after 10,000 years BP corresponding with the steady rise in spruce pollen. The first meaningful fossil pollen–modern pollen analogy, perhaps, can be carried out for the period 8000–9000 years ago (i.e., at the peak in spruce pollen), when mean annual temperatures are estimated to have been possibly at least as low as −1°C. At or shortly after 8000 years BP, a dramatic shift to warmer conditions took place when pine replaced spruce and the tundra elements finally disappeared. The mean annual temperature probably increased on the average from about −1 to 2.5°C at this time.

The warm interval lasted from shortly after 8000 years ago to between 1000 and 1500 years ago. This was the mid-Holocene Hypsithermal interval (Deevey and Flint 1957) when pine, followed by a mixed forest of hemlock, birch, beech, and oak, formed the dominant vegetation. The mean annual temperature reached a maximum value close to 8.5°C at the peak of the Hypsithermal, approximately 4000 years ago, after which it decreased gradually towards the present. Temperatures at that time may have been as much as 2.5°C warmer than present.

The generally high percentages and influx rates of pine between approximately 7500 and 3000 years ago suggest that conditions, for the most part, were warm and dry. Hemlock, however, reached maximum percentages and influx rates between 6500 and 4500 years ago. The notion that such a hemlock maximum is indicative of a more moist climate at this time has been largely discounted in recent years. Similarly, the theory that hemlock in groups or stands produces an exceptionally dense canopy and, as a result, can create its own microclimate, which can differ from the regional climate (Hough 1960), seems inappropriate according to Rogers (1978). On the basis of his hemlock community studies, Rogers (1978) would suggest that the relative success of hemlock reproduction may be partly due to the inability of shade-tolerant competitors, such as sugar maple and yellow birch, to compete with hemlock, particularly on thin or infertile soils.

The decline in both percentage and influx of
hemlock after approximately 5000 years ago and the succeeding hemlock minimum from about 4000–3000 years represent the near elimination of hemlock from the forests. Various factors such as changing soil and climatic conditions, diseases, and competitive interactions have been offered as explanations for this mid-Holocene decline in hemlock. Probably more than anything, the young seedlings and saplings could not adapt to the overall increase in temperature at this time. The initial survival, growth, and reproduction of hemlock seedlings and saplings are most successful in shaded, moist cool sites within the natural range of hemlock (Hough 1960), where the mean annual temperature averages about 6°C (Rowe 1977). Thus, the relative success of the young seedlings and saplings in developing into mature hemlock stands might be indicated by the hemlock pollen maxima which correspond to a temperature range from about 6–8°C on the paleotemperature curve of Fig. 7. The inability of the seedlings and saplings to cope with the higher mean annual temperatures (possibly as much as 8.5°C), and even higher growing season temperatures at the warmest part of the Holocene, may well explain the decline in the hemlock pollen curve and the subsequent hemlock pollen minimum. Repeated failure of the young trees from reaching maturity would understandably bring about a net decrease in hemlock pollen production, dispersion, and, hence, deposition (influx) at this time.

A significant decrease in the mean annual temperature and an increase in moisture is inferred after approximately 3000 years ago. This is reflected by the second increase in the hemlock pollen curve, by increases in spruce, beech, Ericaceae, and Sphagnum, and by decreases in pine and oak.

At approximately 1300 years ago, a cooler climate is inferred again on the basis of further increasing trends in spruce and fir and corresponding decreases in pine and the hardwoods. The mean annual temperature may have decreased by almost 1°C from close to 7.5°C at 1500 years ago to about 6.5°C at approximately 1000 years ago.

The uppermost part of the Sphagnum curve in Fig. 7 is characterized by sharp peaks in the percentages of Sphagnum. These peaks are generally found to coincide with periods of renewed Sphagnum peat growth (recurrence surfaces), brought about during times of increased atmospheric moisture (Ogden 1960; Tallis 1964; Nichols 1967). Nichols (1967) related similar peaks in his Sphagnum spore profiles from subarctic Canada to relatively warm, wet conditions when the arctic front lay farther north in summer. In the Portage Bog diagram, the Sphagnum spore peaks become especially prominent after spruce, fir, and Ericaceae increase and pine decreases toward the surface. The climate, thus, apparently not only has become cooler since about 1300 years ago, but presumably wetter as well.

Discussion and Conclusions

The history of the Holocene vegetation on a regional basis and of the modern flora of Prince Edward Island become reasonably clear when the pollen assemblage zones are compared with those from the mainland. Figure 8 is a palynostratigraphic chart showing the pollen zonation scheme as outlined for Prince Edward Island compared with that for southwestern New Brunswick (Mott 1975) and eastern Nova Scotia (Livingstone 1968). The Prince Edward Island zonation supplements that in Mott (1975) and thus provides additional data for a more regional synthesis of vegetation migration in eastern Canada. It also extends the correlation of broad-scale patterns of Holocene vegetation as carried out by Davis (1976) and by Bernabo and Webb (1977) for northeastern North America.

The lowermost birch–herbs pollen zone of the Prince Edward Island profiles is equivalent to the herbs and birch–aspen zones of southwestern New Brunswick and the birch–herbs zone of eastern Nova Scotia. Deductions based on these zones indicate that tundra vegetation was widespread throughout the Maritime Provinces soon after the retreat of late Wisconsinan ice. The revegetation process, like deglaciation, apparently was not synchronous everywhere in the region. Tundra vegetation arrived in southwestern New Brunswick probably as early as 13,000 years ago (Mott 1975) and perhaps not until as much as 2000 years later in Prince Edward Island and eastern Nova Scotia. It lasted up to just after 12,000 years BP in New Brunswick and to about 10,000 years BP in Prince Edward Island and eastern Nova Scotia. Just after 10,000 years ago, there was an obvious change in the early Holocene vegetation in Prince Edward Island. Tundra vegetation gave way to spruce–dominated forest–tundra in the west and to a birch-dominated, forest–tundra vegetation in the east. Thus, the spruce–birch zone of western Prince Edward Island corresponds with the spruce and (or) spruce–birch zones of southwestern New Brunswick, whereas in eastern Prince Edward Island, where the roles of spruce and birch apparently had been reversed, there is a closer similarity with the pollen zonation of eastern Nova Scotia.

First arrivals for pine occurred at approximately
Fig. 8. Chart showing correlation of pollen zones from Prince Edward Island with those from southwestern New Brunswick (Mott 1975) and eastern Nova Scotia (Livingstone 1968).

9500 years ago in southwestern New Brunswick, slightly later in Nova Scotia (Mott 1975), and not until 7500–8000 years ago in Prince Edward Island. By 7500 years ago the vegetation of the Maritime Provinces was everywhere synchronous for the first time in the Holocene (see also the palynostratigraphic chart in Mott (1975)). This is supported by the fact that hemlock arrived at between 6000 and 7000 years BP throughout the Maritime region as a whole. Synchronicity continued well into the time of the hemlock maximum to about 5000 years ago.

From about 5000 years BP to present, pollen zone correlation between New Brunswick, Prince Edward Island, and Nova Scotia is much more difficult, primarily as a result of the differential rates of migration of birch and beech. Birch increased dramatically, particularly in the eastern part of the island about 4000 years ago, some 1000 years later than in southwestern New Brunswick. The beech migration, which is the last major vegetative event of the Holocene in this region, was also late in reaching Prince Edward Island. Beech arrived in southwestern New Brunswick just over 5000 years ago (Mott 1975), shortly after 4500 years ago in west and south-central Nova Scotia (Hadden 1975; Livingstone 1968), and not until about 3400 years ago in western Prince Edward Island. On the whole, however, good pollen zone correlation seems to exist in late Holocene time between western Prince Edward Island and southwestern New Brunswick, and between eastern Prince Edward Island and eastern Nova Scotia.

The ease of migration of any one tree species is partly dependent upon the availability of suitable migrational pathways. In the case of beech, its migration to Prince Edward Island happened to coincide with the mid-Holocene rise of sea level in Northumberland Strait. According to Kranck (1972), a land bridge extended across Northumberland Strait connecting Prince Edward Island with the mainland prior to about 5000 years ago. Consequently, up until that time, the land bridge presumably would have provided easy access for vegetation migration across to the island; this confirms Erskine's (1961) contention that the disrupted ranges of a group of plant species now confined to the Gulf of St. Lawrence coasts (Prince Edward Island, northeastern New Brunswick, northwestern Cape Breton Island), but not the Northumberland Strait coasts, are remnants of a previous continuity when Prince Edward Island was connected to the mainland. The isthmus to Prince Edward Island, however, was breached 5000 years ago, and Northumberland Strait became a continuous body of water for the first time since glacial ice withdrew from the strait (Kranck 1972). Such a water barrier may well have provided enough of an impediment to disrupt any previously formed plant distributions, to delay the migration of the late Holocene vegetation, beech in particular, and possibly explain its late arrival on Prince Edward Island.

The manner in which the mid- to late-Holocene vegetation has evolved may account for several differences between the present-day flora of Prince Edward Island and that of the mainland and possibly explain some irregularities in the range patterns of various species or groups of species peculiar to the island. For example, Erskine (1961) concluded that 98% of the flora on the island occurs in Nova Scotia, but only 80% of the indigenous flora of Nova Scotia crosses to the island. At least 15 species are present on the island and in New Brunswick but do not occur in Nova Scotia, and more than 30 species occur in the western part of the island and in New Brunswick only. Of 144 species with restricted ranges, 30% have ranges which are confined to west of the isthmus at Summerside, and another 15% are widely scattered and scarce east of the isthmus, suggesting a late spread eastward. Only a few plant species which form the understory of hardwood forests occur, and only in localized areas.

Erskine (1961) maintained that these plants of restricted ranges arrived by chance after formation of Northumberland Strait and by ineffective dispersal mechanisms. Many species or groups of species, more than likely, did not arrive until after 4000 years ago in association with the middle to late
Holocene mixed conifer–hardwood forest, which, as the pollen stratigraphy demonstrates, was the forerunner of the modern flora. The pollen evidence, therefore, corroborates Erskine's view that most of the native plant species of Prince Edward Island are late arrivals and slow to inhabit the scattered ecological niches.

Summary

Tundra vegetation was widespread up until about 10,000 years BP at which time it gave way to a forest–tundra transition vegetation dominated first by nonarboreal birch and later by spruce. Pine (mainly white pine) replaced spruce approximately 8000 years BP. Hemlock appeared for the first time at 7000 years ago; it declined in significance between about 4500 and 3000 years ago, reappeared, and dominated with birch and beech until modern times.

The inferred Holocene climatic history of the island is one of gradual warming before 8000 years ago followed by rapid warming since about 8000 years BP. The warmest part of the Holocene corresponds with the resurgence of pine and birch at 3000–4000 years ago, when mean annual temperatures, possibly as much as 2.5°C warmer than present, were attained. Conditions are considered to have been relatively dry up to about 3000 years ago, but have been wetter since that time. Near the top of the Prince Edward Island pollen diagrams is the rise in spruce, recorded also in New England (Davis 1977), in southwestern New Brunswick (Mott 1975), and in Nova Scotia (Livingstone 1968), signifying that the inferred late Holocene cooling trend is regional in extent although it may not be time-synchronous everywhere.

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